Filaments___Loops

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Space Weather Live
https://www.spaceweatherlive.com/en.html

. For a review on ***the main properties of filaments***, the reader is referred to, for example, Tandberg-Hanssen (1995), Mackay et al. (2010), Parenti (2014), and Vial & Engvold (2015).

A New Comprehensive Data Set of Solar Filaments of 100 yr Interval. I
GangHua **Lin**, GaoFei Zhu, Xiao Yang, YongLiang Song, Mei Zhang, Suo Liu, XiaoFan Wang, JiangTao Su, Sheng Zheng, JiaFeng Zhang, DongYi Tao, ShuGuang Zeng, HaiMin Wang, Chang Liu, Yan Xu
ApJS **249** 11 **2020**
https://arxiv.org/pdf/2006.09082.pdf
https://doi.org/10.3847/1538-4365/ab92a5
Hα archive is at http://sun.bao.ac.cn/solarfilament/

A Catalog of Prominence Eruptions Detected Automatically in the SDO/AIA 304 Å Images
2010-2016 https://cdaw.gsfc.nasa.gov/CME_list/autope/

Solar Prominences **Book**
Editors: Jean-Claude **Vial,** Oddbjørn Engvold
Astrophysics and Space Science Library
Volume 415 **2015** **File**
http://link.springer.com/book/10.1007/978-3-319-10416-4#page-1
https://link.springer.com/content/pdf/10.1007%2F978-3-319-10416-4.pdf

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"Nature of solar prominences and their role in Space Weather", **Book**
Proceedings of IAU Symposion 300Paris, France, June 10-14, **2013**,
B. **Schmieder**, J.-M. Malherbe & S. T. Wu, eds.
Table of Contents:
http://journals.cambridge.org/action/displayIssue?jid=IAU&volumeId=8&seriesId=0&issueId=S300

UV core dimming in coronal streamer belt and the projection effects★
L. **Abbo**1, S. Giordano1 and L. Ofman
A&A 623, A95 (**2019**)

sci-hub.tw/10.1051/0004-6361/201834299
During solar minimum activity, the coronal structure is dominated by a tilted streamer belt, associated with the sources of the slow solar wind. It is known that some UV coronal spectral observations show a quite evident core dimming in heavy ions emission in quiescent streamers. In this paper, our purpose is to investigate this phenomenon by comparing observed and simulated UV coronal ion spectral line intensities. First, we computed the emissivities and the intensities of HI Lyα and OVI spectral lines starting from the physical parameters of a time-dependent 3D three-fluid MHD model of the coronal streamer belt. The model is applied to a tilted dipole (10°) solar minimum magnetic structure. Next, we compared the results obtained from the model in the extended corona (from 1.5 to 4 R⨀) to the UV spectroscopic data from the Ultraviolet Coronagraph Spectrometer (UVCS) onboard SOHO during the minimum of solar activity (1996). We investigate the line-of-sight integration and projection effects in the UV spectroscopic observations, disentangled by the 3D multifluid model. The results demonstrate that the core dimming in heavy ions is produced by the physical processes included in the model (i.e., combination of the effects of heavy ion gravitational settling, and energy exchange of the preferentially heated heavy ions through the interaction with electrons and protons) but it is visible only in some cases where the magnetic structure is simple, such as a (tilted) dipole.

Coronal Pseudo-Streamer and Bipolar Streamer Observed by SOHO/UVCS in March 2008

Lucia **Abbo**, Roberto Lionello, Pete Riley, Yi-Ming Wang
Solar Phys. Volume 290, Issue 7, pp 2043-2054 **2015**
http://arxiv.org/pdf/1505.05649v1.pdf
The last solar minimum is characterized by several peculiar aspects and by the presence of a complex magnetic topology with two different kinds of coronal streamers: pseudo-streamers and bipolar streamers. Pseudo-streamers or unipolar streamer are coronal structures which separate coronal holes of the same polarity, without a current sheet in the outer corona; unlike bipolar streamer that separate coronal holes of opposite magnetic polarity. In this study, two examples of these structures have been identified in the period of Carrington rotation 2067, by applying a potential-field source-surface extrapolation of the photospheric field measurements. We present a spectroscopic analysis of a pseudo-streamer and a bipolar streamer observed in the period **12-17 March 2008** at high spectral and spatial resolution by the Ultraviolet Coronagraph Spectrometer (UVCS; Kohl et al., 1995) onboard Solar and Heliospheric Observatory (SOHO). The solar wind plasma parameters, such as kinetic temperature, electron density and outflow velocity, are inferred in the extended corona (from 1.7 to 2.1 Rsun) analysing the O VI doublet and Ly alpha line spectra.
The coronal magnetic topology is taken into account and has been extrapolated by a 3D magneto-hydrodynamic model of the global corona. The results of the analysis show some peculiarities of the pseudo-streamer physical parameters in comparison with those obtained for bipolar streamers: in particular, we have found higher kinetic temperature and higher outflow velocities of O VI ions and lower electron density values. In conclusion, we point out that pseudo-streamers produce a "hybrid" type of outflow that is intermediate between slow and fast solar wind and they are a possible source of slow/fast wind in not dipolar solar magnetic field configuration.

Observations of Excitation and Damping of Transversal Oscillations in Coronal Loops by AIA/SDO

A. **Abedini**
Solar Physics February **2018**, 293:22
https://link.springer.com/content/pdf/10.1007%2Fs11207-018-1240-6.pdf
https://arxiv.org/pdf/1801.09217.pdf
The excitation and damping of the transversal coronal loop oscillations and quantitative relation between damping time, damping property (damping time per period), oscillation amplitude, dissipation mechanism and the wake phenomena are investigated. The observed time series data with the Atmospheric Imaging Assembly (AIA) telescope on NASA's Solar Dynamics Observatory (SDO) satellite on **2015 March 2**, consisting of 400 consecutive images with 12 s cadence in the 171 A˚A˚ pass band is analyzed for evidence of transversal oscillations along the coronal loops by the Lomb–Scargle periodgram. In this analysis signatures of transversal coronal loop oscillations that are damped rapidly were found with dominant oscillation periods in the range of P=12.25--15.80min. Also, damping times and damping properties of the transversal coronal loop oscillations at dominant oscillation periods are estimated in the range of τd=11.76--21.46 min and τd/P=0.86--1.49, respectively. The observational results of this analysis show that damping properties decrease slowly with increasing amplitude of the oscillation, but the periods of the oscillations are not sensitive functions of the amplitude of the oscillations. The order of magnitude of the damping properties and damping times are in good agreement with previous findings and the theoretical prediction for damping of kink mode oscillations by the dissipation mechanism. Furthermore, oscillations of the loop segments attenuate with time roughly as t−α and the magnitude values of α for 30 different segments change from 0.51 to 0.75.

Phase speed and frequency-dependent damping of longitudinal intensity oscillations in coronal loop structures observed with AIA/SDO
A. **Abedini**
AP&SS **2016**
http://arxiv.org/pdf/1603.04207v1.pdf
Longitudinal intensity oscillations along coronal loops that are interpreted as signatures of magneto-acoustic waves are observed frequently in different coronal structures. The aim of this paper is to estimate the physical parameters of the slow waves and the quantitative dependence of these parameters on their frequencies in the solar corona loops that are situated above active regions with the Atmospheric Imaging Assembly (AIA) onboard Solar Dynamic Observatory (SDO). The observed data on **2012-Feb-12**, consisting of 300 images with an interval of 24 seconds in the 171 $\rm{\AA}$ and 193 $\rm{\AA}$ passbands is analyzed for evidence of propagating features as slow waves along the loop structures. Signatures of longitudinal intensity oscillations that are damped rapidly as they travel along the loop structures were found, with periods in the range of a few minutes to few tens of minutes. Also, the projected (apparent) phase speeds, projected damping lengths, damping times and damping qualities of filtered intensities centred on the dominant frequencies are measured in the range of Cs≃38−79 kms−1, Ld≃23−68 Mm, τd≃7−21 min and τd/P≃0.34−0.77, respectively. The theoretical and observational results of this study indicate that the damping times and damping lengths increase with increasing the oscillation periods, and are highly sensitive function of oscillation period, but the projected speeds and the damping qualities are not very sensitive to the oscillation periods. Furthermore, the magnitude values of physical parameters are in good agreement with the prediction of the theoretical dispersion relations of high-frequency MHD waves (>1.1 mHz) in a coronal plasma with electron number density in the range of ne≃107−1012 cm−3.

Gravitational instability of solar prominence threads
I. Curved magnetic fields without dips
A. **Adrover-González**, J. Terradas, R. Oliver, M. Carbonell
A&A 649, A142 **2021**
https://arxiv.org/pdf/2103.11756.pdf
https://www.aanda.org/articles/aa/pdf/2021/05/aa39677-20.pdf
https://doi.org/10.1051/0004-6361/202039677
Prominence threads are dense and cold structures lying on curved magnetic fields that can be suspended in the solar atmosphere against gravity. The gravitational stability of threads, in the absence of non-ideal effects, is comprehensively investigated in the present work by means of an elementary but effective model. Based on purely hydrodynamic equations in one spatial dimension and applying line-tying conditions at the footpoints of the magnetic field lines, we derive analytical expressions for the different feasible equilibria and the corresponding frequencies of oscillation. We find that the system allows for stable and unstable equilibrium solutions subject to the initial position of the thread, its density contrast and length, and the total length of the magnetic field lines. The transition between the two types of solutions is produced at specific bifurcation points that have been determined analytically in some particular cases. When the thread is initially at the top of the concave magnetic field, that is at the apex, we find a supercritical pitchfork bifurcation, while for a shifted initial thread position with respect to this point the symmetry is broken and the system is characterised by an S-shaped bifurcation. The plain results presented in this paper shed new light on the behaviour of threads in curved magnetic fields under the presence of gravity and help to interpret more complex numerical magnetohydrodynamics (MHD) simulations about similar structures.

3D numerical simulations of oscillations in solar prominences
A. **Adrover-González**, J. Terradas
A&A 633, A113 **2020**
https://arxiv.org/pdf/1912.03930.pdf
https://doi.org/10.1051/0004-6361/201936841
Oscillations in solar prominences are a frequent phenomenon, and they have been the subject of many studies. A full understanding of the mechanisms that drive them and their attenuation has not been reached yet. We numerically investigate the periodicity and damping of transverse and longitudinal oscillations in a 3D model of a curtain-shaped prominence. We carried out a set of numerical simulations of vertical, transverse and longitudinal oscillations with the high-order finite-difference Pencil Code. We solved the ideal magnetohydrodynamic (MHD) equations for a wide range of parameters, including the width and density of the prominence, and the magnetic field strength (B) of the solar corona. We studied the periodicity and attenuation of the induced oscillations. We found that longitudinal oscillations can be fit with the pendulum model, whose restoring force is the field aligned component of gravity, but other mechanisms such as pressure gradients may contribute to the movement. On the other hand, transverse oscillations are subject to magnetic forces. The analysis of the parametric survey shows, in agreement with observational studies, that the oscillation period (P) increases with the prominence width. For transverse oscillations we obtained that P increases with density and decreases with B. For longitudinal oscillations we also found that P increases with density, but there are no variations with B. The attenuation of transverse oscillations was investigated

by analysing the velocity distribution and computing the Alfvén continuum modes. We conclude that resonant absorption is the mean cause. Damping of longitudinal oscillations is due to some kind of shear numerical viscosity.

Excitation of decay-less transverse oscillations of coronal loops by random motions

A.N. **Afanasyev**, T. Van Doorsselaere, V.M. Nakariakov

A&A Letters 633, L8 (**2020**)

https://arxiv.org/pdf/1912.07980.pdf

The relatively large-amplitude decaying regime of transverse oscillations of coronal loops has been known for two decades and interpreted in terms of MHD kink modes of cylindrical plasma waveguides. Recent observational analysis has revealed the so-called decay-less small-amplitude oscillations, with a multi-harmonic structure being detected. Several models have been proposed to explain them. In particular, decay-less oscillations have been described in terms of standing kink waves driven with continuous monoperiodic motions of loop footpoints, in terms of a simple oscillator model of forced oscillations due to harmonic external force, and as a self-oscillatory process due to the interaction of a loop with quasi-steady flows. However, an alternative mechanism is needed to explain the simultaneous excitation of several longitudinal harmonics of the oscillation. We study the mechanism of random excitation of decay-less transverse oscillations of coronal loops. With a spatially one-dimensional and time-dependent analytical model taking into account effects of the wave damping and kink speed variation along the loop, we consider transverse loop oscillations driven by random motions of footpoints. The footpoint motions are modelled by broad-band coloured noise. We have found the excitation of loop eigenmodes and analysed their frequency ratios as well as the spatial structure of the oscillations along the loop. The obtained results successfully reproduce the observed properties of decay-less oscillations. In particular, excitation of eigenmodes of a loop as a resonator can explain the observed quasi-monochromatic nature of decay-less oscillations and generation of multiple harmonics detected recently. We propose the mechanism that can interpret decay-less transverse oscillations of coronal loops in terms of kink waves randomly driven at the loop footpoints.

Coronal Loop Transverse Oscillations Excited by Different Driver Frequencies

Andrey **Afanasyev**1,2, Konstantinos Karampelas1, and Tom Van Doorsselaere1

2019 ApJ 876 100

sci-hub.se/10.3847/1538-4357/ab1848

https://arxiv.org/pdf/1905.05716.pdf

We analyze transverse oscillations of a coronal loop excited by continuous monoperiodic motions of the loop footpoint at different frequencies in the presence of gravity. Using the MPI-AMRVAC code, we perform three-dimensional numerical magnetohydrodynamic simulations, considering the loop as a magnetic flux tube filled in with denser, hotter, and gravitationally stratified plasma. We show the resonant response of the loop to its external excitation and analyze the development of the Kelvin–Helmholtz instability at different heights. We also study the spatial distribution of plasma heating due to transverse oscillations along the loop. The positions of the maximum heating are in total agreement with those for the intensity of the Kelvin–Helmholtz instability, and correspond to the standing wave antinodes in the resonant cases. The initial temperature configuration and plasma mixing effect appear to play a significant role in plasma heating by transverse footpoint motions. In particular, the development of the Kelvin–Helmholtz instability in a hotter loop results in the enhancement of the mean plasma temperature in the domain.

Prediction of Solar Eruptions Using Filament Metadata

Ashna **Aggarwal**1,2, Nicole Schanche2,3, Katharine K. Reeves2, Dustin Kempton4, and Rafal Angryk

2018 ApJS 236 15

http://sci-hub.tw/http://iopscience.iop.org/0067-0049/236/1/15/

We perform a statistical analysis of erupting and non-erupting solar filaments to determine the properties related to the eruption potential. In order to perform this study, we correlate filament eruptions documented in the Heliophysics Event Knowledgebase (HEK) with HEK filaments that have been grouped together using a spatiotemporal tracking algorithm. The HEK provides metadata about each filament instance, including values for length, area, tilt, and chirality. We add additional metadata properties such as the distance from the nearest active region and the magnetic field decay index. We compare trends in the metadata from erupting and non-erupting filament tracks to discover which properties present signs of an eruption. We find that a change in filament length over time is the most important factor in discriminating between erupting and non-erupting filament tracks, with erupting tracks being more likely to have decreasing length. We attempt to find an ensemble of predictive filament metadata using a Random Forest Classifier approach, but find the probability of correctly predicting an eruption with the current metadata is only slightly better than chance. **2012/01/09-13**

Toward Filament Segmentation Using Deep Neural Networks

Azim **Ahmadzadeh**, Sushant S. Mahajan, Dustin J. Kempton, Rafal A. Angryk, Shihao Ji

IEEE BigData **2019**

https://arxiv.org/pdf/1912.02743.pdf

We use a well-known deep neural network framework, called Mask R-CNN, for identification of solar filaments in full-disk H-alpha images from Big Bear Solar Observatory (BBSO). The image data, collected from BBSO's archive, are integrated with the spatiotemporal metadata of filaments retrieved from the Heliophysics Events Knowledgebase (HEK) system. This integrated data is then treated as the ground-truth in the training process of the model. The available spatial metadata are the output of a currently running filament-detection module developed and maintained by the Feature Finding Team; an international consortium selected by NASA. Despite the known challenges in the identification and characterization of filaments by the existing module, which in turn are inherited into any other module that intends to learn from such outputs, Mask R-CNN shows promising results. Trained and validated on two years worth of BBSO data, this model is then tested on the three following years. Our case-by-case and overall analyses show that Mask R-CNN can clearly compete with the existing module and in some cases even perform better. Several cases of false positives and false negatives, that are correctly segmented by this model are also shown. The overall advantages of using the proposed model are two-fold: First, deep neural networks' performance generally improves as more annotated data, or better annotations are provided. Second, such a model can be scaled up to detect other solar events, as well as a single multi-purpose module. The results presented in this study introduce a proof of concept in benefits of employing deep neural networks for detection of solar events, and in particular, filaments. **2012.01.03, 2014.02.01 , 2014.02.14 , 2016.02.19**

PATTERNS OF FLOWS IN AN INTERMEDIATE PROMINENCE OBSERVED BY *HINODE*

Kwangsu **Ahn**[1,2], Jongchul Chae[1,2], Wenda Cao[2], and Philip R. Goode[2]

Astrophysical Journal, 721:74–79, **2010**

The investigation of plasma flows in filaments/prominences gives us clues to understanding their magnetic structures.We studied the patterns of flows in an intermediate prominence observed by *Hinode*/SOT. By examining a time series of Hα images and Ca ii H images, we have found horizontal flows in the spine and vertical flows in the barb. Both of these flows have a characteristic speed of 10–20 km s^{-1}. The horizontal flows displayed counterstreaming. Our detailed investigation revealed that most of the moving fragments in fact reversed direction at the end point of the spine near a footpoint close to the associated active region. These returning flows may be one possible explanation of the well-known counterstreaming flows in prominences. In contrast, we have found vertical flows—downward and upward—in the barb. Most of the horizontal flows in the spine seem to switch into vertical flows when they approach the barb, and vice versa. We propose that the net force resulting from a small deviation from magnetohydrostatic equilibrium, where magnetic fields are predominantly horizontal, may drive these patterns of flow. In the prominence studied here, the supposed magnetohydrostatic configuration is characterized by magnetic field lines sagging with angles of 13° and 39° in the spine and the barb, respectively.
2008 January 16

PROBING THE THERMODYNAMICS AND KINEMATICS OF SOLAR CORONAL STREAMERS

V. **Airapetian**[1,2], L. Ofman[1,2,3], E. C. Sittler[2], and M. Kramar[1,2]

Astrophysical Journal, 728:67 (10pp), **2011** February

We present the results of a resistive magnetohydrodynamic (MHD) model of an equatorially confined streamer belt using observational constraints for the heating and acceleration of the solar wind. To initiate the 2.5 dimensional MHD calculations, we used the Potential Field Source Surface model of the coronal magnetic field configuration with the boundary conditions at the photosphere specified by the National Solar Observatory/GONG magnetogram data. Calculations were performed for the fully thermal conductive model with observationally constrained heat flux, $q_{\rm eff}$, and the effective temperature, $T_{\rm eff}$, derived from the semi-empirical steady-state two-dimensional model of the solar corona. We compared the results of the model to a polytropic solution (polytropic index $\gamma = 1.05$), and demonstrate that our MHD model is in better agreement with reconstructed density and observed flow velocity than the polytropic model for the coronal streamer structure observed during **2008 February 1–13** by the COR1 coronagraph on board the *STEREO* spacecraft.

ANTI-PARALLEL EUV FLOWS OBSERVED ALONG ACTIVE REGION FILAMENT THREADS WITH HI-C

Caroline E. **Alexander**[1], Robert W. Walsh[1], Stéphane Régnier[1], Jonathan Cirtain[2], Amy R. Winebarger[2], Leon Golub[3], Ken Kobayashi[4], Simon Platt[5], Nick Mitchell[5], Kelly Korreck[3], Bart DePontieu[6], Craig DeForest[7], Mark Weber[3], Alan Title[6], and Sergey Kuzin

2013 ApJ 775 L32

Plasma flows within prominences/filaments have been observed for many years and hold valuable clues concerning the mass and energy balance within these structures. Previous observations of these flows primarily come from Hα

and cool extreme-ultraviolet (EUV) lines (e.g., 304 Å) where estimates of the size of the prominence threads has been limited by the resolution of the available instrumentation. Evidence of "counter-steaming" flows has previously been inferred from these cool plasma observations, but now, for the first time, these flows have been directly imaged along fundamental filament threads within the million degree corona (at 193 Å). In this work, we present observations of an AR filament observed with the High-resolution Coronal Imager (Hi-C) that exhibits anti-parallel flows along adjacent filament threads. Complementary data from the Solar Dynamics Observatory (SDO)/Atmospheric Imaging Assembly (AIA) and Helioseismic and Magnetic Imager are presented. The ultra-high spatial and temporal resolution of Hi-C allow the anti-parallel flow velocities to be measured (70-80 km s–1) and gives an indication of the resolvable thickness of the individual strands (0."8 ± 0."1). The temperature of the plasma flows was estimated to be log T (K) = 5.45 ± 0.10 using Emission Measure loci analysis. We find that SDO/AIA cannot clearly observe these anti-parallel flows or measure their velocity or thread width due to its larger pixel size. We suggest that anti-parallel/counter-streaming flows are likely commonplace within all filaments and are currently not observed in EUV due to current instrument spatial resolution.

Hi-C observations of EUV anti-parallel filament flows and sparkling dots

Caroline E. **Alexander**, Stephane Regnier and Robert Walsh

UKSP Nugget: 38, Aug **2013**

http://www.uksolphys.org/?p=6961

Hi-C has provided EUV imager data of unprecedented detail, unveiling a number of interesting features (see e.g., [1, 7, 8, 9]). Due to being launched as a rocket flight the dataset has a number of disadvantages (e.g., partial FOV, small time series), but even so, it has shown a very encouraging first look at the sub-arcsecond EUV corona and will undoubtedly influence the design of future imaging instruments. The observations of both the EUV anti-parallel flows and sparkling dots raises important questions for both structures: are these flows and dots commonplace within in the corona? What do these anti-parallel flows tell us about the mass injection/maintenance in filaments? What contribution do the EUV dots make to the global heating of the corona? Using Hi-C as a guide to exploit the available full-Sun, multi-wavelength SDO/AIA data is certainly the next step while data of Hi-C resolution are still a rarity. **11 July 2012**

Hard X-Ray Production in a Failed Filament Eruption

David **Alexander**, Rui Liu, and Holly R. Gilbert

The Astrophysical Journal, Volume 653, Number 1, Page 719-724, **2006**, **File**

We revisit the ''failed'' filament eruption of **2002 May 27**, first studied in detail by Ji et al. (2003). We investigate the temporal and spatial relationship between the filament dynamics and the production of hard X-ray emission using spatially resolved high-cadence data.

http://www.journals.uchicago.edu/cgi-bin/resolve?ApJ65128

Hot coronal loops associated with umbral brightenings⋆

C. E. **Alissandrakis** and S. Patsourakos

A&A 556, A79 (**2013**)

Aims. We aim to investigate the association of umbral brightenings with coronal structures.

Methods. We analyzed AIA/SDO high-cadence images in all bands, HMI/SDO data, soft X-ray images from SXI/GOES-15, and Hα images from the GONG network.

Results. We detected umbral brightenings that were visible in all AIA bands as well as in Hα. Moreover, we identified hot coronal loops that connected the brightenings with nearby regions of opposite magnetic polarity. These loops were initially visible in the 94 Å band, subsequently in the 335 Å band, and in one case in the 211 Å band. A differential emission measure analysis revealed plasma with an average temperature of about 6.5 × 106 K. This behavior suggests cooling of impulsively heated loops**. September 30, 2012, January 19, 2013,**

Standing Slow MHD Waves in Radiatively Cooling Coronal Loops

Khalil Salim **Al-Ghafri**

2015

http://arxiv.org/pdf/1501.02689v1.pdf

The standing slow magneto-acoustic oscillations in cooling coronal loops are investigated. There are two damping mechanisms which are considered to generate the standing acoustic modes in coronal magnetic loops namely thermal conduction and radiation. The background temperature is assumed to change temporally due to optically thin radiation. In particular, the background plasma is assumed to be radiatively cooling. The effects of cooling on longitudinal slow MHD modes is analytically evaluated by choosing a simple form of radiative function that ensures the temperature evolution of the background plasma due to radiation coincides with the observed cooling profile of coronal loops. The assumption of low-beta plasma leads to neglect the magnetic field perturbation and eventually reduces the MHD equations to a 1D system modelling longitudinal MHD oscillations in a cooling coronal loop. The cooling is assumed to occur on a characteristic time scale much larger than the oscillation period that subsequently enables using the WKB theory to study the properties of standing wave. The governing equation describing the time-dependent amplitude of waves is obtained and solved analytically. The analytically derived solutions are numerically evaluated to give further insight into the evolution of the standing acoustic waves. We find that the plasma cooling gives rise to a decrease in the amplitude of oscillations. In spite of the reduction in damping rate caused by rising the cooling, the damping scenario of slow standing MHD waves strongly increases in hot coronal loops.

Longitudinal Magnetohydrodynamics Oscillations in Dissipative, Cooling Coronal Loops

K. S. **Al-Ghafri**, M. S. Ruderman, A. Williamson, and R. Erdélyi

2014 ApJ 786 36

This paper investigates the effect of cooling on standing slow magnetosonic waves in coronal magnetic loops. The damping mechanism taken into account is thermal conduction that is a viable candidate for dissipation of slow magnetosonic waves in coronal loops. In contrast to earlier studies, here we assume that the characteristic damping time due to thermal conduction is not small, but arbitrary, and can be of the order of the oscillation period, i.e., a temporally varying plasma is considered. The approximation of low-beta plasma enables us to neglect the magnetic field perturbation when studying longitudinal waves and consider, instead, a one-dimensional motion that allows a reliable first insight into the problem. The background plasma temperature is assumed to be decaying exponentially with time, with the characteristic cooling timescale much larger than the oscillation period. This assumption enables us to use the WKB method to study the evolution of the oscillation amplitude analytically. Using this method we obtain the equation governing the oscillation amplitude. The analytical expressions determining the wave properties are evaluated numerically to investigate the evolution of the oscillation frequency and amplitude with time. The results show that the oscillation period increases with time due to the effect of plasma cooling. The plasma cooling also amplifies the amplitude of oscillations in relatively cool coronal loops, whereas, for very hot coronal loop oscillations the damping rate is enhanced by the cooling. We find that the critical point for which the amplification becomes dominant over the damping is in the region of 4 MK. These theoretical results may serve as impetus for developing the tools of solar magneto-seismology in dynamic plasmas.

Machine Leaning-Based Investigation of the Associations between CMEs and Filaments

M. **Al-Omari**1, R. Qahwaji1, T. Colak1 and S. Ipson1

Solar Phys. 262(2), 511-539, **2010**

In this work we study the association between eruptive filaments/prominences and coronal mass ejections (CMEs) using machine learning-based algorithms that analyse the solar data available between January 1996 and December 2001. The support vector machine (SVM) learning algorithm is used for the purpose of knowledge extraction from the association results. The aim is to identify patterns of associations that can be represented using SVM learning rules for the subsequent use in near real-time and reliable CME prediction systems. Timing and location data in the US National Geophysical Data Center (NGDC) filament catalogue and the Solar and Heliospheric Observatory/Large Angle and Spectrometric Coronagraph (SOHO/LASCO) CME catalogue are processed to associate filaments with CMEs. In the previous studies, which classified CMEs into gradual and impulsive CMEs, the associations were refined based on the CME speed and acceleration. Then the associated pairs were refined manually to increase the accuracy of the training dataset. In the current study, a data-mining system is created to process and associate filament and CME data, which are arranged in numerical training vectors. Then the data are fed to SVMs to extract the embedded knowledge and provide the learning rules that can have the potential, in the future, to provide automated predictions of CMEs. The features representing the event time (average of the start and end times), duration, type, and extent of the filaments are extracted from all the associated and not-associated filaments and converted to a numerical format that is suitable for SVM use. Several validation and verification methods are used on the extracted dataset to determine if CMEs can be predicted solely and efficiently based on the associated filaments. More than 14 000 experiments are carried out to optimise the SVM and determine the input features that provide the best performance.

Helical Eruptive Prominence Associated with a Pair of Overlapping CMEs on 21 April 2001

Syed Salman **Ali** ·Wahab Uddin · Ramesh Chandra · D.L. Mary · Bojan Vršnak

Solar Phys (**2007**) 240: 89–105, **File**

The eruption of limb prominence on 21 April 2001 associated with two coronal mass ejections (CMEs) is investigated. Hα images reveal two large-scale eruptions (a prominence body and a southern foot-point arch), both showing helical internal structure. These two eruptions are found to be spatially and temporally associated with the corresponding CMEs. The kinematics and the study of geometrical parameters of the prominence show that the eruption was quite impulsive (with peak acceleration ≈470 ms^{-2}) and has taken place for relatively low pitch angle of helical threads, not exceeding tan $\theta \approx 1.2$. The stability criteria of the prominence are revisited in the light of the model of Vršnak (1990, *Solar Phys.* **129**, 295) and the analysis shows that the eruption violates the instability criteria of that model. Finally, the energy stored in the prominence circuit and the energies (kinetic, potential, and magnetic) of the associated CMEs are estimated and it is found that there was enough energy stored in the prominence to drive the two CMEs.

Хорошее Ввведение.

The need for new techniques to identify the high-frequency MHD waves of an oscillating coronal loop

Farhad **Allian**, Rekha Jain

A&A 650, A91 **2021**

https://arxiv.org/pdf/2105.08189.pdf

https://doi.org/10.1051/0004-6361/202039763

https://www.aanda.org/articles/aa/pdf/2021/06/aa39763-20.pdf

Magnetic arcades in the solar atmosphere, or coronal loops, are common structures known to host magnetohydrodynamic (MHD) waves and oscillations. Of particular interest are the observed properties of transverse loop oscillations, such as their frequency and mode of oscillation, which have received significant attention in recent years because of their seismological capability. Previous studies have relied on standard data analysis techniques, such as a fast Fourier transform (FFT) and wavelet transform (WT), to correctly extract periodicities and identify the MHD modes. However, how these methods can lead to artefacts requires investigation. We assess whether these two common spectral analysis techniques in coronal seismology can successfully identify high-frequency waves from an oscillating coronal loop. We examine extreme ultraviolet images of a coronal loop observed by the Atmospheric Imaging Assembly in the 171 Åwaveband on board the Solar Dynamics Observatory. We perform a spectral analysis of the loop waveform and compare our observation with a basic simulation. The spectral FFT and WT power of the observed loop waveform is found to reveal a significant signal with frequency 2.67 mHz superposed onto the dominant mode of oscillation of the loop (1.33 mHz), that is, the second harmonic of the loop. The simulated data show that the second harmonic is completely artificial even though both of these methods identify this mode as a real signal. This artificial harmonic, and several higher modes, are shown to arise owing to the periodic but non-uniform brightness of the loop. We further illustrate that the reconstruction of the 2.67 mHz component in the presence of noise yields a false perception of oscillatory behaviour that does not otherwise exist. We suggest that additional techniques such as a forward model of a 3D coronal arcade are necessary to verify such high-frequency waves. **2014 January 27**

Connecting the Low to High Corona: A Method to Isolate Transients in STEREO/COR1 Images

Nathalia **Alzate**, Huw Morgan, Nicholeen Viall, Angelos Vourlidas

ApJ **919** 98 **2021**

https://arxiv.org/pdf/2107.02644.pdf

https://doi.org/10.3847/1538-4357/ac10ca

We present a method that isolates time-varying components from coronagraph and EUV images, allowing sub-streamer transients propagating within streamers to be tracked from the low to high corona. The method uses a temporal bandpass filter with a transmission bandwidth of ~2.5-10 hours that suppresses both high and low frequency variations in observations made by the STEREO/SECCHI suite. We demonstrate that this method proves crucial in linking the low corona where the magnetic field is highly non-radial, to their counterparts in the high corona where the magnetic field follows a radial path through the COR1 instrument. We also applied our method to observations by the COR2 and EUVI instruments onboard SECCHI and produced height-time profiles that revealed small density enhancements, associated with helmet streamers, propagating from ~1.2 Rs out to beyond 5 Rs. Our processing method reveals that these features are common during the period of solar minimum in this study. The features recur on timescales of hours, originate very close to the Sun, and remain coherent out into interplanetary space. We measure the speed of the features and classify them as: slow (a few to tens of km/s) and fast (~100 km/s). Both types of features serve as an observable tracer of a variable component of the slow solar wind to its source regions. Our methodology helps overcome the difficulties in tracking small-scale features through COR1. As a result, it proved successful in measuring the connectivity between the low and high corona and in measuring velocities of small-scale features. **10-23 January 2008**

Horizontal flow below solar filaments

P. **Ambrož**1 and W. Pötzi2

A&A 613, A39 (**2018**)

https://www.aanda.org/articles/aa/pdf/2018/05/aa31162-17.pdf

Context. Observations of the internal fine structures of solar filaments indicate that the threads of filaments follow magnetic field lines. The magnetic field inside the filament has a strong axial component. Some models of magnetic fields suggest that the field structure in filaments could be caused by the horizontal plasma velocity field near both sides below the filament, where observable shearing effects from the axial component are expected.
Aims. The horizontal velocity field in the vicinity of polarity inversion lines is measured in order to determine, if it exhibits a systematic movement that induces shear along the filament axis and convergence perpendicular to the axis.
Methods. The horizontal velocity was obtained from the displacement of supergranules, which were derived from Doppler measurements in the solar photosphere. Dopplergrams corrected for rigid rotation and p-mode oscillations were further analyzed by local correlation tracking.
Results. Vector fields of the horizontal velocities were measured in 16 areas during 8 time intervals in the years 2000–2002 on both solar hemispheres, each for a few consecutive days. For 64 selected filaments the nearby horizontal velocity vectors were split up into a component along the filament axis and a perpendicular component.
Conclusions. Differences between the axial velocities on both sides of the filaments were calculated. In almost all cases the velocity gradient corresponds to the inclination of the threads observed in Hα images. The average transverse velocity does not show any preferred tendency towards a divergence or convergence to the filament axis. Testing the horizontal velocity for the creation of the differential rotation profile in the photosphere reveals a strong dependence of the averaging process on the scale of our velocities. **August 23, 2000, January 9–12, 2002, July 28–31, 2002**

Resonant Absorption of Kink MHD Waves in Inclined and Asymmetric Coronal Loops

Sirwan **Amiri**, Kayoomars Karami, Zanyar Ebrahimi

2021

https://arxiv.org/pdf/2104.01825.pdf

This paper separately evaluates the effects of inclination and asymmetry of solar coronal loops on the resonant absorption of kink magnetohydrodynamic (MHD) oscillations. We modelled a typical coronal loop by a straight and axisymmetric cylindrical magnetic flux tube filled with cold plasma. We solved the dispersion relation numerically for different values of the longitudinal mass density stratification. We show that, in inclined and asymmetric loops, the frequencies and their corresponding damping rates of the fundamental and first-overtone modes of kink oscillations are smaller in comparison with semi-circular uninclined loops with the same lengths. The results also indicate that, the period ratio P1/P2, increases with increasing the inclination of the loop, but it decreases less than 2% while imposing the asymmetry to each loop side, up to 9.66% of the loop length. The ratio of each mode frequency to its corresponding damping rate remain unchanged approximately while the inclination or the asymmetry imposed. Hence, we conclude that these ratios are reliable for inferring the physical parameters of coronal loops and coronal medium, regardless of the loop shape or the state of its inclination. In addition, in contrast with the effect of asymmetry which is not significant on the period ratio P1/P2, when an observed oscillating loop has a smaller apex height, the state of its inclination is an important factor that should be considered, especially when the period ratio P1/P2, is taken into consideration for coronal seismology.

Differences between Doppler velocities of ions and neutral atoms in a solar prominence

Tetsu **Anan**, Kiyoshi Ichimoto, Andrew. Hillier

A&A **2017**

https://arxiv.org/pdf/1703.02132.pdf

In astrophysical systems with partially ionized plasma the motion of ions is governed by the magnetic field while the neutral particles can only feel the magnetic field's Lorentz force indirectly through collisions with ions. The drift in the velocity between ionized and neutral species plays a key role in modifying important physical processes like magnetic reconnection, damping of magnetohydrodynamic waves, transport of angular momentum in plasma through the magnetic field, and heating. This paper investigates the differences between Doppler velocities of calcium ions and neutral hydrogen in a solar prominence to look for velocity differences between the neutral and ionized species. We simultaneously observed spectra of a prominence over an active region in H I 397 nm, H I 434 nm, Ca II 397 nm, and Ca II 854 nm using a high dispersion spectrograph of the Domeless Solar Telescope at Hida observatory, and compared the Doppler velocities, derived from the shift of the peak of the spectral lines presumably emitted from optically-thin plasma. There are instances when the difference in velocities between neutral atoms and ions is significant, e.g. 1433 events (~ 3 % of sets of compared profiles) with a difference in velocity between neutral hydrogen atoms and calcium ions greater than 3sigma of the measurement error. However, we also found significant differences between the Doppler velocities of two spectral lines emitted from the same species, and the probability density functions of velocity difference between the same species is not significantly different from those between neutral atoms and ions. We interpreted the difference of Doppler velocities as a result of motions of different components in the prominence along the line of sight, rather than the decoupling of neutral atoms from plasma. **2015-05-05**

Novel data analysis techniques in coronal seismology **Review**

Sergey A. **Anfinogentov**, Patrick Antolin, Andrew R. Inglis, Dmitrii Kolotkov, Elena G. Kupriyanova, James A. McLaughlin, Giuseppe Nisticò, David J. Pascoe, S. Krishna Prasad, Ding Yuan
2022
https://arxiv.org/pdf/2112.13577.pdf
We review novel data analysis techniques developed or adapted for the field of coronal seismology. We focus on methods from the last ten years that were developed for extreme ultraviolet (EUV) imaging observations of the solar corona, as well as for light curves from radio and X-ray. The review covers methods for the analysis of transverse and longitudinal waves; spectral analysis of oscillatory signals in time series; automated detection and processing of large data sets; empirical mode decomposition; motion magnification; and reliable detection, including the most common pitfalls causing artefacts and false detections. We also consider techniques for the detailed investigation of MHD waves and seismological inference of physical parameters of the coronal plasma, including restoration of the three-dimensional geometry of oscillating coronal loops, forward modelling and Bayesian parameter inference.
May 9, 2007, June 27, 2007., 2013-01-21

Magnetohydrodynamic Seismology of Quiet Solar Active Regions

Sergey A. **Anfinogentov**, Valery. M. Nakariakov
ApJL **884** L40 **2019**
https://arxiv.org/pdf/1910.03809.pdf
https://doi.org/10.3847/2041-8213/ab4792
The ubiquity of recently discovered low-amplitude decayless kink oscillations of plasma loops allows for the seismological probing of the corona on a regular basis. In particular, in contrast to traditionally applied seismology which is based on the large-amplitude decaying kink oscillations excited by flares and eruptions, decayless oscillations can potentially provide the diagnostics necessary for their forecasting. We analysed decayless kink oscillations in several distinct loops belonging to active region NOAA 12107 on **10 July 2010** during its quiet time period, when it was observed on the West limb in EUV by the Atmospheric Imaging Assembly on-board Solar Dynamics Observatory. The oscillation periods were estimated with the use of the motion magnification technique. The lengths of the oscillating loops were determined within the assumption of its semicircular shape by measuring the position of their foot-points. The density contrast in the loops was estimated from the observed intensity contrast accounting for the unknown spatial scale of the background plasma. The combination of those measurements allows us to determine the distribution of kink and Alfvén speeds in the active region. Thus, we demonstrate the possibility to obtain seismological information about coronal active regions during the quiet periods of time.

Decayless low-amplitude kink oscillations: a common phenomenon in the solar corona?

S. A. **Anfinogentov**, V. M. Nakariakov, G. Nisticò
A&A **2015**
http://arxiv.org/pdf/1509.05519v1.pdf
We investigate the decayless regime of coronal kink oscillations recently discovered in the Solar Dynamics Observatory (SDO)/AIA data. In contrast to decaying kink oscillations that are excited by impulsive dynamical processes, this type of transverse oscillations is not connected to any external impulsive impact, such as a flare or CME, and does not show any significant decay. Moreover the amplitude of these decayless oscillations is typically lower than that of decaying oscillations. The aim of this research is to estimate the prevalence of this phenomenon and its characteristic signatures. We analysed 21 active regions (NOAA 11637--11657) observed in January 2013 in the 171 A channel of SDO/AIA. For each active region we inspected six hours of observations, constructing time-distance plots for the slits positioned across pronounced bright loops. The oscillatory patterns in time-distance plots were visually identified and the oscillation periods and amplitudes were measured. We also estimated the length of each oscillating loop. Low-amplitude decayless kink oscillations are found to be present in the majority of the analysed active regions. The oscillation periods lie in the range from 1.5 to 10~minutes. In two active regions with insufficient observation conditions we did not identify any oscillation patterns. The oscillation periods are found to increase with the length of the oscillating loop. The considered type of coronal oscillations is a common phenomenon in the corona. The established dependence of the oscillation period on the loop length is consistent with their interpretation in terms of standing kink waves.

Decay-less kink oscillations in coronal loops

S.A. **Anfinogentov**, G. Nistico, V. M. Nakariakov

E-print, Aug 2013; A&A, 560, A107 (**2013**)

Kink oscillations of coronal loops in an off-limb active region are detected with the Imaging Assembly Array (AIA) instruments of the Solar Dynamics Observatory (SDO) at 171~AA. We aim to measure periods and amplitudes of kink oscillations of different loops and to determinate the evolution of the oscillation phase along the oscillating loop. Oscillating coronal loops were visually identified in the field of view of SDO/AIA and STEREO/EUVI-A: the loop length was derived by three-dimensional analysis. Several slits were taken along the loops to assemble time-distance maps. We identified oscillatory patterns and retrieved periods and amplitudes of the oscillations. We applied the cross-correlation technique to estimate the phase shift between oscillations at different segments of oscillating loops. We found that all analysed loops show low-amplitude undamped transverse oscillations. Oscillations periods of loops in the same active region range from 2.5 to 11 min, and are different for different loops. The displacement amplitude is lower than 1~Mm. The oscillation phase is constant along each analysed loop. The spatial structure of the phase of the oscillations corresponds to the fundamental standing kink mode. We conclude that the observed behaviour is consistent with the empirical model in terms of a damped harmonic resonator affected by a non-resonant continuously operating external force.

Influence of Resonant Absorption on the Generation of the Kelvin-Helmholtz Instability

Patrick **Antolin**1* and Tom Van Doorsselaere2

Front. Phys., **2019**

sci-hub.se/10.3389/fphy.2019.00085

The inhomogeneous solar corona is continuously disturbed by transverse MHD waves. In the inhomogeneous environment of coronal flux tubes, these waves are subject to resonant absorption, a physical mechanism of mode conversion in which the wave energy is transferred to the transition boundary layers at the edge between these flux tubes and the ambient corona. Recently, transverse MHD waves have also been shown to trigger the Kelvin-Helmholtz instability (KHI) due to the velocity shear flows across the boundary layer. Also, continuous driving of kink modes in loops has been shown to lead to fully turbulent loops. It has been speculated that resonant absorption fuels the instability by amplifying the shear flows. In this work, we show that this is indeed the case by performing simulations of impulsively triggered transverse MHD waves in loops with and without an initially present boundary layer, and with and without enhanced viscosity that prevents the onset of KHI. In the absence of the boundary layer, the first unstable modes have high azimuthal wavenumber. A boundary layer is generated relatively late due to the mixing process of KHI vortices, which allows the late onset of resonant absorption. As the resonance grows, lower azimuthal wavenumbers become unstable, in what appears as an inverse energy cascade. Regardless of the thickness of the initial boundary layer, the velocity shear from the resonance also triggers higher order azimuthal unstable modes radially inwards inside the loop and a self-inducing process of KHI vortices occurs gradually deeper at a steady rate until basically all the loop is covered by small-scale vortices. We can therefore make the generalization that all loops with transverse MHD waves become fully turbulent and that resonant absorption plays a key role in energizing and spreading the transverse wave-induced KHI rolls all over the loop.

In-situ generation of transverse MHD waves from colliding flows in the solar corona

Patrick **Antolin**, Paolo Pagano, Ineke De Moortel, Valery M. Nakariakov

ApJL **2018**

https://arxiv.org/pdf/1807.00395.pdf

Transverse MHD waves permeate the solar atmosphere and are a candidate for coronal heating. However, the origin of these waves is still unclear. In this work, we analyse coordinated observations from \textit{Hinode}/SOT and \textit{IRIS} of a prominence/coronal rain loop-like structure at the limb of the Sun. Cool and dense downflows and upflows are observed along the structure. A collision between a downward and an upward flow with an estimated energy flux of 107−108~erg~cm−2~s−1 is observed to generate oscillatory transverse perturbations of the strands with an estimated ≈40 km~s−1 total amplitude, and a short-lived brightening event with the plasma temperature increasing to at least 105 K. We interpret this response as sausage and kink transverse MHD waves based on 2D MHD simulations of plasma flow collision. The lengths, density and velocity differences between the colliding clumps and the strength of the magnetic field are major parameters defining the response to the collision. The presence of asymmetry between the clumps (angle of impact surface and/or offset of flowing axis) is crucial to generate a kink mode. Using the observed values we successfully reproduce the observed transverse perturbations and brightening, and show adiabatic heating to coronal temperatures. The numerical modelling indicates that the plasma β in this loop-like structure is confined between 0.09 and 0.36. These results suggest that such collisions from counter-streaming flows can be a source of in-situ transverse MHD waves, and that for cool and dense prominence conditions such waves could have significant amplitudes. **April 3rd, 2014**

Resonant Absorption of Transverse Oscillations and Associated Heating in a Solar Prominence. II- Numerical aspects

Patrick **Antolin**, Takenori J. Okamoto, Bart De Pontieu, Han Uitenbroek, Tom Van Doorsselaere, Takaaki Yokoyama
ApJ **809** 72 **2015**
http://arxiv.org/pdf/1506.09108v1.pdf
Transverse magnetohydrodynamic (MHD) waves are ubiquitous in the solar atmosphere and may be responsible for generating the Sun's million-degree outer atmosphere. However, direct evidence of the dissipation process and heating from these waves remains elusive. Through advanced numerical simulations combined with appropriate forward modeling of a prominence flux tube, we provide the observational signatures of transverse MHD waves in prominence plasmas. We show that these signatures are characterized by thread-like substructure, strong transverse dynamical coherence, an out-of-phase difference between plane-of-the-sky motions and LOS velocities, and enhanced line broadening and heating around most of the flux tube. A complex combination between resonant absorption and Kelvin-Helmholtz instabilities (KHI) takes place in which the KHI extracts the energy from the resonant layer and dissipates it through vortices and current sheets, which rapidly degenerate into turbulence. An inward enlargement of the boundary is produced in which the turbulent flows conserve the characteristic dynamics from the resonance, therefore guaranteeing detectability of the resonance imprints. We show that the features described in the accompanying paper (Okamoto et al. 2015) through coordinated Hinode and IRIS observations match well the numerical results.

Fine strand-like structure in the solar corona from MHD transverse oscillations

P. **Antolin**, T. Yokoyama, T. Van Doorsselaere
ApJL, **2014**
http://arxiv.org/pdf/1405.0076v1.pdf
Current analytical and numerical modelling suggest the existence of ubiquitous thin current sheets in the corona that could explain the observed heating requirements. On the other hand, new high resolution observations of the corona indicate that its magnetic field may tend to organise itself in fine strand-like structures of few hundred kilometres widths. The link between small structure in models and the observed widths of strand-like structure several orders of magnitude larger is still not clear. A popular theoretical scenario is the nanoflare model, in which each strand is the product of an ensemble of heating events. Here, we suggest an alternative mechanism for strand generation. Through forward modelling of 3D MHD simulations we show that small amplitude transverse MHD waves can lead in a few periods time to strand-like structure in loops in EUV intensity images. Our model is based on previous numerical work showing that transverse MHD oscillations can lead to Kelvin-Helmholtz instabilities that deform the cross-sectional area of loops. While previous work has focused on large amplitude oscillations, here we show that the instability can occur even for low wave amplitudes for long and thin loops, matching those presently observed in the corona. We show that the vortices generated from the instability are velocity sheared regions with enhanced emissivity hosting current sheets. Strands result as a complex combination of the vortices and the line-of-sight angle, last for timescales of a period and can be observed for spatial resolutions of a tenth of loop radius.

On-Disk Coronal Rain

Patrick **Antolin**, Gregal Vissers, Luc Rouppe van der Voort
Solar Physics, October **2012**, Volume 280, Issue 2, pp 457-474
Small and elongated, cool and dense blob-like structures are being reported with high resolution telescopes in physically different regions throughout the solar atmosphere. Their detection and the understanding of their formation, morphology, and thermodynamical characteristics can provide important information on their hosting environment, especially concerning the magnetic field, whose understanding constitutes a major problem in solar physics. An example of such blobs is coronal rain, a phenomenon of thermal non-equilibrium observed in active region loops, which consists of cool and dense chromospheric blobs falling along loop-like paths from coronal heights. So far, only off-limb coronal rain has been observed, and few reports on the phenomenon exist. In the present work, several data sets of on-disk Hα observations with the CRisp Imaging SpectroPolarimeter (CRISP) at the Swedish 1-m Solar Telescope (SST) are analyzed. A special family of on-disk blobs is selected for each data set, and a statistical analysis is carried out on their dynamics, morphology, and temperature. All characteristics present distributions which are very similar to reported coronal rain statistics. We discuss possible interpretations considering other similar blob-like structures reported so far and show that a coronal rain interpretation is the most likely one. The chromospheric nature of the blobs and the projection effects (which eliminate all direct possibilities of height estimation) on one side, and their small sizes, fast dynamics, and especially their faint character (offering low contrast with the background intensity) on the other side, are found as the main causes for the absence until now of the detection of this on-disk coronal rain counterpart.

OBSERVING THE FINE STRUCTURE OF LOOPS THROUGH HIGH-RESOLUTION SPECTROSCOPIC OBSERVATIONS OF CORONAL RAIN WITH THE CRISP INSTRUMENT AT THE SWEDISH SOLAR TELESCOPE

P. **Antolin**1 and L. Rouppe van der Voort

2012 ApJ 745 152

Observed in cool chromospheric lines, such as Hα or Ca II H, coronal rain corresponds to cool and dense plasma falling from coronal heights. Considered as a peculiar sporadic phenomenon of active regions, it has not received much attention since its discovery more than 40 years ago. Yet, it has been shown recently that a close relationship exists between this phenomenon and the coronal heating mechanism. Indeed, numerical simulations have shown that this phenomenon is most likely due to a loss of thermal equilibrium ensuing from a heating mechanism acting mostly toward the footpoints of loops. We present here one of the first high-resolution spectroscopic observations of coronal rain, performed with the CRisp Imaging Spectro Polarimeter (CRISP) instrument at the Swedish Solar Telescope. This work constitutes the first attempt to assess the importance of coronal rain in the understanding of the coronal magnetic field in active regions. With the present resolution, coronal rain is observed to literally invade the entire field of view. A large statistical set is obtained in which dynamics (total velocities and accelerations), shapes (lengths and widths), trajectories (angles of fall of the blobs), and thermodynamic properties (temperatures) of the condensations are derived. Specifically, we find that coronal rain is composed of small and dense chromospheric cores with average widths and lengths of ~310 km and ~710 km, respectively, average temperatures below 7000 K, displaying a broad distribution of falling speeds with an average of ~70 km s–1, and accelerations largely below the effective gravity along loops. Through estimates of the ion-neutral coupling in the blobs we show that coronal rain acts as a tracer of the coronal magnetic field, thus supporting the multi-strand loop scenario, and acts as a probe of the local thermodynamic conditions in loops. We further elucidate its potential in coronal heating. We find that the cooling in neighboring strands occurs simultaneously in general suggesting a similar thermodynamic evolution among strands, which can be explained by a common footpoint heating process. Constraints for coronal heating models of loops are thus provided. Estimates of the fraction of coronal volume with coronal rain give values between 7% and 30%. Estimates of the occurrence time of the phenomenon in loops set times between 5 and 20 hr, implying that coronal rain may be a common phenomenon, in agreement with the frequent observations of cool downflows in extreme-ultraviolet lines. The coronal mass drain rate in the form of coronal rain is estimated to be on the order of 5 × 109 g s–1, a significant quantity compared to the estimate of mass flux into the corona from spicules.

TRANSVERSE OSCILLATIONS OF LOOPS WITH CORONAL RAIN OBSERVED BY HINODE/SOLAR OPTICAL TELESCOPE

P. **Antolin**1,3 and E. Verwichte

2011 ApJ 736 121

The condensations composing coronal rain, falling down along loop-like structures observed in cool chromospheric lines such as Hα and Ca II H, have long been a spectacular phenomenon of the solar corona. However, considered a peculiar sporadic phenomenon, it has not received much attention. This picture is rapidly changing due to recent high-resolution observations with instruments such as the Hinode/Solar Optical Telescope (SOT), CRISP of the Swedish 1-m Solar Telescope, and the Solar Dynamics Observatory. Furthermore, numerical simulations have shown that coronal rain is the loss of thermal equilibrium of loops linked to footpoint heating. This result has highlighted the importance that coronal rain can play in the field of coronal heating. In this work, we further stress the importance of coronal rain by showing the role it can play in the understanding of the coronal magnetic field topology. We analyze Hinode/SOT observations in the Ca II H line of a loop in which coronal rain puts in evidence in-phase transverse oscillations of multiple strand-like structures. The periods, amplitudes, transverse velocities, and phase velocities are calculated, allowing an estimation of the energy flux of the wave and the coronal magnetic field inside the loop through means of coronal seismology. We discuss the possible interpretations of the wave as either standing or propagating torsional Alfvén or fast kink waves. An estimate of the plasma beta parameter of the condensations indicates a condition that may allow the often observed separation and elongation processes of the condensations. We also show that the wave pressure from the transverse wave can be responsible for the observed low downward acceleration of coronal rain.

Global prominence oscillations

U. **Anzer**

A&A 497, 521-524 (**2009**)

Aims. The question of the different oscillation periods for global modes of quiescent prominences is discussed.

Methods. Simple 1D prominence configurations are used to describe the magnetohydrostatic equilibrium and

their oscillations for small amplitudes.
Results. Three basic modes of oscillations were found and their periods as a function of the magnetic field configuration and the assumed geometry are given.

Prominence modelling: from observed emission measures to temperature profiles

U. **Anzer** and P. Heinzel

A&A 480, 537-542 (2008)

*Aims.*We outline the construction of prominence - corona transition region models based upon the observations of one particular prominence.
*Methods.*The differential emission measure curves from observations were approximated by simple analytical functions. On this basis we constructed the temperature curve and calculated the radiative losses, the gains by thermal conduction, and some estimates for the wave heating.
*Results.*The temperature curve was calculated in the range between 23 000 K and 450 000 K. The resulting transition region can be divided into an inner region where the temperature is low and the radiative losses are very large, a part with a very steep temperature rise from 40 000 K to around 250 000 K over a width of only 500 km, and an extended high temperature region. Both the conductive heating and our estimates for a possible wave cooling/heating peak very sharply in the region with the very large temperature gradient. The consequences for the energy balance are discussed.

Is the magnetic field in quiescent prominences force-free?

U. **Anzer**[1] and P. Heinzel[2, 1]

A&A 467, 1285-1288 (2007), File

The existing observational determinations of the magnetic field are summarised and the calculation of the plasma β is outlined.
In many cases of well-developed quiescent prominences the field can deviate substantially from the force-free situation and gravity fully determines the structure of the magnetic dips.

Solar Filaments and Interplanetary Magnetic Field Bz

V. **Aparna** and Petrus C. Martens

2020 ApJ 897 68

https://doi.org/10.3847/1538-4357/ab908b
https://sci-hub.st/10.3847/1538-4357/ab908b

The direction of the axis of an interplanetary coronal mass ejection (ICME) plays an important role in determining if it will cause a geomagnetic disturbance in the Earth's magnetosphere upon impact. Long period southward-pointing ICME fields are known to cause significant space weather impacts and thus geomagnetic storms. We present an extensive analysis of CME–ICME directionality using 86 halo-CMEs observed between 2007 and 2017 to compare the direction of the source filament axial magnetic field on the Sun and the direction of the interplanetary magnetic field near the Earth at the L1 Lagrangian point. Excluding 12 cases that were too ambiguous to determine, for the remaining 74 ICMEs, we find an agreement in terms of the northward/southward orientation of B z between ICMEs and their CME source regions in 85% of cases. Some of the previous studies discussed here have obtained an agreement of 77% and 55%. We therefore suggest that our method can be meaningful as a first step in efficiently predicting geoeffective ICMEs by observing and analyzing the source regions of CMEs on the Sun. **2012.03.26, 2013.04.14, 2013.12.08, 2014.12.21, 2016.01.01**

A FLUX EMERGENCE MODEL FOR SOLAR ERUPTIONS

V. **Archontis**1 and A. W. Hood1

The Astrophysical Journal, 674:L113–L116, **2008** February 20

http://www.journals.uchicago.edu/doi/pdf/10.1086/529377

We have simulated the three-dimensional (3D) emergence and interaction of two twisted flux tubes, which rise from the interior into the outer atmosphere of the Sun. We present evidence for the multiple formation and eruption of flux ropes inside the emerging flux systems and hot arcade-like structures in between them. Their formation is due to internal reconnection, occurring between oppositely directed, highly stretched, and sheared field lines at photospheric heights. Most of the eruptions escape into the corona, but some are confined and fade away without leaving the low atmosphere. As these flux ropes erupt, new reconnected field lines accumulate around the main axis of the initial magnetic flux systems. We also show the complex 3D field-line geometry and the structure of the multiple current sheets, which form as a result of the reconnection between the emerging flux systems.

Superoscillations in solar MHD waves and their possible role in heating coronal loops

A. López **Ariste**, M. Facchin

A&A **2018**

https://arxiv.org/pdf/1801.08330.pdf

Aims: To study the presence of superoscillations in coronal magnetoacoustic waves and its possible role in heating coronal loops through the strong and localized gradients they generate on the wave. Methods: An analytic model is built for the transition between a sausage and a kink wave modes propagating along field lines in the corona. We compute in this model the local frequencies, the wave gradients and the associated heating rates due to compressive viscosity. Results: We find superoscillations associated with the transition between wave modes accompanying the wave dislocation that shifts through the wave domain. Frequencies 10 times higher than the normal frequency are found. This means that a typical 3-minute coronal wave will locally oscillate in 10 to 20 seconds. Such high frequencies bring up strong gradients that efficiently dissipate the wave through compressive viscosity. We compute the associated heating rates. Locally, they are very strong, largely compensating typical radiative losses. Conclusions: We find a new heating mechanism associated to magnetoacoustic waves in the corona. Heating due to superoscillations only happens along particular field lines with small cross sections, comparable in size to coronal loops, inside the much larger magnetic flux tubes and wave propagation domain.

Bayesian evidence for two slow-wave damping models in hot coronal loops

I. **Arregui**, D. Y. Kolotkov, V. M. Nakariakov

A&A **2023**

https://arxiv.org/pdf/2307.02439.pdf

We compute the evidence in favour of two models, one based on field-aligned thermal conduction alone and another that includes thermal misbalance as well, in explaining the damping of slow magneto-acoustic waves in hot coronal loops. Our analysis is based on the computation of the marginal likelihood and the Bayes factor for the two damping models. We quantify their merit in explaining the apparent relationship between slow mode periods and damping times, measured with SOHO/SUMER in a set of hot coronal loops. The results indicate evidence in favour of the model with thermal misbalance in the majority of the sample, with a small population of loops for which thermal conduction alone is more plausible. The apparent possibility of two different regimes of slow-wave damping, if due to differences between the loops of host active regions and/or the photospheric dynamics, may help with revealing the coronal heating mechanism.

Bayesian evidence for a nonlinear damping model for coronal loop oscillations

I. **Arregui**

ApJ **915** L25 **2021**

https://arxiv.org/pdf/2106.12243.pdf

https://doi.org/10.3847/2041-8213/ac0d53

Recent observational and theoretical studies indicate that the damping of solar coronal loop oscillations depends on the oscillation amplitude. We consider two mechanisms, linear resonant absorption and a nonlinear damping model. We confront theoretical predictions from these models with observed data in the plane of observables defined by the damping ratio and the oscillation amplitude. The structure of the Bayesian evidence in this plane displays a clear separation between the regions where each model is more plausible relative to the other. There is qualitative agreement between the regions of high marginal likelihood and Bayes factor for the nonlinear damping model and the arrangement of observed data. A quantitative application to 101 loop oscillation cases observed with SDO/AIA results in the marginal likelihood for the nonlinear model being larger in the majority of them. The cases with conclusive evidence for the nonlinear damping model outnumber considerably those in favor of linear resonant absorption.

Inference of magnetic field strength and density from damped transverse coronal waves

I. **Arregui**, M. Montes-Solis, A. Asensio Ramos

A&A 625, A35 **2019**

https://arxiv.org/pdf/1903.05437.pdf

A classic application of coronal seismology uses transverse oscillations of waveguides to obtain estimates of the magnetic field strength. The procedure requires information on the density of the structures. Often, it ignores the damping of the oscillations. We computed marginal posteriors for parameters such as the waveguide density; the density contrast; the transverse inhomogeneity length-scale; and the magnetic field strength, under the assumption that the oscillations can be modelled as standing magnetohydrodynamic (MHD) kink modes damped by resonant absorption. Our results show that the magnetic field strength can be properly inferred, even if the densities inside and outside the structure are largely unknown. Incorporating observational estimates of plasma density further constrains the obtained posteriors. The amount of information one is willing to include (a priori) for the density and the density contrast influences their corresponding posteriors, but very little the inferred magnetic field strength. The decision to include or leave out the information on the damping and the damping time-scales have a minimal impact on the obtained magnetic field strength. In contrast to the classic method which provides with numerical estimates with error bars or possible ranges of variation for the magnetic field strength, Bayesian methods offer the full distribution of plausibility over the considered range of possible values. The methods are applied to available datasets of observed transverse loop oscillations, can be extended to prominence fine structures or chromospheric spicules and implemented to propagating waves in addition to standing oscillations.

Prominence oscillations Review

Iñigo **Arregui**, Ramón Oliver, José Luis Ballester

Living Reviews in Solar Physics December **2018**, 15:3 **File**

http://sci-hub.tw/http://link.springer.com/10.1007/s41116-018-0012-6

Prominences are intriguing, but poorly understood, magnetic structures of the solar corona. The dynamics of solar prominences has been the subject of a large number of studies, and of particular interest is the study of prominence oscillations. Ground- and space-based observations have confirmed the presence of oscillatory motions in prominences and they have been interpreted in terms of magnetohydrodynamic waves. This interpretation opens the door to perform prominence seismology, whose main aim is to determine physical parameters in magnetic and plasma structures (prominences) that are difficult to measure by direct means. Here, we review the observational information gathered about prominence oscillations as well as the theoretical models developed to interpret small and large amplitude oscillations and their temporal and spatial attenuation. Finally, several prominence seismology applications are presented. **30 Nov 2006**,

Model comparison for the density structure along solar prominence threads

I. **Arregui**, R. Soler

A&A 578, A130 **2015**

http://arxiv.org/pdf/1505.03448v1.pdf

Quiescent solar prominence fine structures are typically modelled as density enhancements, called threads, which occupy a fraction of a longer magnetic flux tube. The profile of the mass density along the magnetic field is however unknown and several arbitrary alternatives are employed in prominence wave studies. We present a comparison of theoretical models for the field-aligned density along prominence fine structures. We consider Lorentzian, Gaussian, and parabolic profiles. We compare their theoretical predictions for the period ratio between the fundamental transverse kink mode and the first overtone to obtain estimates for the ratio of densities between the central part of the tube and its foot-points and to assess which one would better explain observed period ratio data. Bayesian parameter inference and model comparison techniques are developed and applied. Parameter inference requires the computation of the posterior distribution for the density gradient parameter conditional on the observable period ratio. Model comparison involves the computation of the marginal likelihood as a function of the period ratio to obtain the plausibility of each density model and the computation of Bayes Factors to quantify the relative evidence for each model, given a period ratio observation. A Lorentzian density profile, with plasma density concentrated around the centre of the tube seems to offer the most plausible inversion result. A Gaussian profile would require unrealistically large values of the density gradient parameter and a parabolic density distribution does not enable us to obtain well constrained posterior probability distributions. However, our model comparison results indicate that the evidence points to the Gaussian and parabolic profiles for period ratios in between 2 and 3, while the Lorentzian profile is preferred for larger period ratio values.

Determination of the cross-field density structuring in coronal waveguides using the damping of transverse waves

I. **Arregui** and A. Asensio Ramos

E-print, April **2014**

Time and spatial damping of transverse magnetohydrodynamic (MHD) kink oscillations is a source of information on the cross-field variation of the plasma density in coronal waveguides. We show that a probabilistic approach to the problem of determining the density structuring from the observed damping of transverse oscillations enables us to obtain information on the two parameters that characterise the cross-field density profile. The inference is performed by computing the marginal posterior distributions for density contrast and transverse inhomogeneity length-scale using Bayesian analysis and damping ratios for transverse oscillations under the assumption that damping is produced by resonant absorption. The obtained distributions show that, for damping times of a few oscillatory periods, low density contrasts and short inho- mogeneity length scales are more plausible in explaining observations. This means that valuable information on the cross-field density profile can be obtained even if the inversion problem, with two unknowns and one observable, is a mathematically ill-posed problem.

Prominence seismology A review

I. **Arregui**, J. L. Ballester, R. Oliver, R. Soler, J. Terradas

E-print, Feb 2012, 4th Hinode Science Meeting: Unsolved Problems and New Insights ASP Conference Series, Vol. 455, pp. 211-218 (**2012**)

Given the difficulty in directly determining prominence physical parameters from observations, prominence seismology stands as an alternative method to probe the nature of these structures. We show recent examples of the application of magnetohydrodynamic (MHD) seismology techniques to infer physical parameters in prominence plasmas. They are based on the application of inversion techniques using observed periods, damping times, and plasma flow speeds of prominence thread oscillations. The contribution of Hinode to the subject has been of central importance. We show an example based on data obtained with Hinode's Solar Optical Telescope. Observations show an active region limb prominence, composed by a myriad of thin horizontal threads that flow following a path parallel to the photosphere and display synchronous vertical oscillations. The coexistence of waves and flows can be firmly established. By making use of an interpretation based on transverse MHD kink oscillations, a seismological analysis of this event is performed. It is shown that the combination of high quality Hinode observations and proper theoretical models allows flows and waves to become two useful characteristics for our understanding of the nature of solar prominences.

Damping Mechanisms for Oscillations in Solar Prominences

Arregui, I., Ballester, J.L.:

2011, Space Sci. Rev. 158, No. 2-4, 169-204.

Small amplitude oscillations are a commonly observed feature in prominences/filaments. These oscillations appear to be of local nature, are associated to the fine structure of prominence plasmas, and simultaneous flows and counterflows are also present. The existing observational evidence reveals that small amplitude oscillations, after excited, are damped in short spatial and temporal scales by some as yet not well determined physical mechanism(s). Commonly, these oscillations have been interpreted in terms of linear magnetohydrodynamic (MHD) waves, and this paper reviews the theoretical damping mechanisms that have been recently put forward in order to explain the observed attenuation scales. These mechanisms include thermal effects, through non-adiabatic processes, mass flows, resonant damping in non-uniform media, and partial ionization effects. The relevance of each mechanism is assessed by comparing the spatial and time scales produced by each of them with those obtained from observations. Also, the application of the latest theoretical results to perform prominence seismology is discussed, aiming to determine physical parameters in prominence plasmas that are difficult to measure by direct means.

Magnetohydrodynamic kink waves in two-dimensional non-uniform prominence threads

I. **Arregui**1, R. Soler2, J. L. Ballester1 and A. N. Wright

A&A 533, A60 (**2011**)

Aims. We analyse the oscillatory properties of resonantly damped transverse kink oscillations in two-dimensional prominence threads.

Methods. The fine structures are modelled as cylindrically symmetric magnetic flux tubes with a dense central part with prominence plasma properties and an evacuated part, both surrounded by coronal plasma. The equilibrium density is allowed to vary non-uniformly in both the transverse and the longitudinal directions. We examine the influence of longitudinal density structuring on periods, damping times, and damping rates for transverse kink modes computed by numerically solving the linear resistive magnetohydrodynamic (MHD) equations.

Results. The relevant parameters are the length of the thread and the density in the evacuated part of the tube, two quantities that are difficult to directly estimate from observations. We find that both of them strongly influence the oscillatory periods and damping times, and to a lesser extent the damping ratios. The analysis of the spatial distribution of perturbations and of the energy flux into the resonances allows us to explain the obtained damping times.

Conclusions. Implications for prominence seismology, the physics of resonantly damped kink modes in two-dimensional magnetic flux tubes, and the heating of prominence plasmas are discussed.

Helical Twisting Number and Braiding Linkage Number of Solar Coronal Loops

Markus J. **Aschwanden**

2019 *ApJ* **874** 131

https://arxiv.org/pdf/1902.10612.pdf

sci-hub.se/10.3847/1538-4357/ab0b42

Coronal loops in active regions are often characterized by quasi-circular and helically twisted (sigmoidal) geometries, which are consistent with dipolar potential field models in the former case, and with nonlinear force-free field models with vertical currents in the latter case. Alternatively, Parker-type nanoflare models of the solar corona hypothesize that a braiding mechanism operates between unresolved loop strands, which is a more complex topological model. In this study we use the vertical-current approximation of a nonpotential magnetic field solution (that fulfills the divergence-free and force-free conditions) to characterize the number of helical turns Ntwist in twisted coronal loops. We measure the helical twist in 15 active regions observed with AIA and HMI/SDO and find a mean nonpotentiality angle (between the potential and nonpotential field directions) of μNP=15∘±3∘. The resulting mean rotational twist angle is φ=49∘±11∘, which corresponds to Ntwist=φ/360∘=0.14±0.03 turns with respect to the untwisted potential field, with an absolute upper limit of $N_{twist} \lapprox 0.5$, which is far below the kink

instability limit of $|N_{twist}| \gapprox 1$. The number of twist turns Ntwist corresponds to the Gauss linkage number Nlink in braiding topologies. We conclude that any braided topology (with |Nlink|≥1) cannot explain the observed stability of loops in a force-free corona, nor the observed low twist number. Parker-type nanoflaring can thus occur in non-forcefree environments only, such as in the chromosphere and transition region. **2011 November 08**
Table 1: Data (2010-2011)

The Width Distribution of Loops and Strands in the Solar Corona -- Are we Hitting Rock Bottom ?

Markus J. **Aschwanden**, Hard Peter
ApJ 840 4 **2017**
https://arxiv.org/pdf/1701.01177v1.pdf
http://www.lmsal.com/~aschwand/eprints/2016_width.pdf
In this study we analyze {\sl Atmospheric Imaging Assembly (AIA)} and Hi-C images in order to investigate absolute limits for the finest loop strands. We develop a model of the occurrence-size distribution function of coronal loop widths, characterized by a lower limit of widths wmin, a peak width wp, a peak occurrence number np, and a power law slope a. Our data analysis includes automated tracing of curvi-linear features with the OCCULT-2 code, automated sampling of the cross-sectional widths of coronal loops, and fitting of the theoretical size distribution to the observed distribution. With Monte-Carlo simulations and variable pixel sizes Δx we derive a first diagnostic criterion to discriminate whether the loop widths are unresolved (wp/Δx≈2.5±0.2), or fully resolved (if wp/Δx>2.7). For images with resolved loop widths we can apply a second diagnostic criterion that predicts the lower limit of loop widths, wmin≈3(Δxcrit−0.37") as a function of the critical resolution Δxcrit. We find that the loop widths are marginally resolved in AIA images, but are fully resolved in Hi-C images, where our model predicts a lower limit of loop widths at wmin≈100 km and a most frequent (peak) value at wp≈300 km, in agreement with recent results of Brooks et al. This result agrees with the statistics of photospheric granulation sizes and thus supports coronal heating mechanisms operating on the macroscopic scale of photospheric magneto-convection, rather than nanoflare heating models with unresolved microscopic scales. **2011 Feb 14**

Blind Stereoscopy of the Coronal Magnetic Field

Markus J. **Aschwanden**, Carolus J. Schrijver, Anna Malanushenko
Solar Phys. **2015**
http://arxiv.org/pdf/1506.04713v1.pdf
We test the feasibility of 3D coronal-loop tracing in stereoscopic EUV image pairs, with the ultimate goal of enabling efficient 3D reconstruction of the coronal magnetic field that drives flares and coronal mass ejections (CMEs). We developed an automated code designed to perform triangulation of coronal loops in pairs (or triplets) of EUV images recorded from different perspectives. The automated (or blind) stereoscopy code includes three major tasks: (i) automated pattern recognition of coronal loops in EUV images, (ii) automated pairing of corresponding loop patterns from two different aspect angles, and (iii) stereoscopic triangulation of 3D loop coordinates. We perform tests with simulated stereoscopic EUV images and quantify the accuracy of all three procedures. In addition we test the performance of the blind stereoscopy code as a function of the spacecraft-separation angle and as a function of the spatial resolution. We also test the sensitivity to magnetic non-potentiality. The automated code developed here can be used for analysis of existing {\sl Solar TErrestrial RElationship Observatory (STEREO)} data, but primarily serves for a design study of a future mission with dedicated diagnostics of non-potential magnetic fields. For a pixel size of 0.6\arcsec (corresponding to the {\sl Solar Dynamics Observatory (SDO) Atmospheric Imaging Assembly (AIA)} spatial resolution of 1.4\arcsec), we find an optimum spacecraft-separation angle of αs≈5∘. **15 February 2011**

Solar Stereoscopy with STEREO/EUVI A and B Spacecraft from Small (6∘) to Large (170∘) Spacecraft Separation Angles

Markus J. **Aschwanden**, Jean-Pierre Wülser, Nariaki Nitta, James Lemen
Solar Physics, November **2012**, Volume 281, Issue 1, pp 101-119
We performed for the first time stereoscopic triangulation of coronal loops in active regions over the entire range of spacecraft separation angles (α sep≈6∘,43∘,89∘,127∘,and 170∘). The accuracy of stereoscopic correlation depends mostly on the viewing angle with respect to the solar surface for each spacecraft, which affects the stereoscopic correspondence identification of loops in image pairs. From a simple theoretical model we predict an optimum range of α sep≈22∘–125∘, which is also experimentally confirmed. The best accuracy is generally obtained when an active region passes the central meridian (viewed from Earth), which yields a symmetric view for both STEREO spacecraft and causes minimum horizontal foreshortening. For the extended angular range of α sep≈6∘–127∘ we find a mean 3D misalignment angle of μ PF≈21∘–39∘ of stereoscopically triangulated loops with magnetic potential-field models, and μ FFF≈15∘–21∘ for a force-free field model, which is partly caused by stereoscopic

uncertainties μ SE≈9∘. We predict optimum conditions for solar stereoscopy during the time intervals of 2012 – 2014, 2016 – 2017, and 2021 – 2023. **30 April 2007**

FIRST THREE-DIMENSIONAL RECONSTRUCTIONS OF CORONAL LOOPS WITH THE STEREO A+B SPACECRAFT. IV. MAGNETIC MODELING WITH TWISTED FORCE-FREE FIELDS

Markus J. **Aschwanden**, Jean-Pierre Wuelser, Nariaki V. Nitta, James R. Lemen, Marc L. DeRosa, and Anna Malanushenko

2012 ApJ 756 124

The three-dimensional coordinates of stereoscopically triangulated loops provide strong constraints for magnetic field models of active regions in the solar corona. Here, we use STEREO/A and B data from some 500 stereoscopically triangulated loops observed in four active regions (**2007 April 30, May 9, May 19, and December 11**), together with SOHO/MDI line-of-sight magnetograms. We measure the average misalignment angle between the stereoscopic loops and theoretical magnetic field models, finding a mismatch of μ = 19°-46° for a potential field model, which is reduced to μ = 14°-19° for a non-potential field model parameterized by twist parameters. The residual error is commensurable with stereoscopic measurement errors (μSE 8°-12°). We developed a potential field code that deconvolves a line-of-sight magnetogram into three magnetic field components (Bx , By , Bz), as well as a non-potential field forward-fitting code that determines the full length of twisted loops (L 50-300 Mm), the number of twist turns (median N twist = 0.06), the nonlinear force-free α-parameter (median α 4 × 10–11 cm–1), and the current density (median jz 1500 Mx cm–2 s–1). All twisted loops are found to be far below the critical value for kink instability, and Joule dissipation of their currents is found to be far below the coronal heating requirement. The algorithm developed here, based on an analytical solution of nonlinear force-free fields that is accurate to second order (in the force-free parameter α), represents the first code that enables fast forward fitting to photospheric magnetograms and stereoscopically triangulated loops in the solar corona.

A Nonlinear Force-Free Magnetic Field Approximation Suitable for Fast Forward-Fitting to Coronal Loops. II. Numeric Code and Tests

Markus J. **Aschwanden**

E-print, July **2012**, Solar Phys.

Based on a second-order approximation of nonlinear force-free magnetic field solutions in terms of uniformly twisted field lines derived in Paper I, we develop here a numeric code that is capable to forward-fit such analytical solutions to arbitrary magnetogram (or vector magnetograph) data combined with (stereoscopically triangulated) coronal loop 3D coordinates. We test the code here by forward-fitting to six potential field and six nonpotential field cases simulated with our analytical model, as well as by forward-fitting to an exactly force-free solution of the Low and Lou (1990) model. The forward-fitting tests demonstrate: (i) a satisfactory convergence behavior (with typical misalignment angles of mu approx 1°-10°), (ii) relatively fast computation times (from seconds to a few minutes), and (iii) the high fidelity of retrieved force-free α -parameters (α m fitα m model approx 0.9-1.0$ for simulations and α m fitα m model approx 0.7pm0.3$ for the Low and Lou model). The salient feature of this numeric code is the relatively fast computation of a quasi-forcefree magnetic field, which closely matches the geometry of coronal loops in active regions, and complements the existing {sl nonlinear force-free field (NLFFF)} codes based on photospheric magnetograms without coronal constraints.

A Nonlinear Force-Free Magnetic Field Approximation Suitable for Fast Forward-Fitting to Coronal Loops. I. Theory

Markus J. **Aschwanden**

E-print, July **2012**, Solar Phys.

We derive an analytical approximation of nonlinear force-free magnetic field solutions (NLFFF) that can efficiently be used for fast forward-fitting to solar magnetic data, constrained either by observed line-of-sight magnetograms and stereoscopically triangulated coronal loops, or by 3D vector-magnetograph data. The derived NLFFF solutions provide the magnetic field components B_x({□f x}), B_y({□f x}), B_z({□f x}), the force-free parameter α {□f x})$, the electric current density {□f j}({□f x}), and are accurate to second-order (of the nonlinear force-free α -parameter). The explicit expressions of a force-free field can easily be applied to modeling or forward-fitting of many coronal phenomena.

CORONAL LOOP OSCILLATIONS OBSERVED WITH ATMOSPHERIC IMAGING ASSEMBLY—KINK MODE WITH CROSS-SECTIONAL AND DENSITY OSCILLATIONS

Markus J**. Aschwanden** and Carolus J. Schrijver

2011 ApJ 736 102

A detailed analysis of a coronal loop oscillation event is presented, using data from the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory (SDO) for the first time. The loop oscillation event occurred on **2010 October 16**, 19:05-19:35 UT and was triggered by an M2.9 GOES-class flare, located inside a highly inclined cone of a narrow-angle coronal mass ejection. This oscillation event had a number of unusual features: (1) excitation of kink-mode oscillations in vertical polarization (in the loop plane), (2) coupled cross-sectional and density oscillations with identical periods, (3) no detectable kink amplitude damping over the observed duration of four kink-mode periods (P=6.3 minutes), (4) multi-loop oscillations with slightly (10%) different periods, and (5) a relatively cool loop temperature of T 0.5 MK. We employ a novel method of deriving the electron density ratio external and internal to the oscillating loop from the ratio of Alfvénic speeds deduced from the flare trigger delay and the kink-mode period, i.e., ne /ni = (vA /v Ae)2 = 0.08 ± 0.01. The coupling of the kink mode and cross-sectional oscillations can be explained as a consequence of the loop length variation in the vertical polarization mode. We determine the exact footpoint locations and loop length with stereoscopic triangulation using STEREO/EUVI/A data. We model the magnetic field in the oscillating loop using Helioseismic and Magnetic Imager/SDO magnetogram data and a potential-field model and find agreement with the seismological value of the magnetic field, B kink = 4.0 ± 0.7 G, within a factor of two.

SOLAR CORONA LOOP STUDIES WITH THE ATMOSPHERIC IMAGING ASSEMBLY. I. CROSS-SECTIONAL TEMPERATURE STRUCTURE

Markus J. **Aschwanden** and Paul Boerner

2011 ApJ 732 81

We present a first systematic study on the cross-sectional temperature structure of coronal loops using the six coronal temperature filters of the Atmospheric Imaging Assembly (AIA) instrument on the Solar Dynamics Observatory (SDO). We analyze a sample of 100 loop snapshots measured at 10 different locations and 10 different times in active region NOAA 11089 on **2010 July 24**, 21:00-22:00 UT. The cross-sectional flux profiles are measured and a cospatial background is subtracted in six filters in a temperature range of T 0.5-16 MK, and four different parameterizations of differential emission measure (DEM) distributions are fitted. We find that the reconstructed DEMs consist predominantly of narrowband peak temperature components with a thermal width of σlog (T) ≤ 0.11 ± 0.02, close to the temperature resolution limit of the instrument, consistent with earlier triple-filter analysis from the Transition Region and Coronal Explorer by Aschwanden & Nightingale and from EIS/Hinode by Warren et al. or Tripathi et al. We find that 66% of the loops could be fitted with a narrowband single-Gaussian DEM model, and 19% with a DEM consisting of two narrowband Gaussians (which mostly result from pairs of intersecting loops along the same line of sight). The mostly isothermal loop DEMs allow us also to derive an improved empirical response function of the AIA 94 Å filter, which needs to be boosted by a factor of q 94 = 6.7 ± 1.7 for temperatures at log (T) 6.3. The main result of near-isothermal loop cross-sections is not consistent with the predictions of standard nanoflare scenarios, but can be explained by flare-like heating mechanisms that drive chromospheric evaporation and upflows of heated plasma coherently over loop cross-sections of w 2-4 Mm.

Modeling of Hot Plasma in the Solar Active Region Core

M. **Asgari-Targhi**1, J. T. Schmelz2, S. Imada3, S. Pathak2, and G. M. Christian

2015 ApJ 807 146

Magnetically confined plasma with temperatures $\gtrsim 5$ MK are a feature of hot coronal loops observed in the core of active regions. In this paper, using observations and MHD modeling of coronal loops, we investigate whether wave heating (Alternating Current) models can describe the high temperature loops observed in the active region of **2012 September 7**. We construct three-dimensional MHD models for the Alfvén wave turbulence within loops with high temperature. We find that for the Alfvén waves to create enough turbulence to heat the corona, the rms velocity at the footpoints must be 5–6 $\mathrm{km\ s^{-1}}$. We conclude that the Alfvén wave turbulence model may be a candidate for explaining how the hot loops are heated, provided the loops have a high velocity at their photospheric footpoints.

Comparison of Extreme Ultraviolet Imaging Spectrometer Observations of Solar Coronal Loops with Alfvén Wave Turbulence Models

M. **Asgari-Targhi**, A. A. van Ballegooijen, and S. Imada

2014 ApJ 786 28

The observed non-thermal widths of coronal emission lines could be due to Alfvén wave turbulence. To test this idea, we examine and analyze the dynamics of an active region observed on **2012 September 7**. We use spectral line profiles of Fe XII, Fe XIII, Fe XV, and Fe XVI obtained by the Extreme-ultraviolet Imaging Spectrometer on the it Hinode spacecraft. The observations show non-thermal velocities, Doppler outflows, and intensities for loops in this active region. The observed non-thermal velocities are compared with predictions from models for Alfvén wave turbulence in the observed coronal loops. This modeling takes into account the relationship between the width of the coronal emission lines and the orientation of the coronal loops with respect to the line-of-sight direction. We find that in order to produce the observed line widths we need to introduce a random parallel-flow component in addition to the perpendicular velocity due to Alfvén waves. The observed widths are consistent with photospheric footpoint velocities in the range 0.3-1.5 km s–1. We conclude that the Alfvén wave turbulence model is a strong candidate for explaining how the observed loops are heated.

Effects of Pseudostreamer Boundary Dynamics on Heliospheric Field and Wind

V. **Aslanyan**1, D. I. Pontin2, P. F. Wyper3, R. B. Scott4, S. K. Antiochos5, and C. R. DeVore5

2021 ApJ 909 10

https://doi.org/10.3847/1538-4357/abd6e6

https://iopscience.iop.org/article/10.3847/1538-4357/abd6e6/pdf

Interchange reconnection has been proposed as a mechanism for the generation of the slow solar wind, and a key contributor to determining its characteristic qualities. In this paper we study the implications of interchange reconnection for the structure of the plasma and field in the heliosphere. We use the Adaptively Refined Magnetohydrodynamic Solver to simulate the coronal magnetic evolution in a coronal topology containing both a pseudostreamer and helmet streamer. We begin with a geometry containing a low-latitude coronal hole that is separated from the main polar coronal hole by a pseudostreamer. We drive the system by imposing rotating flows at the solar surface within and around the low-latitude coronal hole, which leads to a corrugation (at low altitudes) of the separatrix surfaces that separate open from closed magnetic flux. Interchange reconnection is induced both at the null points and separators of the pseudostreamer, and at the global helmet streamer. We demonstrate that a preferential occurrence of interchange reconnection in the "lanes" between our driving cells leads to a filamentary pattern of newly opened flux in the heliosphere. These flux bundles connect to but extend far from the separatrix-web (S-Web) arcs at the source surface. We propose that the pattern of granular and supergranular flows on the photosphere should leave an observable imprint in the heliosphere.

Thermal Non-Equilibrium Revealed by Periodic Pulses of Random Amplitudes in Solar Coronal Loops

F. **Auchère**, C. Froment, K. Bocchialini, E. Buchlin, J. Solomon

2016 *ApJ* **827** 152

http://arxiv.org/pdf/1608.03789v1.pdf

Models of loops including stratified and quasi-steady heating predict the development of a state of thermal non-equilibrium (TNE): cycles of evaporative upflows at the footpoints followed by falling condensations at the apex. Based on Fourier and wavelet analysis, we demonstrate that the observed periodic signals are indeed not signatures of vibrational modes. Instead, superimposed on the power law expected from the stochastic background emission, the power spectra of the time series exhibit the discrete harmonics and continua expected from periodic trains of pulses of random amplitudes. These characteristics reinforce our earlier interpretation of these pulsations as being aborted TNE cycles.

Mass Motion in a Prominence Bubble Revealing a Kinked Flux Rope Configuration

Arun Kumar **Awasthi**, Rui Liu

Front. Phys. 7:218. **2019**

https://arxiv.org/pdf/1911.12100.pdf

https://doi.org/10.3389/fphy.2019.00218

https://www.frontiersin.org/articles/10.3389/fphy.2019.00218/full?utm_source=F-AAE&utm_medium=EMLF&utm_campaign=MRK_1209521_64_Physic_20200114_arts_A

Prominence bubbles are cavities rising into quiescent prominences from below. The bubble-prominence interface is often the active location for the formation of plumes, which flow turbulently into quiescent prominences. Not only the origin of prominence bubbles is poorly understood, but most of their physical characteristics are still largely unknown. Here, we investigate the dynamical properties of a bubble, which is observed since its early emergence beneath the spine of a quiescent prominence on **20 October 2017** in the Hα line-center and in ±0.4 Å line-wing wavelengths by the 1-m New Vacuum Solar Telescope. We report the prominence bubble to be exhibiting a disparate morphology in the Hα line-center compared to its line-wings' images, indicating a complex pattern of mass motion along the line-of-sight. Combining Doppler maps with flow maps in the plane of sky derived from a Nonlinear Affine Velocity Estimator, we obtained a comprehensive picture of mass motions revealing a counter-clockwise rotation inside the bubble; with blue-shifted material flowing upward and red-shifted material flowing downward. This sequence of mass motions is interpreted to be either outlining a kinked flux rope configuration of the prominence bubble or providing observational evidence of the internal kink instability in the prominence plasma.

Spectroscopic Diagnostic of the Footpoints of the Cool loops

B. Suresh **Babu**, Pradeep Kayshap, Sharad C. Tripathi, P. Jelinek, B. N. Dwivedi

MNRAS Volume 528, Issue 2, February **2024**, Pages 2474–2489,

https://arxiv.org/pdf/2401.07005.pdf

https://academic.oup.com/mnras/article-pdf/528/2/2474/56485911/stae166.pdf

Statistically, the cool loop's footpoints are diagnosed using Si~{\sc iv} resonance lines observations provided by Interface Region Imaging Spectrograph (IRIS). The intensity and Full Width at Half Maximum (FWHM) of the loop's footpoints in β{--}γ active regions (ARs) are higher than the corresponding parameters of footpoints in β ARs. However, the Doppler velocity of footpoints in both ARs are almost similar to each other. The intensities of footpoints from β{--}γ AR is found to be around 9 times that of β AR when both ARs are observed nearly at the same time. The same intensity difference reduces nearly to half (4 times) when considering all ARs observed over 9 years. Hence, the instrument degradation affects comparative intensity analysis. We find that Doppler velocity and FWHM are well-correlated while peak intensity is neither correlated with Doppler velocity nor FWHM. The loop's footpoints in β-γ ARs have around four times more complex Si~{\sc iv} spectral profiles than that of β ARs. The intensity ratios (Si~{\sc iv} 1393.78~Å/1402.77~Å) of the significant locations of footpoints differ, marginally, (i.e., either less than 1.9 or greater than 2.10) from the theoretical ratio of 2, i.e., 52\% (55\%) locations in β (β{--}γ) ARs significantly deviate from 2. Hence, we say that more than half of the footpoint locations are either affected by the opacity or resonance scattering. We conclude that the nature and attributes of the footpoints of the cool loops in β-γ ARs are significantly different from those in β ARs.

Seismology of Oscillating Flux Tube with Twisted Magnetic Field and Plasma Flow

Karam **Bahari**

Solar Physics August **2017**, 292:110

Transverse oscillations of a thin coronal loop in a zero-beta plasma in the presence of a twisted magnetic field and flow are investigated. The dispersion relation is obtained in the limit of weak twist. The twisted magnetic field modifies the phase difference and asymmetry of standing kink oscillations caused by the flow. Using data from observations the kink speed and flow speed have been determined. The presence of the twisted magnetic field can cause underestimation or overestimation of the flow speed in coronal loops depending on the direction of the flow and twisted magnetic field, but a twisted magnetic field has little effect on the estimated value of the kink speed.

THE MAGNETIC STRUCTURE OF SOLAR PROMINENCE CAVITIES: NEW OBSERVATIONAL SIGNATURE REVEALED BY CORONAL MAGNETOMETRY

Urszula **Ba¸k-Ste¸ślicka1**,5, Sarah E. Gibson2, Yuhong Fan2, Christian Bethge2, Blake Forland3, and Laurel A. Rachmeler

2013 ApJ 770 L28

The Coronal Multi-Channel Polarimeter (CoMP) obtains daily full-Sun above-the-limb coronal observations in linear polarization, allowing, for the first time, a diagnostic of the coronal magnetic field direction in quiescent prominence cavities. We find that these cavities consistently possess a characteristic "lagomorphic" signature in linear polarization indicating twist or shear extending up into the cavity above the neutral line. We demonstrate that such a signature may be explained by a magnetic flux-rope model, a topology with implications for solar eruptions. We find corroborating evidence for a flux-rope structure in the pattern of concentric rings within cavities seen in CoMP line-of-sight velocity.

THE DISAPPEARING SOLAR FILAMENT OF 2003 JUNE 11: A THREE-BODY PROBLEM

K. S. **Balasubramaniam**1, A. A. Pevtsov2, E. W. Cliver3, S. F. Martin4 and O. Panasenco

2011 ApJ 743 202

The eruption of a large quiescent filament on **2003 June 11** was preceded by the birth of a nearby active region—a common scenario. In this case, however, the filament lay near a pre-existing active region and the new active region did not destabilize the filament by direct magnetic connection. Instead it appears to have done so indirectly via magnetic coupling with the established region. Restructuring between the perturbed fields of the old region and the filament then weakened the arcade overlying the midpoint of filament, where the eruption originated. The inferred rate (~11° day–1) at which the magnetic disturbance propagates from the mature region to destabilize the filament is larger than the mean speed (~5º-6° day–1) but still within the scatter obtained for Bruzek's empirical relationship between the distance from a newly formed active region to a quiescent filament and the time from active region appearance to filament disappearance. The higher propagation speed in the 2003 June 11 case may be due to the "broadside" (versus "end-on") angle of attack of the (effective) new flux to the coronal magnetic fields overlying a central section of the axis of the filament.

Dissipative instability in a partially ionised prominence plasma slab

I. **Ballai**1;2, B. Pint_er3, R Oliver4 and M. Alexandrou

A&A **2017**

https://arxiv.org/pdf/1703.07452.pdf

We investigate the nature of dissipative instability appearing in a prominence planar thread filled with partially ionised plasma in the incompressible limit. The importance of partial ionisation is investigated in terms of the ionisation factor and wavelength of waves propagating in the slab. To highlight the role of partial ionisation, we have constructed models describing various situations we can meet in solar prominence fine structure. Matching the solutions for the transversal component of the velocity and total pressure at the interfaces between the prominence slab and surrounding plasmas, we derived a dispersion relation whose imaginary part describes the evolution of the instability. Results are obtained in the limit of weak dissipation. We have investigated the appearance of instabilities in prominence dark plumes using single and two-fluid approximations. We show that dissipative instabilities appear for flow speeds that are less than the Kelvin-Helmholtz instability threshold. The onset of instability is determined by the equilibrium flow strength, the ionisation factor of the plasma, the wavelength of waves and the ion-neutral collisional rate. For a given wavelength and for ionisation degrees closer to a neutral gas, the propagating waves become unstable for a narrow band of flow speeds, meaning that neutrals have a stabilising effect. Our results show that the partially ionised plasma describing prominence dark plumes becomes unstable only in a two-fluid (charged particles-neutrals) model, that is for periods that are smaller than the ion-neutral collision time. The present study improves our understanding of stability of solar prominences and the role of partial ionisation in destabilising the plasma. We show the necessity of two-fluid approximation when discussing the nature of instabilities: waves in a single fluid approximation show a great deal of stability.

Dissipative instability in partially ionised prominence plasmas

Ballai, R. OIiver, M. Alexandrou

A&A 577, A82 **2015**

E-print, March 2015

http://arxiv.org/pdf/1503.07917v1.pdf

We investigate the nature of dissipative instability at the boundary (seen here as tangential discontinuity) between the viscous corona and the partially ionised prominence plasma in the incompressible limit. The importance of the partial ionisation is investigated in terms of the ionisation fraction. Matching the solutions for the transversal component of the velocity and total pressure at the interface between the prominence and coronal plasmas, we derive a dispersion relation whose imaginary part describes the evolution of the instability. Results are obtained in the limit of weak dissipation. Using simple analytical methods, we show that dissipative instabilities appear for flow speeds that are lower than the Kelvin-Helmholtz instability threshold. While viscosity tends to destabilise the plasma, the effect of partial ionisation (through the Cowling resistivity) will act towards stabilising the interface. For ionisation degrees closer to a neutral gas the interface will be unstable for larger values of equilibrium flow. The same principle is assumed when studying the appearance of instability at the interface between prominences and dark plumes. The unstable mode appearing in this case has a very small growth rate and dissipative instability cannot explain the appearance of flows in plumes. The present study improves our understanding of the complexity of dynamical processes at the interface of solar prominences and solar corona, and the role partial ionisation can have on the stability of the plasma. Our results clearly show that the problem of partial ionisation introduces new aspects of plasma stability with consequences on the evolution of solar prominences.

Transverse kink oscillations of expanding coronal loops

I. **Ballai** and B. Orza

A&A 545, A118 (**2012**)

Aims. We investigate the nature of transverse kink oscillations of loops expanding through the solar corona and examine how can oscillations be used to diagnose plasma parameters and the magnetic field. In particular, we aim to analyse how the temporal dependence of the loop length (here modelling the expansion) will affect the P1/P2 period ratio of transverse loop oscillations.

Methods. Due to the uncertainty of the loop's shape through its expansion, we discuss separately the case of the loop that maintains its initial semi-circular shape and the case of the loop that evolves into an elliptical-shape loop from a semi-circular shape. The equations that describe the oscillations in an expanding flux tube are complicated due to the spatial and temporal dependence of coefficients. Using the WKB approximation, we find approximative values for periods and their evolution as well as the period ratio. For small values of time (near the start of the expansion), we can employ a regular perturbation method to find approximative relations for eigenfunctions and eigenfrequencies.

Results. Using simple analytical and numerical methods, we show that the period of oscillations are affected by the rising of the coronal loop. The change in the period due to the increase in the loop's length is more pronounced for loops that expand into a more structured (or cooler) corona. The deviation of periods will have significant implications in determining the degree of stratification in the solar corona. The effect of expansion on the periods of oscillations is considerable only when the loop is expanding but not after it has reached its final stage.
Conclusions. The present study improves our understanding of the complexity of dynamical processes in the solar corona, in particular the changes of periods of kink oscillations due to temporal changes in the characteristics of the coronal loop. Our results clearly show that the problem of expansion of coronal loops can introduce significant changes in the period of oscillations, with consequences on the seismological diagnostics of the plasma and magnetic field.

TRACE observations of driven loop oscillations

I. **Ballai**1, D. B. Jess2 and M. Douglas

A&A 534, A13 (**2011**)

Aims. On **13 June 1998**, the TRACE satellite was fortuitously well placed to observe the effects of a flare-induced **EIT wave** in the corona, and its subsequent interaction with coronal magnetic **loops**. In this study, we use these TRACE observations to corroborate previous theoretical work, which determined the response of a coronal loop to a harmonic driver in the context of ideal magnetohydrodynamics, as well as estimate the magnetic field strength and the degree of longitudinal inhomogeneity.
Methods. Loop edges are tracked, both spatially and temporally, using wavelet modulus maxima algorithms, with corresponding loop displacements from its quiescent state analysed by fitting scaled sinusoidal functions. The physical parameters of the coronal loop are subsequently determined using seismological techniques.
Results. The studied coronal loop is found to oscillate with two distinct periods, 501 ± 5 s and 274 ± 7 s, which could be interpreted as belonging to the fundamental kink mode and first harmonic, or could reflect the stage of an overdriven loop. Additional scenarios for explaining the two periods are listed, each resulting in a different value of the magnetic field and the intrinsic and sub-resolution properties of the coronal loop. When assuming the periods belong to the fundamental kink mode and its first harmonic, we obtain a magnetic field strength inside the oscillating coronal loop of 2.0 ± 0.7 G. In contrast, interpreting the oscillations as a combination of the loop's natural kink frequency and a harmonic EIT wave provides a magnetic field strength of 5.8 ± 1.5 G. Using the ratio of the two periods, we find that the gravitational scale height in the loop is 73 ± 3 Mm.
Conclusions. We show that the observation of two distinct periods in a coronal loop does not necessarily lead to a unique conclusion. Multiple plausible scenarios exist, suggesting that both the derived strength of the magnetic field and the sub-resolution properties of the coronal loop depend entirely on which interpretation is chosen. The interpretation of the observations in terms of a combination of the natural kink mode of the coronal loop, driven by a harmonic EIT wave seems to result in values of the magnetic field consistent with previous findings. Other interpretations, which are realistic, such as kink fundamental mode/first harmonic and the oscillations of two sub-resolution threads result in magnetic field strengths that are below the average values found before.

The first adiabatic exponent in a partially ionized prominence plasma: Effect on the period of slow waves

J. L. **Ballester**1,3, R. Soler1,3, M. Carbonell2,3 and J. Terradas1,3

A&A 656, A159 (**2021**)

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Partially ionized plasmas are found in many different astrophysical environments. The study of partially ionized plasmas is of great interest for solar physics because some layers of the solar atmosphere (photosphere and chromosphere) as well as solar structures, such as spicules and prominences, are made of these kinds of plasmas. To our knowledge, despite it being known that the adiabatic coefficient, γ, or the first adiabatic exponent, $\Gamma 1$, depend on the ionization degree, this fact has been disregarded in all the studies related to magnetohydrodynamic waves in solar partially ionized plasmas. However, in other astrophysical areas, the dependence of γ or $\Gamma 1$ on the plasma ionization degree has been taken into account. Therefore, our aim here is to study how, in a plasma with prominence physical properties, the joint action of the temperature, density, and ionization degree modifies the numerical values of the first adiabatic exponent $\Gamma 1$ which affects the adiabatic sound speed and the period of slow waves. In our computations, we have used two different approaches; first of all, we assume local thermodynamic equilibrium (LTE) and, later, we consider a non-local thermodynamic equilibrium (non-LTE) model. When comparing the results in the LTE and non-LTE cases, the numerical values of $\Gamma 1$ are clearly different for both and they are probably strongly dependent on the assumed model which determines how the ionization degree evolves with temperature. Finally, the effect of the ionization degree dependence of Γ1 on the period of slow waves has been determined showing that it can be of great importance for seismological studies of partially ionized solar structures.

The temporal behaviour of MHD waves in a partially ionized prominence-like plasma: Effect of heating and cooling

J. L. **Ballester**1,2, M. Carbonell3,2, R. Soler1,2 and J. Terradas

A&A 609, A6 (**2017**)

Context. During heating or cooling processes in prominences, the plasma microscopic parameters are modified due to the change of temperature and ionization degree. Furthermore, if waves are excited on this non-stationary plasma, the changing physical conditions of the plasma also affect wave dynamics.
Aims. Our aim is to study how temporal variation of temperature and microscopic plasma parameters modify the behaviour of magnetohydrodynamic (MHD) waves excited in a prominence-like hydrogen plasma.
Methods. Assuming optically thin radiation, a constant external heating, the full expression of specific internal energy, and a suitable energy equation, we have derived the profiles for the temporal variation of the background temperature. We have computed the variation of the ionization degree using a Saha equation, and have linearized the single-fluid MHD equations to study the temporal behaviour of MHD waves.
Results. For all the MHD waves considered, the period and damping time become time dependent. In the case of Alfvén waves, the cut-off wavenumbers also become time dependent and the attenuation rate is completely different in a cooling or heating process. In the case of slow waves, while it is difficult to distinguish the slow wave properties in a cooling partially ionized plasma from those in an almost fully ionized plasma, the period and damping time of these waves in both plasmas are completely different when the plasma is heated. The temporal behaviour of the Alfvén and fast wave is very similar in the cooling case, but in the heating case, an important difference appears that is related with the time damping.
Conclusions. Our results point out important differences in the behaviour of MHD waves when the plasma is heated or cooled, and show that a correct interpretation of the observed prominence oscillations is very important in order to put accurate constraints on the physical situation of the prominence plasma under study, that is, to perform prominence seismology.

Prominence oscillations: Effect of a time-dependent background temperature

J. L. **Ballester**1,3, M. Carbonell2,3, R. Soler1,3 and J. Terradas

A&A 591, A109 (**2016**)

Context. Small amplitude oscillations in prominences have been known about for a long time, and from a theoretical point of view, these oscillations have been interpreted in terms of standing or propagating linear magnetohydrodynamic (MHD) waves. In general, these oscillations were studied by producing small perturbations in a background equilibrium with stationary physical properties.
Aims. Taking into account that prominences are dynamic plasma structures, the assumption of a stationary equilibrium is not realistic. Therefore, our main aim is to study the effects produced by a non-stationary background on slow MHD waves, which could be responsible for prominence oscillations.
Methods. Assuming that the radiation term is proportional to temperature and constant external heating, we have derived an expression for the temporal variation of the background temperature, which depends on the imbalance between heating and cooling processes. Furthermore, radiative losses, together with parallel thermal conduction, have also been included as damping mechanisms for the waves.
Results. As temperature increases with time, the period of slow waves decreases and the amplitude of the velocity perturbations is damped. The inclusion of radiative losses enhances the damping. As temperature decreases with time, the period of slow waves increases and the amplitude of velocity perturbations grows while, as expected, the inclusion of radiative losses contributes to the damping of oscillations.
Conclusions. There is observational evidence that, in different locations of the same prominence, oscillations are damped or amplified with time. This temporal damping or amplification can be obtained by a proper combination of a variable background temperature, together with radiative damping. Furthermore, decayless oscillations can also be obtained with an appropriate choice of the characteristic radiation time.

An Analytical Model of the Kelvin–Helmholtz Instability of Transverse Coronal Loop Oscillations

Mihai **Barbulescu**1, Michael S. Ruderman1,2, Tom Van Doorsselaere3, and Robert Erdélyi

2019 ApJ 870 108
sci-hub.tw/10.3847/1538-4357/aaf506
https://arxiv.org/pdf/1901.06132.pdf

Recent numerical simulations have demonstrated that transverse coronal loop oscillations are susceptible to the Kelvin–Helmholtz (KH) instability due to the counterstreaming motions at the loop boundary. We present the first

analytical model of this phenomenon. The region at the loop boundary where the shearing motions are greatest is treated as a straight interface separating time-periodic counterstreaming flows. In order to consider a twisted tube, the magnetic field at one side of the interface is inclined. We show that the evolution of the displacement at the interface is governed by Mathieu's equation, and we use this equation to study the stability of the interface. We prove that the interface is always unstable and that, under certain conditions, the magnetic shear may reduce the instability growth rate. The result, that the magnetic shear cannot stabilize the interface, explains the numerically found fact that the magnetic twist does not prevent the onset of the KH instability at the boundary of an oscillating magnetic tube. We also introduce the notion of the loop σ-stability. We say that a transversally oscillating loop is σ-stable if the KH instability growth time is larger than the damping time of the kink oscillation. We show that even relatively weakly twisted loops are σ-stable.

Two-horn quiescent prominence observed in Hα and Mg II h&k lines with THEMIS and IRIS⋆

Krzysztof **Barczynski**1,2, Brigitte Schmieder3,4,5, Bernard Gelly6, Aaron W. Peat4,7 and Nicolas Labrosse4

A&A 680, A63 (**2023**)
https://doi.org/10.1051/0004-6361/202345970
https://www.aanda.org/articles/aa/pdf/2023/12/aa45970-23.pdf

Context. Prominences are large magnetic structures in the corona filled by cool plasma with fast evolving fine structure.
Aims. We aim to better understand the plasma conditions in the fine structure of a quiescent prominence including two transient horns observed at the bottom of the cavity using the high resolution Interface Region Imaging Spectrograph (IRIS) and the MulTi-Raies (MTR) spectrograph of the Télescope Heliographique pour l'Etude du Magnétisme et des Instabilités Solaires (THEMIS) in the Canary Islands.
Methods. We analysed the spectra obtained in Hα by THEMIS and Mg II by IRIS and compare them with a grid of 23 940 1D radiative transfer models which include a prominence-to-corona transition region (PCTR). The full observed profiles of Mg II in each pixel are fitted completely by synthesised profiles with ×RMS (Cross RMS; an improved version of the rolling root mean square (rRMS) method). When the RMS is below a certain threshold value, we recover the plasma conditions from the parameters of the model best fitting the observed line profile. This criterion is met in two regions (the horns and edge of the prominence) where the line profiles can generally be described as single peaked.
Results. The 1D models suggest that two different kinds of model atmospheres correspond to these two regions. The region at the edge is found to be fitted mainly with isothermal and isobaric models, while the other area (the horns) is seen to be fitted with models with a PCTR that have optical thicknesses of less than 5. In the prominence edge, the theoretical relationship between the integrated intensities in Hα and Mg II is verified and corresponds to low emission measure values. In these regions the electron density is around 1010 cm−3, while it is one order of magnitude less in the horn regions around 109 cm−3.
Conclusions. In the horns, we find some profiles are best fitted with models with high mean temperatures. This suggests that the hot PCTR found in the horns could be interpreted as prominence plasma in condensation phase at the bottom of the coronal cavity.

A Statistical Comparison of EUV Brightenings Observed by SO/EUI with Simulated Brightenings in Non-potential Simulations

Krzysztof **Barczynski**, Karen A. Meyer, Louise K. Harra, Duncan H. Mackay, Frederic Auchere, David Berghmans

Solar Phys. **2022**
https://arxiv.org/pdf/2210.09129

The High Resolution Imager (HRI_EUV) telescope of the Extreme Ultraviolet Imager (EUI) instrument onboard Solar Orbiter has observed EUV brightenings, so-called campfires, as fine-scale structures at coronal temperatures. The goal of this paper is to compare the basic geometrical (size, orientation) and physical (intensity, lifetime) properties of the EUV brightenings with regions of energy dissipation in a non-potential coronal magnetic field simulation. In the simulation, HMI line-of-sight magnetograms are used as input to drive the evolution of solar coronal magnetic fields and energy dissipation. We applied an automatic EUV brightening detection method to EUV images obtained on 30 May 2020 by the HRI_EUV telescope. We applied the same detection method to the simulated energy dissipation maps from the non-potential simulation to detect simulated brightenings. We detected EUV brightenings with density of 1.41x10^{-3} brightenings/Mm^2 in the EUI observations and simulated brightenings between 2.76x10^{-2} - 4.14x10^{-2} brightenings/Mm^2 in the simulation, for the same time range. Although significantly more brightenings were produced in the simulations, the results show similar distributions of the key geometrical and physical properties of the observed and simulated brightenings. We conclude that the non-potential simulation can successfully reproduce statistically the characteristic properties of the EUV brightenings (typically with more than 85% similarity); only the duration of the events is significantly different between

observations and simulation. Further investigations based on high-cadence and high-resolution magnetograms from Solar Orbiter are under consideration to improve the agreement between observation and simulation.

Miniature loops in the solar corona

Krzysztof **Barczynski**, Hardi Peter, Sabrina L. Savage

A&A 599, A137 (**2017**)

https://arxiv.org/pdf/1611.08513v1.pdf

Magnetic loops filled with hot plasma are the main building blocks of the solar corona. Usually they have lengths of the order of the barometric scale height in the corona that is 50 Mm. Previously it has been suggested that miniature versions of hot loops exist. These would have lengths of only 1 Mm barely protruding from the chromosphere and spanning across just one granule in the photosphere. Such short loops are well established at transition region temperatures (0.1 MK), and we investigate if such miniature loops also exist at coronal temperatures (>1 MK). We used extreme UV imaging (EUV) observations from the High-resolution Coronal Imager (Hi-C) at an unprecedented spatial resolution of 0.3" to 0.4". Together with EUV imaging and magnetogram data from the Solar Dynamics Observatory (SDO) and X-Ray Telescope (XRT) data from Hinode we investigated the spatial, temporal and thermal evolution of small loop-like structures in the solar corona above a plage region close to an active region and compared this to a moss area within the active region. We find that the size, motion and temporal evolution of the loop-like features are consistent with photospheric motions, suggesting a close connection to the photospheric magnetic field. Aligned magnetograms show that one of their endpoints is rooted at a magnetic concentration. Their thermal structure, as revealed together with the X-ray observations, shows significant differences to moss-like features. Considering different scenarios, these features are most probably miniature versions of hot loops rooted at magnetic concentrations at opposite sides of a granule in small emerging magnetic loops (or flux tubes).
11th July, 2012

Energy release in driven twisted coronal loops

M.R. **Bareford**, M. Gordovskyy, P.K. Browning, A.W. Hood

Solar Phys. January **2016**, Volume 291, Issue 1, pp 187-209

http://arxiv.org/pdf/1506.01312v1.pdf

In the present study we investigate magnetic reconnection in twisted magnetic fluxtubes with different initial configurations. In all considered cases, energy release is triggered by the ideal kink instability, which is itself the result of applying footpoint rotation to an initially potential field. The main goal of this work is to establish the influence of the field topology and various thermodynamic effects on the energy release process. Specifically, we investigate convergence of the magnetic field at the loop footpoints, atmospheric stratification, as well as thermal conduction. In all cases, the application of vortical driving at the footpoints of an initally potential field leads to an internal kink instability. With the exception of the curved loop with high footpoint convergence, the global geometry of the loop change little during the simulation. Footpoint convergence, curvature and atmospheric structure clearly influences the rapidity with which a loop achieves instability as well as the size of the subsequent energy release. Footpoint convergence has a stabilising influence and thus the loop requires more energy for instability, which means that the subsequent relaxation has a larger heating effect. Large-scale curvature has the opposite result: less energy is needed for instability and so the amount of energy released from the field is reduced. Introducing a stratified atmosphere gives rise to decaying wave phenomena during the driving phase, and also results in a loop that is less stable.

Spectropolarimetric analysis of an active region filament. II. Evidence of the limitations of a single component model

C. J. Díaz **Baso**, M.J. Martínez González, A. Asensio Ramos

A&A 625, A129 **2019**

https://arxiv.org/pdf/1904.10688.pdf

Our aim is to demonstrate the limitations of using a single component model to study the magnetic field of an active region filament. For that we have analyzed the polarimetric signals of the He I 10830 A multiplet acquired with the infrared spectrograph GRIS of the GREGOR telescope (Tenerife, Spain). After a first analysis of the general properties of the filament using Hazel under the assumption of a single component model atmosphere, in this second part we focus our attention on the observed Stokes profiles and the signatures which cannot be explained with this model. We have found an optically thick filament where the blue and the red components have the same sign in the linear polarization as an indication of radiative transfer effects. Moreover, the circular polarization signals inside the filament show the presence of strong magnetic field gradients. We have also shown that even a filament with such high absorption still shows signatures of the circular polarization generated by the magnetic field below the filament. The reason is that the absorption of the spectral line decays very quickly towards the wings, just where the circular polarization has a larger amplitude. In order to separate both contributions, we explore the possibility of a two component model but the inference becomes impossible to overcome as a high number of solutions is compatible with the observations.

Spectropolarimetric analysis of an active region filament. I. Magnetic and dynamical properties from single component inversions

C. J. Díaz **Baso**, M. J. Martínez González, A. Asensio Ramos

A&A 625 A128 **2019**

https://arxiv.org/pdf/1904.09593.pdf

The determination of the magnetic filed vector in solar filaments is possible by interpreting the Hanle and Zeeman effects in suitable chromospheric spectral lines like those of the He I multiplet at 10830 A. We study the vector magnetic field of an active region filament (NOAA 12087). Spectropolarimetric data of this active region was acquired with the GRIS instrument at the GREGOR telescope and studied simultaneously in the chromosphere with the He I 10830 A multiplet and in the photosphere with the Si I 10827 A line. As it is usual from previous studies, only a single component model is used to infer the magnetic properties of the filament. The results are put into a solar context with the help of the Solar Dynamic Observatory images. Some results clearly point out that a more complex inversion had to be done. Firstly, the Stokes V map of He I does not show any clear signature of the presence of the filament. Secondly, the local azimuth map follows the same pattern than Stokes V as if the polarity of Stokes V were conditioning the inference to very different magnetic field even with similar linear polarization signals. This indication suggests that the Stokes V could be dominated by the below magnetic field coming from the active region, and not, from the filament itself. Those and more evidences will be analyzed in depth and a more complex inversion will be attempted in the second part of this series. **17th of June 2014**

Diagnostic potential of the Ca II 8542A line for solar filaments

C. J. Díaz **Baso**, M. J. Martínez González, A. Asensio Ramos, J. de la Cruz Rodríguez

A&A 625, A178 **2019**

https://arxiv.org/pdf/1902.06574.pdf

In this study we explore the diagnostic potential of the chromospheric Ca II line at 8542A for studying the magnetic and dynamic properties of solar filaments. We have acquired high spatial resolution spectropolarimetric observations in the Ca II 8542A line using the CRISP instrument at the Swedish 1-m Solar Telescope. We use the NICOLE inversion code to infer physical properties from observations of a solar filament. We discuss the validity of the results due to the assumption of hydrostatic equilibrium. We have used observations from other telescopes such as CHROTEL and SDO, in order to study large scale dynamics and the long term evolution of the filament. We show that the Ca II 8542A line encodes information of the temperature, line-of-sight velocity and magnetic field vector from the region where the filament is located. The current noise level only allow us to estimate an upper limit of 260G for the total magnetic field of the filament. Our study also reveals that if we only consider information from the aforementioned spectral line, the geometric height, the temperature and the density can be degenerated parameters outside the hydrostatic equilibrium approach. **22 July 2013**

Active region filaments might harbor weak magnetic fields

C. J. Díaz **Baso**, M. J. Martínez González, A. Asensio Ramos

2016 *ApJ* **822** 50

http://arxiv.org/pdf/1603.04645v1.pdf

Recent spectropolarimetric observations of active region filaments have revealed polarization profiles with signatures typical of the strong field Zeeman regime. The conspicuous absence in those observations of scattering polarization and Hanle effect signatures was then pointed out by some authors. This was interpreted either as a signature of mixed "turbulent" field components or as a result of optical thickness. In this article, we present a natural scenario to explain these Zeeman-only spectro-polarimetric observations of active region filaments. We propose a two-component model, one on top of the other. Both components have horizontal fields, the azimuth difference between them being close to 90 degrees. The component that lies lower in the atmosphere is permeated by a strong field of the order of 600 G, while the upper component has much weaker fields, of the order of 10 G. The ensuing scattering polarization signatures of the individual components have opposite signs, so that its combination along the line of sight reduces --and even can cancel out-- the Hanle signatures, giving rise to an apparent only-Zeeman profile. This model is also applicable to other chromospheric structures seen in absorption above active regions.

Prominence Cavity Regions Observed Using SWAP 174 Å Filtergrams and Simultaneous Eclipse Flash Spectra

C. **Bazin**, S. Koutchmy, E. Tavabi

Solar Physics, August **2013**, Volume 286, Issue 1, pp 255-270

SWAP images from PROBA2 taken at 174 Å in the Fe ix/x lines are compared with simultaneous slitless flash spectra obtained during the solar total eclipse of **11 July 2010**. Myriad faint low-excitation emission lines together with the He i and He ii Paschen α chromospheric lines are recorded on eclipse spectra where regions of limb prominences are obtained with space-borne imagers. We analyzed a deep flash spectrum obtained by summing 80 individual spectra to evaluate the intensity modulations of the continuum. Intensity deficits are observed and measured at the prominences boundaries in both eclipse and SWAP images. The prominence cavities interpreted as a relative depression of plasma density, produced inside the corona surrounding the prominences, and some intense heating occurring in these regions, are discussed. Photometric measurements are shown at different scales and different, spectrally narrow, intervals for both the prominences and the coronal background.

Dispersion of Slow Magnetoacoustic Waves in the Active Region Fan Loops Introduced by Thermal Misbalance

Sergey **Belov**, Nonna Molevich, Dmitrii Zavershinskii

Solar Phys. **2021**

https://arxiv.org/pdf/2107.10600.pdf

Slow magnetoacoustic waves observed in the solar corona are used as seismological probes of plasma parameters. It has been shown that dispersion properties of such waves can vary significantly under the influence of the wave-induced thermal misbalance. In the current research, we study the effect of misbalance on waves inside the magnetic-flux tube under the second-order thin-flux-tube approximation. Using the parameters of active region fan coronal loops, we calculated wave properties such as the phase speed and decrement. It is shown that neglecting thermal misbalance may be the reason for the substantial divergence between seismological and spectrometric estimations of plasma parameters. We also show that the frequency dependence of phase speed is affected by two features, namely the geometric dispersion and the dispersion caused by the thermal misbalance. In contrast to the phase speed, the wave decrement primarily is affected by the thermal misbalance only. The dependencies of the phase speed and decrement of the slow wave on magnetic field and tube cross-section are also analyzed.

The structure of fast sausage waves in current-carrying coronal loops,

Bembitov, D. B., Mikhalyaev, B. B., and Ruderman, M. S.:

Ann. Geophys., 32, 1189-1193, **2014**

We study fast sausage waves in a model coronal loop that consists of a cylindrical core with axial magnetic field and coaxial annulus with purely azimuthal magnetic field. The magnetic field is discontinuous at the tube and core boundaries, and there are surface currents with the opposite directions on these boundaries. The principal mode of fast sausage waves in which the magnetic pressure perturbation has no nodes in the radial direction can exist for arbitrary wavelength. The results for the fundamental radial mode of sausage waves are applied to the interpretation of observed periodic pulsations of microwave emission in flaring loops with periods of a few tens of seconds. Radial plasma motion has opposite directions at the tube and core boundaries. This leads to the periodic contraction and expansion of the annulus. We assume that the principal mode of fast sausage waves in the current-carrying coronal loops is able to produce a current sheet. However, the nonlinear analysis is needed to confirm this conjecture.

Rotation of an erupting filament observed by the STEREO EUVI and COR1 instruments

A. **Bemporad**, M. Mierla and D. Tripathi

A&A 531, A147 (**2011**), **File**

On **August 31, 2007**, a prominence eruption was observed by the Solar TErrestrial RElations Observatory (STEREO) in the Extreme-UltraViolet Imager (EUVI) 304 images and later on, as the core of a three-part coronal mass ejection (CME) in images acquired by the inner STEREO coronagraph (COR1). Because they were covered by both STEREO spacecraft from right vantage points, these observations provide an excellent opportunity to perform a three-dimensional (3D) prominence reconstruction and study its evolution. We employed the tie-pointing technique to reconstruct the 3D shape and trajectory of the prominence, which has been followed from an heliocentric distance of ~1.3 up to ~2.4 $R_\odot$ during the first 1.3 h of eruption. Data show evidence for a progressive clockwise prominence rotation by ~90° occurring not only in the early phase of the eruption sampled by EUVI, but also at larger heliocentric distances as seen by COR1. Interestingly, a counter-clockwise rotation of the filament was observed in Hα images in the week before the eruption; the filament does not show a twisted shape. In the same period, the potential field extrapolated at different times shows a clockwise rotation of closed lines overlying the filament. This suggests that a magnetic helicity storage occurred not in the filament itself, but in the global magnetic field configuration of the surrounding corona. Moreover, close inspection to the high-resolution EUVI images revealed a small scale helical feature along the erupting prominence. The sense of rotation of this helix agrees with the observed prominence rotation, providing evidence for the conversion of twist into writhe. The observed rotation of an erupting prominence, if representative of the flux rope rotation, may have a strong impact on the definition of geo-effectiveness of CMEs for space weather forecasting purposes.

Two movies are available in electronic form at http://www.aanda.org

Rotation of an erupting filament observed by STEREO EUVI and COR1 instruments (Corrigendum)

A. **Bemporad**, M. Mierla and D. Tripathi

A&A 537, C1 (**2012**)

Prominence 3D reconstruction in the STEREO era: A review

Bemporad A.

Journal of Atmospheric and Solar-Terrestrial Physics
Volume 73, Issue 10, 20 June **2011**, Pages 1117-1128, **File**

Since the launch of the STEREO mission (October 2006) the determination of the real prominence shapes and trajectories during eruptions in three dimensions (3D) became easily viable, thanks to the stereoscopic observations, available for the first time, acquired by the twin STEREO spacecraft. These data give us now a unique capability to identify twisted or ribbon-like structures, helical or planar motions, and to investigate the existence of a real critical height for prominence eruptions without projection effects. All these parameters are of fundamental importance for understanding the physical phenomena triggering the eruption and affecting their early evolution. Many different techniques have been developed and employed after the beginning of the “STEREO era”, but important information on the 3D structure of prominences was also derived before STEREO. Hence, the present paper is aimed at reviewing different reconstruction techniques developed both before and after the availability of stereoscopic observations and discusses the advancement made so far on these issues thanks to the pre- and post-STEREO data.

Research highlights

► Physical processes responsible for stability/instability of prominences are unclear. ► Determination of their 3D structure and evolution is very important. ► STEREO data provide today the first stereoscopic observations of prominences. ► Many successful attempts also performed before the availability of STEREO data. ► The full potential of STEREO data has not been utilized so far.

Multispacecraft observations of a prominence eruption

A. **Bemporad**1, G. Del Zanna2, V. Andretta3, G. Poletto4, and M. Magrí3

Ann. Geophys., 27, 3841-3851, **2009; File**

On **9 May 2007** a prominence eruption occurred at the West limb. Remarkably, the event was observed by the STEREO/EUVI telescopes and by the HINODE/EIS and SOHO/UVCS spectrometers. We present results from all these instruments. High-cadence (~37 s) data from STEREO/EUVI A and B in the He II λ304 line were used to study the 3-D shape and expansion of the prominence. The high spatial resolution EUVI images (~1.5"/pixel) have been used to infer via triangulation the 3-D shape and orientation of the prominence 12 min after the eruption onset. At this time the prominence has mainly the shape of a "hook" highly inclined southward, has an average thickness of 0.068 $R_\odot$, a length of 0.43 $R_\odot$ and lies, in first approximation, on a plane. Hence, the prominence is mainly a 2-D structure and there is no evidence for a twisted flux rope configuration. HINODE/EIS was scanning with the 2" slit the region where the filament erupted. The EIS spectra show during the eruption remarkable non-thermal broadening (up to ~100 km s^{-1}) in the region crossed by the filament in spectral lines emitted at different temperatures, possibly with differences among lines from higher Fe ionization stages. The CME was also observed by the SOHO/UVCS instrument: the spectrograph slit was centered at 1.7 $R_\odot$, at a latitude of 5° SW and recorded a sudden increase in the O VI λλ1032–1037 and Si XII λ520 spectral line intensities, representative of the CME front transit.

STEREOSCOPIC RECONSTRUCTION FROM *STEREO/*EUV IMAGERS DATA OF THE THREE-DIMENSIONAL SHAPE AND EXPANSION OF AN ERUPTING PROMINENCE

A. **Bemporad**

Astrophysical Journal, 701:298–305, **2009; File**

On **2007 May 9**, a prominence eruption was observed in the He ii λ304 filter by the two EUV Imagers (EUVI) telescopes aboard the *STEREO A* and *B* spacecrafts. The high spatial resolution (~1._5 pixel-1) EUVI images have been used to infer via triangulation the three-dimensional (3D) shape and orientation of the prominence _12 minutes after the beginning (13:40 UT) of the eruption. At this time, the prominence has the shape of a “hook” with the base anchored at the Sun. The “hook” prominence is highly inclined southward with respect to the radial direction, has an average thickness of 0.061*R*_, a length of 0.43*R*_, and lies in first approximation on a plane inclined by ~54.◦5 with respect to the line of sight. Thanks to the very high temporal cadence (~37 s) of EUVI observations it has been possible also to infer the 3D early eruption trajectory. In the following ~20 minutes the prominence rotates westward, undergoing a strong latitudinal acceleration, ~3 times larger than the radial acceleration. In this time interval, the prominence expands in a direction mainly parallel to the plane of the sky; the total volume occupied by the plasma increases by a factor of ~8, while the prominence thickness increases only by ~12%. This is related to the fact that the early prominence expansion is anisotropic and occurs mainly on a plane parallel to the plane of the sky. Even if the smallscale spatial distribution of the erupting material observed in the He ii EUVI images is quite complex, both the approximately planar shape and the successive planar expansion suggest that on larger spatial scales the prominence can be globally approximated as a two-dimensional "ribbon-like" feature, instead of a 3D twisted flux tube.

Quiescent prominence dynamics observed with the Hinode Solar Optical Telescope . II. Prominence Bubble Boundary Layer Characteristics and the Onset of a Coupled Kelvin-Helmholtz Rayleigh-Taylor Instability

Thomas **Berger**, Andrew Hillier, Wei Liu

2017 *ApJ* **850** 60

https://arxiv.org/pdf/1707.05265.pdf

We analyze solar quiescent prominence bubble characteristics and instability dynamics using Hinode Solar Optical Telescope (SOT) data. We measure bubble expansion rate, prominence downflows, and the profile of the boundary layer brightness and thickness as a function of time. The largest bubble analyzed rises into the prominence with a speed of about 1.3 km/s until it is destabilized by a localized shear flow on the boundary. Boundary layer thickness grows gradually as prominence downflows deposit plasma onto the bubble with characteristic speeds of 20 to 35 km/s. Lateral downflows initiate from the thickened boundary with characteristic speeds of 25 to 50 km/s, draining the layer of plasma. Strong shear flow across one bubble boundary leads to a coupled Kelvin-Helmholtz Rayleigh-Taylor (KHRT) instability. We measure shear flow speeds above the bubble of 10 km/s and infer interior bubble flow speeds on the order of 100 km/s. Comparing the measured growth rate of the instability to analytic expressions, we infer a magnetic flux density across the bubble boundary of 0.001 T (10 gauss) at an angle of approximately 70 degrees to the prominence plane. The results are consistent with the hypothesis that prominence bubbles are caused by magnetic flux that emerges below a prominence, setting up the conditions for RT, or combined KHRT, instability flows that transport flux, helicity, and hot plasma upward into the overlying coronal magnetic flux rope.
08-August-2007, 16-August-2007,

SDO/AIA DETECTION OF SOLAR PROMINENCE FORMATION WITHIN A CORONAL CAVITY

Thomas E. **Berger**1, Wei Liu2,3, and B. C. Low

2012 ApJ 758 L37

We report the first analyses of SDO/AIA observations of the formation of a quiescent polar crown prominence in a coronal cavity. The He II 304 Å (log T max ~ 4.8 K) data show both the gradual disappearance of the prominence due to vertical drainage and lateral transport of plasma followed by the formation of a new prominence 12 hr later. The formation is preceded by the appearance of a bright emission "cloud" in the central region of the coronal cavity. The peak brightness of the cloud progressively shifts in time from the Fe XIV 211 Å channel, through the Fe XII 193 Å channel, to the Fe IX 171 Å channel (log T max ~ 6.2, 6.1, 5.8 K, respectively) while simultaneously decreasing in altitude. Filter ratio analysis estimates the initial temperature of the cloud to be approximately log T ~ 6.25 K with evidence of cooling over time. The subsequent growth of the prominence is accompanied by darkening of the cavity in the 211 Å channel. The observations imply prominence formation via in situ condensation of hot plasma from the coronal cavity, in support of our previously proposed process of magnetothermal convection in coronal magnetic flux ropes.

QUIESCENT PROMINENCE DYNAMICS OBSERVED WITH THE *HINODE* SOLAR OPTICAL TELESCOPE. I. TURBULENT UPFLOW PLUMES

Thomas E. **Berger**1, Gregory Slater1, Neal Hurlburt1, Richard Shine1, Theodore Tarbell1, Alan Title1, Bruce W. Lites2, Takenori J. Okamoto3, Kiyoshi Ichimoto3, Yukio Katsukawa3, Tetsuya Magara3, Yoshinori Suematsu3, and Toshifumi Shimizu4

Astrophysical Journal, 716:1288–1307, **2010** June

*Hinode/*Solar Optical Telescope (SOT) observations reveal two newdynamic modes in quiescent solar prominences: large-scale (20–50 Mm) "arches" or "bubbles" that "inflate" from below into prominences, and smaller-scale (2–6 Mm) dark turbulent upflows. These novel dynamics are related in that they are always dark in visible-light spectral bands, they rise through the bright prominence emission with approximately constant speeds, and the small-scale upflows are sometimes observed to emanate from the top of the larger bubbles. Here we present detailed kinematic measurements of the small-scale turbulent upflows seen in several prominences in the SOT database. The dark upflows typically initiate vertically from 5 to 10Mm wide dark cavities between the bottom of the prominence and the top of the chromospheric spicule layer. Small perturbations on the order of 1 Mm or less in size grow on the upper boundaries of cavities to generate plumes up to 4–6 Mm across at their largest widths. All plumes develop highly turbulent profiles, including occasional Kelvin–Helmholtz vortex "roll-up" of the leading edge. The flows typically rise 10–15 Mm before decelerating to equilibrium. We measure the flowfield characteristics with a manual tracing method and with the Nonlinear Affine Velocity Estimator (NAVE) "optical flow" code to derive velocity, acceleration, lifetime, and height data for several representative plumes. Maximum initial speeds are in the range of 20–30 km s^{-1}, which is supersonic for a ~10,000 K plasma. The plumes decelerate in the final few Mm of their trajectories resulting in mean ascent speeds of 13–17 km s^{-1}. Typical lifetimes range from 300 to 1000 s (~5–15 minutes). The area growth rate of the plumes (observed as two-dimensional objects in the plane of the sky) is initially linear and ranges from 20,000 to 30,000 km^2 s^{-1} reaching maximum projected areas from 2 to 15 Mm^2. Maximum contrast of the dark flows relative to the bright prominence plasma in SOT images is negative and ranges from −10% for smaller flows to −50% for larger flows. Passive scalar "cork movies" derived from NAVE measurements show that prominence plasma is entrained by the upflows, helping to counter the ubiquitous downflow streams in the prominence. Plume formation shows no clear temporal periodicity. However, it is common to find "active cavities" beneath prominences that can spawnmany upflows in succession before going dormant. The mean flow recurrence time in these active locations is roughly 300–500 s (5–8 minutes). Locations remain active on timescales of tens of minutes up to several hours. Using a column density ratio measurement and reasonable assumptions on plume and prominence geometries, we estimate that the mass density in the dark cavities is at most 20% of the visible prominence density, implying that a single large plume could supply up to 1% of the mass of a typical quiescent prominence. We hypothesize that the plumes are generated from a Rayleigh–Taylor instability taking place on the boundary between the buoyant cavities and the overlying prominence. Characteristics, such as plume size and frequency, may be modulated by the strength and direction of the cavity magnetic field relative to the prominence magnetic field. We conclude that buoyant plumes are a source of quiescent prominence mass as well as a mechanism by which prominence plasma is advected upward, countering constant gravitational drainage.

HINODE SOT OBSERVATIONS OF SOLAR QUIESCENT PROMINENCE DYNAMICS

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The Astrophysical Journal, 676: L89–L92, **2008** March 20
http://www.journals.uchicago.edu/doi/pdf/10.1086/587171
We report findings from multihour 0.2_ resolution movies of solar quiescent prominences (QPs) observed with the Solar Optical Telescope (SOT) on the ***Hinode*** satellite. The observations verify previous findings of filamentary downflows and vortices in QPs. SOT observations also verify large-scale transverse oscillations in QPs, with periods of 20–40 minutes and amplitudes of 2–5 Mm. The upward propagation speed of several waves is found to be ~10 km s , comparable to the sound speed of a 10,000 K plasma, implying that the waves are magnetoacoustic in _1 origin. Most significantly, *Hinode* SOT observations reveal that dark, episodic upflows are common in QPs. The upflows are 170–700 km in width, exhibit turbulent flow, and rise with approximately constant speeds of ~20 km s from the base of the prominence to heights of ~10–20 Mm. The upflows are visible in both the Ca ii H-line _1 and Hα bandpasses of SOT. The new flows are seen in about half of the QPs observed by SOT to date. The dark upflows resemble buoyant starting plumes in both their velocity profile and flow structure. We discuss thermal and magnetic mechanisms as possible causes of the plumes.

2D radiative-magnetohydrostatic model of a prominence observed by Hinode, SoHO/SUMER and Meudon/MSDP

A. **Berlicki**1,2,3, S. Gunar1, P. Heinzel1,3, B. Schmieder3 and P. Schwartz1
A&A 530, A143 (**2011**)
Aims. Prominences observed by Hinode show very dynamical and intriguing structures. To understand the mechanisms that are responsible for these moving structures, it is important to know the physical conditions that prevail in fine-structure threads. In the present work we analyse a quiescent prominence with fine structures, which exhibits dynamic behaviour, which was observed in the hydrogen Hα line with Hinode/SOT, Meudon/MSDP and Ondřejov/HSFA2, and simultaneously in hydrogen Lyman lines with SoHO/SUMER during a coordinated campaign. We derive the fine-structure physical parameters of this prominence and also address the questions of the role of the magnetic dips and of the interpretation of the flows.
Methods. We calibrate the SoHO/SUMER and Meudon/MSDP data and obtain the line profiles of the hydrogen Lyman series (Lβ to L6), the Ciii (977.03 Å) and Svi (933.40 Å), and Hα along the slit of SoHO/SUMER that crosses the Hinode/SOT prominence. We employ a complex 2D radiation-magnetohydrostatic (RMHS) modelling technique to properly interpret the observed spectral lines and derive the physical parameters of interest. The model was constrained not only with integrated intensities of the lines, but also with the hydrogen line profiles.

Results. The slit of SoHO/SUMER is crossing different prominence structures: threads and dark bubbles. Comparing the observed integrated intensities, the depressions of Hα bubbles are clearly identified in the Lyman, Ciii, and Svi lines. To fit the observations, we propose a new 2D model with the following parameters: T = 8000 K, pcen = 0.035 dyn cm-2, B = 5 Gauss, ne = 1010 cm-3, 40 threads each 1000 km wide, plasma β is 3.5 × 10-2. Conclusions. The analysis of Ciii and Svi emission in dark Hα bubbles allows us to conclude that there is no excess of a hotter plasma in these bubbles. The new 2D model allows us to diagnose the orientation of the magnetic field versus the LOS. The 40 threads are integrated along the LOS. We demonstrate that integrated intensities alone are not sufficient to derive the realistic physical parameters of the prominence. The profiles of the Lyman lines and also those of the Hα line are necessary to constrain 2D RMHS models. The magnetic field in threads is horizontal, perpendicular to the LOS, and in the form of shallow dips. With this geometry the dynamics of fine structures in prominences could be interpreted by a shrinkage of the quasi-horizontal magnetic field lines and apparently is not caused by the quasi-vertical bulk flows of the plasma, as Hinode/SOT movies seemingly suggest.

ERUPTION OF A SOLAR FILAMENT CONSISTING OF TWO THREADS

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2012 ApJ 758 42

The trigger and driving mechanism for the eruption of a filament consisting of two dark threads was studied with unprecedented high cadence and resolution of He II 304 Å observations made by the Atmospheric Imagining Assembly (AIA) on board the Solar Dynamics Observatory (SDO) and the observations made by the Solar Magnetic Activity Research Telescope and the Extreme Ultraviolet Imager (EUVI) telescope on board the Solar Terrestrial Relations Observatory Ahead (STEREO-A). The filament was located at the periphery of the active region NOAA 11228 and erupted on **2011 June 6**. At the onset of the eruption, a turbulent filament thread was found to be heated and to elongate in stride over a second one. After it rose slowly, most interestingly, the elongating thread was driven to contact and interact with the second one, and it then erupted with its southern leg being wrapped by a newly formed thread produced by the magnetic reconnection between fields carried by the two threads. Combining the observations from STEREO-A/EUVI and SDO/AIA 304 Å images, the three-dimensional shape of the axis of the filament was obtained and it was found that only the southern leg of the eruptive filament underwent rotation. We suggest that the eruption was triggered by the reconnection of the turbulent filament thread and the surrounding magnetic field, and that it was mainly driven by the kink instability of the southern leg of the eruptive filament that possessed a more twisted field introduced by the reconnection-produced thread.

Heating and cooling of coronal loops with turbulent suppression of parallel heat conduction

Bian, Nicolas; Emslie, A. Gordon; Horne, Duncan; Kontar, Eduard P.

ApJ **2017**

https://arxiv.org/pdf/1711.11388.pdf

Using the "enthalpy-based thermal evolution of loops" (EBTEL) model, we investigate the hydrodynamics of the plasma in a flaring coronal loop in which heat conduction is limited by turbulent scattering of the electrons that transport the thermal heat flux. The EBTEL equations are solved analytically in each of the two (conduction-dominated and radiation-dominated) cooling phases. Comparison of the results with typical observed cooling times in solar flares shows that the turbulent mean free-path λ_T lies in a range corresponding to a regime in which classical (collision-dominated) conduction plays at most a limited role. We also consider the magnitude and duration of the heat input that is necessary to account for the enhanced values of temperature and density at the beginning of the cooling phase and for the observed cooling times. We find through numerical modeling that in order to produce a peak temperature $\simeq 1.5 \times 10^7$~K and a 200~s cooling time consistent with observations, the flare heating profile must extend over a significant period of time; in particular, its lingering role must be taken into consideration in any description of the cooling phase. Comparison with observationally-inferred values of post-flare loop temperatures, densities, and cooling times thus leads to useful constraints on both the magnitude and duration of the magnetic energy release in the loop, as well as on the value of the turbulent mean free-path λ_T.

Anomalous Cooling of Coronal Loops with Turbulent Suppression of Thermal Conduction

Nicolas H. **Bian**, Jonathan M. Watters, Eduard P. Kontar, A. Gordon Emslie

ApJ **2016**

https://arxiv.org/pdf/1610.04732v1.pdf

We investigate the impact of turbulent suppression of parallel heat conduction on the cooling of post-flare coronal loops. Depending on the value of the mean free path λT associated with the turbulent scattering process, we identify four main cooling scenarios. The overall temperature evolution, from an initial temperature in excess of 107~K, is modeled in each case, highlighting the evolution of the dominant cooling mechanism throughout the cooling process. Comparison with observed cooling times allows the value of λT to be constrained, and interestingly this range corresponds to situations where collision-dominated conduction plays a very limited role, or even no role at all, in the cooling of post-flare coronal loops.

On the nature of coronal loops above the quiet sun network

S. **Bingert**, , , P. Zacharias[a], H. Peter[a] and B.V. Gudiksen[b]

Advances in Space Research, Volume 45, Issue 2, 15 January **2010**, Pages 310-313

The structure and dynamics of a box in a stellar corona can be modeled employing a 3D MHD model for different levels of magnetic activity. Depending on the magnetic flux through the surface the nature of the resulting coronal structures can be quite different. We investigate a model of an active region for two sunspots surrounded by magnetic field patches comparable in magnetic flux to the sunspots. The model results in emission from the model corona being concentrated in loop structures. In Gudiksen and Nordlund (2005) the loops seen in EUV and X-ray emission outline the magnetic field, following the general paradigm. However, in our model, where the magnetic field is far from a force-free state, the loops seen in X-ray emission do not follow the magnetic field lines. This result is of interest especially for loops as found in areas where the magnetic field emerging from active regions interacts with the surrounding network.

Toward detailed prominence seismology
II. Charting the continuous magnetohydrodynamic spectrum

J. W. S. **Blokland**[1] and R. Keppens

A&A 532, A94 (**2011**)

Context. Starting from accurate magnetohydrodynamic flux rope equilibria containing prominence condensations, we initiate a systematic survey of their linear eigenoscillations. This paves the way for more detailed prominence seismology, which thus far has made dramatic simplifications about the prevailing magnetic field topologies.
Aims. To quantify the full spectrum of linear MHD eigenmodes, we require knowledge of all flux-surface localized modes, charting out the continuous parts of the MHD spectrum. We combine analytical and numerical findings for the continuous spectrum for realistic prominence configurations, where a cool prominence is embedded in a hotter cavity, or where the flux rope contains multiple condensations supported against gravity.
Methods. The equations governing all eigenmodes for translationally symmetric, gravitating equilibria containing an axial shear flow, are analyzed, along with their flux-surface localized limit. The analysis is valid for general 2.5D equilibria, where either density, entropy, or temperature vary from one flux surface to another. We analyze the intricate mode couplings caused by the poloidal variation in the flux rope equilibria, by performing a small gravity parameter expansion. We contrast the analytical results with continuous spectra obtained numerically.
Results. For equilibria where the density is a flux function, we show that continuum modes can be overstable, and we present the stability criterion for these convective continuum instabilities. Furthermore, for all equilibria, a four-mode coupling scheme between an Alfvénic mode of poloidal mode number m and three neighboring ($m - 1, m, m + 1$) slow modes is identified, occurring in the vicinity of rational flux surfaces. For realistically structured prominence equilibria, this coupling is shown to play an important role, from weak to stronger gravity parameter g values. The analytic predictions for small g are compared with numerical spectra, and progressive deviations for larger g are identified.
Conclusions. The unstable continuum modes could be relevant for short-lived prominence configurations. The gaps created by poloidal mode coupling in the continuous spectrum need further analysis, as they form preferred frequency ranges for global eigenoscillations.

Oscillatory motions observed in eruptive filaments

K. **Bocchialini**[1], F. Baudin[1], S. Koutchmy[2], G. Pouget[1] and J. Solomon

A&A 533, A96 (**2011**)

Context. The origin of the variable component of the solar wind is of great intrinsic interest for heliophysics and spaceweather, e.g. the initiation of coronal mass ejections and the problem of mass loss of all stars. It is also related to the physics of coronal neutral sheets and streamers, which occur above lines of magnetic polarity reversal. Filaments and prominences correspond to the cool coronal component of these regions.
Aims. We examine the dynamical behaviour of these structures where reconnection and dissipation of magnetic energy in the turbulent plasma are occurring. The link between the observed oscillatory motions and the eruption occurrence is investigated in detail for two different events.
Methods. Two filaments were analysed using two different datasets: time series of spectra using a transition region line (He I at 584.33 Å) and a coronal line (Mg X at 609.79 Å) measured with CDS on-board SOHO, observed on **May 30, 2003**, and time series of intensity and velocity images from the NSO/Dunn Solar Telescope in the Hα line on September 18, 1994 for the other. The oscillatory content was investigated using Fourier transform and wavelet analysis and compared to different models.

Results. In both filaments, oscillations are clearly observed, in intensity and velocity in the He I and Mg X lines, in velocity in Hα, with similar periods from a few minutes up to 80 min, with a main range from 20 to 30 min, simultaneously with eruptions. Both filaments exhibit vertical oscillating motions. For the filament observed in the UV (He I and Mg X lines), we provide evidence of damped velocity oscillations, and for the filament observed in the visible (Hα line), we provide evidence that parts of the filament are oscillating, while the filament is moving over the solar surface, before its disappearance.

24 synoptic maps of 296 prominence average magnetic fields measured by Hanle effect during cycle XXI ascending phase

V. **Bommier**, J.L. Leroy, S. Sahal-Brechot

Astronomy & Astrophysics, section "Catalogs and Data" **2020**

https://arxiv.org/pdf/2007.08219.pdf

Aims : The aim of the present paper is to publish 24 synoptic maps of solar filaments, in which 296 prominence average unambiguous magnetic field vectors were determined by Pic-du-Midi observations between 1974 and 1982, which is the ascending phase of cycle XXI. Methods : The magnetic field was determined by interpretation of the Hanle effect observed in the He I D3 line. Previous results about the prominence field polarity and prominence chirality were applied to solve the fundamental ambiguity. The measurements were averaged in each prominence for accuracy reasons. Results : The result is twofold. First, alternating field directions can be observed from one neutral line to the next one. Second, a general field alignment is found along a solar North-South field distorted under the differential rotation effect.

Formation, Interaction and Merger of an Active Region and a Quiescent Filament Prior to Their Eruption on 19 May 2007

L.A. **Bone** · L. van Driel-Gesztelyi · J.L. Culhane · G. Aulanier · P. Liewer

Solar Phys (**2009**) 259: 31–47, **File**

We report observations of the formation of two filaments – one active and one quiescent, and their subsequent interactions prior to eruption. The active region filament appeared on 17 May 2007, followed by the quiescent filament about 24 hours later. In the 26 hour interval preceding the eruption, which occurred at around 12:50 UT on 19 May 2007, we see the two filaments attempting to merge and filament material is repeatedly heated suggesting magnetic reconnection. The filament structure is observed to become increasingly dynamic preceding the eruption with two small hard X-ray sources seen close to the active part of the filament at around 01:38 UT on 19 May 2007 during one of the activity episodes. The final eruption on 19 May at about 12:51 UT involves a complex CME structure, a flare and a coronal wave. A magnetic cloud is observed near Earth by the STEREO-B andWIND spacecraft about 2.7 days later. Here we describe the behaviour of the two filaments in the period prior to the eruption and assess the nature of their dynamic interactions.

Automation of the Filament Tracking in the Framework of the HELIO Project

X. **Bonnin**, J. Aboudarham, N. Fuller, A. Csillaghy, R. Bentley

Solar Physics, March **2013**, Volume 283, Issue 1, pp 49-66

We present a new method to automatically track filaments over the solar disk. The filaments are first detected on Meudon Spectroheliograph Hα images of the Sun, applying the technique developed by Fuller, Aboudarham, and Bentley (Solar Phys. 227, 61, 2005). This technique combines cleaning processes, image segmentation based on region growing, and morphological parameter extraction, including the determination of filament skeletons. The coordinates of the skeleton pixels, given in a heliocentric system, are then converted to a more appropriate reference frame that follows the rotation of the Sun surface. In such a frame, a co-rotating filament is always located around the same position, and its skeletons (extracted from each image) are thus spatially close, forming a group of adjacent features. In a third step, the shape of each skeleton is compared with its neighbours using a curve-matching algorithm. This step will permit us to define the probability [P] that two close filaments in the co-rotating frame are actually the same one observed on two different images. At the end, the pairs of features, for which the corresponding probability is greater than a threshold value, are associated using tracking identification indices. On a representative sample of filaments, the good agreement between automated and manual tracking confirms the reliability of the technique to be applied on large data sets. This code is already used in the framework of the Heliophysics Integrated Observatory (HELIO) to populate a catalogue dedicated to solar and heliospheric features (HFC). An extension of this method to other filament observations, and possibly sunspots, faculae, and coronal-holes tracking, can also be envisaged.

Judgment of paradigms for magnetic reconnection in coronal loops

Allen H **Boozer**

2022

https://arxiv.org/pdf/2210.02209.pdf
The traditional paradigm for magnetic field lines changing connections ignores magnetic field line chaos and requires an extremely large current density, jmax∝Rm, flowing in thin sheets of thickness 1/Rm, where Rm is the magnetic Reynolds number. The time required for a general natural evolution to take a smooth magnetic field into such a state is rarely considered. Natural evolutions generally cause magnetic field lines to become chaotic. A fast change in field line connections then arises on the timescale defined by the evolution multiplied by a ln(Rm) factor, and the required maximum current density scales as ln(Rm). Even when simulations support the new paradigm based on chaos, they have been interpreted as supporting the old. How this could happen is an important example for plasma physics of Kuhn's statements about the acceptance of paradigm change and on Popper's views on the judgment of truth in science.

Scaling laws of coronal loops compared to a 3D MHD model of an Active Region

Philippe-A. **Bourdin** (1 and 2), Sven Bingert (3), Hardi Peter

A&A 589, A86 **2016**

Context. The structure and heating of coronal loops are investigated since decades. Established scaling laws relate fundamental quantities like the loop apex temperature, pressure, length, and the coronal heating. Aims. We test such scaling laws against a large-scale 3D MHD model of the Solar corona, which became feasible with nowadays high-performance computing. Methods. We drive an active region simulation a with photospheric observations and found strong similarities to the observed coronal loops in X-rays and EUV wavelength. A 3D reconstruction of stereoscopic observations showed that our model loops have a realistic spatial structure. We compare scaling laws to our model data extracted along an ensemble of field lines. Finally, we fit a new scaling law that represents well hot loops and also cooler structures, which was not possible before only based on observations. Results. Our model data gives some support for scaling laws that were established for hot and EUV-emissive coronal loops. For the RTV scaling law we find an offset to our model data, which can be explained by 1D considerations of a static loop with a constant heat input and conduction. With a fit to our model data we set up a new scaling law for the coronal heat input along magnetic field lines. Conclusions. RTV-like scaling laws were fitted to hot loops and therefore do not predict well the coronal heat input for cooler structures that are hardly observable. The basic differences between 1D and self-consistent 3D modeling account for deviations between our and earlier scaling laws. We also conclude that a heating mechanism by MHD-turbulent dissipation within a braided flux tube would heat the corona stronger than consistent with our model corona.

Coronal loops above an Active Region - observation versus model

Philippe-A. **Bourdin**, Sven Bingert, Hardi Peter

Publ. Astron. Soc. Japan (**2014**) 66 (SP1), S7 (1–8)

http://arxiv.org/pdf/1410.1216v1.pdf

http://pasj.oxfordjournals.org/content/66/SP1/S7.full.pdf+html

We conducted a high-resolution numerical simulation of the solar corona above a stable active region. The aim is to test the field-line braiding mechanism for a sufficient coronal energy input. We also check the applicability of scaling laws for coronal loop properties like the temperature and density. Our 3D-MHD model is driven from below by Hinode observations of the photosphere, in particular a high-cadence time series of line-of-sight magnetograms and horizontal velocities derived from the magnetograms. This driving applies stress to the magnetic field and thereby delivers magnetic energy into the corona, where currents are induced that heat the coronal plasma by Ohmic dissipation. We compute synthetic coronal emission that we directly compare to coronal observations of the same active region taken by Hinode. In the model, coronal loops form at the same places as they are found in coronal observations. Even the shapes of the synthetic loops in 3D space match those found from a stereoscopic reconstruction based on STEREO spacecraft data. Some loops turn out to be slightly over-dense in the model, as expected from observations. This shows that the spatial and temporal distribution of the Ohmic heating produces the structure and dynamics of a coronal loops system close to what is found in observations. **2007 November 14**

MULTI-STRAND CORONAL LOOP MODEL AND FILTER-RATIO ANALYSIS

Sofiane Bourouaine and Eckart Marsch

2010 *ApJ* **708** 1281-1289

We model a coronal loop as a bundle of seven separate strands or filaments. Each of the loop strands used in this model can independently be heated (near their left footpoints) by Alfvén/ion-cyclotron waves via wave-particle interactions. The Alfvén waves are assumed to penetrate the strands from their footpoints, at which we consider different wave energy inputs. As a result, the loop strands can have different heating profiles, and the differential heating can lead to a varying cross-field temperature in the total coronal loop. The simulation of *Transition Region and Coronal Explorer* (*TRACE*) observations by means of this loop model implies two uniform temperatures along the loop length, one inferred from the 171:195 filter ratio and the other from the 171:284 ratio. The reproduced flat temperature profiles are consistent with those inferred from the observed extreme-ultraviolet coronal loops.

According to our model, the flat temperature profile is a consequence of the coronal loop consisting of filaments, which have different temperatures but almost similar emission measures in the cross-field direction. Furthermore, when we assume certain errors in the simulated loop emissions (e.g., due to photometric uncertainties in the *TRACE* filters) and use the triple-filter analysis, our simulated loop conditions become consistent with those of an isothermal plasma. This implies that the use of *TRACE* or EUV Imaging Telescope triple filters for observation of a warm coronal loop may not help in determining whether the cross-field isothermal assumption is satisfied or not.

Scaling Laws for Dynamic Solar Loops

Stephen J. **Bradshaw**, A. Gordon Emslie

ApJ **2020**

https://arxiv.org/pdf/2010.02837.pdf

The scaling laws which relate the peak temperature TM and volumetric heating rate EH to the pressure P and length L for static coronal loops were established over 40 years ago; they have proved to be of immense value in a wide range of studies. Here we extend these scaling laws to {\it dynamic} loops, where enthalpy flux becomes important to the energy balance, and study impulsive heating/filling characterized by upward enthalpy flows. We show that for collision-dominated thermal conduction, the functional dependencies of the scaling laws are the same as for the static case, when the radiative losses scale as T−1/2, but with a different constant of proportionality that depends on the Mach number M of the flow. The dependence on the Mach number is such that the scaling laws for low to moderate Mach number flows are almost indistinguishable from the static case. When thermal conduction is limited by turbulent processes, however, the much weaker dependence of the scattering mean free path (and hence thermal conduction coefficient) on temperature leads to a limiting Mach number for return enthalpy fluxes driven by thermal conduction between the corona and chromosphere.

Coronal Loop Scaling Laws for Various Forms of Parallel Heat Conduction

Stephen J. **Bradshaw**, A. Gordon Emslie, Nicolas H. Bian, Eduard P. Kontar

2019 *ApJ* **880** 80

https://arxiv.org/pdf/1906.03332.pdf

The solar atmosphere is dominated by loops of magnetic flux which connect the multi-million-degree corona to the much cooler chromosphere. The temperature and density structure of quasi-static loops is determined by the continuous flow of energy from the hot corona to the lower solar atmosphere. Loop scaling laws provide relationships between global properties of the loop (such as peak temperature, pressure, and length); they follow from the physical variable dependencies of various terms in the energy equation, and hence the form of the loop scaling law provides insight into the key physics that controls the loop structure. Traditionally, scaling laws have been derived under the assumption of collision-dominated thermal conduction. Here we examine the impact of different regimes of thermal conduction -- collision-dominated, turbulence-dominated, and free-streaming -- on the form of the scaling laws relating the loop temperature and heating rate to its pressure and half-length. We show that the scaling laws for turbulence-dominated conduction are fundamentally different than those for collision-dominated and free-streaming conduction, inasmuch as the form of the scaling laws now depend primarily on conditions at the low-temperature, rather than high-temperature, part of the loop. We also establish regimes in temperature and density space in which each of the applicable scaling laws prevail.

THE COOLING OF CORONAL PLASMAS. III. ENTHALPY TRANSFER AS A MECHANISM FOR ENERGY LOSS

S. J. **Bradshaw** 1,2 and P. J. Cargill

ApJ 717, 163, **2010**

The cooling of impulsively heated coronal loops is examined with emphasis on the phase when optically thin radiation is dominant over conduction. It is shown that this regime cannot be described as purely "radiative cooling" because an enthalpy flux to the transition region plays an important and, on occasions, a dominant role. The scaling between coronal temperature and density (T n δ) during such cooling is reconsidered. The parameter δ is determined by the relative importance of the coronal radiative losses to the enthalpy flux to the transition region, which in turn powers the transition region radiation. It is seen that δ is in the region of 2 for short loops, while gravitational stratification reduces δ to below 2 and values of 1 occur for very long, tenuous loops. This can be understood by noting that for given transition region parameters (and hence required inward enthalpy flux), stratification reduces the coronal losses. It is thus appropriate to refer to this stage of coronal evolution as "radiative-enthalpy cooling."

Magnetic field amplification and structure formation by the Rayleigh-Taylor instability

B. Popescu **Braileanu**, V. S. Lukin, E. Khomenko

A&A **2022**

https://arxiv.org/pdf/2112.13043.pdf

We report on results of high resolution two fluid non-linear simulations of the Rayleigh Taylor Instability (RTI) at the interface between a solar prominence and the corona. These follow results reported earlier by Popescu Braileanu et al. (2021a,b) on linear and early non-linear RTI dynamics in this environment. The simulations use a two fluid model that includes collisions between neutrals and charges, including ionization/recombination, energy and momentum transfer, and frictional heating. High resolution 2.5D magnetized RTI simulations with the magnetic field dominantly normal to and slightly sheared with respect to the prominence plane demonstrate that in a fully developed state of RTI a large fraction of the gravitational energy of a prominence thread can be converted into quasi-turbulent energy of the magnetic field. RTI magnetic energy generation is further accompanied by magnetic and plasma density structure formation, including dynamic formation, break-up, and merging of current sheets and plasmoid sub-structures. The simulations show the role of flow decoupling and ionization/recombination reactions between the neutrals and charges on the structure formation in magnetized RTI. We provide a careful examination of sources and form of numerical dissipation of the evolving magnetic field structures.

Two-fluid simulations of Rayleigh-Taylor instability in a magnetized solar prominence thread II. Effects of collisionality

B. Popescu **Braileanu**, V. S. Lukin, E. Khomenko, A. de Vicente

A&A 650, A181 **2021**
https://arxiv.org/pdf/2101.12731.pdf
https://www.aanda.org/articles/aa/pdf/2021/06/aa40425-21.pdf
https://doi.org/10.1051/0004-6361/202140425

In this work, we explore the dynamical impacts and observable signatures of two-fluid effects in the parameter regimes when ion-neutral collisions do not fully couple the neutral and charged fluids. The purpose of this study is to deepen our understanding of the RTI and the effects of the partial ionization on the development of RTI using non-linear two-fluid numerical simulations. Our two-fluid model takes into account neutral viscosity, thermal conductivity, and collisional interaction between neutrals and charges: ionization/recombination, energy and momentum transfer, and frictional heating. In this paper II, the sensitivity of the RTI dynamics to collisional effects for different magnetic field configurations supporting the prominence thread is explored. This is done by artificially varying, or eliminating, effects of both elastic and inelastic collisions by modifying the model equations. We find that ionization and recombination reactions between ionized and neutral fluids, if in equilibrium prior to the onset of the instability, do not substantially impact the development of the primary RTI. However, such reactions can impact development of secondary structures during mixing of the cold prominence and hotter surrounding coronal material. We find that collisionality within and between ionized and neutral particle populations play an important role in both linear and non-linear development of RTI, with ion-neutral collision frequency as the primary determining factor in development or damping of small scale structures. We also observe that degree and signatures of flow decoupling between ion and neutral fluids can depend both on the inter-particle collisionality and the magnetic field configuration of the prominence thread.

Two-fluid simulations of Rayleigh-Taylor instability in a magnetized solar prominence thread. I. Effects of prominence magnetization and mass loading

B. Popescu **Braileanu**, V. S. Lukin, E. Khomenko, A. de Vicente

A&A 646, A93 **2021**
https://arxiv.org/pdf/2007.15984.pdf
https://doi.org/10.1051/0004-6361/202039053

Solar prominences are formed by partially ionized plasma with inter-particle collision frequencies generally warranting magnetohydrodynamic treatment. In this work, we explore the dynamical impacts and observable signatures of two-fluid effects in the parameter regimes when ion-neutral collisions do not fully couple the neutral and charged fluids. We perform 2.5D two-fluid (charges - neutrals) simulations of the Rayleigh-Taylor instability (RTI) at a smoothly changing interface between a solar prominence thread and the corona. The purpose of this study is to deepen our understanding of the RTI and the effects of the partial ionization on the development of RTI using non-linear two-fluid numerical simulations. Our two-fluid model takes into account viscosity, thermal conductivity, and collisional interaction between neutrals and charges: ionization/recombination, energy and momentum transfer, and frictional heating. In this paper I, the sensitivity of the RTI dynamics to the prominence equilibrium configuration, including the impact of the magnetic field strength and shear supporting the prominence thread, and the amount of prominence mass-loading is explored. We show that, at small scales, a realistically smooth prominence-corona interface leads to qualitatively different linear RTI evolution than that expected for a discontinuous interface, while magnetic field shear has the stabilizing effect of reducing the growth rate or eliminating the instability. In the non-linear phase, we observe that in the presence of field shear the development of the instability leads to formation of coherent and interacting 2.5D magnetic structures, which, in turn, can lead to substantial plasma flow across magnetic field lines and associated decoupling of the fluid velocities of charges and neutrals.

A solar coronal loop in a box: Energy generation and heating

C. **Breu**, H. Peter, R. Cameron, S.K. Solanki, D. Przybylski, M. Rempel, L.P. Chitta

A&A 658, A45 **2022**

https://arxiv.org/pdf/2112.11549.pdf

https://www.aanda.org/articles/aa/pdf/2022/02/aa41451-21.pdf

Coronal loops are the basic building block of the upper solar atmosphere. Comprehending how these are energized, structured, and evolve is key to understanding stellar coronae.

Here we investigate how the energy to heat the loop is generated by photospheric magneto-convection, transported into the upper atmosphere, and how the internal structure of a coronal loop forms.

In a 3D magnetohydrodynamics (MHD) model, we study an isolated coronal loop rooted with both footpoints in a shallow layer within the convection zone using the MURaM code. To resolve its internal structure, we limited the computational domain to a rectangular box containing a single coronal loop as a straightened magnetic flux tube. Field-aligned heat conduction, gray radiative transfer in the photosphere and chromosphere, and optically thin radiative losses in the corona were taken into account. The footpoints were allowed to interact self-consistently with the granulation surrounding them.

The loop is heated by a Poynting flux that is self-consistently generated through small-scale motions within individual magnetic concentrations in the photosphere. Turbulence develops in the upper layers of the atmosphere as a response to the footpoint motions. We see little sign of heating by large-scale braiding of magnetic flux tubes from different photospheric concentrations at a given footpoint. The synthesized emission, as it would be observed by the Atmospheric Imaging Assembly or the X-ray Telescope, reveals transient bright strands that form in response to the heating events. Overall, our model roughly reproduces the properties and evolution of the plasma as observed within coronal loops.

With this model we can build a coherent picture of how the energy flux to heat the upper atmosphere is generated near the solar surface and how this process drives and governs the heating and dynamics of a coronal loop.

Corrigendum: A&A 669, C1 (**2023**) https://www.aanda.org/articles/aa/pdf/2023/01/aa41451e-21.pdf

Measurements of Coronal Magnetic Field Strengths in Solar Active Region Loops

David H. **Brooks**, Harry P. Warren, Enrico Landi

ApJL **915** L24 **2021**

https://arxiv.org/pdf/2106.10884.pdf

https://doi.org/10.3847/2041-8213/ac0c84

The characteristic electron densities, temperatures, and thermal distributions of 1MK active region loops are now fairly well established, but their coronal magnetic field strengths remain undetermined. Here we present measurements from a sample of coronal loops observed by the Extreme-ultraviolet Imaging Spectrometer (EIS) on Hinode. We use a recently developed diagnostic technique that involves atomic radiation modeling of the contribution of a magnetically induced transition (MIT) to the Fe X 257.262A spectral line intensity. We find coronal magnetic field strengths in the range of 60--150G. We discuss some aspects of these new results in the context of previous measurements using different spectropolarimetric techniques, and their influence on the derived Alfvén speeds and plasma β in coronal loops. **2007, December 12**

Properties of the diffuse emission around warm loops in solar active regions

David H. **Brooks**

ApJ **873** 26 **2019**

https://arxiv.org/pdf/1901.07741.pdf

Coronal loops in active regions are the subjects of intensive investigation, but the important diffuse 'unresolved' emission in which they are embedded has received relatively little attention. Here we measure the densities and emission measure (EM) distributions of a sample of background-foreground regions surrounding warm (2 MK) coronal loops, and introduce two new aspects to the analysis. First, we infer the EM distributions only from temperatures that contribute to the same background emission. Second, we measure the background emission co-spatially with the loops so that the results are truly representative of the immediate loop environment. The second aspect also allows us to take advantage of the presence of embedded loops to infer information about the (unresolvable) magnetic field in the background. We find that about half the regions in our sample have narrow but not quite isothermal EM distributions with a peak temperature of 1.4--2 MK. The other half have broad EM distributions (Gaussian width >3×105 K), and the width of the EM appears to be correlated with peak temperature. Densities in the diffuse background are log (n/cm−3) = 8.5-9.0. Significantly, these densities and temperatures imply that the co-spatial background is broadly comptabile with static equilibrium theory (RTV scaling laws) provided the unresolved field length is comparable to the embedded loop length. For this agreement to break down, the field length in most cases would have to be substantially longer than the loop length, a factor of 2--3 on average, which for our sample approaches the dimensions of only the largest active regions. **15 Apr 2011, 22 Apr 2011**

Properties and Modeling of Unresolved Fine Structure Loops Observed by IRIS
David H. **Brooks**, Jeffrey W. Reep, Harry P. Warren
ApJ **2016**
http://arxiv.org/pdf/1606.05440v1.pdf
Recent observations from the Interface Region Imaging Spectrograph (IRIS) have discovered a new class of numerous low-lying dynamic loop structures, and it has been argued that they are the long-postulated unresolved fine structures (UFS) that dominate the emission of the solar transition region. In this letter, we combine IRIS measurements of the properties of a sample of 108 UFS (intensities, lengths, widths, lifetimes) with 1-D non-equilibrium ionization simulations using the HYDRAD hydrodynamic model to examine whether the UFS are now truly spatially resolved in the sense of being individual structures rather than composed of multiple magnetic threads. We find that a simulation of an impulsively heated single strand can reproduce most of the observed properties suggesting that the UFS may be resolved, and the distribution of UFS widths implies that they are structured on a spatial scale of 133km on average. Spatial scales of a few hundred km appear to be typical for a range of chromospheric and coronal structures, and we conjecture that this could be an important clue to the coronal heating process. **7Jan 2014**

HIGH SPATIAL RESOLUTION OBSERVATIONS OF LOOPS IN THE SOLAR CORONA
David H. **Brooks**1,4, Harry P. Warren2, Ignacio Ugarte-Urra1, and Amy R. Winebarger
2013 ApJ 772 L19
Understanding how the solar corona is structured is of fundamental importance to determine how the Sun's upper atmosphere is heated to high temperatures. Recent spectroscopic studies have suggested that an instrument with a spatial resolution of 200 km or better is necessary to resolve coronal loops. The High Resolution Coronal Imager (Hi-C) achieved this performance on a rocket flight in 2012 July. We use Hi-C data to measure the Gaussian widths of 91 loops observed in the solar corona and find a distribution that peaks at about 270 km. We also use Atmospheric Imaging Assembly data for a subset of these loops and find temperature distributions that are generally very narrow. These observations provide further evidence that loops in the solar corona are often structured at a scale of several hundred kilometers, well above the spatial scale of many proposed physical mechanisms.

SOLAR CORONAL LOOPS RESOLVED BY HINODE AND THE SOLAR DYNAMICS OBSERVATORY
David H. **Brooks**1,3, Harry P. Warren2, and Ignacio Ugarte-Urra
2012 ApJ 755 L33
https://arxiv.org/pdf/1205.5814.pdf
Despite decades of studying the Sun, the coronal heating problem remains unsolved. One fundamental issue is that we do not know the spatial scale of the coronal heating mechanism. At a spatial resolution of 1000 km or more, it is likely that most observations represent superpositions of multiple unresolved structures. In this Letter, we use a combination of spectroscopic data from the Hinode EUV Imaging Spectrometer and high-resolution images from the Atmospheric Imaging Assembly on the Solar Dynamics Observatory to determine the spatial scales of coronal loops. We use density measurements to construct multi-thread models of the observed loops and confirm these models using the higher spatial resolution imaging data. The results allow us to set constraints on the number of threads needed to reproduce a particular loop structure. We demonstrate that in several cases million degree loops are revealed to be single monolithic structures that are fully spatially resolved by current instruments. The majority of loops, however, must be composed of a number of finer, unresolved threads, but the models suggest that even for these loops the number of threads could be small, implying that they are also close to being resolved. These results challenge heating models of loops based on the reconnection of braided magnetic fields in the corona.

The influence of flux rope heating models on solar prominence formation
N. **Brughmans**, J.M. Jenkins, R. Keppens
A&A 668, A47 **2022**
https://arxiv.org/pdf/2210.13195
https://www.aanda.org/articles/aa/pdf/2022/12/aa44071-22.pdf
Aims. We begin by exploring the influence of two classes of commonly adopted heating models on the formation behaviour of solar prominences. These models consider either an exponential variation dependent on height alone, or local density and magnetic field conditions. We highlight and address some of the limitations inherent to these early approximations by proposing a new, dynamic 2D flux rope heating model that qualitatively accounts for the 3D topology of the twisted flux rope field. Methods. We performed 2.5D grid-adaptive numerical simulations of prominence formation via the levitation-condensation mechanism. A linear force-free arcade is subjected to shearing

and converging motions, leading to the formation of a flux rope containing material that may succumb to thermal instability. The eventual formation and subsequent evolution of prominence condensations was then quantified as a function of the specific background heating prescription adopted. For the simulations that consider the topology of the flux rope, reduced heating was considered within a dynamically evolving ellipse that traces the flux rope cross-section. This ellipse is centred on the flux rope axis and tracked during runtime using an approach based on the instantaneous magnetic field curvature. Results. We find that the nature of the heating model is clearly imprinted on the evolution and morphology of any resulting prominences: one large, low-altitude condensation is obtained for the heating model based on local parameters, while the exponential model leads to the additional formation of smaller blobs throughout the flux rope which then relocate as they tend towards achieving hydrostatic equilibrium. Finally, a study of the condensation process in phase space reveals a non-isobaric evolution with an eventual recovery of uniform pressure balance along flux surfaces.

Formation of a solar Ha filament from orphan penumbrae

D. **Buehler**, A. Lagg, M. van Noort, S.K. Solanki

A&A 589, A31 **2016**

http://arxiv.org/pdf/1603.05899v1.pdf

The formation of an Ha filament in active region (AR) 10953 is described. Observations from the Solar Optical Telescope (SOT) aboard the Hinode satellite starting on **27th April 2007 until 1st May 2007** were analysed. 20 scans of the 6302A Fe I line pair recorded by SOT/SP were inverted using the SPINOR code. The inversions were analysed together with SOT/BFI G-band and Ca II H and SOT/NFI Ha observations. Following the disappearance of an initial Ha filament aligned along the polarity inversion line (PIL) of the AR, a new Ha filament formed in its place some 20 hours later, which remained stable for at least 1.5 days. The creation of the new Ha filament was driven by the ascent of horizontal magnetic fields from the photosphere into the chromosphere at three separate locations along the PIL. The magnetic fields at two of these locations were situated directly underneath the initial Ha filament and formed orphan penumbrae already aligned along the Ha filament channel. The 700 G orphan penumbrae were stable and trapped in the photosphere until the disappearance of the overlying initial Ha filament, after which they started to ascend into the chromosphere at 10pm5 m/s. Each ascent was associated with a simultaneous magnetic flux reduction of up to 50% in the photosphere. The ascended orphan penumbrae formed dark 'seed' structures in Ha in parallel with the PIL, which elongated and merged to form an Ha filament. The filament channel featured horizontal magnetic fields of on average 260 G at log(tau)=-2 suspended above the nearly field-free lower photosphere. The fields took on an 'inverse' configuration at log(tau)=-2 suggesting a flux rope for the new Ha filament. The orphan penumbral fields ascend into the chromosphere 9-24 hours before the Ha filament is fully formed. The destruction of the initial Ha filament was likely caused by the flux emergence at the third location along the PIL.

Хорошее Введение по волокнам

Heating Mechanisms for Intermittent Loops in Active Region Cores from AIA/SDO EUV Observations

A.C. **Cadavid**, J.K. Lawrence, D.J. Christian, D.B. Jess, G. Nigro

2014 ApJ 795 48

http://arxiv.org/pdf/1404.7824v1.pdf

We investigate intensity variations and energy deposition in five coronal loops in active region cores. These were selected for their strong variability in the AIA/SDO 94 {\AA} intensity channel. We isolate the hot Fe XVIII and Fe XXI components of the 94 {\AA} and 131 {\AA} by modeling and subtracting the "warm" contributions to the emission. HMI/SDO data allow us to concentrate on "inter-moss" regions in the loops. The detailed evolution of the inter-moss intensity time series reveals loops that are impulsively heated in a mode compatible with a nanoflare storm, with a spike in the hot 131 {\AA} signals leading and the other five EUV emission channels following in progressive cooling order. A sharp increase in electron temperature tends to follow closely after the hot 131 {\AA} signal confirming the impulsive nature of the process. A cooler process of growing emission measure follows more slowly. The Fourier power spectra of the hot 131 {\AA} signals, when averaged over the five loops, present three scaling regimes with break frequencies at (0.1/min) and (0.7/min). The low frequency regime corresponds to 1/f noise; the intermediate indicates a persistent scaling process and the high frequencies show white noise. Very similar results are found for the energy dissipation in a 2-D "hybrid" shell model of loop magneto-turbulence, based on reduced magnetohydrodynamics, which is compatible with nanoflare statistics. We suggest that such turbulent dissipation is the energy source for our loops. **2011 July 13, 14, 15.**

The Alignment of High-resolution Solar Prominence Images Observed by the New Vacuum Solar Telescope

Yunfang **Cai**, Yongyuan Xiang, and Kaifan Ji

2024 ApJ 977 186

https://iopscience.iop.org/article/10.3847/1538-4357/ad9006/pdf

High spatial resolution observation of solar prominence is an important observation subject of the New Vacuum Solar Telescope (NVST). While the current level of observation and image reconstruction technologies for solar prominences are advanced, a significant challenge remains in achieving high-precision alignment among high-resolution prominence images observed at different times and different off-bands. Existing alignment approaches either become ineffective or yield low accuracy, and always require manual intervention during the alignment. These limitations are largely due to the stronger edge gradient and lower structural contrast of the prominence images compared with the solar surface ones. In response to this challenge, our study aims to develop an effective and robust algorithm for high-precision alignment of the prominence images. We thoroughly consider the unique structural characteristics of prominence images and the specific application conditions of various alignment algorithms. Consequently, we propose a comprehensive alignment method that incorporates the optical flow field of the solar surface, the gradient of the solar edge, and the cross-correlation within the solar prominence region. This method is designed to accurately determine the movement displacements among the prominence images. Our results demonstrate that this alignment method excels in both accuracy and robustness, making it well-suited for handling the diverse postures of solar prominence images captured by the NVST. **2016 June 4, 2016 August 17**

Sensitivity of Coronal Loop Sausage Mode Frequencies and Decay Rates to Radial and Longitudinal Density Inhomogeneities: A Spectral Approach

Paul S. **Cally**, Ming Xiong

J. Phys. A: Math. Theor. **2017**

https://arxiv.org/pdf/1711.00256.pdf

Fast sausage modes in solar magnetic coronal loops are only fully contained in unrealistically short dense loops. Otherwise they are leaky, losing energy to their surrounds as outgoing waves. This causes any oscillation to decay exponentially in time. Simultaneous observations of both period and decay rate therefore reveal the eigenfrequency of the observed mode, and potentially insight into the tubes' nonuniform internal structure. In this article, a global spectral description of the oscillations is presented that results in an implicit matrix eigenvalue equation where the eigenvalues are associated predominantly with the diagonal terms of the matrix. The off-diagonal terms vanish identically if the tube is uniform. A linearized perturbation approach, applied with respect to a uniform reference model, is developed that makes the eigenvalues explicit. The implicit eigenvalue problem is easily solved numerically though, and it is shown that knowledge of the real and imaginary parts of the eigenfrequency is sufficient to determine the width and density contrast of a boundary layer over which the tubes' enhanced internal densities drop to ambient values. Linearized density kernels are developed that show sensitivity only to the extreme outside of the loops for radial fundamental modes, especially for small density enhancements, with no sensitivity to the core. Higher radial harmonics do show some internal sensitivity, but these will be more difficult to observe. Only kink modes are sensitive to the tube centres. {Variation in internal and external Alfv\'en speed along the loop is shown to have little effect on the fundamental dimensionless eigenfrequency, though the associated eigenfunction becomes more compact at the loop apex as stratification increases, or may even displace from the apex.

EVIDENCE OF FILAMENT UPFLOWS ORIGINATING FROM INTENSITY OSCILLATIONS ON THE SOLAR SURFACE

Wenda **Cao**[1,2], Zongjun Ning[2,3], Philip R. Goode[1,2], Vasyl Yurchyshyn[2], and Haisheng Ji[3]

Astrophysical Journal Letters, 719:L95–L98, **2010**

A filament footpoint rooted in an active region (NOAA 11032) was well observed for about 78 minutes with the1.6 m New Solar Telescope at the Big Bear Solar Observatory on **2009 November 18** in Hα $\pm$0.75 Å. This data set had high cadence (~15 s) and high spatial resolution (~0._1) and offered a unique opportunity to study filament dynamics. As in previous findings from space observations, several dark intermittent upflows were identified, and they behave in groups at isolated locations along the filament. However, we have two new findings. First, we find that the dark upflows propagating along the filament channel are strongly associated with the intensity oscillations on the solar surface around the filament footpoints. The upflows start at the same time as the peak in the oscillations, illustrating that the upflow velocities are well correlated with the oscillations. Second, the intensity of one of the seven upflows detected in our data set exhibits a clear periodicity when the upflow propagates along the filament. The periods gradually vary from ~10 to ~5 minutes. Our results give observational clues on the driving mechanism of the upflows in the filament.

Static and dynamic solar coronal loops with cross-sectional area variations

P. J. **Cargill**, S. J. Bradshaw, J. A. Klimchuk, W. T. Barnes

MNRAS **2021**

https://arxiv.org/pdf/2111.09339.pdf

The Enthalpy Based Thermal Evolution of Loops (EBTEL) approximate model for static and dynamic coronal loops is developed to include the effect of a loop cross-sectional area which increases from the base of the transition region (TR) to the corona. The TR is defined as the part of a loop between the top of the chromosphere and the location where thermal conduction changes from an energy loss to an energy gain. There are significant differences from constant area loops due to the manner in which the reduced volume of the TR responds to conductive and enthalpy fluxes from the corona. For static loops with modest area variation the standard picture of loop energy balance is retained, with the corona and TR being primarily a balance between heating and conductive losses in the corona, and downward conduction and radiation to space in the TR. As the area at the loop apex increases, the TR becomes thicker and the density in TR and corona larger. For large apex areas, the coronal energy balance changes to one primarily between heating and radiation, with conduction playing an increasingly unimportant role, and the TR thickness becoming a significant fraction of the loop length. Approximate scaling laws are derived that give agreement with full numerical solutions for the density, but not the temperature. For non-uniform areas, dynamic loops have a higher peak temperature and are denser in the radiative cooling phase by of order 50% than the constant area case for the examples considered. They also show a final rapid cooling and draining once the temperature approaches 1 MK. Although the magnitude of the emission measure will be enhanced in the radiative phase, there is little change in the important observational diagnostic of its temperature dependence.

CORONAL DENSITY STRUCTURE AND ITS ROLE IN WAVE DAMPING IN LOOPS

P. J. **Cargill**1,2, I. De Moortel2, and G. Kiddie2

2016 ApJ 823 31

It has long been established that gradients in the Alfvén speed, and in particular the plasma density, are an essential part of the damping of waves in the magnetically closed solar corona by mechanisms such as resonant absorption and phase mixing. While models of wave damping often assume a fixed density gradient, in this paper the self-consistency of such calculations is assessed by examining the temporal evolution of the coronal density. It is shown conceptually that for some coronal structures, density gradients can evolve in a way that the wave-damping processes are inhibited. For the case of phase mixing we argue that (a) wave heating cannot sustain the assumed density structure and (b) inclusion of feedback of the heating on the density gradient can lead to a highly structured density, although on long timescales. In addition, transport coefficients well in excess of classical are required to maintain the observed coronal density. Hence, the heating of closed coronal structures by global oscillations may face problems arising from the assumption of a fixed density gradient, and the rapid damping of oscillations may have to be accompanied by a separate (non-wave-based) heating mechanism to sustain the required density structuring.

THE COOLING OF CORONAL PLASMAS. IV. CATASTROPHIC COOLING OF LOOPS

P. J. **Cargill**1,2 and S. J. Bradshaw

2013 ApJ 772 40

We examine the radiative cooling of coronal loops and demonstrate that the recently identified catastrophic cooling is due to the inability of a loop to sustain radiative/enthalpy cooling below a critical temperature, which can be >1 MK in flares, 0.5-1 MK in active regions, and 0.1 MK in long tenuous loops. Catastrophic cooling is characterized by a rapid fall in coronal temperature, while the coronal density changes by a small amount. Analytic expressions for the critical temperature are derived and show good agreement with numerical results. This effect considerably limits the lifetime of coronal plasmas below the critical temperature.

ENTHALPY-BASED THERMAL EVOLUTION OF LOOPS. II. IMPROVEMENTS TO THE MODEL

P. J. **Cargill**1,2, S. J. Bradshaw3, and J. A. Klimchuk

2012 ApJ 752 161

This paper develops the zero-dimensional (0D) hydrodynamic coronal loop model "Enthalpy-based Thermal Evolution of Loops" (EBTEL) proposed by Klimchuk et al., which studies the plasma response to evolving coronal heating, especially impulsive heating events. The basis of EBTEL is the modeling of mass exchange between the corona and transition region (TR) and chromosphere in response to heating variations, with the key parameter being the ratio of the TR to coronal radiation. We develop new models for this parameter that now include gravitational stratification and a physically motivated approach to radiative cooling. A number of examples are presented, including nanoflares in short and long loops, and a small flare. The new features in EBTEL are important for accurate tracking of, in particular, the density. The 0D results are compared to a 1D hydro code (Hydrad) with generally good agreement. EBTEL is suitable for general use as a tool for (1) quick-look results of loop evolution in response to a given heating function, (2) extensive parameter surveys, and (3) situations where the modeling of hundreds or thousands of elemental loops is needed. A single run takes a few seconds on a contemporary laptop.

A Catalog of Faculae, Prominences, and Filaments for the Period 1929–1944 from the Astronomical Observatory of the University of Coimbra

V. M. S. **Carrasco**1,2 and J. M. Vaquero2,3

2022 ApJS 262 44
https://iopscience.iop.org/article/10.3847/1538-4365/ac85dd/pdf
The Astronomical Observatory of the University of Coimbra (Portugal) published a catalog with solar observations such as sunspots, faculae, prominences, and filaments for the period 1929–1944. In previous works, a machine-readable version on sunspot observations made in Coimbra was published. Here we extend that work and present a digital version of the facula, prominence, and filament observations made in that observatory. We have applied a quality control to the catalog, obtaining that the percentage of problematic or suspicious data found is lower than 1% of the total number of observations. In addition, we show an analysis of this catalog, as well as some comparisons between solar indices calculated from Coimbra data and those from other sources. Historical observations of faculae, prominences, and filaments are not as common as sunspot records, and in addition, few historical series of these solar features are available in digital version. For that reason, the catalog of solar observations published by the Coimbra Observatory is of enormous value. The recovery, publication, and availability of this catalog provide the scientific community with a valuable data set of solar characteristics that will help us to study in more detail the past solar magnetic field and long-term solar activity.

POLARIMETRIC DIAGNOSTICS OF UNRESOLVED CHROMOSPHERIC MAGNETIC FIELDS

R. Casini1, R. Manso Sainz2 and B. C. Low1
ApJ 701 L43-L46, **2009** doi: 10.1088/0004-637X/701/1/L43
For about a decade, spectropolarimetry of He I λ10830 has been applied to the magnetic diagnostics of the solar chromosphere. This resonance line is very versatile as it is visible both on disk and in off-limb structures, and it has a good sensitivity to both the weak-field Hanle effect and the strong-field Zeeman effect. Recent observations of an active-region filament showed that the linear polarization was dominated by the transverse Zeeman effect, with very little or no hint of scattering polarization. This is surprising, since the He I levels should be significantly polarized in a conventional scattering scenario. To explain the observed level of atomic depolarization by collisional or radiative processes, one must invoke plasma densities larger by several orders of magnitude than currently known values for prominences. We show that such depolarization can be explained quite naturally by the presence of an unresolved, highly entangled magnetic field, which averages to give the ordered field inferred from spectropolarimetric data, over the typical temporal and spatial scales of the observations. We present a modeling of the polarized He I λ10830 in this scenario, and discuss its implications for the magnetic diagnostics of prominences and spicules, and for the general study of unresolved magnetic field distributions in the solar atmosphere.

Dynamics of Vertical Threads and Descending Knots in a Hedgerow Prominence

Jongchul **Chae**
BBSO #1419, **2010;** Astrophysical Journal, 714:618–629, **2010** May
The existence and behavior of vertical fine structures of plasma — threads and knots — is a significant observational clue to understanding the magnetic structure and dynamics of quiescent prominences on the quiet Sun. Based on the equation of motion in ideal MHD, we reason that the non-hydrostatic support of plasma against gravity in general requires either the motion of plasma with a high value of downward acceleration (dynamical support) or the role of horizontal magnetic fields (magnetic support). By carefully tracking the motion of several bright threads seen in a hedgerow prominence observed by the Solar Optical Telescope aboard *Hinode*, we confirm that these threads are essentially static and stable, which negates the dynamic support. The application of the Kippenhahn-Schlüter solution suggests that they may be supported by sagged magnetic field lines with a sag angle of about 43°. We also track several bright descending knots and find that their descending speeds range from 10 to 30 km s^{-1}, with a mean value of 16 km s^{-1}, and their vertical accelerations from -0.10 to 0.10 km s^{-2}, with a mean of practically zero. This finding suggests that these knots are basically supported by horizontal magnetic fields against gravity even when they descend, and the complex variations of their descending speeds should be attributed to small imbalances between gravity and the force of magnetic tension. Furthermore, some knots are observed to impulsively get accelerated downward from time to time. We conjecture that these impulsive accelerations are a result of magnetic reconnection and the subsequent interchange of magnetic configuration between a knot and its surrounding structure. It is proposed that this process of reconnection-and-interchange not only initiate the descending motion of the knots, but also allow knots to keep falling long-distance through the medium permeated by horizontal magnetic fields.

Persistent Horizontal Flows and Magnetic Support of Vertical Threads in a Quiescent Prominence

Jongchul **Chae**, Kwangsoo Ahn, Eun-Kyung Lim, G. S. Choe, and Takashi Sakurai
The Astrophysical Journal Letters, Vol. 689, No. 1: L73-L76.
http://www.journals.uchicago.edu/doi/abs/10.1086/595785
There has been some controversy as to whether the magnetic fields of vertical threads seen in quiescent prominences are predominantly vertical or horizontal. We report finding special patterns of flow in a quiescent

prominence observed by the Solar Optical Telescope aboard *Hinode*. This prominence is a small hedgerow prominence composed of many vertical threads. To one side of it, we found a pattern of persistent horizontal flows of Hα-emitting plasma. These flows originated from a region in the chromosphere, rose to coronal heights, and then extended horizontally for a long distance until they reached the main body of the prominence. In the higher altitudes the flows either moved across vertical threads or lifted them up, while in the lower altitudes they often formed bright blobs of plasma and shed them, resulting in a sudden change of flow direction from horizontal to vertical. The observed persistent horizontal flows support a configuration of initially horizontal magnetic fields, and our results appear to be consistent with the traditional theory that vertical threads in quiescent prominences are stacks of plasma supported against gravity by the sagging of initially horizontal magnetic field lines.

Simulating Rayleigh-Taylor induced magnetohydrodynamic turbulence in prominences

Madhurjya **Changmai**, Jack M. Jenkins, J.-B. Durrive, Rony Keppens

A&A 672, A152 **2023**

https://arxiv.org/pdf/2302.04707

https://www.aanda.org/articles/aa/pdf/2023/04/aa43034-22.pdf

Solar prominences represent large-scale condensations suspended against gravity within the solar atmosphere. The Rayleigh-Taylor (RT) instability is proposed to be one of the important fundamental processes leading to the generation of dynamics at many spatial and temporal scales within these long-lived, cool, and dense structures amongst the solar corona. We run 2.5D ideal magnetohydrodynamic (MHD) simulations with the open-source MPI-AMRVAC code far into the nonlinear evolution of an RT instability perturbed at the prominence-corona interface. Our simulation achieves a resolution down to ∼23 km on a 2D (x,y) domain of size 30 Mm × 30 Mm. We follow the instability transitioning from a multi-mode linear perturbation to its nonlinear, fully turbulent state. Over the succeeding ∼25 minute period, we perform a statistical analysis of the prominence at a cadence of ∼0.858 s. We find the dominant guiding Bz component induces coherent structure formation predominantly in the vertical velocity Vy component, consistent with observations, demonstrating an anisotropic turbulence state within our prominence. We find power-law scalings in the inertial range for the velocity, magnetic, and temperature fields. The presence of intermittency is evident from the probability density functions of the field fluctuations, which depart from Gaussianity as we consider smaller and smaller scales. In exact agreement, the higher-order structure functions quantify the multifractality, in addition to different scale characteristics and behavior between the longitudinal and transverse directions. Thus, the statistics remain consistent with the conclusions from previous observational studies, enabling us to directly relate the RT instability to the turbulent characteristics found within quiescent prominence.

THE THREE-DIMENSIONAL STRUCTURE OF AN ACTIVE REGION FILAMENT AS EXTRAPOLATED FROM PHOTOSPHERIC AND CHROMOSPHERIC OBSERVATIONS

L. Yelles **Chaouche**1,2, C. Kuckein1,2, V. Martínez Pillet1,2 and F. Moreno-Insertis

2012 ApJ 748 23

The three-dimensional structure of an active region filament is studied using nonlinear force-free field extrapolations based on simultaneous observations at a photospheric and a chromospheric height. To that end, we used the Si I 10827 Å line and the He I 10830 Å triplet obtained with the Tenerife Infrared Polarimeter at the Vacuum Tower Telescope (Tenerife). The two extrapolations have been carried out independently from each other and their respective spatial domains overlap in a considerable height range. This opens up new possibilities for diagnostics in addition to the usual ones obtained through a single extrapolation from, typically, a photospheric layer. Among those possibilities, this method allows the determination of an average formation height of the He I 10830 Å signal of 2 Mm above the surface of the Sun. It allows, as well, a cross-check of the obtained three-dimensional magnetic structures to verify a possible deviation from the force-free condition, especially at the photosphere. The extrapolations yield a filament formed by a twisted flux rope whose axis is located at about 1.4 Mm above the solar surface. The twisted field lines make slightly more than one turn along the filament within our field of view, which results in 0.055 turns Mm–1. The convex part of the field lines (as seen from the solar surface) constitutes dips where the plasma can naturally be supported. The obtained three-dimensional magnetic structure of the filament depends on the choice of the observed horizontal magnetic field as determined from the 180° solution of the azimuth. We derive a method to check for the correctness of the selected 180° ambiguity solution.

A Comparison of EIT and TRACE Loop Widths

S. I. **Chastain**, J. T. Schmelz

2017

https://arxiv.org/pdf/1705.06776.pdf

In this study we have compared coronal loops in the Extreme ultraviolet Imaging Telescope (EIT) on-board the Solar and Heliospheric Observatory (SOHO) with coronal loops from the Transition Region and Coronal Explorer (TRACE). The purpose of which is to quantitatively and qualitatively examine the effects of spatial resolution on the width of coronal loops and implications for how a coronal loop is defined. Out of twenty-two loop sections analyzed, we find that none of them were resolved in EIT and none of them were close to the width of the TRACE loops. These findings suggest that coronal loops are unresolved in EIT. We also find examples of how unresolved loops can be quite misleading. We have also found that many of the TRACE loops that we have analyzed may be unresolved as well. Our findings emphasize the importance of studying loop width in order to better understand coronal loops and also emphasize the need for instruments with higher spatial resolution. 1999 November 06, 2000 January 13, 2000 March 24, 2000 June 11, 2000 July 11, 2001 August 12

Detecting Prominences from Century-long Disc-blocked C\MakeLowercase{a}~{\sc ii}~K Spectroheliograms of Kodaikanal Observatory

Subhamoy **Chatterjee**, Manjunath Hegde, Dipankar Banerjee, B. Ravindra
ApJ **2018**
https://arxiv.org/pdf/1802.07556.pdf

Kodaikanal Solar Observatory (KoSO) has recently digitised the long-term (1906-2002) disc-blocked Ca~{\sc ii}~K spectroheliograms. This data has been archived at \url{this https URL}. The intriguing features seen in the images are the off-limb prominences which provides a proxy for understanding the solar magnetic activities over a long period of time. To make use of this unique dataset we performed calibration of the raw data and developed an automated technique to identify the prominence locations on daily images. We use the recorded prominence latitudes to generate their time-latitude distribution and find clear signature of poleward migration for about 8 cycles complementing the Ha observation in KoSO. We study the drift rate of polar prominences across solar cycles and latitudes. North-South asymmetries of the drift rates are also computed. We show how latitudinal distribution of prominences vary over a period of 11 years and the dominant latitudes in the aggregate distribution. As one of major sources of coronal mass ejection (CME) is eruptive prominence, the latitudinal distribution of prominences can provide additional input for the understanding of the generation of CMEs, particularly the slow CMEs. Clear depiction of polar rush for multiple cycles presented in this work should be valuable in the study of prediction of solar cycles.

Long term study of the solar filaments from the Synoptic Maps as derived from Hα Spectroheliograms of Kodaikanal Observatory

Subhamoy **Chatterjee**, Manjunath Hegde, Dipankar Banerjee, B. Ravindra
ApJ **849** 44 **2017**
https://arxiv.org/pdf/1707.05658.pdf

The century long (1914-2007) Hα (656.28 nm) spectroheliograms from Kodaikanal Solar Observatory (KSO) have been recently digitised. Using these newly calibrated, processed images we study the evolution of dark elongated on disk structures called filaments, potential representatives of magnetic activities on the Sun. To our knowledge this is the oldest uniform digitised dataset with daily images available today in Hα. We generate Carrington maps for entire time duration and try to find the correspondences with maps of same rotation from Ca II K KSO data. Filaments are segmented from Carrington maps using a semi-automated technique and are studied individually to extract their centroids and tilts. We plot the time-latitude distribution of filament centroids producing Butterfly diagram, which clearly shows presence of poleward migration. We separate polar filaments for each cycle and try to estimate the delay between the polar filament number cycle and sunspot number cycle peaks. We correlate this delay with the same between polar reversal and sunspot number maxima. This provides new insight on the role of polar filaments on polar reversal.

Analysis of full disc Hα observations: Carrington maps and filament properties over 1909-2022

Theodosios **Chatzistergos**, Ilaria Ermolli, Dipankar Banerjee, Teresa Barata, +++
A&A 680, A15 **2023**
https://arxiv.org/pdf/2309.09591.pdf
https://www.aanda.org/articles/aa/pdf/2023/12/aa47536-23.pdf

Full disc observations of the Sun in the Hα line provide information about the solar chromosphere and in particular about the filaments, which are dark and elongated features that lie along magnetic field polarity inversion lines. This makes them important for studies of solar magnetism. Since full disc Hα observations have been performed at various sites since 1800s, with regular photographic data having started in the beginning of the 20th century, they are an invaluable source of information on past solar magnetism. In this work we aimed at deriving accurate information about filaments from historical and modern full disc Hα observations. We have consistently processed observations from 15 Hα archives spanning 1909-2022. Our data processing includes photometric calibration of the data stored on photographic plates. We have constructed also Carrington maps from the calibrated Hα images. We find that filament areas are affected by the bandwidth of the observation. Thus, cross-calibration of the filament areas derived from different archives is needed. We have produced a composite of filament areas from individual archives by scaling all of them to the Meudon series. Our composite butterfly diagram shows very distinctly the common features of filament evolution, that is the poleward migration as well as a decrease in the mean latitude of filaments as the cycle progresses. We also find that during activity maxima, filaments on average cover about 1% of the solar surface. We see only a weak change in the amplitude of cycles in filament areas, in contrast to sunspot and plage areas. Analysis of Hα data for archives with contemporaneous Ca II K observations allowed us to identify and verify archive inconsistencies, which will also have implications for reconstructions of past solar magnetism and irradiance from Ca II K data.

Measuring local physical parameters in coronal loops with spatial seismology

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A&A 678, A205 (**2023**)
https://www.aanda.org/articles/aa/pdf/2023/10/aa46393-23.pdf

Context. The method of spatial seismology can be applied to the amplitude profile of transverse coronal loop oscillations to constrain the distributions of physical parameters, such as the loop density, magnitude of the magnetic field, and so on.
Aims. We intend to develop and apply a practical spatial seismology technique to detect physical parameters of plasma and validate its effectiveness by comparing it with other methods.
Methods. A spatial seismology inversion was conducted by numerically optimizing a parametric dynamic model of the loop's density stratification and magnetic field variation to best fit the measured amplitude profile of the loop.
Results. The spatial seismology inversion technique developed here was applied to a transverse coronal loop oscillation that occurred on **2013 April 11**, whose oscillation amplitude profile of both the fundamental mode and first overtone was reported in previous work. The consistency between the time domain analysis and spatial seismology has been verified. Meanwhile, we accounted for the asymmetric profile of the fundamental mode by forward modeling and we derived the magnetic field distribution by inverse modeling, which is coincident with that of the extrapolated one. In addition, spatial seismology inversion was applied to the transverse oscillation event on 2022 March 30 to obtain the distribution of the loop's density and magnetic field, which are compared with the results derived from the differential emission measure (DEM) diagnostics and the direct potential field extrapolation
Conclusions. Spatial seismology inversion can be used as an effective method to independently measure various physical parameters, for example the density and magnetic field of coronal loops, which are consistent with the results obtained by DEM diagnostics and potential field extrapolation.

Coronal loop kink oscillation periods derived from the information of density, magnetic field, and loop geometry

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A&A 664, A48 (**2022**)
https://www.aanda.org/articles/aa/pdf/2022/08/aa42711-21.pdf

Context. Coronal loop oscillations can be triggered by solar eruptions, for example, and are observed frequently by the Atmospheric Imaging Assembly (AIA) on board Solar Dynamics Observatory (SDO). The Helioseismic and Magnetic Imager (HMI) on board SDO offers us the opportunity to measure the photospheric vector magnetic field and carry out solar magneto-seismology (SMS).
Aims. By applying SMS, we aim to verify the consistency between the observed period and the one derived from the information of coronal density, magnetic field, and loop geometry, that is, the shape of the loop axis.
Methods. We analysed the data of three coronal loop oscillation events detected by SDO/AIA and SDO/HMI. First, we obtained oscillation parameters by fitting the observational data. Second, we used a differential emission measure (DEM) analysis to diagnose the temperature and density distribution along the coronal loop. Subsequently, we applied magnetic field extrapolation to reconstruct the three-dimensional magnetic field and then, finally, used the shooting method to compute the oscillation periods from the governing equation.
Results. The average magnetic field determined by magnetic field extrapolation is consistent with that derived by SMS. A new analytical solution is found under the assumption of exponential density profile and uniform magnetic field. The periods estimated by combining the coronal density and magnetic field distribution and the associated loop geometry are closest to the observed ones, and are more realistic than when the loop geometry is regarded as being semi-circular or having a linear shape.
Conclusions. The period of a coronal loop is sensitive to not only the density and magnetic field distribution but also the loop geometry. **2010 October 16, 6 Sep 2011, 7 Mar 2012**

Solar Prominence Bubble and Plumes Caused By an Eruptive Magnetic Flux Rope

Changxue **Chen**1,2, Yang Su1,2, Jianchao Xue1, Weiqun Gan1, and Yu Huang1
ApJL 923 L10 **2021**
https://iopscience.iop.org/article/10.3847/2041-8213/ac3bd0/pdf
https://doi.org/10.3847/2041-8213/ac3bd0

Prominence bubbles and plumes often form near the lower prominence–corona boundary. They are believed to play an important role in mass supply and evolution of solar prominences. However, how they form is still an open question. In this Letter we present a unique high-resolution Hα observation of a quiescent prominence by the New

Vacuum Solar Telescope. Two noteworthy bubble–plume events are studied in detail. The two events are almost identical, except that an erupting mini filament appeared below the prominence–bubble interface in the second event, unlike the first one or any of the reported bubble observations. Analysis of the Hα and extreme-ultraviolet data indicates that the rising magnetic flux rope (MFR) in the mini filament is the cause of bubble expansion and that the interaction between the prominence and MFR results in plume formation. These observations provided clear evidence that emerging MFR may be a common trigger of bubbles and suggested a new mechanism of plumes in addition to Rayleigh–Taylor instability and reconnection. **14 April 2021**

High-resolution Chromospheric Observations of a Solar Minifilament: Formation and Destabilization

Hechao **Chen**1,2,3, Junchao Hong1,3,4, Bo Yang1,3, Zhe Xu5,3, and Jiayan Yang

2020 ApJ 902 8

https://doi.org/10.3847/1538-4357/abb1c1

Using Hα line core and off-band imaging data from the New Vacuum Solar Telescope in China, we present a high-resolution observation on the entire life cycle of a solar minifilament from its birth to its final eruption. We find that the minifilament originates from a series of cascade-like reconfigurations of chromospheric fine structures. During which, owing to strong photospheric shearing and converging flows near its polarity inversion line, basic short chromospheric fibrils first slowly coalesce to elongated dark threads, and then further create a longer filament channel in a "head-to-tail" linkage scenario. In this course, obvious magnetic flux cancelation simultaneously proceeds below it, and further facilitates its destabilization. In its onset phase, clear clues indicate that the minifilament first starts to rise without brightening signals; instead, after a slow-to-fast acceleration, obvious runaway reconnection soon takes over its final jet-like eruption. Besides, off-band observations further reveal that the formed minifilament has a possible flux-rope configuration, and chromospheric upflows that detected in its early forming phase persistently supplies cool plasma into its channel. This observation is consistent with earlier observations and supports the view that both miniature and large-scale filaments may share analogous formation and destabilization mechanisms.

Some interesting topics provoked by the solar filament research in the past decade **Review**

P. F. **Chen**, A. A. Xu, M. D. Ding

Research in Astron. Astrophys. **2020**

https://arxiv.org/pdf/2010.02462.pdf

Solar filaments are an intriguing phenomenon, like cool clouds suspended in the hot corona. Similar structures exist in the intergalactic medium as well. Despite being a long-studied topic, solar filaments have continually attracted intensive attention because of their link to the coronal heating, coronal seismology, solar flares, and coronal mass ejections (CMEs). In this review paper, by combing through the solar filament-related work done in the past decade, we discuss several controversial topics, such as the fine structures, dynamics, magnetic configurations, and helicity of filaments. With high-resolution and high-sensitivity observations, combined with numerical simulations, it is expected that resolving these disputes will definitely lead to a huge leap in understanding the physics related to solar filaments, and even shed light on galactic filaments.

Formation of Two Homologous Transequatorial Loops

Jie **Chen**, Alexei A. Pevtsov, Jiangtao Su, Robertus Erdélyi, Yuanyong Deng, Shangbin Yang & Yongliang Song

Solar Physics volume 295, Article number: 59 (**2020**)

https://link.springer.com/content/pdf/10.1007/s11207-020-01625-z.pdf

The formation mechanism of two homologous transequatorial loops (TLs) of **July 7–8, 1999** (SOL1999-07-07) is studied. The TLs connected active region AR 8614 from the northern hemisphere to AR 8626 in the southern hemisphere. The first TL appeared as a distinct structure at 12:49 UT on July 7, the second TL appeared at 06:21 UT, on July 8. Important results are obtained in this analysis: (i) The configuration of the two TLs is similar in X-rays. (ii) The sizes of the two active regions related to the TLs increased before and during the formation of the two TLs, this induced the expansion of their coronal loops. (iii) Both TLs formed globally on a time scale shorter than 110 min (time resolution of observations). (iv) An X-shaped coronal structure was observed. This observational evidence suggests that the two TLs formed by the same physical mechanism, magnetic reconnection, between the two expanding magnetic configurations of the two ARs.

The Formation of a Small-scale Filament after Flux Emergence on the Quiet Sun

Hechao **Chen**, Jiayan Yang, Bo Yang, Kaifan Ji, Yi Bi

Solar Phys. 293:93 **2018**

https://arxiv.org/pdf/1806.03830.pdf

https://link.springer.com/content/pdf/10.1007%2Fs11207-018-1311-8.pdf

We present observations of the formation process of a small-scale filament on the quiet Sun during **5-6 February 2016** and investigate its formation cause. Initially, a small dipole emerged and its associated arch filament system was found to reconnect with overlying coronal fields accompanied by numerous EUV bright points. When bright points faded out, many elongated dark threads formed bridging the positive magnetic element of dipole and external negative network fields. Interestingly, an anti-clockwise photospheric rotational motion (PRM) set in within the positive endpoint region of newborn dark threads following the flux emergence and lasted for more than 10 hours. Under the drive of the PRM, these dispersive dark threads gradually aligned along the north-south direction and finally coalesced into an inverse S-shaped filament. Consistent with the dextral chirality of the filament, magnetic helicity calculations show that an amount of negative helicity was persistently injected from the rotational positive magnetic element and accumulated during the formation of the filament. These observations suggest that twisted emerging fields may lead to the formation of the filament via reconnection with pre-existing fields and release of its inner magnetic twist. The persistent PRM might trace a covert twist relaxation from below photosphere to the low corona.

A reexamination of a filament oscillation event on 2013 March 15

Jialin **Chen**, Wenbin Xie, Yuhao Zhou, Kai Yang, Yu Ouyang, P. F. Chen

Astrophysics and Space Science September **2017**, 362:165

The key element in the research of solar activities is the coronal magnetic field, which is however difficult to measure directly. Filament (or prominence) oscillations offer a new approach to derive important information of the coronal magnetic field, which is called prominence seismology. However, it is vital to determine the oscillation mode before applying the prominence seismology since for a given magnetic structure of a filament, the two different modes of oscillation, namely, the longitudinal and transverse, have different eigen frequencies. In low-resolution observations, it is hard to distinguish the oscillation mode since both modes of oscillations are associated with lateral displacements, and the subtle difference between the two modes becomes unresolvable. On 2013 March 15, there is a filament oscillation event with a period of ∼63 minutes and a decay timescale of ∼105 minutes, which was explained in the literature to be a transverse oscillation or a mixture of both transversal and longitudinal components with the same period. With the analysis of the high-resolution SDO/AIA data, we reexamine the filament oscillation event, and argue that this event is a longitudinal oscillation. We tentatively propose a new method on how to identify the oscillation mode when the observational resolution is not so high. A numerical simulation is also provided in order to match the observations, which leads to the ratio between the depth and the width of the magnetic dip being 0.1.

Periods and damping rates of fast sausage oscillations in multi-shelled coronal loops

Shao-Xia **Chen**, Bo Li, Li-Dong Xia, Hui Yu

Solar Phys. **2015**

http://arxiv.org/pdf/1507.02169v1.pdf

Standing sausage modes are important in interpreting quasi-periodic pulsations in the lightcurves of solar flares. Their periods and damping times play an important role in seismologically diagnosing key parameters like the magnetic field strength in regions where flare energy is released. Usually such applications are based on theoretical results neglecting unresolved fine structures in magnetized loops. However, the existence of fine structuring is suggested on both theoretical and observational grounds. Adopting the framework of cold magnetohydrodynamics (MHD), we model coronal loops as magnetized cylinders with a transverse equilibrium density profile comprising a monolithic part and a modulation due to fine structuring in the form of concentric shells. The equation governing the transverse velocity perturbation is solved with an initial-value-problem approach, and the effects of fine structuring on the periods P and damping times τ of global, leaky, standing sausage modes are examined. A parameter study shows that fine structuring, be it periodically or randomly distributed, brings changes of only a few percent to P and τ when there are more than about ten shells. The monolithic part, its steepness in particular, plays a far more important role in determining P and τ. We conclude that when measured values of P and τ of sausage modes are used for seismological purposes, it is justified to use theoretical results where the effects due to fine structuring are neglected.

Magnetic Jam in the Corona of the Sun

F. **Chen**, H. Peter, S. Bingert, M.C.M. Cheung

Nature Physics, **2015**

http://arxiv.org/pdf/1505.01174v1.pdf

The outer solar atmosphere, the corona, contains plasma at temperatures of more than a million K, more than 100 times hotter that solar surface. How this gas is heated is a fundamental question tightly interwoven with the structure of the magnetic field in the upper atmosphere. Conducting numerical experiments based on magnetohydrodynamics we account for both the evolving three-dimensional structure of the atmosphere and the complex interaction of magnetic field and plasma. Together this defines the formation and evolution of coronal loops, the basic building block prominently seen in X-rays and extreme ultraviolet (EUV) images. The structures seen as coronal loops in the EUV can evolve quite differently from the magnetic field. While the magnetic field continuously expands as new magnetic flux emerges through the solar surface, the plasma gets heated on successively emerging fieldlines creating an EUV loop that remains roughly at the same place. For each snapshot the EUV images outline the magnetic field, but in contrast to the traditional view, the temporal evolution of the magnetic field and the EUV loops can be different. Through this we show that the thermal and the magnetic evolution in the outer atmosphere of a cool star has to be treated together, and cannot be simply separated as done mostly so far.

Imaging and Spectroscopic Observations of a Filament Channel and the Implications for the Nature of Counter-streamings

P. F. **Chen**, L. K. Harra, and C. Fang

2014 ApJ 784 50

The dynamics of a filament channel are observed with imaging and spectroscopic telescopes before and during the filament eruption on **2011 January 29**. The extreme ultraviolet (EUV) spectral observations reveal that there are no EUV counterparts of the Hα counter-streamings in the filament channel, implying that the ubiquitous Hα counter-streamings found by previous research are mainly due to longitudinal oscillations of filament threads, which are not in phase between each other. However, there exist larger-scale patchy counter-streamings in EUV along the filament channel from one polarity to the other, implying that there is another component of unidirectional flow (in the range of ±10 km s–1) inside each filament thread in addition to the implied longitudinal oscillation. Our results suggest that the flow direction of the larger-scale patchy counter-streaming plasma in the EUV is related to the intensity of the plage or active network, with the upflows being located at brighter areas of the plage and downflows at the weaker areas. We propose a new method to determine the chirality of an erupting filament on the basis of the skewness of the conjugate filament drainage sites. This method suggests that the right-skewed drainage corresponds to sinistral chirality, whereas the left-skewed drainage corresponds to dextral chirality.

Effects of Field-Aligned Flows on Standing Kink and Sausage Modes Supported by Coronal Loops

S.-X. **Chen**, B. Li, L.-D. Xia, Y.-J. Chen, H. Yu

Solar Physics, May **2014**, Volume 289, Issue 5, pp 1663-1681

Fundamental standing modes and their overtones play an important role in coronal seismology. We examine the effects of a significant field-aligned flow on standing modes that are supported by coronal loops, which are modeled here as cold magnetic slabs. Of particular interest are the period ratios of the fundamental to its (n−1)th overtone [P 1/nP n] for kink and sausage modes, and the threshold half-width-to-length ratio for sausage modes. For standing kink modes, the flow significantly reduces P 1/nP n in general, the effect being particularly strong for higher n and weaker density contrast [ρ0/ρe] between loops and their surroundings. That said, even when ρ0/ρe approaches infinity, this effect is still substantial, reducing the minimal P 1/nP n by up to 13.7 % (24.5 %) for n=2 (n=4) relative to the static case, when the Alfvén Mach number [M A] reaches 0.8, where M A measures the loop flow speed in units of the internal Alfvén speed. Although it is not negligible for standing sausage modes, the flow effect in reducing P 1/nP n is not as strong. However, the threshold half-width-to-length ratio is considerably higher in the flowing case than in its static counterpart. For ρ0/ρe in the range [9,1024] and M A in the range [0,0.5], an exhaustive parameter study yields that this threshold is well fitted by … , which involves the two parameters in a simple way. This allows one to analytically constrain the combination (ρ0/ρe, MA) for a loop with a known width-to-length ratio when a standing sausage oscillation is identified. It also allows one to examine the idea of partial sausage modes in more detail, and the flow is found to significantly reduce the spatial extent where partial modes are allowed.

Prominence Formation and Oscillations **Review**

P. F. **Chen**

ASI Conference Series, **2013**, Vol. 10, pp 1-10

Prominences, or filaments, are a striking phenomenon in the solar atmosphere. Besides their own rich features and dynamics, they are related to many other activities, such as solar flares and coronal mass ejections (CMEs). In the past several years we have been investigating the prominence formation, oscillations, and eruptions through both data analysis and radiative hydrodynamic and magnetohydrodynamic (MHD) simulations. This paper reviews our progress on these topics, which includes: (1) With updated radiative cooling function, the coronal condensation becomes a little faster than previous work; (2) Once a seed condensation is formed, it can grow via siphon flow spontaneously even if the evaporation stops; (3) A scaling law was obtained to relate the length of the prominence thread to various parameters, indicating that higher prominences tend to have shorter threads, which is consistent with the fact that threads are long in active region prominences and short in quiescent prominences; (4) It was proposed that long-time prominence oscillations out of phase might serve as a precursor for prominence eruptions and CMEs; (5) An ensemble of oscillating prominence threads may explain the counter-streaming motion.

Overlying Extreme-ultraviolet Arcades Preventing Eruption of a Filament Observed by AIA/SDO

Huadong **Chen**1,2, Suli Ma1, and Jun **Zhang**

2013 ApJ 778 70

http://arxiv.org/pdf/1407.1413v1.pdf

Using the multi-wavelength data from the Atmospheric Imaging Assembly/Solar Dynamic Observatory (AIA/SDO) and the Sun Earth Connection Coronal and Heliospheric Investigation/Solar Terrestrial Relations Observatory (SECCHI/STEREO), we report a failed filament eruption in NOAA AR 11339 on **2011 November 3**. The eruption was associated with an X1.9 flare, but without any coronal mass ejection (CME), coronal dimming, or extreme ultraviolet (EUV) waves. Some magnetic arcades above the filament were observed distinctly in EUV channels, especially in the AIA 94 Å and 131 Å wavebands, before and during the filament eruption process. Our results show that the overlying arcades expanded along with the ascent of the filament at first until they reached a projected height of about 49 Mm above the Sun's surface, where they stopped. The following filament material was observed to be confined by the stopped EUV arcades and not to escape from the Sun. After the flare, a new filament formed at the low corona where part of the former filament remained before its eruption. These results support that the overlying arcades play an important role in preventing the filament from successfully erupting outward. We also discuss in this paper the EUV emission of the overlying arcades during the flare. It is rare for a failed filament eruption to be associated with an X1.9 class flare, but not with a CME or EUV waves. Therefore, this study also provides valuable insight into the triggering mechanism of the initiation of CMEs and EUV waves.

A CORONAL SEISMOLOGICAL STUDY WITH STREAMER WAVES

Y. **Chen**1, S. W. Feng1, B. Li1, H. Q. Song1, L. D. Xia1, X. L. Kong1, and Xing Li2

Astrophysical Journal, 728:147 (6pp), **2011, File**

We present a novel method to evaluate the Alfv´en speed and the magnetic field strength along the streamer plasma sheet in the outer corona. The method is based on recent observations of streamer waves, which are regarded as the fast kink body mode carried by the plasma sheet structure and generated upon the impact of a fast coronal mass ejection (CME) on a nearby streamer. The mode propagates outward with a phase speed consisting of two components. One is the phase speed of the mode in the plasma rest frame and the other is the speed of the solar wind streaming along the plasma sheet. The former can be well represented by the Alfv´en speed outside the plasma sheet, according to a linear wave dispersion analysis with a simplified slab model of magnetized plasmas. The radial profiles of the Alfv´en speed can be deduced with constraints put on the speed of the solar wind, which is done by making use of the measurements of streamer blobs flowing passively in the wind. The radial profiles of the strength of the coronal magnetic field can be depicted once the electron density distribution is specified, this is done by inverting the observed polarized brightness data. Comparing the diagnostic results corresponding to the first wave trough and the following crest, we find that both the Alfv´en speed and magnetic field strength at a fixed distance decline with time. This is suggestive of the recovering process of the CME-disturbed corona.

An EUV Jet and Hα Filament Eruption Associated with Flux Cancelation in a Decaying Active Region

Huadong **Chen**, Yunchun Jiang, Suli Ma

Solar Phys (**2009**) 255: 79–90

Using data from the *Transition Region and Coronal Explorer* (TRACE), *Solarand Heliospheric Observatory* (SOHO), *Ramaty High Energy Solar Spectroscopic Imager*(RHESSI), and Hida Observatory (HO), we present a detailed study of an EUV jet and the associated H〈 filament eruption in a major flare in the active region NOAA 10044 on **29 July 2002**. In the H〈 line wings, a small filament was found to erupt out from the magnetic neutral line of the active region during the flare. Two bright EUV loops were observed rising and expanding with the filament eruption, and both hot and cool EUV plasma ejections were observed to form the EUV jet. The two thermal components spatially separated from each other and lasted for about 25 minutes. In the white-light corona data, a narrow coronal mass ejection (CME) was found to respond to this EUV jet. We cannot find obvious emerging flux in the photosphere accounting for the filament eruption and the EUV jet. However, significant sunspot decay and magnetic-flux cancelation owing to collision of opposite flux before the events were noticed. Based on the hard X-ray data from RHESSI, which showed evidence of magnetic reconnection along the main magnetic neutral line, we think that all of the observed dynamical phenomena, including the EUV jet, filament eruption, flare, and CME, should have a close relation to the flux cancelation in the low atmosphere.

SOHO/SUMER Observations of Prominence Oscillation Before Eruption

P. F. **Chen**, D. E. Innes, & S. K. Solanki

E-print, Feb 2008; A&A, 484 (**2008**) 487-493

http://lanl.arxiv.org/PS_cache/arxiv/pdf/0802/0802.1961v1.pdf

Coronal mass ejections (CMEs), as a large-scale eruptive phenomenon, often reveal some precursors in the initiation phase, e.g., X-ray brightening, filament darkening, etc, which are useful for CME modeling and space weather forecast. With the SOHO/SUMER spectroscopic observations of the **2000 September 26** event, we propose another precursor for CME eruptions, namely, long-time prominence oscillations. The prominence oscillation-and-eruption event was observed by ground-based H$alpha$ telescopes and space-borne white-light, EUV imaging and spectroscopic instruments. In particular, the SUMER slit was observing the prominence in a sit-and-stare mode. The observations indicate that a siphon flow was moving from the proximity of the prominence to a site at a projected distance of 270$"$, which was followed by repetitive H$alpha$ surges and continual prominence oscillations. The oscillation lasted 4 hours before the prominence erupted as a blob-like CME. The analysis of the multiwavelength data indicates that the whole series of processes fits well into the emerging flux trigger mechanism for CMEs. In this mechanism, emerging magnetic flux drives a siphon flow due to increased gas pressure where the background polarity emerges. It also drives H$alpha$ surges through magnetic reconnection where the opposite polarity emerges. The magnetic reconnection triggers the prominence oscillations, as well as its loss of equilibrium, which finally leads to the eruption of the prominence. It is also found that the reconnection between the emerging flux and the pre-existing magnetic loop proceeds in an intermittent, probably quasi-periodic, way.

The Flux-Rope Scaling of the Acceleration of Coronal Mass Ejections and Eruptive Prominences

J. **Chen**, C. Marque, A. Vourlidas, J. Krall, and P. W. Schuck

The Astrophysical Journal, 649:452-463, 2006, file

The new flux-rope scaling law of the acceleration of coronal mass ejections (CMEs) derived by Chen and Krall (2003) (Paper 1) is quantitatively tested by comparing the theoretical prediction with the near-Sun acceleration profiles of 13 eruptive prominences (EPs) and four CMEs.

On the Relationship Between a Hot-channel-like Solar Magnetic Flux Rope and its embedded Prominence

X. **Cheng**, M. D. Ding, J. Zhang, A. K. Srivastava, Y. Guo, P. F. Chen, J. Q. Sun

2014, ApJ Letters

http://arxiv.org/pdf/1406.4196v1.pdf

Magnetic flux rope (MFR) is a coherent and helical magnetic field structure that is recently found probably to appear as an elongated hot-channel prior to a solar eruption. In this paper, we investigate the relationship between the hot-channel and associated prominence through analyzing a limb event on **2011 September 12**. In the early rise phase, the hot-channel was cospatial with the prominence initially. It then quickly expanded, resulting in a separation of the top of the hot-channel from that of the prominence. Meanwhile, both of them experienced an instantaneous morphology transformation from a Λ shape to a reversed-Y shape and the top of these two structures showed an exponential increase in height. These features are a good indication for the occurrence of the kink instability. Moreover, the onset of the kink instability is found to coincide in time with the impulsive enhancement of the flare emission underneath the hot-channel, suggesting that the ideal kink instability likely also plays an important role in triggering the fast flare reconnection besides initiating the impulsive acceleration of the hot-channel and distorting its morphology. We conclude that the hot-channel is most likely the MFR system and the prominence only corresponds to the cool materials that are collected in the bottom of the helical field lines of the MFR against the gravity.

The early phases of a solar prominence eruption and associated flare: a multi-wavelength analysis

C. **Chifor**, H. E. Mason1, D. Tripathi1, H. Isobe1,2, A. Asai3

A&A 458, 965-973 (**2006**), File

2005 July 27. We discuss the observed precursor brightenings with respect to possible mechanisms that

might be responsible for the prominence destabilisation and acceleration. Our observations suggest that reconnection events localised beneath the erupting footpoint may eventually destabilise the entire prominence, causing the eruption.
E-print file

X-ray precursors to flares and filament eruptions

C. **Chifor**, D. Tripathi, H. E. Mason, B. R. Dennis

E-print, July 2007, A&A 472 (2007) 967-979

The preflare brightenings are precursors to the flare and filament eruption. These precursors represent distinct, localised instances of energy release, rather than a gradual energy release prior to the main flare. The X-ray precursors represent clearly observable signatures in the early stages of the eruption. Together with the timing of the filament fast-rise at or after the main flare onset, the X-ray precursors provide evidence for a tether-cutting mechanism initially manifested as localised magnetic reconnection being a common trigger for both flare emission and filament eruption.

3D solar coronal loop reconstructions with machine learning

Iulia **Chifu**, Ricardo Gafeira

ApJL **910** L10 **2021**

https://arxiv.org/pdf/2103.09960.pdf
https://iopscience.iop.org/article/10.3847/2041-8213/abed53/pdf
https://doi.org/10.3847/2041-8213/abed53

The magnetic field plays an essential role in the initiation and evolution of different solar phenomena in the corona. The structure and evolution of the 3D coronal magnetic field are still not very well known. A way to get the 3D structure of the coronal magnetic field is by performing magnetic field extrapolations from the photosphere to the corona. In previous work, it was shown that by prescribing the 3D reconstructed loops' geometry, the magnetic field extrapolation finds a solution with a better agreement between the modeled field and the reconstructed loops. Also, it improves the quality of the field extrapolation. Stereoscopy represents the classical method for performing 3D coronal loop reconstruction. It uses at least two view directions. When only one vantage point of the coronal loops is available, other 3D reconstruction methods must be applied. Within this work, we present a method for the 3D loop reconstruction based on machine learning. Our purpose for developing this method is to use as many observed coronal loops in space and time for the modeling of the coronal magnetic field. Our results show that we can build machine learning models that can retrieve 3D loops based only on their projection information. In the end, the neural network model will be able to use only 2D information of the coronal loops, identified, traced and extracted from the EUV images, for the calculation of their 3D geometry.

Hot prominence spicules launched from turbulent cool solar prominences

L. P. **Chitta**, H. Peter, L. Li

A&A Letters 627, L5 **2019**

https://arxiv.org/pdf/1906.09125.pdf
https://www.aanda.org/articles/aa/pdf/2019/07/aa36027-19.pdf

A solar filament is a dense cool condensation that is supported and thermally insulated by magnetic fields in the rarefied hot corona. Its evolution and stability, leading to either an eruption or disappearance, depend on its coupling with the surrounding hot corona through a thin transition region, where the temperature steeply rises. However, the heating and dynamics of this transition region remain elusive. We report extreme-ultraviolet observations of quiescent filaments from the Solar Dynamics Observatory that reveal prominence spicules propagating through the transition region of the filament-corona system. These thin needle-like jet features are generated and heated to at least 0.7 MK by turbulent motions of the material in the filament. We suggest that the prominence spicules continuously channel the heated mass into the corona and aid in the filament evaporation and decay. Our results shed light on the turbulence-driven heating in magnetized condensations that are commonly observed on the Sun and in the interstellar medium. **2015-02-14|15**

Solar coronal loops associated with small-scale mixed polarity surface magnetic fields

L. P. **Chitta**, H. Peter, S. K. Solanki, P. Barthol, A. Gandorfer, L. Gizon, J. Hirzberger, T. L. Riethmueller, M. van Noort, J. Blanco Rodriguez, J. C. Del Toro Iniesta, D. Orozco Suarez, W. Schmidt, V. Martinez Pillet, M. Knoelker

Astrophysical Journal Supplement Series **2016**

https://arxiv.org/pdf/1610.07484v1.pdf

How and where are coronal loops rooted in the solar lower atmosphere? The details of the magnetic environment and its evolution at the footpoints of coronal loops are crucial to understanding the processes of mass and energy supply to the solar corona. To address the above question, we use high resolution line-of-sight magnetic field data from the Imaging Magnetograph eXperiment (IMaX) instrument on the Sunrise balloon-borne observatory and coronal observations from the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO) of an emerging active region. We find that the coronal loops are often rooted at the locations with minor small-scale but persistent opposite polarity magnetic elements very close to the larger dominant polarity. These opposite polarity small-scale elements continually interact with the dominant polarity underlying the coronal loop through flux cancellation. At these locations we detect small inverse Y-shaped jets in chromospheric Ca II H images obtained from the Sunrise Filter Imager (SuFI) during the flux cancellation. Our results indicate that magnetic flux cancellation and reconnection at the base of coronal loops due to mixed-polarity fields might be a crucial feature for the supply of mass and energy into the corona. 2013 June 12

A closer look at a coronal loop rooted in a sunspot umbra

L. P. **Chitta**, H. Peter, P. R. Young

A&A 587, A20 **2016**

http://arxiv.org/pdf/1512.03831v1.pdf

Extreme UV (EUV) and X-ray loops in the solar corona connect regions of enhanced magnetic activity, but usually they are not rooted in the dark umbrae of sunspots. This is because there the strong magnetic field suppresses convection and thus the Poynting flux of magnetic energy into the upper atmosphere is not significant within the umbra, as long as there are no light bridges, umbral dots. Here we report a rare observation of a coronal loop rooted in the dark umbra of a sunspot without any traces of light bridges or umbral dots. We used the slit-jaw images and spectroscopic data from the IRIS and concentrate on the line profiles of O IV and Si IV that show persistent strong redshifted components in the loop rooted in the umbra. Using the ratios of O IV, we can estimate the density and thus investigate the mass flux. The coronal context and temperature diagnostics of these observations is provided through the EUV channels of the AIA. The coronal loop, embedded within cooler downflows, is hosting supersonic downflows. The speed of more than 100 km s−1 is of the same order of magnitude in the transition region lines of O IV and Si IV, and is even seen at comparable speed in the chromospheric Mg II lines. At a projected distance of within 1" from the footpoint, we see a shock transition to smaller downflow speeds of about 15 km s−1 being consistent with mass conservation across a stationary isothermal shock. We see no (direct) evidence for energy input into the loop because the loop is rooted in the dark uniform part of the umbra, with no light bridges or umbral dots around. Thus one might conclude that we see a siphon flow driven from the footpoint at the other end of the loop. However, for a final result one would need data of similar quality at the other footpoint, which is too far away to be covered by the field-of-view of IRIS. **9 Jul 2014**

OBSERVATIONS AND MODELING OF THE EMERGING EXTREME-ULTRAVIOLET LOOPS IN THE QUIET SUN AS SEEN WITH THE SOLAR DYNAMICS OBSERVATORY

L. P. **Chitta**1,2, R. Kariyappa2, A. A. van Ballegooijen1, E. E. DeLuca1, S. S. Hasan2, and A. Hanslmeier

2013 ApJ 768 32

We used data from the Helioseismic and Magnetic Imager (HMI) and the Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory (SDO) to study coronal loops at small scales, emerging in the quiet Sun. With HMI line-of-sight magnetograms, we derive the integrated and unsigned photospheric magnetic flux at the loop footpoints in the photosphere. These loops are bright in the EUV channels of AIA. Using the six AIA EUV filters, we construct the differential emission measure (DEM) in the temperature range 5.7-6.5 in log T (K) for several hours of observations. The observed DEMs have a peak distribution around log T 6.3, falling rapidly at higher temperatures. For log T < 6.3, DEMs are comparable to their peak values within an order of magnitude. The emission-weighted temperature is calculated, and its time variations are compared with those of magnetic flux. We present two possibilities for explaining the observed DEMs and temperatures variations. (1) Assuming that the observed loops are composed of a hundred thin strands with certain radius and length, we tested three time-dependent heating models and compared the resulting DEMs and temperatures with the observed quantities. This modeling used enthalpy-based thermal evolution of loops (EBTEL), a zero-dimensional (0D) hydrodynamic code. The comparisons suggest that a medium-frequency heating model with a population of different heating amplitudes can roughly reproduce the observations. (2) We also consider a loop model with steady heating and non-uniform cross-section of the loop along its length, and find that this model can also reproduce the observed DEMs, provided the loop expansion factor $\gamma \sim$ 5-10. More observational constraints are required to better understand the nature of coronal heating in the short emerging loops on the quiet Sun.

Thermal instabilities: Fragmentation and field misalignment of filament fine structure

Niels **Claes**, Rony Keppens, Chun Xia

A&A **2020**

https://arxiv.org/pdf/2003.10947.pdf

Prominences show a surprising amount of fine structure and it is widely believed that their threads, as seen in Hα observations, provide indirect information concerning magnetic field topology. We investigate the spontaneous emergence and evolution of fine structure in high-density condensations formed through the process of thermal instability under typical solar coronal conditions. Our study reveals intricate multidimensional processes that occur through in situ condensations in a representative coronal volume in a low plasma beta regime. We performed 2D and 3D numerical simulations of interacting slow magnetohydrodynamic (MHD) wave modes when all relevant non-adiabatic effects are included.
We show that the interaction of multiple slow MHD wave modes in a regime unstable to the thermal mode leads to thermal instability. This initially forms pancake-like structures almost orthogonal to the local magnetic field, while low-pressure induced inflows of matter generate rebound shocks. This is succeeded by the rapid disruption of these pancake sheets through thin-shell instabilities evolving naturally from minute ram pressure imbalances. This eventually creates high-density blobs accompanied by thread-like features from shear flow effects. The further evolution of the blobs follows the magnetic field lines, such that a dynamical realignment with the background magnetic field appears. However, the emerging thread-like features are not at all field-aligned, implying only a very weak link between fine structure orientation and magnetic field topology which has far-reaching implications for field topology interpretations based on Hα observations.

Great geomagnetic storm of 9 November 1991: Association with a disappearing solar filament

E. W. **Cliver**, K. S. Balasubramaniam, N. V. Nitta, X. Li

J. Geophys. Res., 114, A00A20, 2009, doi:10.1029/2008JA013232.

http://dx.doi.org/10.1029/2008JA013232

We attribute the great geomagnetic storm on 8–10 November 1991 to a large-scale eruption that encompassed the disappearance of a ~25° solar filament in the southern solar hemisphere. The resultant soft X-ray arcade spanned ~90° of solar longitude. The rapid growth of an active region lying at one end of the X-ray arcade appears to have triggered the eruption. This is the largest geomagnetic storm yet associated with the eruption of a quiescent filament. The minimum hourly *Dst* value of **−354 nT on 9 November 1991** compares with a minimum *Dst* value of −161 nT for the largest 27-day recurrent (coronal hole) storm observed from 1972 to 2005 and the minimum −559 nT value observed during the flare-associated storm of 14 March 1989, the greatest magnetic storm recorded during the space age. Overall, the November 1991 storm ranks 15th on a list of *Dst* storms from 1905 to 2004, surpassing in intensity such well-known storms as 14 July 1982 (−310 nT) and 15 July 2000 (−317 nT). We used the Cliver et al. and Gopalswamy et al. empirical models of coronal mass ejection propagation in the solar wind to provide consistency checks on the eruption/storm association.

Study of transverse oscillations in coronal loops excited by flares and eruptions

Sandra M. **Conde** C, Rekha Jain, Vera Jatenco-Pereira

ApJ **931** 151 **2022**

https://arxiv.org/pdf/2205.12063.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/ac6c8d/pdf

We present measurements of periodicity for transverse loop oscillations during the periods of activity of two remote and separated (both temporally and spatially) flares. The oscillations are observed in the same location more than 100 Mm away from the visible footpoints of the loops. Evidence for several possible excitation sources is presented. After close examination, we find that the eruptions during the flaring activities play an important role in triggering the oscillations. We investigate periodicities using time-distance, Fast Fourier Transform, and Wavelet techniques. Despite different excitation sources in the vicinity of the loops and the changing nature of amplitudes, the periodicity of multiple oscillations is found to be 4 - 6 minutes. **27-28 Jan 2014**

Excitation Sources of Oscillations in Solar Coronal Loops: A Multi-wavelength Analysis

Sandra M. **Conde** C.1,2, Rekha Jain3, and Vera Jatenco-Pereira1

2020 ApJL 890 L21

https://iopscience.iop.org/article/10.3847/2041-8213/ab7348/pdf

An investigation into the excitation sources of oscillations detected in a coronal loop structure is carried out using the images obtained with Interface Region Imaging Spectrometer (IRIS) and the Atmospheric Imaging Assembly (AIA) instrument on board the Solar Dynamics Observatory (SDO). A loop structure in the active region AR 11967 on **2014 January 28**, oscillating in the vicinity of a strong eruption and an M3.6 class flare site, is clearly noticeable in SDO/AIA 171 Å images. We study in detail, the oscillations with detected periods between 4 and 13 minutes and their connection in IRIS SJI 1330 Å and SDO/AIA 1700 Å images; both of these wavelengths sample the lower parts of the solar atmosphere. The simultaneous presence of many oscillations in the region of interest in all three wavelength passbands suggest that these oscillations were excited in the lower-chromosphere–photosphere plasma connected to the loop structure and then propagated at higher heights. We further investigate the Doppler velocity measurements from the spectrograph snapshots in IRIS C ii 1336 Å, Si iv 1403 Å and Mg ii k 2796 Å. These show signatures of upflows in the vicinity of the loop structure's endpoints estimated from 171 Å images. We suggest that some of the oscillations observed in AIA 171 Å have been triggered by plasma ejections and perturbations seen in the lower layers of the solar atmosphere. Based on the estimated phase speeds, the oscillations are likely to be slow magnetoacoustic in nature.

A MODEL OF CORONAL STREAMERS WITH UNDERLYING FLUX ROPES

M. **Cottaar**1 and Y. Fan

Astrophysical Journal, 704:576–590, **2009** October

We present global two-dimensional axisymmetric isothermal MHD simulations of the dynamic evolution of a coronal helmet streamer, driven at the lower boundary by the emergence of a twisted flux rope. By varying both the detached toroidal and poloidal fluxes emerged into the corona, but fixing the normal flux distribution at the surface at the end of the emergence, we obtain solutions that either settle to a new steady state of a stable helmet streamer containing a flux rope, or result in a disruption of the helmet with the underlying flux rope being expelled in a coronal mass ejection (CME)-like eruption. In all of the cases studied, we find that the transition from a stable to an eruptive state takes place at a magnetic energy that is very close to the Aly open field energy. Furthermore, we find that the transition from a stable to an eruptive end state does not occur at a single critical value of the total relative magnetic helicity, but depends on the profile of the underlying flux rope. Cases where the detached flux rope contains a higher amount of self-helicity, i.e., higher internal twist or detached poloidal flux, are found to become eruptive at a significantly lower total helicity. For the eruptive cases, the detached flux rope after emergence first rises quasi-statically due to a gradual opening of the field lines at the edge of the streamer and a slow reconnection below the flux rope, which continues to slowly increase the amount of the detached flux. This decreases the downward magnetic tension on the flux rope. The dynamic eruption is initiated when the magnetic pressure gradient no longer decreases fast enough to balance the decrease in the magnetic tension. Later rapid reconnections below the flux rope are important for accelerating the flux rope. For the stable helmets, we find that no cavities are formed due to the simplifying assumption of isothermal energetics and the uniform density lower boundary condition. However during the eruption we see the development of the 3-part structure of a CME.

Comparison of interplanetary signatures of streamers and pseudostreamers

N. U. **Crooker**1,*, R. L. McPherron2 andM. J. Owens

JGR, Volume 119, Issue 6, pages 4157–4163, June **2014**

If the source of the slow solar wind is a web comprising pseudostreamer belts connected to the streamer belt, then one expects the properties of interplanetary pseudostreamer flows to be similar to those of streamer flows. That expectation is tested with data from the slow wind preceding stream interfaces in stream interaction regions at 1 AU, where the interfaces separate what was originally slow and fast wind. Pseudostreamer cases were separated from streamer cases with the aid of the streamer identification tool developed by Owens et al. (2013), and superposed epoch analysis was performed to compare the patterns of a number of plasma and composition parameters. The results reveal that pseudostreamer flows have all of the slow-wind characteristics of streamer flows except that they are slightly less pronounced than streamer characteristics when compared to fast wind. The results are consistent with the concept that the solar wind displays a continuum of dynamic states rather than only slow and fast states.

The SUMER Ly-α line profile in quiescent prominences

Curdt, W.; Tian, H.; Teriaca, L.; Schühle, U.

Astronomy and Astrophysics, Volume 511, id.L4, 4 pp., **2010**

http://arxiv.org/pdf/1002.1197v1.pdf

Aims: As the result of a novel observing technique, we publish for the first time SoHO-SUMER observations of the true spectral line profile of hydrogen Lyman-α in quiescent prominences. Because SoHO is not in Earth orbit, our high-quality data set is free of geocoronal absorption. We studied the line profile to complement earlier observations of the higher Lyman lines and to substantiate recent model predictions.

Methods: We applied the reduced-aperture observing mode to two prominence targets and did a statistical analysis of the line profiles in both data sets. In particular, we investigated the shape of the profile, the radiance distribution, and the line shape-to-radiance interrelation. We also compared Ly-α data to co-temporal λ 1206 Si iii data.

Results: We find that the average profile of Ly-α has a blue-peak dominance and is reversed more if the line-of-sight is perpendicular to the field lines. The contrast of Ly-α prominence emission rasters is very low, and the radiance distribution differs from the log-normal distribution of the disk. Features in the Si iii line are not always co-spatial with Ly-α emission.

Conclusions: Our empirical results support recent multi-thread models, which predict that asymmetries and depths of the self-reversal depend on the orientation of the prominence axis relative to the line-of-sight.

9-15 June 2009

Doppler shift of hot coronal lines in a moss area of an active region

N. **Dadashi**1,2, L. Teriaca1, D. Tripathi3, S. K. Solanki1,4 and T. Wiegelmann

A&A 548, A115 **(2012)**

The moss is the area at the footpoint of the hot (3 to 5 MK) loops forming the core of the active region where emission is believed to result from the heat flux conducted down to the transition region from the hot loops. Studying the variation of Doppler shift as a function of line formation temperatures over the moss area can give clues on the heating mechanism in the hot loops in the core of the active regions. We investigate the absolute Doppler shift of lines formed at temperatures between 1 MK and 2 MK in a moss area within active region NOAA 11243 using a novel technique that allows determining the absolute Doppler shift of EUV lines by combining observations from the SUMER and EIS spectrometers. The inner (brighter and denser) part of the moss area shows roughly constant blue shift (upward motions) of 5 km s-1 in the temperature range of 1 MK to 1.6 MK. For hotter lines the blue shift decreases and reaches 1 km s-1 for Fe xv 284 Å (~2 MK). The measurements are discussed in relation to models of the heating of hot loops. The results for the hot coronal lines seem to support the quasi-steady heating models for nonsymmetric hot loops in the core of active regions.

The role of filament activation in a solar eruption

F. Rubio **da Costa**1,2, F. Zuccarello1, L. Fletcher2, P. Romano3 and N. Labrosse

A&A 539, A27 (**2012**), **File**

Context. Observations show that the mutual relationship between filament eruptions and solar flares cannot be described in terms of an unique scenario. In some cases, the eruption of a filament appears to trigger a flare, while in others the observations are more consistent with magnetic reconnection that produces both the flare observational signatures (e.g., ribbons, plasma jets, post-flare loops, etc.) and later the destabilization and eruption of a filament.

Aims. Contributing to a better comprehension of the role played by filament eruptions in solar flares, we study an event which occurred in NOAA 8471, where a flare and the activation of (at least) two filaments were observed on **28 February 1999.**

Methods. By using imaging data acquired in the 1216, 1600, 171 and 195 Å TRACE channels and by BBSO in the continnum and in the Hα line, a morphological study of the event is carried out. Moreover, using TRACE 1216 and 1600 Å data, an estimate of the “pure” Lyα power is obtained. The extrapolation of the magnetic field lines is done using the SOHO/MDI magnetograms and assuming a potential field.

Results. Initially an area hosting a filament located over a δ spot becomes brighter than the surroundings, both in the chromosphere and in the corona. This area increases in brightness and extension, eventually assuming a two-ribbon morphology, until it reaches the eastern part of the active region. Here a second filament becomes activated and the brightening propagates to the south, passing over a large supergranular cell. The potential magnetic field extrapolation indicates that the field line connectivity changes after the flare.

Conclusions. The event is triggered by the destabilization of a filament located between the two polarities of a δ spot. This destabilization involves the magnetic arcades of the active region and causes the eruption of a second filament, that gives rise to a CME and to plasma motions over a supergranular cell. We conclude that in this event the two filaments play an active and decisive role, albeit in different stages of the phenomenon, in fact the destabilization of one filament causes brightenings, reconnection and ribbons, while the second one, whose eruption is caused by the field reconfiguration resulting from the previous reconnection, undergoes the greatest changes and causes the CME.

Observations of a solar flare and filament eruption in Lyman α and X-rays

Rubio **da Costa**, F.; Fletcher, L.; Labrosse, N.; Zuccarello, F.

Astronomy and Astrophysics, Volume 507, Issue 2, **2009**, pp.1005-1014

Context: Lα is a strong chromospheric emission line, which has been relatively rarely observed in flares. The Transition Region and Coronal Explorer (TRACE) has a broad “Lyman α” channel centered at 1216 Å used primarily at the beginning of the mission. A small number of flares were observed in this channel.

Aims: We aim to characterise the appearance and behaviour of a flare and filament ejection which occurred on 8th September 1999 and was observed by TRACE in Lα, as well as by the Yohkoh Soft and Hard X-ray telescopes. We explore the flare energetics and its spatial and temporal evolution. We have in mind the fact that the Lα line is a target for the Extreme Ultraviolet Imaging telescope (EUI) which has been selected for the Solar Orbiter mission, as well as the LYOT telescope on the proposed SMESE mission.

Methods: We use imaging data from the TRACE 1216 Å, 1600 Å and 171 Å channels, and the Yohkoh hard and soft X-ray telescopes. A correction is applied to the TRACE data to obtain a better estimate of the pure Lα signature. The Lα power is obtained from a knowledge of the TRACE response function, and the flare electron energy budget is estimated by interpreting Yohkoh/HXT emission in the context of the collisional thick target model.

Results: We find that the Lα flare is characterised by strong, compact footpoints (smaller than the UV ribbons) which correlate well with HXR footpoints. The Lα power radiated by the flare footpoints can be estimated, and is found to be on the order of 1026 erg s-1 at the peak. This is less than 10% of the power inferred for the electrons which generate the co-spatial HXR emission, and can thus readily be provided by them. The early stages of the

filament eruption that accompany the flare are also visible, and show a diffuse, roughly circular spreading sheet-like morphology, with embedded denser blobs.
Conclusions: On the basis of this observation, we conclude that flare and filament observations in the Lα line with the planned EUI and LYOT telescopes will provide valuable insight into solar flare evolution and energetics, especially when accompanied by HXR imaging and spectroscopy.

Dependence of Coronal Loop Temperature on Loop Length and Magnetic Field Strength

R. B. **Dahlburg**1, G. Einaudi2, I. Ugarte-Urra3, A. F. Rappazzo4, and M. Velli4
2018 ApJ 868 116
sci-hub.tw/10.3847/1538-4357/aae535
The temperature characteristics of solar coronal loops over a wide range of lengths and magnetic field strengths are investigated by means of numerical simulations. A very high correlation between magnetic field strength (B 0) and maximum temperature (T max) is found. Shorter loops rooted at stronger fields are those that reach higher maximum temperatures. High temperatures constitute a small part of the loop volume. For loops of equal length, those with stronger magnetic fields have broader emission measure distributions. The conditions underlying the variety of loops observed in the solar corona are discussed, an explanation of why both cold and hot loops exist is provided, and suggestions are given as to what observations need to be made to confirm the results. Data in the analysis are provided by numerical simulations using HYPERION, an explicit massively parallel Fourier collocation–finite-difference code. In the simulations footpoints are convected with a randomized large-scale flow. This produces a Poynting flux which leads to the buildup of magnetic energy in the loop. The magnetic energy is then transformed into thermal energy by a magnetic reconnection process occurring within current sheets formed locally by an energy cascade toward small scales.

Ponderomotive Acceleration in Coronal Loops

R. B. **Dahlburg**, J. M. Laming, B. D. Taylor, K. Obenschain
ApJ **2016**
http://arxiv.org/pdf/1608.04372v1.pdf
Ponderomotive acceleration has been asserted to be a cause of the First Ionization Potential (FIP) effect, the by now well known enhancement in abundance by a factor of 3-4 over photospheric values of elements in the solar corona with FIP less than about 10 eV. It is shown here by means of numerical simulations that ponderomotive acceleration occurs in solar coronal loops, with the appropriate magnitude and direction, as a "byproduct" of coronal heating. The numerical simulations are performed with the HYPERION code, which solves the fully compressible three-dimensional magnetohydrodynamic equations including nonlinear thermal conduction and optically thin radiation. Numerical simulations of a coronal loops with an axial magnetic field from 0.005 Teslas to 0.02 Teslas and lengths from 25000 km to 75000 km are presented. In the simulations the footpoints of the axial loop magnetic field are convected by random, large-scale motions. There is a continuous formation and dissipation of field-aligned current sheets which act to heat the loop. As a consequence of coronal magnetic reconnection, small scale, high speed jets form. The familiar vortex quadrupoles form at reconnection sites. Between the magnetic footpoints and the corona the reconnection flow merges with the boundary flow. It is in this region that the ponderomotive acceleration occurs. Mirroring the character of the coronal reconnection, the ponderomotive acceleration is also found to be intermittent.

Observational Signatures of Coronal Loop Heating and Cooling Driven by Footpoint Shuffling

R. B. **Dahlburg**, G. Einaudi, B. D. Taylor, I. Ugarte-Urra, H. P. Warren, A. F. Rappazzo, M. Velli
ApJ **2015**
http://arxiv.org/pdf/1512.03079v1.pdf
The evolution of a coronal loop is studied by means of numerical simulations of the fully compressible three-dimensional magnetohydrodynamic equations using the HYPERION code. The footpoints of the loop magnetic field are advected by random motions. As a consequence the magnetic field in the loop is energized and develops turbulent nonlinear dynamics characterized by the continuous formation and dissipation of field-aligned current sheets: energy is deposited at small scales where heating occurs. Dissipation is non-uniformly distributed so that only a fraction of the coronal mass and volume gets heated at any time. Temperature and density are highly structured at scales which, in the solar corona, remain observationally unresolved: the plasma of our simulated loop is multi-thermal, where highly dynamical hotter and cooler plasma strands are scattered throughout the loop at sub-observational scales. Numerical simulations of coronal loops of 50000 km length and axial magnetic field intensities ranging from 0.01 to 0.04 Tesla are presented. To connect these simulations to observations we use the computed number densities and temperatures to synthesize the intensities expected in emission lines typically observed with the Extreme ultraviolet Imaging Spectrometer (EIS) on Hinode. These intensities are used to compute differential emission measure distributions using the Monte Carlo Markov Chain code, which are very similar to those derived from observations of solar active regions. We conclude that coronal heating is found to be strongly intermittent in

space and time, with only small portions of the coronal loop being heated: in fact, at any given time, most of the corona is cooling down.

Generalized Coronal Loop Scaling Laws and Their Implication for Turbulence in Solar Active Region Loops

Y. **Dai**1,2, J. J. Xiang1, and M. D. Ding1,2
2024 ApJ 965 2
https://iopscience.iop.org/article/10.3847/1538-4357/ad3031/pdf
Recent coronal loop modeling has emphasized the importance of combining both Coulomb collisions and turbulent scattering to characterize field-aligned thermal conduction, which invokes a hybrid loop model. In this work, we generalize the hybrid model by incorporating a nonuniform heating and cross section that are both formulated by a power-law function of temperature. Based on the hybrid model solutions, we construct scaling laws that relate loop-top temperature (Ta) and heating rate (Ha) to other loop parameters. It is found that the loop-top properties for turbulent loops are additionally power-law functions of the turbulent mean free path (λT), with the functional forms varying from situation to situation, depending on the specification of the heating and/or areal parameters. More importantly, both a sufficiently footpoint-concentrated heating and a cross-sectional expansion with height can effectively weaken (strengthen) the negative (positive) power-law dependence of Ta (Ha) on λT. The reason lies in a notable reduction of heat flux by footpoint heating and/or cross-sectional expansion in the turbulence-dominated coronal part, where turbulent scattering introduces a much weaker dependence of the conduction coefficient on temperature. In this region, therefore, the reduction of the heat flux predominately relies on a backward flattening of the temperature gradient. Through numerical modeling that incorporates more realistic conditions, this scenario is further consolidated. Our results have important implications for solar active region (AR) loops. With the factors of nonuniform heating and cross section taken into account, AR loops can bear relatively stronger turbulence while still keeping a physically reasonable temperature for nonflaring loops.

Simultaneous Horizontal and Vertical Oscillation of a Quiescent Filament Observed by CHASE and SDO

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2023 ApJ 959 71 Focus on Early Results from the Chinese Hα Solar Explorer (CHASE) Mission
https://arxiv.org/pdf/2310.19228.pdf
https://iopscience.iop.org/article/10.3847/1538-4357/ad0839/pdf
In this paper, we present the imaging and spectroscopic observations of the simultaneous horizontal and vertical large-amplitude oscillation of a quiescent filament triggered by an extreme-ultraviolet (EUV) wave on **2022 October 2**. Particularly, the filament oscillation involved winking phenomenon in Hα images and horizontal motions in EUV images. Originally, a filament and its overlying loops across AR 13110 and 13113 erupted with a highly inclined direction, resulting in an X1.0 flare and a non-radial coronal mass ejection. The fast lateral expansion of loops excited an EUV wave and the corresponding Moreton wave propagating northward. Once the EUV wave front arrived at the quiescent filament, the filament began to oscillate coherently along the horizontal direction, and the "winking filament" appeared concurrently in Hα images. The horizontal oscillation involved an initial amplitude of ∼10.2 Mm and a velocity amplitude of ∼46.5 km s−1, lasting for ∼3 cycles with a period of ∼18.2 minutes and a damping time of ∼31.1 minutes. The maximum Doppler velocities of the oscillating filament are 18 km s−1 (redshift) and −24 km s−1 (blueshift), which were derived from the spectroscopic data provided by the Chinese Hα Solar Explorer/Hα Imaging Spectrograph. The three-dimensional velocity of the oscillation is determined to be ∼50 km s−1 at an angle of ∼50° to the local photosphere plane. Based on the wave–filament interaction, the minimum energy of the EUV wave is estimated to be 2.7 × 1020 J. Furthermore, this event provides evidence that Moreton waves should be excited by the highly inclined eruptions.

Transverse oscillation of a coronal loop induced by a flare-related jet⋆

J. **Dai**1,2, Q. M. Zhang1,2,3, Y. N. Su1,2 and H. S. Ji1,2
A&A 646, A12 (**2021**)
https://arxiv.org/pdf/2012.07074.pdf
https://www.aanda.org/articles/aa/pdf/2021/02/aa39013-20.pdf
Context. Kink oscillations in coronal loops are ubiquitous, and we apply the observed parameters of oscillations to estimate the magnetic field strength of the loops.
Aims. In this work, we report our multiwavelength observations of the transverse oscillation of a large-scale coronal loop with a length of ≥350 Mm. The oscillation was induced by a blowout coronal jet, which was related to a C4.2 circular-ribbon flare (CRF) in active region 12434 on **2015 October 16**. We aim to determine the physical parameters in the coronal loop, including the Alfvén speed and the magnetic field strength.
Methods. The jet-induced kink oscillation was observed in extreme ultraviolet (EUV) wavelengths by the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO). Line-of-sight

magnetograms were observed by the Helioseismic and Magnetic Imager (HMI) on board the SDO. We took several slices along the loop to assemble time-distance diagrams and used an exponentially decaying sine function to fit the decaying oscillation. The initial amplitude, period, and damping time of kink oscillations were obtained. Coronal seismology of the kink mode was applied to estimate the Alfvén speed and the magnetic field strength in the oscillating loop. In addition, we measured the magnetic field of the loop through nonlinear force-free field (NLFFF) modeling using the flux rope insertion method.
Results. The oscillation is most pronounced in AIA 171 and 131 Å. The oscillation is almost in phase along the loop with a peak initial amplitude of ∼13.6 Mm, meaning that the oscillation belongs to the fast standing kink mode. The oscillation lasts for ∼3.5cycles with an average period of ∼462 s and an average damping time of ∼976 s. The values of τ/P lie in the range of 1.5–2.5. Based on coronal seismology, the Alfvén speed in the oscillating loop is estimated to be ∼1210 km s^{-1}. Two independent methods are applied to calculate the magnetic field strength of the loop, resulting in 30–43 G using coronal seismology and 21–23 G using NLFFF modeling.
Conclusions. The magnetic field strength estimated using two different approaches are on the same order of magnitude, which confirms the reliability of coronal seismology by comparing with NLFFF modeling.

Properties of Streamer Wave Events Observed During the STEREO Era

Bieke **Decraemer**, Andrei N. Zhukov, Tom Van Doorsselaere

ApJ **893** 78 **2020**

https://arxiv.org/pdf/2003.12350.pdf

https://doi.org/10.3847/1538-4357/ab8194

Transverse waves are sometimes observed in solar helmet streamers, typically after the passage of a coronal mass ejection (CME). The CME-driven shock wave moves the streamer sideways, and a decaying oscillation of the streamer is observed after the CME passage. Previous works generally reported observations of streamer oscillations taken from a single vantage point (typically the SOHO spacecraft). We conduct a data survey searching for streamer wave events observed by the COR2 coronagraphs onboard the STEREO spacecraft. For the first time, we report observations of streamer wave events from multiple vantage points, by using the COR2 instrument on both STEREO A and B, as well as the SOHO/LASCO C2+C3 coronagraphs. We investigate the properties of streamer waves by comparing the different events and performing a statistical analysis. Common observational features give us additional insight on the physical nature of streamer wave events. The most important conclusion is that there appears to be no relation between the speed of the CME and the phase speed of the resulting streamer wave, indicating that the streamer wave speed is determined by the physical properties of the streamer rather than the properties of the CME. This result makes streamer waves events excellent candidates for coronal seismology studies. From a comparison between the measured phase speeds and the phase speeds calculated from the measured periods and wavelengths, we could determine that the speed of the post-shock solar wind flow in our streamers is around 300 km s^{-1}. **2013-02-06**

Table 1. Summary of the physical parameters measured for the 22 streamer wave events identi_ed with STEREO/COR2.

Three-dimensional Density Structure of a Solar Coronal Streamer Observed by SOHO/LASCO and STEREO/COR2 in Quadrature

Bieke **Decraemer**, Andrei N. Zhukov, Tom Van Doorsselaere

ApJ **883** 152 **2019**

https://arxiv.org/pdf/1908.05034.pdf

https://doi.org/10.3847/1538-4357/ab3b58

Helmet streamers are a prominent manifestation of magnetic structures with current sheets in the solar corona. These large-scale structures are regions with high plasma density, overlying active regions and filament channels. We investigate the three-dimensional (3D) structure of a coronal streamer, observed simultaneously by white-light coronagraphs from two vantage points near quadrature (SOHO/LASCO and STEREO/COR2). We design a forward model based on plausible assumptions about the 3D streamer structure taken from physical models (a plasma slab centered around a current sheet). The streamer stalk is approximated by a plasma slab, with electron density that is characterized by three separate functions describing the radial, transverse and face-on profiles respectively. For the first time, we simultaneously fit the observational data from SOHO and STEREO using a multivariate minimization algorithm. The streamer plasma sheet contains a number of brighter and darker ray-like structures with the density contrast up to about a factor 3 between them. The densities derived using polarized and unpolarized data are similar. We demonstrate that our model corresponds well to the observations. **April 30, 2011**

SDO AIA and Hinode EIS observations of “warm” loops⋆

G. **Del Zanna**, B. O’Dwyer and H. E. Mason

A&A 535, A46 (**2011**)
We present simultaneous observations of active region “warm” (1 MK) loops using the Solar Dynamics Observatory (SDO) Atmospheric Imaging Assembly (AIA) and Hinode EUV Imaging Spectrometer (EIS). Sample EIS spectra for a loop footpoint and a lop leg region are presented, and are used to describe the spectral lines which contribute to the six AIA EUV channels, both directly and predicted with DEM modeling. We find good overall agreement between observed and predicted count rates for the 131 Å, 193 Å, and 335 Å bands, but highlight a number of problems, partly to be ascribed to inter-calibration issues, partly due to the fact that a large number of lines remain unidentified for the 94 Å, 171 Å, and 211 Å bands. We also found that the 335 Å band is severely affected by cross-talk with the 131 Å band and by second order contributions. We extend our previous work where we highlighted the multi-thermal nature of the SDO AIA bands to show that emission from lines formed at typical transition region temperatures ($\log T[K] = 5.0–5.8$) can be significant for all the EUV channels, and even dominant in some cases. We also assess the possibility of deriving accurate emission measures from the AIA observations. We have found that the inversion of the AIA data to obtain a description of the thermal characteristics of warm loops is unreliable. We highlight the need for further work on the relevant atomic data before the AIA data can be reliably used for plasma diagnostic purposes.

Transverse, Propagating Velocity Perturbations in Solar Coronal Loops

I. **De Moortel**, D.J. Pascoe, A.N. Wright, A.W. Hood
2015
http://arxiv.org/pdf/1510.00976v1.pdf
This short review paper gives an overview of recently observed transverse, propagating velocity perturbations in coronal loops. These ubiquitous perturbations are observed to undergo strong damping as they propagate. Using 3D numerical simulations of footpoint-driven transverse waves propagating in a coronal plasma with a cylindrical density structure, in combination with analytical modelling, it is demonstrated that the observed velocity perturbations can be understood in terms of coupling of different wave modes in the inhomogeneous boundaries of the loops. Mode coupling in the inhomogeneous boundary layers of the loops leads to the coupling of the transversal (kink) mode to the azimuthal (Alfven) mode, observed as the decay of the transverse kink oscillations. Both the numerical and analytical results show the spatial profile of the damped wave has a Gaussian shape to begin with, before switching to exponential decay at large heights. In addition, recent analysis of CoMP (Coronal Multi-channel Polarimeter) Doppler shift observations of large, off- limb, trans-equatorial loops shows that Fourier power at the apex appears to be higher in the high-frequency part of the spectrum than expected from theoretical models. This excess high-frequency FFT power could be tentative evidence for the onset of a cascade of the low-to-mid frequency waves into (Alfvenic) turbulence.

Possible Evidence for Alfvenic Turbulence in Coronal Loops

Ineke **De Moortel**
New UKSP Nugget: 48, June **2014**
http://www.uksolphys.org/uksp-nugget/48-possible-evidence-for-alfvenic-turbulence-in-coronal-loops/
High-frequency waves in loops contain more energy than expected – are we seeing the onset of Alfvenic turbulence? **10 April 2012**

ESTIMATING THE CHROMOSPHERIC ABSORPTION OF TRANSITION REGION MOSS EMISSION

Bart De Pontieu[1], Viggo H. Hansteen[1,2], Scott W. McIntosh[3] and Spiros Patsourakos[4,5]
ApJ 702 1016-1024, **2009** doi: 10.1088/0004-637X/702/2/1016
Many models for coronal loops have difficulty explaining the observed EUV brightness of the transition region, which is often significantly less than theoretical models predict. This discrepancy has been addressed by a variety of approaches including filling factors and time-dependent heating, with varying degrees of success. Here, we focus on an effect that has been ignored so far: the absorption of EUV light with wavelengths below 912 Å by the resonance continua of neutral hydrogen and helium. Such absorption is expected to occur in the low-lying transition region of hot, active region loops that is colocated with cool chromospheric features and called "moss" as a result of the reticulated appearance resulting from the absorption. We use cotemporal and cospatial spectroheliograms obtained with the *Solar and Heliospheric Observatory*/SUMER and *Hinode*/EIS of Fe XII 1242 Å, 195 Å, and 186.88 Å, and compare the density determination from the 186/195 Å line ratio to that resulting from the 195/1242 Å line ratio. We find that while coronal loops have compatible density values from these two line pairs, upper transition region moss

has conflicting density determinations. This discrepancy can be resolved by taking into account significant absorption of 195 Å emission caused by the chromospheric inclusions in the moss. We find that the amount of absorption is generally of the order of a factor of 2. We compare to numerical models and show that the observed effect is well reproduced by three-dimensional radiative MHD models of the transition region and corona. We use *STEREO A*/*B* data of the same active region and find that increased angles between line of sight and local vertical cause additional absorption. Our determination of the amount of chromospheric absorption of TR emission can be used to better constrain coronal heating models.

Criteria for Flux Rope Eruption: Non Equilibrium versus Torus Instability

P. **Demoulin** and G. Aulanier

E-print, June **2010**, ApJ, 718(2), 1388-1399; **File**

The coronal magnetic configuration of an active region typically evolves quietly during few days before becoming suddenly eruptive and launching a coronal mass ejection (CME). The precise origin of the eruption is still debated. Among several mechanisms, it has been proposed that a loss of equilibrium, or an ideal magneto-hydrodynamic (MHD) instability such as the torus instability, could be responsible for the sudden eruptivity. Distinct approaches have also been formulated for limit cases having circular or translation symmetry. We revisit the previous theoretical approaches, setting them in the same analytical framework. The coronal field results from the contribution of a non-neutralized current channel added to a background magnetic field, which in our model is the potential field generated by two photospheric flux concentrations. The evolution on short Alfvenic time scale is governed by ideal MHD. We show analytically first that the loss of equilibrium and the stability analysis are two different views of the same physical mechanism. Second, we identify that the same physics is involved in the instability of circular and straight current channels. Indeed, they are just two particular limiting case of more general current paths. A global instability of the magnetic configuration is present when the current channel is located at a coronal height, h, large enough so that the decay index of the potential field, (d ln |Bp|) / (d ln h) is larger than a critical value. At the limit of very thin current channels, previous analysis found a critical decay index of 1.5 and 1 for circular and straight current channels, respectively. However, with current channels being deformable and as thick as expected in the corona, we show that this critical index has similar values for circular and straight current channels, typically in the range [1.1,1.3].

Potential Evidence for the Onset of Alfvénic Turbulence in Trans-equatorial Coronal Loops

I. **De Moortel**1, S. W. McIntosh2, J. Threlfall1, C. Bethge3, and J. Liu

2014 ApJ 782 L34

This study investigates Coronal Multi-channel Polarimeter Doppler-shift observations of a large, off-limb, trans-equatorial loop system observed on **2012 April 10-11**. Doppler-shift oscillations with a broad range of frequencies are found to propagate along the loop with a speed of about 500 km s–1. The power spectrum of perturbations travelling up from both loop footpoints is remarkably symmetric, probably due to the almost perfect north-south alignment of the loop system. Compared to the power spectrum at the footpoints of the loop, the Fourier power at the apex appears to be higher in the high-frequency part of the spectrum than expected from theoretical models. We suggest this excess high-frequency power could be tentative evidence for the onset of a cascade of the low-to-mid frequency waves into (Alfvénic) turbulence.

Rise of a Dark Bubble through a Quiescent Prominence

G. **de Toma**, R. Casini, J. T. Burkepile, and B. C. Low

The Astrophysical Journal Letters, Vol. 687, No. 2: L123-L126, 2008.

http://www.journals.uchicago.edu/doi/abs/10.1086/593326

We report on a dynamical event observed in a quiescent prominence on 2007 November 8: a well-formed dark “bubble” with a bright core rose vertically through the prominence without causing it to erupt. This event was observed in Hα and He i 1083 nm with the instruments of the Mauna Loa Solar Observatory. The dark bubble had a size of over and rose from the prominence base, at an average speed of ~12 km s , forming _ _1 40 a bright compression front as it traversed the prominence. It finally assumed a “keyhole” shape before fading. The bright core embedded in the dark bubble was observed to rise from the solar limb, accelerating from ~12 to ~20 km s_{-1}, leaving a thin trail of material behind. Subsequent observations indicate that this was not an exceptional event, but rather that similar disturbances do occur occasionally in prominences without disrupting them. In this Letter we present the November 8 observations, and propose a possible interpretation of the physical mechanism behind these dynamic events.

Homologous Confined Filament Eruptions via Magnetic Breakout

C. Richard **DeVore** and Spiro K. Antiochos

The Astrophysical Journal, Vol. 680, No. 1: 740-756, **2008**.

http://www.journals.uchicago.edu/doi/pdf/10.1086/588011

We describe magnetohydrodynamic simulations of a bipolar active region embedded in the Sun's global background field and subjected to twisting footpoint displacements concentrated near its polarity inversion lines to produce strong magnetic shear. The dipole moments of the active region and background field are antiparallel, so that the initially potential magnetic field contains a coronal null. This configuration supports magnetic breakout eruptions in our simulations that exhibit three novel features. First, the eruptions are multiple and homologous: the flare reconnection following each eruption reforms the magnetic null, setting the stage for a subsequent episode of breakout reconnection and eruption driven by the ongoing footpoint motions. Second, the eruptions are confined; that is, their rapidly rising, moderately sheared field lines do not escape the Sun but instead come to rest in the outer corona, comprising a large coronal loop formed by reconnection during the rise phase. Third, the most strongly sheared field lines of the active region are quite flat prior to eruption, expand upward sharply during the event, and lose most of their shear through reconnection with overlying flux, while lower lying field lines survive the eruption and recover their flat configuration within a few hours. These behaviors are consistent with filament disappearance followed by reformation in place.We also find that the upward motion of the erupting sheared flux exhibits a distinct three-phase acceleration profile. All of these features of our simulations—homology, confinement, reformation, and multiphase acceleration—are well established aspects of solar eruptions.

Prominence Oscillations activated by an EUV wave

Pooja **Devi**, Ramesh Chandra, Reetika Joshi, P. F. Chen, Brigitte Schmieder, Wahab Uddin, Yong-Jae Moon

Adv. Space Res. **2022**

https://arxiv.org/pdf/2202.13147.pdf

Prominence oscillations are one of interesting phenomena in the solar atmosphere, which can be utilized to infer the embedded magnetic field magnitude. We present here the transverse oscillations of two different prominences located at the East solar limb on **2011 February 11** using the multi-wavebands data of the Atmospheric Imaging Assembly (AIA) on-board the Solar Dynamics Observatory (SDO) satellite. A prominence eruption was observed towards the east direction with an average speed of ~275 km/s. The eruption is fitted with the combination of a linear and an exponential functions of time. An extreme ultraviolet (EUV) wave event was associated with the prominence eruption. This EUV wave triggered the oscillations of both prominences on the East limb. We computed the period of each prominence using the wavelet analysis method. The oscillation period varies from 14 to 22 min. The magnetic field of the prominences was derived, which ranges from 14 to 20 G.

Observations of Photospheric Vortical Motions During the Early Stage of Filament Eruption

Sajal Kumar **Dhara**, B. Ravindra, Ravinder Kumar Banyal

Solar Phys. **2014**

Solar filaments/prominences exhibit rotational motion during different phases of their evolution from their formation to eruption. We have observed the rotational/vortical motion in the photosphere near the ends of ten filaments during their initial phase of eruption, at the onset of the fast rise phase. All the filaments were associated with active regions. The photospheric vortical motions we observed lasted for 4 – 20 minutes. In the vicinity of the conjugate ends of the filament the direction of rotation was opposite, except for two cases, where rotational motion was observed at only one end point. The sudden onset of a large photospheric vortex motion could have played a role in destabilizing the filament by transporting axial flux into the activated filament thereby increasing the outward magnetic pressure in it. The outward magnetic pressure may have pushed the filament/flux rope to the height where the torus instability criterion was satisfied, and hence it could have caused the filament instability and eruption.

Numerical simulations of turbulence in prominence threads induced by torsional oscillations

Sergio **Díaz-Suárez**, Roberto Soler

A&A 684, A13 **2024**

https://arxiv.org/pdf/2401.09122.pdf

https://www.aanda.org/articles/aa/pdf/2024/04/aa48216-23.pdf

Threads are the main constituents of prominences and are subjected to oscillations that might be interpreted as MHD waves. Moreover, the Kelvin-Helmholtz instability (KHI) has been reported in prominences. Both waves and KHI may affect the thermodynamic state of the threads. We investigate the triggering of turbulence in a thread caused by the nonlinear evolution of standing torsional Alfvén waves as well as possible observational signatures of this dynamics and the plasma heating. We modeled the thread as a radially and longitudinally nonuniform cylindrical flux tube with a uniform axial magnetic field embedded in a coronal environment. We perturbed the flux tube with the longitudinally fundamental mode of standing torsional Alfvén waves and numerically solved the 3D MHD equations to study the temporal evolution in both ideal and dissipative scenarios. We also performed forward modeling to calculate the synthetic H{\alpha} imaging. Standing torsional Alfvén waves undergo phase-mixing owing to the radially nonuniform density. The phase-mixing generates azimuthal shear flows that eventually trigger the KHI and, later, turbulence. If nonideal effects are included, plasma heating is localized in an annulus region at the thread boundary and does not increase the temperature in the cool core. Instead, the average temperature in the thread decreases owing to the mixing of internal and external plasmas. In the synthetic observations, first we find periodic pulsations in the H{\alpha} intensity caused by the integration of the phase-mixing flows along the line of sight. Later, we find fine strands that may be associated with the KHI vortices. Turbulence can be generated by standing torsional Alfvén waves in a thread after the onset of KHI, but this mechanism is not enough to heat globally the structure. The dynamics could be seen in high-resolution H{\alpha} observations.

Transition to turbulence in nonuniform coronal loops driven by torsional Alfvén waves. II. Extended analysis and effect of magnetic twist

Sergio **Díaz-Suárez**, Roberto Soler

A&A 665, A113 **2022**

https://arxiv.org/pdf/2207.06315.pdf

https://www.aanda.org/articles/aa/pdf/2022/09/aa44175-22.pdf

It has been shown in a previous work that torsional Alfvén waves can drive turbulence in nonuniform coronal loops with a purely axial magnetic field. Here we explore the role of the magnetic twist. We model a coronal loop as a transversely nonuniform straight flux tube, anchored in the photosphere, and embedded in a uniform coronal environment. We consider that the magnetic field is twisted and control the strength of magnetic twist by a free parameter of the model. We excite the longitudinally fundamental mode of standing torsional Alfvén waves, whose temporal evolution is obtained by means of high-resolution three-dimensional ideal magnetohydrodynamic numerical simulations. We find that phase mixing of torsional Alfvén waves creates velocity shear in the direction perpendicular to the magnetic field lines. The velocity shear eventually triggers the Kelvin-Helmholtz instability (KHi). In weakly twisted magnetic tubes, the KHi is able to grow nonlinearly and, subsequently, turbulence is driven in the coronal loop in a similar manner as in the untwisted case. Provided that magnetic twist remains weak, the effect of magnetic twist is to delay the onset of the KHi and to slow down the development of turbulence. In contrast, magnetic tension can suppress the nonlinear growth of the KHi when magnetic twist is strong enough, even if the KHi has locally been excited by the phase-mixing shear. Thus, turbulence is not generated in strongly twisted loops

Transition to turbulence in nonuniform coronal loops driven by torsional Alfven waves

S. **Díaz-Suárez**, R. Soler

A&A **2021**

https://arxiv.org/pdf/2102.06464.pdf

Both observations and numerical simulations suggest that Alfvenic waves may carry sufficient energy to sustain the hot temperatures of the solar atmospheric plasma. However, the thermalization of wave energy is inefficient unless very short spatial scales are considered. Phase mixing is a mechanism that can take energy down to dissipation lengths, but it operates over too long a timescale. Here, we study how turbulence, driven by the nonlinear evolution of phase-mixed torsional Alfven waves in coronal loops, is able to take wave energy down to the dissipative scales much faster than the theory of linear phase mixing predicts. We consider a simple model of a transversely nonuniform cylindrical flux tube with a constant axial magnetic field. The flux tube is perturbed by the fundamental mode of standing torsional Alfven waves. We solved the three-dimensional (3D) ideal magnetohydrodynamics equations numerically to study the temporal evolution. Initially, torsional Alfven waves undergo the process of phase mixing because of the transverse variation of density. After only few periods of torsional waves, azimuthal shear flows generated by phase mixing eventually trigger the Kelvin-Helmholtz instability (KHi), and the flux tube is subsequently driven to a turbulent state. Turbulence is very anisotropic and develops transversely only to the background magnetic field. The obtained power law for the energy cascade to small scales is compatible with theoretical predictions of nearly 2D weak Alfvenic turbulence. After the onset of turbulence, the effective Reynolds number decreases in the flux tube much faster than in the initial linear stage governed by phase mixing alone. We conclude that the nonlinear evolution of torsional Alfven waves, and the associated KHi, is a viable mechanism for the onset of turbulence in coronal loops.

Imaging spectropolarimetry for magnetic field diagnostics in solar prominences

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A&A 644, A89 (**2020**)
https://doi.org/10.1051/0004-6361/202037931
Context. Narrowband imaging spectropolarimetry is one of the most powerful tools available to infer information about the intensity and topology of the magnetic fields present in extended plasma structures in the solar atmosphere.
Aims. We describe the instrumental set-up and the observing procedure that we have developed and optimized at the Istituto Ricerche Solari Locarno in order to perform imaging spectropolarimetry. A measurement that highlights the potential of the ensuing observations for magnetic field diagnostics in solar prominences is presented.
Methods. Monochromatic images of solar prominences were obtained by combining a tunable narrowband filter, based on two Fabry-Perot etalons, with a Czerny-Turner spectrograph. Linear and circular polarization were measured at every pixel of the monochromatic image with the Zurich Imaging Polarimeter, ZIMPOL. A wavelength scan was performed across the profile of the considered spectral line. The HAZEL inversion code was applied to the observed Stokes profiles to infer a series of physical properties of the observed structure.
Results. We carried out a spectropolarimetric observation of a prominence, consisting of a set of quasi-monochromatic images across the He I D3 line at 5876 Å in the four Stokes parameters. The map of observed Stokes profiles was inverted with HAZEL, finding magnetic fields with intensities between 15 and 30 G and directed along the spine of the prominence, which is in agreement with the results of previous works.

A Universal Method for Solar Filament Detection from H-alpha Observations using Semi-supervised Deep Learning

Andrea **Diercke**, Robert Jarolim, Christoph Kuckein, Sergio J. González Manrique, Marco Ziener, Astrid M. Veronig, Carsten Denker, Werner Pötzi, Tatiana Podladchikova, Alexei A. Pevtsov
A&A **2024**
https://arxiv.org/pdf/2402.15407.pdf
Filaments are omnipresent features in the solar atmosphere. Their location, properties and time evolution can provide information about changes in solar activity and assist the operational space weather forecast. Therefore, filaments have to be identified in full disk images and their properties extracted from these images. Manual extraction is tedious and takes much time; extraction with morphological image processing tools produces a large number of false-positive detections. Automatic object detection, segmentation, and extraction in a reliable manner allows to process more data in a shorter time. The Chromospheric Telescope (ChroTel), Tenerife, Spain, the Global Oscillation Network Group (GONG), and the Kanzelhöhe Observatory (KSO), Austria, provide regular full-disk observations of the Sun in the core of the chromospheric H-alpha absorption line. We present a deep learning method that provides reliable extractions of filaments from H-alpha filtergrams. First, we train the object detection algorithm YOLOv5 with labeled filament data of ChroTel. We use the trained model to obtain bounding-boxes from the full GONG archive. In a second step, we apply a semi-supervised training approach, where we use the bounding boxes of filaments, to learn a pixel-wise classification of filaments with u-net. Here, we make use of the increased data set size to avoid overfitting of spurious artifacts from the generated training masks. Filaments are predicted with an accuracy of 92%. With the resulting filament segmentations, physical parameters such as the area or tilt angle can be easily determined and studied. This we demonstrate in one example, where we determine the rush-to-the pole for Solar Cycle 24 from the segmented GONG images. In a last step, we apply the filament detection to H-alpha observations from KSO which demonstrates the general applicability of our method to H-alpha filtergrams.

Filigree in the Surroundings of Polar Crown and High-Latitude Filaments

A. **Diercke**, C. Kuckein, M. Verma, C. Denker
Solar Phys. **296**, Article number: 35 (**2021**)
https://arxiv.org/pdf/2012.04349.pdf
High-resolution observations of polar crown and high-latitude filaments are scarce. We present a unique sample of such filaments observed in high-resolution Hα narrow-band filtergrams and broad-band images, which were obtained with a new fast camera system at the Vacuum Tower Telescope (VTT), Tenerife, Spain. The Chromospheric Telescope (ChroTel) provided full-disk context observations in Hα, Ca II K, and He I 10830 A. The Helioseismic and Magnetic Imager (HMI) and the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO) provided line-of-sight magnetograms and ultraviolet (UV) 1700 A filtergrams, respectively. We study filigree in the vicinity of polar crown and high-latitude filaments and relate their locations to magnetic concentrations at the filaments' footpoints. Bright points are a well studied phenomenon in the photosphere at low latitudes, but they were not yet studied in the quiet network close to the poles. We examine size, area, and eccentricity of bright points and find that their morphology is very similar to their counterparts at lower latitudes, but their sizes and areas are larger. Bright points at the footpoints of polar crown filaments are preferentially located at stronger magnetic flux concentrations, which are related to bright regions at the border of supergranules as observed in UV filtergrams. Examining the evolution of bright points on three consecutive days reveals that their amount increases while the filament decays, which indicates they impact the equilibrium of the cool plasma contained in filaments. **21-26 Sep 2018**

Chromospheric Synoptic Maps of Polar Crown Filaments

Andrea **Diercke**, Carsten Denker

Solar Phys. 294:152 **2019**

https://arxiv.org/pdf/1910.07943.pdf

https://link.springer.com/content/pdf/10.1007%2Fs11207-019-1538-z.pdf

Polar crown filaments form above the polarity inversion line between the old magnetic flux of the previous cycle and the new magnetic flux of the current cycle. Studying their appearance and their properties can lead to a better understanding of the solar cycle. We use full-disk data of the Chromospheric Telescope (ChroTel) at the Observatorio del Teide, Tenerife, Spain, which were taken in three different chromospheric absorption lines (H-alpha 6563A, CaII-K 3933A, and HeI 10830A), and we create synoptic maps. In addition, the spectroscopic HeI data allow us to compute Doppler velocities and to create synoptic Doppler maps. ChroTel data cover the rising and decaying phase of Solar Cycle 24 on about 1000 days between 2012 and 2018. Based on these data, we automatically extract polar crown filaments with image-processing tools and study their properties. We compare contrast maps of polar crown filaments with those of quiet-Sun filaments. Furthermore, we present a super-synoptic map summarizing the entire ChroTel database. In summary, we provide statistical properties, i.e. number and location of filaments, area, and tilt angle for both the maximum and declining phase of Solar Cycle 24. This demonstrates that ChroTel provides a promising data set to study the solar cycle.

Counter-streaming flows in a giant quiet-Sun filament observed in the extreme ultraviolet

A. **Diercke**, C. Kuckein, M. Verma, C. Denker

A&A 611, A64 **2018**

https://arxiv.org/pdf/1801.01036.pdf

A giant solar filament was visible on the solar surface from **2011 Nov. 8-23**. The filament stretched over more than half a solar diameter. Multiwavelength data from the SDO instrument AIA (171, 193, 304, and 211\AA) were used to examine counter-streaming flows within the spine of the filament. Hα images from the Kanzelh\"ohe Solar Observatory provided context information. We apply local correlation tracking (LCT) to a two-hour time series on **2011 Nov. 16** of the AIA images to derive horizontal flow velocities of the filament. To enhance the contrast of the AIA images, noise adaptive fuzzy equalization is employed, which allows us to identify and quantify counter-streaming flows in the filament. We detect counter-streaming flows in the filament, which are visible in the time-lapse movies in all examined AIA wavelength bands. In the time-lapse movies we see that these persistent flows lasted for at least two hours. Furthermore, by applying LCT to the images we clearly determine counter-streaming flows in time series of 171 and 193\AA\ images. In the 304\AA\ wavelength band, we only see minor indications for counter-streaming flows with LCT, while in the 211\AA\ wavelength band the counter-streaming flows are not detectable. The average horizontal flows reach mean flow speeds of 0.5 km/s. The highest horizontal flow speeds are identified in the 171\AA\ band with flow speeds of up to 2.5 km/s. The results are averaged over a time series of 90 min. Because the LCT sampling window has finite width, a spatial degradation cannot be avoided leading to lower estimates of the flow velocities as compared to feature tracking or Doppler measurements. The counter-streaming flows cover about 15-20% of the whole area of the EUV filament channel and are located in the central part of the spine. In conclusion, we confirm the omnipresence of counter-streaming flows also in giant quiet-Sun filaments.

H_ and hard X-ray observations of a two-ribbon flare associated with a filament eruption

M. D. **Ding**, Q. R. Chen, J. P. Li, and P. F. Chen

E-print, 2002; File; Ap.J.

We perform a multi-wavelength study of a two-ribbon flare on 2002 September 29 and its associated filament eruption, observed simultaneously in the H_ line by a ground-based imaging spectrograph and in hard X-rays by RHESSI. The flare ribbons contain several H_ bright kernels that show different evolutional behaviors. In particular, we find two kernels that may be the footpoints of a loop. A single hard X-ray source appears to cover these two kernels and to move across the magnetic neutral line. We explain this as a result of the merging of two footpoint sources that show gradually asymmetric emission owing to an asymmetric magnetic topology of the newly reconnected loops. In one of the H_ kernels, we detect a continuum enhancement at the visible wavelength. By checking its spatial and temporal relationship with the hard X-ray emission, we ascribe it as being caused by electron beam precipitation. In addition, we derive the line-of-sight velocity of the filament plasma based on the Doppler shift of the filament-caused absorption in the H_ blue wing. The filament shows rapid acceleration during the impulsive phase. These observational features are in principal consistent with the general scenario of the canonical two-ribbon flare model.

Visible light and ultraviolet observations of coronal structures: physical properties of an equatorial streamer and modelling of the F corona

S. **Dolei**, D. Spadaro and R. Ventura

A&A 577, A34 (**2015**)

http://www.aanda.org/articles/aa/pdf/2015/05/aa25387-14.pdf

The present work studies the characteristics of an equatorial streamer visible above the east limb of the Sun on March 2008, during the most recent minimum of solar activity. We analysed the visible light coronagraphic images of SOHO/LASCO and the ultraviolet observations in the H I Lyα spectral line obtained by SOHO/UVCS, and exploited the Doppler dimming effect of the coronal Lyα line to derive the outflow velocity profile of the scattering neutral hydrogen atoms in the streamer region. Taking advantage of the synergy between visible light and ultraviolet observations, we were able to determine all the properties of the coronal structure. In particular, the actual extent of the streamer along the line of sight has been evaluated for the first time. In so doing, the solar wind outflow velocity turned out to be the only free parameter in the theoretical modelling of the Lyαintensity. We found nearly static conditions below 3.5 R⊙ along the streamer axis, whereas the solar wind flows at velocities from 40 km s-1 to 140 km s-1 in the altitude range 2.5–5.0 R⊙ along the southern boundary of the streamer. We also derived the intensity distribution of the F coronal component in the LASCO C2 field of view, by combining total and polarized brightness data. Finally, we investigated the dependence of the Lyα resonant scattering process on the kinetic temperature of the coronal neutral hydrogen atoms and found that the value of this temperature mostly affects the scattering process at low heliocentric distances, where the solar wind flows with low velocity. **March 11, 2008**

Formation of Large Scale Coronal Loops Interconnecting Two Active Regions Through Gradual Magnetic Reconnection and Associated Heating Process

Guohui **Du**, Yao Chen, Chunming Zhu, Chang Liu, Lili Ge, Bing Wang, Chuanyang Li, Haimin Wang

2018

https://arxiv.org/pdf/1805.04831.pdf

Coronal loops interconnecting two active regions, called as interconnecting loops (ILs), are prominent large-scale structures in the solar atmosphere. They carry a significant amount of magnetic flux, therefore are considered to be an important element of the solar dynamo process. Earlier observations show that eruptions of ILs are an important source of CMEs. It is generally believed that ILs are formed through magnetic reconnection in the high corona (>150-200"), and several scenarios have been proposed to explain their brightening in soft X-rays (SXRs). Yet, the detailed IL formation process has not been fully explored and the associated energy release in the corona still remains unresolved. Here we report the complete formation process of a set of ILs connecting two nearby active regions, with successive observations by STEREO-A on the far side of the Sun and SDO and Hinode on the Earth side. We conclude that ILs are formed by gradual reconnection high in the corona, in line with earlier postulations. In addition, we show evidence supporting that ILs become brightened in SXRs and EUVs through heating at or close to the reconnection site in the corona (i.e., through direct heating process of reconnection), a process that has been largely overlooked in earlier studies on ILs. **2015 Dec 06-09, 2015 December 11-12**

Observational signatures of the third harmonic in a decaying kink oscillation of a coronal loop

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A&A 632, A64 (**2019**)

https://doi.org/10.1051/0004-6361/201936822

Aims. An observation of a coronal loop standing kink mode is analysed to search for higher harmonics, aiming to reveal the relation between different harmonics' quality factors.

Methods. Observations of a coronal loop were taken by the Atmospheric Imaging Assembly (AIA) of the Solar Dynamics Observatory (SDO). The loop's axis was tracked at many spatial positions along the loop to generate time series data.

Results. The distribution of spectral power of the oscillatory transverse displacements throughout the loop reveals the presence of two harmonics, a fundamental at a period of ~8 min and its third harmonic at ~2.6 min. The node of the third harmonic is seen at approximately a third of the way along the length of the loop, and cross correlations between the oscillatory motion on opposing sides of the node show a change in phase behaviour. The ratio of periods P1/3P3 was found to be ~0.87, indicating a non-uniform distribution of kink speed through the loop. The quality factor for the fundamental mode of oscillation was measured to be ~3.4. The quality factor of the third harmonic was measured for each spatial location and, where data was reliable, yielded a value of ~3.6. For all locations, the quality factors for the two harmonics were found to agree within error as expected from 1d resonant absorption theory. This is the first time a measurement of the signal quality for a higher harmonic of a kink oscillation has been reported with spatially resolved data.

Detection of the Second Harmonic of Decay-less Kink Oscillations in the Solar Corona

T. **Duckenfield**1, S. A. Anfinogentov1, D. J. Pascoe1, and V. M. Nakariakov1
2018 ApJL 854 L5
EUV observations of a multi-thermal coronal loop, taken by the Atmospheric Imaging Assembly of the Solar Dynamics Observatory, which exhibits decay-less kink oscillations are presented. The data cube of the quiet-Sun coronal loop was passed through a motion magnification algorithm to accentuate transverse oscillations. Time–distance maps are made from multiple slits evenly spaced along the loop axis and oriented orthogonal to the loop axis. Displacements of the intensity peak are tracked to generate time series of the loop displacement. Fourier analysis on the time series shows the presence of two periods within the loop: $P_1 = 10.3^{+1.5}_{-1.7}$ minutes and $P_2 = 7.4^{+1.1}_{-1.3}$ minutes. The longer period component is greatest in amplitude at the apex and remains in phase throughout the loop length. The shorter period component is strongest further down from the apex on both legs and displays an anti-phase behavior between the two loop legs. We interpret these results as the coexistence of the fundamental and second harmonics of the standing kink mode within the loop in the decay-less oscillation regime. An illustration of seismological application using the ratio P1/2P 2 ~ 0.7 to estimate the density scale height is presented. The existence of multiple harmonics has implications for understanding the driving and damping mechanisms for decay-less oscillations and adds credence to their interpretation as standing kink mode oscillations.

A RING OF POLARIZED LIGHT: EVIDENCE FOR TWISTED CORONAL MAGNETISM IN CAVITIES
J. B. **Dove**1, S. E. Gibson2, L. A. Rachmeler2, S. Tomczyk2 and P. Judge
2011 ApJ 731 L1
Coronal prominence cavities may be manifestations of twisted or sheared magnetic fields capable of storing the energy required to drive solar eruptions. The Coronal Multi-Channel Polarimeter (CoMP), recently installed at Mauna Loa Solar Observatory, can measure polarimetric signatures of current-carrying magnetohydrodynamic (MHD) systems. For the first time, this instrument offers the capability of daily full-Sun observations of the forbidden lines of Fe XIII with high enough spatial resolution and throughput to measure polarimetric signatures of current-carrying MHD systems. By forward-calculating CoMP observables from analytic MHD models of spheromak-type magnetic flux ropes, we show that a predicted observable for such flux ropes oriented along the line of sight is a bright ring of linear polarization surrounding a region where the linear polarization strength is relatively depleted. We present CoMP observations of a coronal cavity possessing such a polarization ring.

Imaging and Spectroscopic Observations of a Transient Coronal Loop: Evidence for the Non-Maxwellian κ-Distributions
Jaroslav **Dudik**, Simon Mackovjak, Elena Dzifcakova, Giulio Del Zanna, David R. Williams, Marian Karlicky, Helen E. Mason, Juraj Lorincik, Pavel Kotrc, Frantisek Farnik, Alena Zemanova
ApJ **2015**
http://arxiv.org/pdf/1505.04333v1.pdf
We report on the SDO/AIA and Hinode/EIS observations of a transient coronal loop. The loop brightens up in the same location after the disappearance of an arcade formed during a B8.9-class microflare three hours earlier. EIS captures this loop during its brightening phase as observed in most of the AIA filters. We use the AIA data to study the evolution of the loop, as well as to perform the DEM diagnostics as a function of κ. Fe XI--XIII lines observed by EIS are used to perform the diagnostics of electron density and subsequently the diagnostics of κ. Using ratios involving the Fe XI 257.772\AA selfblend, we diagnose κ ≲ 2, i.e., an extremely non-Maxwellian distribution. Using the predicted Fe line intensities derived from the DEMs as a function of κ, we show that, with decreasing κ, all combinations of ratios of line intensities converge to the observed values, confirming the diagnosed κ ≲ 2. These results represent the first positive diagnostics of κ-distributions in the solar corona despite the limitations imposed by calibration uncertainties. **2013 March 30**

MAGNETIC TOPOLOGY OF BUBBLES IN QUIESCENT PROMINENCES
J. **Dudík**1,5,6,7, G. Aulanier2, B. Schmieder2, M. Zapiór3, and P. Heinzel
2012 ApJ 761 9
We study a polar-crown prominence with a bubble and its plume observed in several coronal filters by the SDO/AIA and in Hα by the MSDP spectrograph in Białków (Poland) to address the following questions: what is the brightness of prominence bubbles in EUV with respect to the corona outside of the prominence and the prominence coronal cavity? What is the geometry and topology of the magnetic field in the bubble? What is the nature of the vertical

threads seen within prominences? We find that the brightness of the bubble and plume is lower than the brightness of the corona outside of the prominence, and is similar to that of the coronal cavity. We constructed linear force-free models of prominences with bubbles, where the flux rope is perturbed by inclusion of parasitic bipoles. The arcade field lines of the bipole create the bubble, which is thus devoid of magnetic dips. Shearing the bipole or adding a second one can lead to cusp-shaped prominences with bubbles similar to the observed ones. The bubbles have complex magnetic topology, with a pair of coronal magnetic null points linked by a separator outlining the boundary between the bubble and the prominence body. We conjecture that plume formation involves magnetic reconnection at the separator. Depending on the viewing angle, the prominence can appear either anvil-shaped with predominantly horizontal structures, or cusp-shaped with predominantly vertical structuring. The latter is an artifact of the alignment of magnetic dips with respect to the prominence axis and the line of sight.

Topological departures from translational invariance along a filament observed by THEMIS

J. **DUDÍK**1,2 · G. AULANIER2 · B. SCHMIEDER2 · V. BOMMIER3 · T. ROUDIER4

E-print, Jan 2008, Solar Physics, 248(1), 29-50, **2008**

http://www.springerlink.com/content/f0124840442w5387/fulltext.pdf

we consider a filament observed on **October 6th, 2004** with THEMIS/MTR, in H_ with the full line profile simulatenously and cospatially with its photospheric vector magnetic field.

6. Discussion of the EUV filament channel

The related flux tube is highly fragmented at low altitudes. This fragmentation is due to small flux concentrations of two types. First, some locally distort the tube, leading to noticeable thickness variations along the filament body. Second, parasitic polarities, associated with filament feet, result in secondary dips above the related local inversion line.

Tracking a *Ulysses* High-latitude ICME Event Back to Its Solar Origins

C. **Dumitrache** · N.A. Popescu · A. Oncica

Solar Phys (**2011**) 272:137–157, **File**

High-latitude interplanetary mass ejections (ICMEs) observed beyond 1 AU are not studied very often. They are useful for improving our understanding of the 3D heliosphere. As there are only few such events registered by the Ulysses spacecraft, the task of detecting their solar counterparts is a challenge, especially during high solar activity periods, because there are dozens coronal mass ejections (CMEs) registered by SOHO that might be chosen as candidates. We analyzed a high-latitude ICME registered by the Ulysses spacecraft on 18 January 2002. Our investigation focused on the correlation between various plasma parameters that allow the identification to be made of the ICME and its components such as the forward shock, the magnetic cloud and the reverse shock.

Using a linear approach and a graphical method we have been able to track the ICME event back to the Sun and to compute the day of the occurrence of the solar CME. In order to decide among several CME candidates which one is the right solar counterpart of our event, we have performed a follow-up computation of these CMEs from the Sun to Ulysses, by using two different speed formulas. First, the computation was simply based on the initial CME velocity, while the other was based on the ICME velocity estimated from the CME initial speed (Lindsay et al. 1999). Differences of hours have been obtained between the arrival time predicted in these two ways, but the second one gave the best results. Both methods indicated the same two CMEs as the solar counterparts. We have found the solar source of these CMEs as being a huge polar filament that erupted in several steps.

This ICME event displayed a double magnetic cloud configuration. A minimum variance analysis helped us to detect the smooth rotation of the clouds and their helicity. Both magnetic clouds show the same helicity as the filament that erupted and released them. A cylinder-shape model of both clouds gives the same helicity sign.

Filament eruption of 8 January 2002.

A Flaring Polar Filament

C. **Dumitrache**

Astrophysics and Space Science Proceedings, eds. S. S. Hasan , R. Rutten, 459-463, **2010**

E-print, Dec **2010**

A special, huge polar filament producing multiple CMEs is analyzed.

Around this double-S shaped filament a two-ribbon flare occurred which rose into a CME. **14 August 2001**

KINK INSTABILITIES TRIGGERING A FILAMENT ERUPTION

CRISTIANA **DUMITRACHE**, DIANA CONSTANTIN

RoAJ 20, 35-44, **2010**

E-print, Dec **2010**

A huge complex filament was observed between 28 December 2000 and 7 January **2001**. We analyze its dynamics and its sudden disappearance. We analyze the

3D coronal magnetic field extrapolated from the MDI photospheric magnetograms and compare with filament coronal images. The filament erupted in a CME after a mild helical upward movement of plasma on **7 January**. We attempt to explain this CME event onset by kink instabilities. An approach to estimate the filament helicity and magnetic flux injection explain the filament destabilization.

A CASE OF FILAMENT - ACTIVE REGION INTERACTION

C. **DUMITRACHE** and L. DUMITRU

Publ. Astron. Obs. Belgrade No. 90 (**2010**), 125 - 130

E-print, Dec **2010**

We analyze a huge filament observed between **5 and 19 September 2001**. In its evolution it is linked to the active region 9612, observed between **7 and 16 September 2001**. The filament has a strange morphology and dynamics: starting as two parallel components (A and B), it becomes a double sigmoid filament when a third component (C) appears linking the other two. An unusual magnetic topology characterizes this evolution: the active region is located between the parallel components. When the third component becomes observable, it links these ones first below the active region. After a spectacular plasma movement registered in filament (A), this one becomes linked to (B) above the active region. In spite of these dramatically changes of the magnetic topology and filament - active region switch, no CME is observed. Only a few °ares occurring in AR9612 are registered and these ones can be seen in the dynamics of the filament as an expression of large scale magnetic reconnections.

Automated Coronal-Loop Detection based on Contour Extraction and Contour Classification from the SOHO/EIT Images

Nurcan **Durak** · Olfa Nasraoui · Joan Schmelz

Solar Phys (**2010**) 264: 383–402

Arch-shaped coronal loops that are isolated from the background are typically acquired manually from massive online image databases to be used in solar coronal research. The manual search for special coronal loops is not only subject to human mistakes but is also time consuming and tedious. In this study, we propose a completely automated imageretrieval system that identifies coronal-loop regions located outside of the solar disk from 17.1 nm EIT images. To achieve this aim, we first apply image-preprocessing techniques to bring out loop structures from their background and to reduce the effect of undesired patterns. Then we extract principal contours from the solar image regions. The geometrical attributes of the extracted principal contours reveal the existence of loops in a given region. Our completely automated decision-making procedure gives promising results in separating the regions with loops from the regions without loops. Based on our loop-detection procedure, we have developed an automated image-retrieval tool that is capable of retrieving images containing loops from a collection of solar images.

The Effect of a Twisted Magnetic Field on the Phase Mixing of the Kink Magnetohydrodynamic Waves in Coronal Loops

Zanyar **Ebrahimi**1, Kayoomars Karami1, and Roberto Soler

2017 ApJ 845 86

http://sci-hub.cc/10.3847/1538-4357/aa7f75

https://arxiv.org/pdf/1708.07957.pdf

There is observational evidence for the existence of a twisted magnetic field in the solar corona. This inspires us to investigate the effect of a twisted magnetic field on the evolution of magnetohydrodynamic (MHD) kink waves in coronal loops. With this aim, we solve the incompressible linearized MHD equations in a magnetically twisted nonuniform coronal flux tube in the limit of long wavelengths. Our results show that a twisted magnetic field can enhance or diminish the rate of phase mixing of the Alfvén continuum modes and the decay rate of the global kink oscillation depending on the twist model and the sign of the longitudinal (k z) and azimuthal (m) wavenumbers. Also, our results confirm that in the presence of a twisted magnetic field, when the sign of one of the two wavenumbers m and k z is changed, the symmetry with respect to the propagation direction is broken. Even a small amount of twist can have an important impact on the process of energy cascading to small scales.

Resonant absorption of kink MHD waves by magnetic twist in coronal loops

Z. **Ebrahimi**, K. Karami

2015

http://arxiv.org/pdf/1507.02653v1.pdf

There is ample evidences of twisted magnetic structures in the corona. This motivates us to consider the magnetic twist as the cause of Alfven frequency continuum in coronal loops, which can support the resonant absorption as the rapid damping mechanism for the observed coronal kink MHD oscillations. For a straight cylindrical compressible zero-beta thin flux tube with a magnetic twist in a thin boundary and straight magnetic field in the interior and exterior regions as well as a step-like radial density profile, we derive the dispersion relation and solve it analytically. Consequently, we obtain the frequencies and damping rates of the fundamental (l=1) and first/second overtones (l=2,3) kink (m=1) MHD modes. We conclude that the resonant absorption by the magnetic twist can justify the rapid damping of kink MHD waves observed in coronal loops. Furthermore, the magnetic twist in the inhomogeneous layer can achieve deviations from P_1/P_2=2 and P_1/P_3=3 of the same order of magnitude as in the observations.

Ultra Low-Frequency Oscillations of a Solar Filament in Hα Revealed With the Data of the Global Oscillation Network Group (Gong)

V.I.**Efremov**, L.D.Parfinenko, A.A.Soloviev

Solar Phys. Volume 291, Issue 11, pp 3357–3367 **2016**

http://arxiv.org/pdf/1602.03137v1.pdf

The data of ground-based telescopes of Global Oscillation Network Group (GONG) obtained in the H-alpha line provide an opportunity to study the long-period oscillations of chromospheric filaments (quiescent prominence). For the first time, on the base of time-series of 5 days duration, combined from the observations of three observatories of the GONG, a new ultra-low mode, with period between 20 and 30 hours, was reliably detected in oscillations of a long-lived dark filament on the solar disc. **2015/05/25-29**

Temperature and Differential Emission Measure Profiles in Turbulent Solar Active Region Loops

A. Gordon **Emslie**, Stephen J. Bradshaw

ApJ **939** 19 **2022**

https://arxiv.org/pdf/2210.01107.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/ac961b/pdf

We examine the temperature structure of static coronal active region loops in regimes where thermal conductive transport is driven by Coulomb collisions, by turbulent scattering, or by a combination of the two. (In the last case collisional scattering dominates the heat transport at lower levels in the loop where temperatures are low and densities are high, while turbulent scattering dominates the heat transport at higher temperatures/lower densities.) Temperature profiles and their corresponding differential emission measure distributions are calculated and compared to observations, and earlier scaling laws relating the loop apex temperature and volumetric heating rate to the loop length and pressure are revisited. Results reveal very substantial changes, compared to the wholly collision-dominated case, to both the loop scaling laws and the temperature/density profiles along the loop. They also show that the well-known excess of differential emission measure at relatively low temperatures in the loop may be a consequence of for by the flatter temperature gradients (and so increased amount of material within a specified temperature range) that results from the predominance of turbulent scattering in the upper regions of the loop.

Description and Classification of Prominences **Review**

Oddbjørn **Engvold**

Solar Prominences

Astrophysics and Space Science Library Volume 415, **2015**, pp 31-60

http://link.springer.com/chapter/10.1007/978-3-319-10416-4_2

Solar prominences are bright cloud-like structures when observed beyond the solar limb and they appear as dark filamentary objects which are termed filaments when seen against the solar disk. The aims of prominence classifications were from the start to establish references and frameworks for understanding the physical conditions for their formation and development through interplay with the solar magnetic environment. The multi-thermal nature of solar prominences became fully apparent once observations from space in UV, VUV, EUV and X-rays could be made. The cool prominence plasma is thermally shielded from the much hotter corona and supported in the field of gravity by small- and large-scale magnetic fields of the filament channels. High cadence, subarcsecond observing facilities on ground and in space have firmly proven the highly dynamic nature of solar prominences down to the smallest observed structural sizes of 100 km. The origin of the ubiquitous oscillations and flowing of the plasma over a variety of spatial and temporal scales, whether the cool dense plasma originates from below via levitation, injections by reconnection or results from condensation processes, are central issues in prominence research today. The unveiling of instabilities leading to prominences eruptions and Coronal Mass Ejections is another important challenge. The objective of this chapter is to review the main characteristics of various types of prominences and their associated magnetic environments, which will all be addressed in details in the following chapters of this book.

MHD simulation of prominence-cavity system

Yuhong **Fan**, Tie Liu

Frontiers in Astronomy and Space Sciences 6:27 **2019**

https://arxiv.org/pdf/1905.08226.pdf

https://www.frontiersin.org/articles/10.3389/fspas.2019.00027/full

https://doi.org/10.3389/fspas.2019.00027

We present magnetohydrodynamic simulation of the evolution from quasi-equilibrium to onset of eruption of a twisted, prominence-forming coronal magnetic flux rope underlying a corona streamer. The flux rope is built up by an imposed flux emergence at the lower boundary. During the quasi-static phase of the evolution, we find the formation of a prominence-cavity system with qualitative features resembling observations, as shown by the synthetic SDO/AIA EUV images with the flux rope observed above the limb viewed nearly along its axis. The cavity contains substructures including ``U"-shaped or horn-liked features extending from the prominence enclosing a central ``cavity" on top of the prominence. The prominence condensations form in the dips of the highly twisted field lines due to runaway radiative cooling and the cavity is formed by the density depleted portions of the prominence-carrying field lines extending up from the dips. The prominence ``horns" are threaded by twisted field lines containing shallow dips, where the prominence condensations have evaporated to coronal temperatures. The central ``cavity" enclosed by the horns is found to correspond to a central hot and dense core containing twisted field lines that do not have dips. The flux rope eventually erupts as its central part rises quasi-statically to a critical height consistent with the onset of the torus instability. The erupting flux rope accelerates to a fast speed of nearly 900 km/s and the associated prominence eruption shows significant rotational motion and a kinked morphology.

On the nature of the X-ray bright core in a stable filament channel

-- Y. **Fan** and S. E. Gibson, E-print, Dec **2006**

development of X-ray ``bright cores" or **``sigmoids'' in a filament channel**

Temperature Analysis of Flaring (AR11283) and non-Flaring (AR12194) Coronal Loops

Narges **Fathalian**, Seyedeh Somayeh Hosseini Rad, Nasibeh Alipour, Hossein Safari

2022

https://arxiv.org/pdf/2201.00214.pdf

Here, we study the temperature structure of flaring and non-flaring coronal loops, using extracted loops from images taken in six extreme ultraviolet (EUV) channels recorded by Atmospheric Imaging Assembly (AIA)/ Solar Dynamic Observatory (SDO). We use data for loops of X2.1-class-flaring active region (AR11283) during 22:10UT till 23:00UT, on **2011, September 6**; and non-flaring active region (AR12194) during 08:00:00UT till 09:00:00UT on **2014, October 26**. By using spatially-synthesized Gaussian DEM forward-fitting method, we calculate the peak temperatures for each strip of the loops. We apply the Lomb-Scargle method to compute the oscillations periods for the temperature series of each strip. The periods of the temperature oscillations for the flaring loops are ranged from 7 min to 28.4 min. These temperature oscillations show very close behavior to the slow-mode oscillation. We observe that the temperature oscillations in the flaring loops are started at least around 10 minutes before the transverse oscillations and continue for a long time duration even after the transverse oscillations are ended. The temperature amplitudes are increased at the flaring time (during 20 min) in the flaring loops. The periods of the temperatures obtained for the non-flaring loops are ranged from 8.5 min to 30 min, but their significances are less (below 0.5) in comparison with the flaring ones (near to one). Hence the detected temperature periods for the non-flaring loops' strips are less probable in comparison with the flaring ones, and maybe they are just fluctuations. Based on our confined observations, it seems that the flaring loops' periods show more diversity and their temperatures have wider ranges of variation than the non-flaring ones. More accurate commentary in this respect requires more extensive statistical research and broader observations.

Oscillations of coronal loops using Rayleigh-Ritz technique

N. **Fathalian**, H. Safari, S. Nasiri

2019

https://arxiv.org/pdf/1909.04880.pdf

In this paper, we apply the Rayleigh-Ritz Variational Scheme for studying the transverse oscillations of a magnetic flux tube. The flux tube is considered in low-β solar coronal condition. The perturbations decomposed into irrotational and solenoidal components and MHD equations are reduced as a matrix eigenvalue problem. In the case of longitudinally stratified thin flux tube, the fundamental and higher order kink frequencies are computed. The results are in good agreements with previous studies.

Extracting the Temperature of a Coronal Loop in the Solar Active Region 11092

Narges **Fathalian**

Iranian Journal of Astronomy and Astrophysics Vol. 4, No. 1, **2017** **2019**

https://arxiv.org/pdf/1908.11369.pdf

Extracting the temperature of coronal loops is effective in the analysis of solar active region's loops and helps in better understanding of coronal events. To this end, various methods have already been developed like the method developed by Aschwanden et al. 2015 \cite{AschwandenB2015} which is based on Gaussian fit for Differential Emission Measure (DEM). Here, we use the intensity ratios of the images in three different wavelengths and the temperature response functions of AIA to extract the temperature of the loop. In this paper, we use EUV images of the solar active region 11092 taken by AIA instrument of the SDO satellite at 171, 193, and 211 A0 wavelengths, at 1th of August, 2010. We select a loop in a subregion of 11092 and extract its temperature by the help of intensity profiles in different wavelengths and thermal response functions of different filters. In this subregion cooling of the loop happens and in the selected loop, highest relative intensity of the wavelengths of 171 A0 to 193 A0 was obtained to be 0.76 and this number was estimated to correspond to the temperature of 1.3 million degree of Kelvin, which is the maximum temperature point of this loop's internal area. The highest values of the intensity ratios at the wavelengths of 211A0 to 193A0, and 211A0 to 171A0 are 0.22 and 0.25, which correspond to temperature values around 10M and 1.4M Kelvin in sequence, related to the temperature of hotter and more superficial points of the loop respectively. These values are very sensitive to time and differ in time series of this event of the loop intensity variation. **2010 August 1**

Transverse Oscillations of Longitudinally Stratified Coronal Loops System

Narges **Fathalian**, Hossein Safari

2010 ApJ...724..411F

https://arxiv.org/pdf/1908.11427.pdf

The collective transverse coronal loop oscillations seem to be detected in the observational studies. In this regard, Luna et al. (2009, ApJ, 692, 1582) modeled the collective kinklike normal modes of several cylindrical loops system using the T-matrix theory.

This paper investigates the effects of longitudinal density stratification along the loop axis, on the collective kinklike modes of system of coronal loops. The coronal loops system is modeled as cylinders of parallel flux tubes, with two ends of each loop at the dense photosphere. The flux tubes are considered as uniform magnetic fields, with stratified density along the loop axis which changes discontinuously at the lateral surface of each cylinder. The MHD equations are reduced to solve a set of two coupled dispersion relations for frequencies and wave numbers, in the presence of stratification parameter. The fundamental and first overtone frequencies and longitudinal wave numbers are computed. The previous results are verified for unstratified coronal loops system.

Finally we would conclude that increased longitudinal density stratification parameter will result in increase of the frequencies. The frequencies ratios, first overtones to fundamentals, are very sensitive functions of density scale height parameter. Therefore, stratification should be included in dynamics of coronal loops systems. For the unstratified coronal loops system, these ratios are the same as monoloop ones.

KELVIN-HELMHOLTZ INSTABILITY OF A CORONAL STREAMER

L. **Feng**1,2, B. Inhester2, and W. Q. Gan

2013 ApJ 774 141

Shear-flow-driven instability can play an important role in energy transfer processes in coronal plasma. We present for the first time the observation of a kink-like oscillation of a streamer that is probably caused by the streaming kink-mode Kelvin-Helmholtz instability (KHI). The wave-like behavior of the streamer was observed by the Large Angle and Spectrometric Coronagraph Experiment C2 and C3 on board the SOlar and Heliospheric Observatory. The observed wave had a period of about 70-80 minutes, and its wavelength increased from 2 R ⊙ to 3 R ⊙ in about 1.5 hr. The phase speeds of its crests and troughs decreased from 406 ± 20 to 356 ± 31 km s–1 during the event. Within the same heliocentric range, the wave amplitude also appeared to increase with time. We attribute the phenomena to the MHD KHI, which occurs at a neutral sheet in a fluid wake. The free energy driving the instability is supplied by the sheared flow and sheared magnetic field across the streamer plane. The plasma properties of the local environment of the streamer were estimated from the phase speed and instability threshold criteria.

Streamer Wave Events Observed in Solar Cycle 23

S. W. **Feng**, Y. Chen, B. Li, H. Q. Song, X. L. Kong, L. D. Xia and X. S. Feng

Solar Phys (**2011**) 272:119–136, **File**

In this paper we conduct a data survey searching for well-defined streamer wave events observed by the Large Angle and Spectrometric Coronagraph (LASCO) on-board the Solar and Heliospheric Observatory (SOHO) throughout Solar Cycle 23. As a result, eight candidate events are found and presented here. We compare different events and find that in most of them the driving CMEs' ejecta are characterized by a high speed and a wide angular span, and the CME–streamer interactions occur generally along the flank of the streamer structure at an altitude no higher than the bottom of the field of view of LASCO C2. In addition, all front-side CMEs have accompanying flares. These common observational features shed light on the excitation conditions of streamer wave events.
We also conduct a further analysis on one specific streamer wave event on 5 June 2003. The heliocentric distances of four wave troughs/crests at various exposure times are determined; they are then used to deduce the wave properties like period, wavelength, and phase speeds. It is found that both the period and wavelength increase gradually with the wave propagation along the streamer plasma sheet, and the phase speed of the preceding wave is generally faster than that of the trailing ones. The associated coronal seismological study yields the radial profiles of the Alfvén speed and magnetic field strength in the region surrounding the streamer plasma sheet. Both quantities show a general declining trend with time. This is interpreted as an observational manifestation of the recovery process of the CME-disturbed corona. It is also found that the Alfvénic critical point is at about 10 $R_\odot$, where the flow speed, which equals the Alfvén speed, is ~ 200 km s^{-1}.

Solar coronal loop dynamics near the null point above active region NOAA 2666

Boris **Filippov**

Publications of the Astronomical Society of Australia (PASA) Vol. 35, e023 **2018**

https://arxiv.org/ftp/arxiv/papers/1805/1805.08540.pdf

sci-hub.tw/10.1017/pasa.2018.20

We analyse observations of a saddle-like structure in the corona above the western limb of the Sun on **2017 July 18**. The structure was clearly outlined by coronal loops with typical coronal temperature no more than 1 MK. The dynamics of loops showed convergence toward the centre of the saddle in the vertical direction and divergence in the horizontal direction. The event is a clear example of smooth coronal magnetic field reconnection. No heating manifestations in the reconnection region or magnetically connected areas were observed. Potential magnetic field calculations, which use as the boundary condition the SDO/HMI magnetogram taken on July 14, showed the presence of a null point at the height of 122" above the photosphere just at the centre of the saddle structure. The shape of field lines fits the fan-spine magnetic configuration above NOAA 2666.

Two-step solar filament eruptions

Boris **Filippov**

MNRAS **2017**

https://arxiv.org/pdf/1712.08173.pdf

Coronal mass ejections (CMEs) are closely related to eruptive filaments and usually are the continuation of the same eruptive process into the upper corona. There are failed filament eruptions when a filament decelerates and stops at some greater height in the corona. Sometimes the filament after several hours starts to rise again and develops into the successful eruption with a CME formation. We propose a simple model for the interpretation of such two-step eruptions in terms of equilibrium of a flux rope in a two-scale ambient magnetic field. The eruption is caused by a slow decrease of the holding magnetic field. The presence of two critical heights for the initiation of the flux-rope vertical instability allows the flux rope to stay after the first jump some time in a metastable equilibrium near the second critical height. If the decrease of the ambient field continues, the next eruption step follows. **2011 October 18**

Filament Shape Versus Coronal Potential Magnetic Field Structure

Boris **Filippov**

MNRAS **2015**

http://arxiv.org/pdf/1510.04546v1.pdf

Solar filament shape in projection on disc depends on the structure of the coronal magnetic field. We calculate the position of polarity inversion lines (PILs) of coronal potential magnetic field at different heights above the photosphere, which compose the magnetic neutral surface, and compare with them the distribution of the filament material in Hα chromospheric images. We found that the most of the filament material is enclosed between two polarity inversion lines (PILs), one at a lower height close to the chromosphere and one at a higher level, which can be considered as a height of the filament spine. Observations of the same filament on the limb by the {\it STEREO} spacecraft confirm that the height of the spine is really very close to the value obtained from the PIL and filament border matching. Such matching can be used for filament height estimations in on-disk observations. Filament barbs are housed within protruding sections of the low-level PIL. On the base of simple model, we show that the similarity of the neutral surfaces in potential and non-potential fields with the same sub-photospheric sources is the reason for the found tendency for the filament material to gather near the potential-field neutral surface. **2012 February 23**

Covert connection of filaments

Boris **Filippov**

MNRAS, **2015**

http://arxiv.org/pdf/1507.08180v1.pdf

We analyse the relationship between two near filaments, which do not show any connection in H-alpha images but reveal close magnetic connectivity during filament activations in Extreme Ultraviolet (EUV) observations. A twisted flux rope, which connects a half of one filament with another filament, becomes visible during several activations but seems to exist all the time of the filaments presence on the disc. Solar Dynamic Observatory} (SDO) and Solar Terrestrial Relations Observatory (STEREO) observed the region with the filaments from two points of view separated by the angle of about 120 deg. On **2012 July 27**, SDO observed the filament activation on disc, while for the STEREO B position the filaments were visible at the limb. Nearly identical interaction episode was observed on **2012 August 04** by STEREO A on disc and by SDO at the limb. This good opportunity allows us to disentangle the 3-D shape of the connecting flux rope and in particular to determine with high reliability the helicity sign of the flux rope, which looks ambiguous in preliminary inspections of on-disc EUV images only.} The complex magnetic structure of the region consists of three braided flux ropes in the vicinity of the coronal null point. Using observations of the flux rope fine structure and plasma motions within it from two points of view, we determine the negative sign of helicity of the flux rope, which corresponds to dextral chirality of the filaments. The observations, despite the tangled fine structure in some EUV images, support flux rope filament models. They give more evidence for the one-to-one relationship between the filament chirality and the flux rope helicity.

Filament eruption with apparent reshuffle of endpoints

Boris **Filippov**

MNRAS, **2014**

http://arxiv.org/pdf/1405.5784v1.pdf

Filament eruption on **30 April - 1 May 2010**, which shows the reconnection of one filament leg with a region far away from its initial position, is analyzed. Observations from three viewpoints are used for as precise as possible measurements of endpoint coordinates. The northern leg of the erupting prominence loop 'jumps' laterally to the latitude lower than the latitude of the originally southern endpoint. Thus, the endpoints reshuffled their positions in the limb view. Although this behaviour could be interpreted as the asymmetric zipping-like eruption, it does not look very likely. It seems more likely to be reconnection of the flux-rope field lines in its northern leg with ambient coronal magnetic field lines rooted in a quiet region far from the filament. From calculations of coronal potential magnetic field, we found that the filament before the eruption was stable for vertical displacements, but was liable to violation of the horizontal equilibrium. This is unusual initiation of an eruption with combination of initial horizontal and vertical flux-rope displacements showing a new unexpected possibility for the start of an eruptive event.

Height of a solar filament before eruption

B. P. **Filippov**

Astronomy Reports, October **2013**, Volume 57, Issue 10, pp 778-78

Astronomicheskii Zhurnal, **2013**, Vol. 90, No. 10, pp. 848–856.

The relationship between the height of a solar filament observed above the photosphere before the eruption on **October 21, 2010**, and the critical height of a stable equilibrium of magnetic flux ropes in the coronal magnetic field is analyzed. Data from the SDO, SOHO, and STEREO space observatories observing at different viewing angles makes it possible to deduce these parameters with high accuracy. It is shown that the filament height slowly increased over several days, with the eruption occuring when the height reached the critical value of 80 Mm.

A FILAMENT ERUPTION ON 2010 OCTOBER 21 FROM THREE VIEWPOINTS

Boris **Filippov**

E-print, June **2013, File; 2013** ApJ 773 10

A filament eruption on **2010 October 21** observed from three different viewpoints by the Solar Terrestrial Relations Observatory and the Solar Dynamic Observatory is analyzed by also invoking data from the Solar and Heliospheric Observatory and the Kanzelhoehe Solar Observatory. The position of the filament just before the eruption at the central meridian not far from the center of the solar disk was favorable for photospheric magnetic field measurements in the area below the filament. Because of this, we were able to calculate with high precision the distribution of the coronal potential magnetic field near the filament. We found that the filament began to erupt when it approached the height in the corona where the magnetic field decay index was greater than 1. We also determined that during the initial stage of the eruption the filament moved along the magnetic neutral surface.

Some properties of the joining of solar filaments

B. P. **Filippov**

Astronomy Reports, Volume 55, Number 6, 541-550, **2011**

Some possibilities for the reconnection of magnetic-field lines of solar filaments that approach when the photospheric polarity inversion lines change their positions, are discussed. The interaction between filaments depends on their internal properties, which are determined by the filament chirality, or the sign of the helicity of the filament magnetic field. In quadrupolar magnetic configurations, filaments with the same chirality can exchange their halves. Filaments with opposite chirality rupture after the reconnection of the polarity inversion lines, since the two fragments of the different filaments cannot be connected continuously. The morphology and connectivity of the filaments are analyzed using daily Hα filtergrams obtained over the period of maximum activity of the 23rd solar cycle. Examples of alterations of the filament connectivity occuring during the evolution of photospheric fields are presented.

Crossing Filaments

Boris **Filippov** and A. K. Srivastava

Solar Physics, Volume 270, Number 1, 151-164, **2011**

Solar filaments show the position of large-scale polarity-inversion lines and are used for the reconstruction of large-scale solar magnetic field structure on the basis of Hα synoptic charts for the periods that magnetographic measurements are not available. Sometimes crossing filaments are seen in Hα filtergrams. We analyze daily Hα filtergrams from the archive of Big Bear Solar Observatory for the period of 1999–2003 to find crossing and interacting filaments. A number of examples are presented and filament patterns are compared with photospheric magnetic field distributions. We have found that all crossing filaments reveal quadrupolar magnetic configurations of the photospheric field and presume the presence of null points in the corona.

Deflection of coronal rays by remote CMEs: shock wave or magnetic pressure?

Boris **Filippov**1 and A.K. Srivastava2

E-print, June **2010**, Solar Phys. (**2010**) 266: 123–134, **, File,** DOI 10.1007/s11207-010-9607-3

We analyze five events of the interaction of coronal mass ejections (CMEs) with the remote coronal rays located up to 90º away from the CME as observed by the SOHO/LASCO C2 coronagraph. Using sequences of SOHO/LASCO C2 images, we estimate the kink propagation in the coronal rays during their interaction with the corresponding CMEs ranging from 180 to 920 km s^{-1} within the interval of radial distances form 3 $R_{\odot}$ to 6 $R_{\odot}$. We conclude that all studied events do not correspond to the expected pattern of shock wave propagation in the corona. Coronal ray deflection can be interpreted as the influence of the magnetic field of a moving flux rope related to a CME. The motion of a large-scale flux rope away from the Sun creates changes in the structure of surrounding field lines, which are similar to the kink propagation along coronal rays. The retardation of the potential should be taken into account since the flux rope moves at high speed comparable with the Alfvén speed.

X-Ray Jet Dynamics in a Polar Coronal Hole Region

Boris **Filippov**, Leon Golub, Serge Koutchmy

Solar Physics, Volume 254 Number 2, Page: 259 – 269, **2009**
DOI: 10.1007/s11207-008-9305-6

New X-ray observations of the north polar region taken from the X-ray Telescope (XRT) of the *Hinode* spacecraft are used to analyze several time sequences showing small loop brightenings with a long ray above. We focus on the formation of the jet and discuss scenarios to explain the main features of the events: the relationship with the expected surface magnetism, the rapid and sudden radial motion, and possibly the heating, based on the assumption that the jet occurs above a null point of the coronal magnetic field. We conclude that 2-D reconnection models should be complemented in order to explain the observational details of these events and suggest that alternative scenarios may exist.

DIAGNOSTICS OF CORONAL HEATING IN ACTIVE-REGION LOOPS

A. **Fludra**1, C. Hornsey1,2, and V. M. Nakariakov
2017 ApJ 834 100
Understanding coronal heating remains a central problem in solar physics. Many mechanisms have been proposed to explain how energy is transferred to and deposited in the corona. We summarize past observational studies that attempted to identify the heating mechanism and point out the difficulties in reproducing the observations of the solar corona from the heating models. The aim of this paper is to study whether the observed extreme ultraviolet (EUV) emission in individual coronal loops in solar active regions can provide constraints on the volumetric heating function, and to develop a diagnostic for the heating function for a subset of loops that are found close to static thermal equilibrium. We reconstruct the coronal magnetic field from Solar Dynamics Observatory/HMI data using a nonlinear force-free magnetic field model. We model selected loops using a one-dimensional stationary model, with a heating rate dependent locally on the magnetic field strength along the loop, and we calculate the emission from these loops in various EUV wavelengths for different heating rates. We present a method to measure a power index β defining the dependence of the volumetric heating rate E H on the magnetic field, $E_H \propto B^\beta$, and controlling also the shape of the heating function: concentrated near the loop top, uniform and concentrated near the footpoints. The diagnostic is based on the dependence of the electron density on the index β. This method is free from the assumptions of the loop filling factor but requires spectroscopic measurements of the density-sensitive lines. The range of applicability for loops of different length and heating distributions is discussed, and the steps to solving the coronal heating problem are outlined.

Ultra-long-period Oscillations in EUV Filaments near to Eruption: Two-wavelength Correlation and Seismology

C. **Foullon** , E. Verwichte and V.M. Nakariakov
E-print, June **2009**; Astrophysical Journal, 700:1658–1665, **2009** August; **File**
We investigate whether or not ultra-long-period oscillations in EUV filaments can be related to their eruption. We report new observations of long-period (~ 10-30 h) oscillatory motions in an apparently quiescent filament as it crosses the solar disk, in a 12-minute-cadence SoHO/EIT 195? uninterrupted dataset. This dataset is chosen to explore characteristics of the filament oscillations depending on its eruptive behaviour, which is observed while the filament is still on the disk. The periods are found to increase in a near-stable regime prior to eruption. For the two sequences reported so far, we compare and link the EUV filament oscillations with pulsations in full-disk solar EUV irradiance from SoHO/CELIAS/SEM 304? flux measurements. In intervals with stationary periods, we find that the 304? pulsations and the 195? filament oscillations have similar periodicities, but are phase-shifted by about a quarter of period. The two-wavelength correlation serves to show that, when the filament is the dominant dynamical feature but can no longer be tracked on the disk, the full-disk irradiance may provide a mean to identify the period increase prior to the filament eruption. We use the periods thus obtained to estimate the height increase of filaments' suspending coronal magnetic field lines, based on a magnetohydrodynamical (MHD) wave interpretation of the oscillations. The results are consistent with changes in prominence heights detected off-limb and thus support the seismological tool employed. Other interpretations connected with thermal over-stability or MHD piston effect are possible. These theoretical predictions however do not explain the quarter-period shift between the two EUV-wavelength signals. In any case, the detected variations may provide a powerful diagnostic tool for the forecasting of prominence eruptions.

Analysis of Flows Inside Quiescent Prominences as Captured by Hinode/Solar Optical Telescope

M. S. **Freed**, D. E. McKenzie, D. W. Longcope, and M. Wilburn
ApJ **2016** 818 57
http://arxiv.org/pdf/1602.03821v1.pdf
Developing an understanding of how magnetic fields can become entangled in a prominence is important for predicting a possible eruption. This work investigates the kinetic energy and vorticity associated with plasma motion residing inside quiescent prominences. These plasma flow characteristics can be utilized to improve our understanding of how the prominence maintains a stable magnetic field configuration. Three different contrast-enhanced solar prominence observations from Hinode/Solar Optical Telescope were used to construct velocity maps -- in the plane of the sky -- via a Fourier local correlation tracking program. The resulting velocities were then used to perform the first ever analysis of the two-dimensional kinetic energy and enstrophy spectra of a prominence. Enstrophy is introduced here as a means of quantifying the vorticity which has been observed in many quiescent prominences. The kinetic energy power spectral density produced indices ranging from -1.00 to -1.60. There was a consistent anisotropy in the kinetic energy spectrum of all three prominences examined. Examination of the intensity power spectral density reveals a different scaling relationship exists between the observed prominence structure and velocity maps. All of the prominences exhibited an inertial range of at least 0.8 \leq k\leq 2.0\; \textrm{rads} \: \textrm{Mm}-1. Quasi-periodic oscillations were also detected in the centroid of the velocity distributions for one prominence. Additionally, a lower limit was placed on the kinetic energy density (\epsilon \, \sim 0.22-7.04\:

\mathrm{km}2\textrm{s}-2) and enstrophy density (\omega \, \sim 1.43-13.69\: x 10-16 \, \textrm{s}-2) associated with each prominence. **2006/11/30, 2007/04/25, 2007/10/03**

Multi-scale observations of thermal non-equilibrium cycles in coronal loops

C. **Froment**, P. Antolin, V. M. J. Henriques, P. Kohutova, L. H. M. Rouppe van der Voort

A&A 633, A11 **2020**

https://arxiv.org/pdf/1911.09710.pdf

https://doi.org/10.1051/0004-6361/201936717

Thermal non-equilibrium (TNE) is a phenomenon that can occur in solar coronal loops when the heating is quasi-constant and highly-stratified. Under such heating conditions, coronal loops undergo cycles of evaporation and condensation. The recent observations of ubiquitous long-period intensity pulsations in coronal loops and their relationship with coronal rain have demonstrated that understanding the characteristics of TNE cycles is an essential step in constraining the circulation of mass and energy in the corona. We report unique observations with the Solar Dynamics Observatory (SDO) and the Swedish 1-m Solar Telescope (SST) that link the captured thermal properties across the extreme spatiotemporal scales covered by TNE processes. Within the same coronal loop bundle, we captured 6 hr period coronal intensity pulsations in SDO/AIA and coronal rain observed off-limb in the chromospheric Halpha and Ca II K spectral lines with SST/CRISP and SST/CHROMIS. We combined a multi-thermal analysis of the cycles with AIA and an extensive spectral characterisation of the rain clumps with the SST. We find clear evidence of evaporation-condensation cycles in the corona which are linked with periodic coronal rain showers. The high-resolution spectroscopic instruments at the SST reveal the fine-structured rain strands and allow us to probe the cooling phase of one of the cycles down to chromospheric temperatures. These observations reinforce the link between long-period intensity pulsations and coronal rain. They also demonstrate the capability of TNE to shape the dynamics of active regions on the large scales as well as on the smallest scales currently resolvable. **August 29, 2017**

On the occurrence of thermal non-equilibrium in coronal loops

C. **Froment**, F. Auchère, Z. Mikić, G. Aulanier, K. Bocchialini, E. Buchlin, J. Solomon, E. Soubrié

ApJ 855:52 **2018**

https://arxiv.org/pdf/1802.04010.pdf

http://iopscience.iop.org/article/10.3847/1538-4357/aaaf1d/pdf

Long-period EUV pulsations, recently discovered to be common in active regions, are understood to be the coronal manifestation of thermal non-equilibrium (TNE). The active regions previously studied with EIT/SOHO and AIA/SDO indicated that long-period intensity pulsations are localized in only one or two loop bundles. The basic idea of this study is to understand why. For this purpose, we tested the response of different loop systems, using different magnetic configurations, to different stratifications and strengths of the heating. We present an extensive parameter-space study using 1D hydrodynamic simulations (1,020 in total) and conclude that the occurrence of TNE requires specific combinations of parameters. Our study shows that the TNE cycles are confined to specific ranges in parameter space. This naturally explains why only some loops undergo constant periodic pulsations over several days: since the loop geometry and the heating properties generally vary from one loop to another in an active region, only the ones in which these parameters are compatible exhibits TNE cycles. Furthermore, these parameters (heating and geometry) are likely to vary significantly over the duration of a cycle, which potentially limits the possibilities of periodic behavior. This study also confirms that long-period intensity pulsations and coronal rain are two aspects of the same phenomenon: both phenomena can occur for similar heating conditions and can appear simultaneously in the simulations. **June 05-08, 2012**

Long-Period Intensity Pulsations in Coronal Loops Explained by Thermal Non-Equilibrium Cycles

Clara **Froment**, Frédéric Auchère, Guillaume Aulanier, Zoran Mikić, Karine Bocchialini, Eric Buchlin,Jacques Solomon

ApJ 835 272 **2017**

https://arxiv.org/pdf/1701.01309v1.pdf

In solar coronal loops, thermal non-equilibrium (TNE) is a phenomenon that can occur when the heating is both highly-stratified and quasi-constant. Unambiguous observational identification of TNE would thus permit to strongly constrain heating scenarios. Up to now, while TNE is the standard interpretation of coronal rain, the long-term periodic evolution predicted by simulations has never been observed yet. However, the detection of long-period intensity pulsations (periods of several hours) has been recently reported with SoHO/EIT, and this phenomenon appears to be very common in loops. Moreover, the three intensity-pulsation events that we recently studied with SDO/AIA show strong evidence for TNE in warm loops. In the present paper, a realistic loop geometry from LFFF extrapolations is used as input to 1D hydrodynamic simulations. Our simulations show that for the present loop geometry, the heating has to be asymmetrical to produce TNE. We analyse in detail one particular simulation that reproduces the average thermal behavior of one of the pulsating loop bundle observed with AIA. We compare the properties of this simulation with the properties deduced from the observations. The magnetic topology of the LFFF extrapolations points to the presence of sites of preferred reconnection at one footpoint, supporting the presence of asymmetric heating. In addition, we can reproduce the temporal large-scale intensity properties of the pulsating loops. This simulation further strengthens the interpretation of the observed pulsations as signatures of TNE. This thus gives important information on the heating localization and time scale for these loops.

Evidence for evaporation-incomplete condensation cycles in warm solar coronal loops

Clara **Froment**, Frédéric Auchère, Karine Bocchialini, Eric Buchlin, Chloé Guennou, Jacques Solomon

ApJ **807** 158 **2015**

http://arxiv.org/pdf/1504.08129v1.pdf

Quasi-constant heating at the footpoints of loops leads to evaporation and condensation cycles of the plasma: thermal non-equilibrium (TNE). This phenomenon is believed to play a role in the formation of prominences and coronal rain. However, it is often discarded to be involved in the heating of warm loops as the models do not reproduce observations. Recent simulations have shown that these inconsistencies with observations may be due to oversimplifications of the geometries of the models. In addition, our recent observations reveal that long-period intensity pulsations (several hours) are common in solar coronal loops. These periods are consistent with those expected from TNE. The aim of this paper is to derive characteristic physical properties of the plasma for some of these events to test the potential role of TNE in loop heating. We analyzed three events in detail using the six EUV coronal channels of SDO/AIA. We performed both a Differential Emission Measure (DEM) and a time-lag analysis, including a new method to isolate the relevant signal from the foreground and background emission. For the three events, the DEM undergoes long-period pulsations, which is a signature of periodic heating even though the loops are captured in their cooling phase, as is the bulk of the active regions. We link long-period intensity pulsations to new signatures of loop heating with strong evidence for evaporation and condensation cycles. We thus witness simultaneously widespread cooling and TNE. Finally, we discuss the implications of our new observations for both static and impulsive heating models. **August 09, 2011, June 07, 2012, December 30, 2012**

Automatic Detection of Prominence Eruption Using Consecutive Solar Images

Gang **Fu**, Frank Y. Shih and Haimin Wang

http://solar.njit.edu/preprints/fu1318.pdf

OBSERVING THE UNOBSERVABLE? MODELING CORONAL CAVITY DENSITIES

J. **Fuller**,1 S. E. Gibson,2 G. de Toma,2 and Y. Fan

The Astrophysical Journal, 678:515Y530, 2008

http://www.journals.uchicago.edu/doi/pdf/10.1086/533527

Prominence cavities in coronal helmet streamers are readily detectable in white-light coronagraph images, yet their interpretation may be complicated by projection effects. In order to determine a cavity's density structure, it is essential to quantify the contribution of noncavity features along the line of sight.We model the coronal cavity as an axisymmetric torus that encircles the Sun at constant latitude and fit it to observations of a white-light cavity observed by the Mauna Loa Solar Observatory (MLSO) MK4 coronagraph from 2006 January 25 to 30. We demonstrate that spurious noncavity contributions (including departures from axisymmetry) are minimal enough to be incorporated in a density analysis as conservatively estimated uncertainties in the data. We calculate a radial density profile for cavity material and for the surrounding helmet streamer (which we refer to as the ''cavity rim'') and find that the cavity density is depleted by a maximumof 40%compared to the surrounding helmet streamer at lowaltitudes (1.18R_) but is consistently higher (double or more) than in coronal holes.We also find that the relative density depletion between cavity and surrounding helmet decreases as a function of height.We show that both increased temperature in the cavity relative to the surrounding helmet streamer and a magnetic flux rope configurationmight lead to such a flattened density profile. Finally, our model provides general observational guidelines that can be used to determine when a cavity is sufficiently unobstructed to be a good candidate for plasma diagnostics.

Development of Flux Imbalances in Solar Activity Nests and the Evolution of Filament Channels

V. **Gaizauskas**

The Astrophysical Journal, Vol. 686, No. 2

http://www.journals.uchicago.edu/doi/abs/10.1086/591633

Resonant absorption as a damping mechanism for the transverse oscillations of the coronal loops observed by SDO/AIA

Javad **Ganjali**, Nastaran Farhang, Shahriar Esmaeili, Mohsen Javaherian, Hossein Safari

2019

https://arxiv.org/pdf/1902.09649.pdf

Solar coronal loops represent the variety of fast, intermediate, and slow normal mode oscillations. In this study, the transverse oscillations of the loops with a few-minutes period and also with damping caused by the resonant absorption were analyzed using extreme ultraviolet (EUV) images of the Sun. We employed the 171 $\AA$ data recorded by Solar Dynamic Observatory (SDO)/Atmospheric Imaging Assembly (AIA) to analyze the parameters of coronal loop oscillations such as period, damping time, loop length, and loop width. For the loop observed on **11 October 2013**, the period and the damping of this loop are obtained to be 19 and 70 minutes, respectively. The damping quality, the ratio of the damping time to the period, is computed about 3.6. The period and damping time for the extracted loop recorded on **22 January 2013** are about 81 and 6.79 minutes, respectively. The damping quality is also computed as 12. It can be concluded that the damping of the transverse oscillations of the loops is in the strong damping regime, so resonant absorption would be the main reason for the damping.

Determining the 3D Structure of the Corona Using Vertical Height Constraints on Observed Active Region Loops

G. Allen **Gary**, Qiang Hu, Jong Kwan Lee, Markus J. Aschwanden

Solar Phys., Volume 289, Issue 10, pp 3703-3721, **2014**

The corona associated with an active region is structured by high-temperature, magnetically dominated closed and open loops. The projected 2D geometry of these loops is captured in EUV filtergrams. In this study using SDO/AIA 171 Å filtergrams, we expand our previous method to derive the 3D structure of these loops, independent of heliostereoscopy. We employ an automated loop recognition scheme (Occult-2) and fit the extracted loops with 2D cubic Bézier splines. Utilizing SDO/HMI magnetograms, we extrapolate the magnetic field to obtain simple field models within a rectangular cuboid. Using these models, we minimize the misalignment angle with respect to Bézier control points to extend the splines to 3D (Gary, Hu, and Lee 2014). The derived Bézier control points give the 3D structure of the fitted loops. We demonstrate the process by deriving the position of 3D coronal loops in three active regions (AR 11117, AR 11158, and AR 11283). The numerical minimization process converges and produces 3D curves which are consistent with the height of the loop structures when the active region is seen on the limb. From this we conclude that the method can be important in both determining estimates of the 3D magnetic field structure and determining the best magnetic model among competing advanced magnetohydrodynamics or force-free magnetic-field computer simulations.

Detection of decayless oscillations in solar transition region loops L4

Yuhang **Gao**, Zhenyong Hou, Tom Van Doorsselaere and Mingzhe Guo

A&A Letter Volume 681, January **2024**

https://doi.org/10.1051/0004-6361/202348702

https://www.aanda.org/articles/aa/pdf/2024/01/aa48702-23.pdf

Context. Decayless kink oscillations have been frequently observed in coronal loops, serving as a valuable diagnostic tool for the coronal magnetic field. Such oscillations have never before been reported in low-lying loops of the transition region (TR).

Aims. The aim of this study is to detect decayless kink oscillations in TR loops for the first time.

Methods. We used the SI IV 1400 Å imaging data obtained from the Interface Region Imaging Spectrograph. We applied the Multiscale Gaussian Normalization method to highlight the TR loops, and generated time–distance maps to analyse the oscillation signals.

Results. Seven oscillation events detected here exhibit a small but sustained displacement amplitude (0.04–0.10 Mm) for more than three cycles. Their periods range from 3 to 5 min. The phase speed is found to increase with loop length, which is consistent with the decrease in Alfvén speed with height. With these newly detected oscillations, we obtain a rough estimate of the magnetic field in the transition region, which is about 5–10 G.

Conclusions. Our results further reveal the ubiquity of decayless kink oscillations in the solar atmosphere. These oscillations in TR loops have the potential to be a diagnostic tool for the TR magnetic field. **2013/09/24, 2013/09/25&26, 2013/10/25, 2013/11/07, 2013/12/27**

Energy Loss of Solar p Modes due to the excitation of Magnetic Sausage Tube Waves: Importance of Coupling the Upper Atmosphere

Andrew **Gascoyne**, Rekha Jain, Bradley Hindman

2014

http://arxiv.org/pdf/1405.0130v1.pdf

We consider damping and absorption of solar p modes due to their energy loss to magnetic tube waves that can freely carry energy out of the acoustic cavity. The coupling of p modes and sausage tube waves is studied in a model atmosphere composed of a polytropic interior above which lies an isothermal upper atmosphere. The sausage tube waves, excited by p modes, propagate along a magnetic fibril which is assumed to be a vertically aligned, stratified, thin magnetic flux-tube. The deficit of p-mode energy is quantified through the damping rate, Γ and absorption coefficient, α. The variation of Γ and α as a function of frequency and the tube's plasma properties is studied in detail. Previous similar studies have considered only a subphotospheric layer, modelled as a polytrope that has been truncated at the photosphere (Bogdan et al. (1996), Hindman & Jain 2008, Gascoyne et al. (2011)). Such studies have found that the resulting energy loss by the p modes is very sensitive to the upper boundary condition, which because of the lack of a upper atmosphere have been imposed in a somewhat ad hoc manner. The model presented here avoids such problems by using an isothermal layer to model the overlying atmosphere (chromosphere), and consequently, allows us to analyse the propagation of p-mode driven sausage waves above the photosphere. In this paper we restrict our attention to frequencies below the acoustic cut-off frequency. We demonstrate the importance of coupling all waves (acoustic, magnetic) in the subsurface solar atmosphere with the overlying atmosphere in order to accurately model the interaction of solar f and p modes with sausage tube waves.

Magnetic Complexity in Eruptive Solar Active Regions and Associated Eruption Parameters

Manolis K. **Georgoulis**

E-print Dec 2007, GRL

Using an efficient magnetic complexity index in the active-region solar photosphere, we quantify the preflare strength of the photospheric magnetic polarity inversion lines in 23 eruptive active regions with flare/CME/ICME events tracked all the way from the Sun to the Earth. We find that active regions with more intense polarity inversion lines host statistically stronger flares and faster, more impulsively accelerated, CMEs. No significant correlation is found between the strength of the inversion lines and the flare soft X-ray rise times, the ICME transit times, and the peak *Dst* indices of the induced geomagnetic storms. Corroborating these and previous results, we speculate on a possible interpretation for the connection between source active regions, flares, and CMEs. Further work is needed to validate this concept and uncover its physical details.

Concurrent Kink and Sausage Waves in A Crescent Shaped Structure Over A Limb Prominence

Maryam **Ghiasi**, Neda Dadashi, Hossein Ebadi

MNRAS **2023**

https://arxiv.org/ftp/arxiv/papers/2311/2311.09981.pdf

A Crescent shaped prominence Structure (CS), over the solar west limb is studied using EIS/HINODE and AIA/SDO. First, the time varying positions of the top and below borders of the CS, along with its central axis are derived. Time evolutions of the Doppler shifts, and Line width of Fe~{\scriptsize \rm XII} 195.119 line are studied over the CS borders. Transverse kink oscillations are observed both in the Solar-Y direction and in the Doppler shifts over the observers' LOS. One explanation could be the oscillatory direction of the main kink wave build an angle with the observers LOS. This angle is calculated to be equal to 27 degrees for the CS top border. The main kink amplitude velocity and periods are obtained to be 5.3 km/s, and 33.4 minutes, respectively. The anti-correlation observed between the brightness and thickness of the CS (with -178.1∘) suggests the presence of sausage modes with periods of 20.8 minutes. Based on the AIA imaging, it is suggested that the occurred jets and their afterward dimming are responsible to trigger the sausage mode. The average electron densities of the CS over the time of the study is obtained to be log(ne)=9.3[cm−3]. The Alfvén velocity, magnetic field, and energy flux of the observed fast kink mode over the CS are estimated to be 16.7 km/s, 2.79 G, 41.93 W/m2. Considering the magnetic flux conservation inside the CS, expanding the CS cross section, causes the magnetic field to decay with the rate of 4.95×10−4G/sec. **3rd April 2014**

Formation and Dynamics of Transequatorial Loops

Avyarthana **Ghosh**, Durgesh Tripathi

A&A 640, A3 **2020**

https://arxiv.org/pdf/2005.12839.pdf

https://www.aanda.org/articles/aa/pdf/2020/08/aa36681-19.pdf

To study the dynamical evolution of trans-equatorial loops (TELs) using imaging and spectroscopy. We have used the images recorded by the Atmospheric Imaging Assembly and the Helioseismic Magnetic Imager on-board the Solar Dynamics Observatory and spectroscopic observations taken from the Extreme-Ultraviolet Imaging Spectrometer on-board Hinode. The data from AIA 193 Å channel show that TELs are formed between AR 12230 and a newly emerging AR 12234 and evolved during **December 10-14, 2014**. The xt-plots for December 12, 2014 obtained using AIA 193 Å data reveal signatures of inflow and outflow towards an X-region. High cadence AIA images also show recurrent intensity enhancements in close proximity to the X-region (P2), which is observed to have higher intensities for spectral lines formed at log T[K] =6.20 and voids at other higher temperatures. The electron densities and temperatures in the X-region (and P2) are maintained steadily at log N_e =8.5-8.7 /cc and log T[K] =6.20, respectively. Doppler velocities in the X-region show predominant redshifts by about 5-8 km/s when closer to the disk centre but blueshifts (along with some zero-velocity pixels) when away from the centre. The Full-Width-Half-Maxima (FWHM) maps reveal non-thermal velocities of about 27-30 km/s for Fe XII, Fe XIII and Fe XV lines. However, the brightest pixels have non-thermal velocities of about 62 km/s for Fe XII and Fe XIII lines. On the contrary, the dark X-region for Fe XV line have the highest non-thermal velocity (roughly 115 km/s). We conclude that the TELs are formed due to magnetic reconnection. We further note that the TELs themselves undergo magnetic reconnection leading to reformation of loops of individual ARs. Moreover, this study, for the first time, provides measurements of plasma parameters in X-regions thereby providing essential constraints for theoretical studies.

Fan Loops Observed by IRIS, EIS, and AIA

Avyarthana **Ghosh**1,2, Durgesh Tripathi1, G. R. Gupta1, Vanessa Polito3, Helen E. Mason3, and Sami K. Solanki4,

2017 ApJ 835 244

A comprehensive study of the physical parameters of active region fan loops is presented using the observations recorded with the Interface Region Imaging Spectrometer (IRIS), the EUV Imaging Spectrometer (EIS) on board Hinode, and the Atmospheric Imaging Assembly (AIA) and the Helioseismic and Magnetic Imager (HMI) on board the Solar Dynamics Observatory (SDO). The fan loops emerging from non-flaring AR 11899 (near the disk center) on **2013 November 19** are clearly discernible in AIA 171 Å images and in those obtained in Fe viii and Si vii images using EIS. Our measurements of electron densities reveal that the footpoints of these loops are at an approximately constant pressure with electron densities of cm−3 at (O iv), and cm−3 at (Si x). The electron temperature diagnosed across the fan loops by means of EM-Loci suggest that two temperature components exist at and 5.95 at the footpoints. These components are picked up by IRIS lines and EIS lines, respectively. At higher heights, the loops are nearly isothermal at , which remained constant along the loop. The measurement of the Doppler shift using IRIS lines suggests that the plasma at the footpoints of these loops is predominantly redshifted by 2–3 km s−1 in C ii, 10–15 km s−1 in Si iv, and 15–20 km s−1 in O iv, reflecting the increase in the speed of downflows with increasing temperature from to 5.15. These observations can be explained by low-frequency nanoflares or impulsive heating, and provide further important constraints on the modeling of the dynamics of fan loops.

Solar Prominences: Theory and Models. Fleshing Out the Magnetic Skeleton **Review**

Gibson, S. E.

Living Rev Sol Phys (**2018**) 15: 7

https://link.springer.com/content/pdf/10.1007%2Fs41116-018-0016-2.pdf

Magnetic fields suspend the relatively cool material of solar prominences in an otherwise hot corona. A comprehensive understanding of solar prominences ultimately requires complex and dynamic models, constrained and validated by observations spanning the solar atmosphere. We obtain the core of this understanding from observations that give us information about the structure of the "magnetic skeleton" that supports and surrounds the prominence. Energetically-sophisticated magnetohydrodynamic simulations then add flesh and blood to the skeleton, demonstrating how a thermally varying plasma may pulse through to form the prominence, and how the plasma and magnetic fields dynamically interact.

Coronal cavities: observations and implications for the magnetic environment of prominences **Review**

Sarah E. **Gibson**

Solar Prominences, Astrophysics and Space Science Library, Volume 415. ISBN 978-3-319-10415-7. Springer International Publishing Switzerland, **2015**, p. 323

https://arxiv.org/pdf/1702.02214.pdf

https://arxiv.org/pdf/1702.02214.pdf

Dark and elliptical, coronal cavities yield important clues to the magnetic structures that cradle prominences, and to the forces that ultimately lead to their eruption. We review observational analyses of cavity morphology, thermal properties (density and temperature), line-of-sight and plane-of-sky flows, substructure including hot cores and central voids, linear polarization signatures, and observational precursors and predictors of eruption. We discuss a magnetohydrodynamic interpretation of these observations which argues that the cavity is a magnetic flux rope, and pose a set of open questions for further study. **July 22 2002, 16 June 2011, March 11-12, 2012, 16 May 2012, 23 July 2012,**

THREE-DIMENSIONAL MORPHOLOGY OF A CORONAL PROMINENCE CAVITY

S. E. **Gibson**1, T. A. Kucera2, D. Rastawicki3, J. Dove4, G. de Toma1, J. Hao5, S. Hill6, H. S. Hudson7, C. Marqu´e8, P. S. McIntosh9, L. Rachmeler1, K. K. Reeves10, B. Schmieder11, D. J. Schmit12, D. B. Seaton8, A. C. Sterling13,16, D. Tripathi14, D. R. Williams15, and M. Zhang5

Astrophysical Journal, 724:1133–1146, **2010**

We present a three-dimensional density model of coronal prominence cavities, and a morphological fit that has been tightly constrained by a uniquely well-observed cavity. Observations were obtained as part of an International Heliophysical Year campaign by instruments from a variety of space- and ground-based observatories, spanning wavelengths from radio to soft X-ray to integrated white light. From these data it is clear that the prominence cavity is the limb manifestation of a longitudinally extended polar-crown filament channel, and that the cavity is a region of low density relative to the surrounding corona. As a first step toward quantifying density and temperature from campaign spectroscopic data, we establish the three-dimensional morphology of the cavity. This is critical for taking line-of-sight projection effects into account, since cavities are not localized in the plane of the sky and the corona is optically thin. We have augmented a global coronal streamer model to include a tunnel-like cavity with elliptical cross-section and a Gaussian variation of height along the tunnel length. We have developed a semi-automated routine that fits ellipses to cross-sections of the cavity as it rotates past the solar limb, and have applied it to Extreme Ultraviolet Imager observations from the two *Solar Terrestrial Relations Observatory* spacecraft. This defines themorphological parameters of our model, fromwhich we reproduce forward modeled cavity observables. We find that cavity morphology and orientation, in combination with the viewpoints of the observing spacecraft, explain the observed variation in cavity visibility for the east versus west limbs.

Coronal prominence structure and dynamics: A magnetic flux rope interpretation

Gibson, S. E.; Fan, Y.

J. Geophys. Res., Vol. 111, No. A12, A12103, **2006**, **File**

The solar prominence is an example of a space physics phenomenon that can be modeled as a twisted magnetic flux tube or magnetic flux ‘‘rope.’’ In such models the prominence is one observable part of a larger magnetic structure capable of storing magnetic energy to drive eruptions. We show how a flux rope model explains a range of observations of prominences and associated structures such as cavities and soft X-ray sigmoids and discuss in particular the observational and dynamic consequences of three-dimensional reconnections in and around the evolving magnetic flux rope. We demonstrate that the flux rope model can describe the prominence’s preeruption structure and dynamics, loss of equilibrium, and behavior during and after an eruption in which part of the flux rope is expelled from the corona.

THE CALM BEFORE THE STORM: THE LINK BETWEEN QUIESCENT CAVITIES AND CORONAL MASS EJECTIONS

S. E. **Gibson**,1 D. Foster,2 J. Burkepile,1 G. de Toma,1 and A. Stanger

The Astrophysical Journal, 641:590–605, **2006, File**

Resonantly damped oscillations of a system of two coronal loops

S. E. **Gijsen** and T. Van Doorsselaere

A&A 562, A38 (**2014**)

Context. Rapidly damped transverse oscillations of coronal loop systems are often observed.
Aims. We aim to study analytically the resonantly damped oscillations of a system of two not necessarily identical coronal loops and their dependence on the equilibrium parameters, improving on and extending the results for two identical coronal loops.
Methods. The linearised magnetohydrodynamic equations for a cold plasma were solved in the long-wavelength limit and for thin boundary layers in bicylindrical coordinates. We investigated the effects of the density contrast between the two loops, the thickness of their inhomogeneous layers, and the separation distance between them. The complex spectrum was also studied.
Results. We obtained more general expressions for the linear damping rate of the transverse oscillations in a system of two coronal loops. The results can be reduced to expressions found previously for the special cases of one vanishing loop or two identical loops. The interaction between the loops results in a stronger damping of the high-

frequency eigenoscillation in comparison with that of the low-frequency eigenoscillation. By decreasing the distance between loops, the efficiency of resonant damping is reduced.

Energy release from impacting prominence material following the 2011 June 7 eruption

H. R. **Gilbert**, A. R. Inglis, M. L. Mays, L. Ofman, B. J. Thompson, C. A. Young

E-print, Sept **2013**; ApJL

Solar filaments exhibit a range of eruptive-like dynamic activity, ranging from the full or partial eruption of the filament mass and surrounding magnetic structure as a coronal mass ejection (CME), to a fully confined or 'failed' eruption. On **2011 June 7**, a dramatic partial eruption of a filament was observed by multiple instruments on SDO and STEREO. One of the interesting aspects of this event is the response of the solar atmosphere as non-escaping material falls inward under the influence of gravity. The impact sites show clear evidence of brightening in the observed EUV wavelengths due to energy release. Two plausible physical mechanisms explaining the brightening are considered: heating of the plasma due to the kinetic energy of impacting material compressing the plasma, or reconnection between the magnetic field of low-lying loops and the field carried by the impacting material. By analyzing the emission of the brightenings in several SDO/AIA wavelengths, and comparing the kinetic energy of the impacting material (7.6 x 10^26 - 5.8 x 10^27 ergs) to the radiative energy (1.9 x 10^25 - 2.5 x 10^26 ergs) we find the dominant mechanism of energy release involved in the observed brightening is plasma compression.

COMPARING SPATIAL DISTRIBUTIONS OF SOLAR PROMINENCE MASS DERIVED FROM CORONAL ABSORPTION

Holly **Gilbert**[1], Gary Kilper[1], David Alexander[2], and Therese Kucera[1]

Astrophysical Journal, 727:25 (12pp), **2011, File**

In a previous study, Gilbert et al. derived the column density and total mass of solar prominences using a new technique, whichmeasures howmuch coronal radiation in the Fe xii (195 Å) spectral band is absorbed by prominence material, while considering the effects of both foreground and background radiation. In the present work, we apply this method to a sample of prominence observations in three different wavelength regimes: one in which only H0 is ionized (504 Å < λ < 911 Å), a second where both H0 and He0 are ionized (228 Å < λ < 504 Å), and finally at wavelengths where H0, He0, and He+ are all ionized (λ < 228 Å). This approach, first suggested by Kucera et al., permits the separation of the contributions of neutral hydrogen and helium to the total column density in prominences. Additionally, an enhancement of the technique allowed the calculation of the two-dimensional (2D) spatial distribution of the column density from the continuum absorption in each extreme-ultraviolet observation. We find the total prominence mass is consistently lower in the 625 Å observations compared to lines in the other wavelength regimes. There is a significant difference in total mass between the 625 Å and 195 Å lines, indicating the much higher opacity at 625 Å is causing a saturation of the continuum absorption and thus, a potentially large underestimation of mass.

Filament Kinking and Its Implications for Eruption and Re-formation

Gilbert, H.R., Alexander, D., Liu, R.:

2007, *Solar Phys.* **245**, 287.

Solar filaments exhibit a range of eruptive-like dynamic activity from the full, or partial, eruption of the filament mass and surrounding magnetic structure, as a CME, to a fully confined dynamic evolution or “failed” eruption, sometimes producing a flare but no CME. Additionally, observations of erupting filaments often show a clear helical structure, indicating the presence of a magnetic flux rope. Dynamic helical structures, in addition to being twisted, frequently show evidence of being kinked, with the axis of the flux rope exhibiting a large-scale writhe. Motivated by the fact that kinking motions are also detected in filaments that fail to erupt, we investigate the possible relationship between the kinking of a filament and its success or failure to erupt. We present an analysis of kinking in filaments and its implications for other filament phenomena such as the nature of the eruption, eruptive acceleration, and post-eruptive re-formation. We elucidate the relationship between kinking and the various filament phenomena via a simple physical picture of the forces involved in kinking together with specific definitions of the types of filament eruption. The present study offers results directly applicable to observations, allowing a thorough exploration of the implications of the observational relationship between kinking and filament phenomena and provides new insight for modelers of CME initiation.

Filament Kinking and Its Implications for Eruption and Re-formation

Holly R. **Gilbert** · David Alexander · Rui Liu

Solar Phys (**2007**) 245: 287–309, **File**

http://www.springerlink.com/content/6u4k147176320j46/fulltext.pdf

Solar filaments exhibit a range of eruptive-like dynamic activity from the full, or partial, eruption of the filament mass and surrounding magnetic structure, as a CME, to a fully confined dynamic evolution or “failed” eruption, sometimes producing a flare but no CME. Additionally, observations of erupting filaments often show a clear helical structure, indicating the presence of a magnetic flux rope. Dynamic helical structures, in addition to being twisted, frequently show evidence of being kinked, with the axis of the flux rope exhibiting a large-scale writhe. Motivated by the fact that kinking motions are also detected in filaments that fail to erupt, we investigate the possible relationship between the kinking of a filament and its success or failure to erupt. We present an analysis of kinking in filaments and its implications for other filament phenomena such as the nature of the eruption, eruptive acceleration, and post-eruptive re-formation. We elucidate the relationship between kinking and the various filament phenomena via a simple physical picture of the forces involved in kinking together with specific definitions of the types of filament eruption. The present study offers results directly applicable to observations, allowing a thorough exploration of the implications of the observational relationship between kinking and filament phenomena and provides new insight for modelers of CME initiation.

OBSERVATIONAL EVIDENCE SUPPORTING CROSS-FIELD DIFFUSION OF NEUTRAL MATERIAL IN SOLAR FILAMENTS

Holly **Gilbert**, Gary Kilper, and David Alexander

The Astrophysical Journal, 671:978Y 989, **2007** December 10

http://www.journals.uchicago.edu/doi/pdf/10.1086/522884

We investigate the temporal and spatial variation of the relative abundance of He to H in a sample of solar filaments by comparing cotemporal observations of H_ and He i k10830 obtained at MLSO.Motivated by indications that cross-field diffusion of neutral filament material is an important mechanism in mass loss, the present study offers results that provide a convincing test of the mechanisms proposed in Gilbert and coworkers. Specifically, when observed across an entire disk passage, we find a majority of stable, quiescent filaments show a relative helium deficit in the upper portions of their structure coupled with a relative helium surplus in the lower regions, a consequence of the large loss timescale for neutral helium compared to neutral hydrogen.Moreover, we find that the variation of the relative He/H ratio is uniform across filament barbs and footpoints on both short and long timescales.

3D Reconstruction from SECCHI-EUVI Images Using an Optical-Flow Algorithm: Method Description and Observation of an Erupting Filament

S.F. **Gissot** · J.-F. Hochedez · P. Chainais · J.-P. Antoine

Solar Phys (**2008**) 252: 397–408, **File**

http://www.springerlink.com/content/w680q280063r165q/fulltext.pdf

SECCHI-EUVI telescopes provide the first EUV images enabling a 3D reconstruction of solar coronal structures.We present a stereoscopic reconstruction method based on the *Velociraptor* algorithm, a multiscale optical-flow method that estimates displacement maps in sequences of EUV images. Following earlier calibration on sequences of SOHOEIT data, we apply the algorithm to retrieve depth information from the two STEREO viewpoints using the SECCHI-EUVI telescope. We first establish a simple reconstruction formula that gives the radial distance to the centre of the Sun of a point identified both in EUVI-A and EUVI-B from the separation angle and the displacement map. We select pairs of images taken in the 30.4 nm passband of EUVI-A and EUVI-B, and apply a rigid transform from the EUVI-B image in order to set both images in the same frame of reference. The optical flow computation provides displacement maps from which we reconstruct a dense map of depths using the stereoscopic reconstruction formula. Finally, we discuss the estimation of the height of an erupting filament.

Temporal evolution of oscillating coronal loops

C. R. **Goddard**, G. Nisticò

A&A 638, A89 **2020**

https://arxiv.org/pdf/2004.14725.pdf

https://www.aanda.org/articles/aa/pdf/2020/06/aa37467-20.pdf

Context. Transverse oscillations of coronal structures are currently intensively studied to explore the associated magnetohydrodynamic wave physics and perform seismology of the local medium. Aims. We make a first attempt to measure the thermodynamic evolution of a sample of coronal loops that undergo decaying kink oscillations in response to an eruption in the corresponding active region. Methods. Using data from the six coronal wavelengths of SDO/AIA, we performed a differential emission measure (DEM) analysis of 15 coronal loops before, during, and after the eruption and oscillation. Results. We find that the emission measure, temperature, and width of the DEM distribution undergo significant variations on time scales relevant for the study of transverse oscillations. There are no clear collective trends of increases or decreases for the parameters we analysed. The strongest variations of the parameters occur during the initial perturbation of the loops, and the influence of background structures may also account for much of this variation. Conclusions. The DEM analysis of oscillating coronal loops in erupting active regions shows evidence of evolution on time scales important for the study of the oscillations. Further work is needed to separate the various observational and physical mechanisms that may be responsible for the variations in temperature, DEM distribution width, and total emission measure.

Evolution of the transverse density structure of oscillating coronal loops inferred by forward modelling of EUV intensity

Christopher Rhys **Goddard**, Patrick Antolin, David James Pascoe

ApJ **863** 167 **2018**

https://arxiv.org/pdf/1808.03476.pdf

http://iopscience.iop.org/article/10.3847/1538-4357/aad3cc/pdf

Recent developments in the observation and modelling of kink oscillations of coronal loops have led to heightened interest over the last few years. The modification of the Transverse Density Profile (TDP) of oscillating coronal loops by non-linear effects, in particular the Kelvin-Helmholtz Instability (KHI), is investigated. How this evolution may be detected is established, in particular, when the KHI vortices may not be observed directly. A model for the loop's TDP is used which includes a finite inhomogeneous layer and homogeneous core, with a linear transition between them. The evolution of the loop's transverse intensity profile from numerical simulations of kink oscillations is analysed. Bayesian inference and forward modelling techniques are applied to infer the evolution of the TDP from the intensity profiles, in a manner which may be applied to observations. The strongest observational evidence for the development of the KHI is found to be a widening of the loop's inhomogeneous layer, which may be inferred for sufficiently well resolved loops, i.e > 15 data points across the loop. The main signatures when observing the core of the loop (for this specific loop model) during the oscillation are: a widening inhomogeneous layer, decreasing intensity, an unchanged radius, and visible fine transverse structuring when the resolution is sufficient. The appearance of these signatures are delayed for loops with wider inhomogeneous layers, and quicker for loops oscillating at higher amplitudes. These cases should also result in stronger observational signatures, with visible transverse structuring appearing for wide loops observed at SDO/AIA resolution.

A statistical study of the inferred transverse density profile of coronal loop threads observed with SDO/AIA

C. R. **Goddard** , D. J. Pascoe , S. Anfinogentov, and V. M. Nakariakov

A&A 605, A65 **2017**

http://www2.warwick.ac.uk/fac/sci/physics/research/cfsa/people/goddard/density_prof_accepted.pdf

Aims. We carry out a statistical study of the inferred coronal loop cross-sectional density profiles using extreme ultraviolet (EUV) imaging data from the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO). Methods. We analysed 233 coronal loops observed during 2015/2016. We consider three models for the density profile; the step function (model S), the linear transition region profile (model L), and a Gaussian profile (model G). Bayesian inference is used to compare the three corresponding forward modelled intensity profiles for each loop. These are constructed by integrating the square of the density from a cylindrical loop cross section along the line of sight, assuming an isothermal cross section, and applying the instrumental point spread function. Results. Calculating the Bayes factors for comparisons between the models, it was found that in 47 % of cases there is very strong evidence for model L over model S and in 45 % of cases very strong evidence for model G over S . Using multiple permutations of the Bayes factor the favoured density profile for each loop was determined for multiple evidence thresholds. There were a similar number of cases where model L or G are favoured, showing evidence for inhomogeneous layers and constantly varying density cross sections, subject to our assumptions and simplifications. Conclusions. For sufficiently well resolved loop threads with no visible substructure it has been shown that using Bayesian inference and the observed intensity profile we can distinguish between the proposed density profiles at a given AIA wavelength and spatial resolution. We have found very strong evidence for inhomogeneous layers, with model L being the most general, and a tendency towards thicker or even continuous layers.

Dependence of kink oscillation damping on the amplitude

Goddard, C.R., Nakariakov, V.M.

A&A **2016**

http://www2.warwick.ac.uk/fac/sci/physics/research/cfsa/people/valery/research/eprints/qfactor_amp.pdf

Context. Kink oscillations of coronal loop are one of the most intensively studied oscillatory phenomena in the solar corona. In the large-amplitude rapidly damped regime these oscillations are observed to have a low quality-factor, with only a few cycles of oscillation detected before they are damped. The specific mechanism responsible for the rapid damping is commonly accepted to be associated with the linear coupling between collective kink oscillations and localised torsional oscillations, the phenomenon ofresonant absorption of the kink mode. However, the role of finite amplitude effects is still not clear.

Aims. We investigated the empirical dependence of the kink oscillation damping time and its quality factor, defined as the ratio of the damping time to the oscillation period, on the oscillation amplitude.

Methods. We analysed decaying kink oscillation events detected previously with TRACE, SDO/AIA and and STEREO/EUVI in the EUV 171 Å band.
Results. We found that the ratio of the kink oscillation damping time to the oscillation period systematically decreases with the oscillation amplitude. The quality factor dependence on the oscillation displacement amplitude has been approximated by the powerlaw dependence with the exponent of -1/2, however we stress that this is a "by eye" estimate, and a more rigorous estimation of the scaling law requires more accurate measurements and increased statistics. We conclude that damping of kink oscillations of coronal loops depends on the oscillation amplitude, indicating the possible role of nonlinear mechanisms for damping.

A statistical study of decaying kink oscillations detected using SDO/AIA

C. R. **Goddard**, G. Nistic`o, V. M. Nakariakov, I. V. Zimovets

A&A 585, A137 **2016**

http://arxiv.org/pdf/1511.03558v1.pdf

Despite intensive studies of kink oscillations of coronal loops in the last decade, a large scale statistically significant investigation of the oscillation parameters has not been made using data from the Solar Dynamics Observatory (SDO).
We carry out a statistical study of kink oscillations using Extreme Ultra-Violet (EUV) imaging data from a previously compiled catalogue.
We analysed 58 kink oscillation events observed by the Atmospheric Imaging Assembly (AIA) onboard SDO during its first four years of operation (2010-2014). Parameters of the oscillations, including the initial apparent amplitude, period, length of the oscillating loop, and damping are studied for 120 individual loop oscillations.
Analysis of the initial loop displacement and oscillation amplitude leads to the conclusion that the initial loop displacement prescribes the initial amplitude of oscillation in general. The period is found to scale with the loop length, and a linear fit of the data cloud gives a kink speed of Ck =(1330+/-50) km s-1 . The main body of the data corresponds to kink speeds in the range Ck =(800-3300) km s-1. Measurements of 52 exponential damping times were made, and it was noted that at least 22 of the damping profiles may be better approximated by a combination of non-exponential and exponential profiles, rather than a purely exponential damping envelope. There are an additional 10 cases where the profile appears to be purely non-exponential, and no damping time was measured. A scaling of the exponential damping time with the period is found, following the previously established linear scaling between these two parameters. **30.05.2012, 20.10.2012, 18.07.2013**
Table 1. A list of 120 coronal loop kink oscillations detected with AIA/SDO and their measured parameters.

On the magnetism and dynamics of prominence legs hosting tornadoes

M. J. Martinez **Gonzalez**, A. Asensio Ramos, I. Arregui, M. Collados, C. Beck, J. de la Cruz Rodriguez

ApJ 825 119 **2016**

http://arxiv.org/pdf/1605.01183v1.pdf
https://iopscience.iop.org/article/10.3847/0004-637X/825/2/119/pdf

Solar tornadoes are dark vertical filamentary structures observed in the extreme ultraviolet associated with prominence legs and filament barbs. Their true nature and relationship to prominences requires understanding their magnetic structure and dynamic properties. Recently, a controversy has arisen: is the magnetic field organized forming vertical, helical structures or is it dominantly horizontal? And concerning their dynamics, are tornadoes really rotating or is it just a visual illusion? Here, we analyze four consecutive spectropolarimetric scans of a prominence hosting tornadoes on its legs which help us shed some light on their magnetic and dynamical properties. We show that the magnetic field is very smooth in all the prominence, probably an intrinsic property of the coronal field. The prominence legs have vertical helical fields that show slow temporal variation probably related to the motion of the fibrils. Concerning the dynamics, we argue that 1) if rotation exists, it is intermittent, lasting no more than one hour, and 2) the observed velocity pattern is also consistent with an oscillatory velocity pattern (waves). **April 24th 2012**.

Spectro-polarimetric Imaging Reveals Helical Magnetic Fields in Solar Prominence Feet

M. J. Martinez **Gonzalez**, R. Manso Sainz, A. Asensio Ramos, C. Beck, J. de la Cruz Rodriguez, A. J. Diaz

ApJ **802** 3 **2015**

http://arxiv.org/pdf/1501.03295v1.pdf

Solar prominences are clouds of cool plasma levitating above the solar surface and insulated from the million-degree corona by magnetic fields. They form in regions of complex magnetic topology, characterized by non-potential fields, which can evolve abruptly, disintegrating the prominence and ejecting magnetized material into the heliosphere. However, their physics is not yet fully understood because mapping such complex magnetic configurations and their evolution is extremely challenging, and must often be guessed by proxy from photometric observations.Using state-of-the-art spectro-polarimetric data, we reconstruct the structure of the magnetic field in a prominence. We find that prominence feet harbor helical magnetic fields connecting the prominence to the solar surface below. **April 24 2011**

Evidence of quiet-Sun chromospheric activity related to an emerging small-scale magnetic loop

P. **Gömöry**1, H. Balthasar2 and K. G. Puschmann

A&A 556, A7 (**2013**)

Aims. We investigate the temporal evolution of magnetic flux emergence in the quiet-Sun atmosphere close to disk center.

Methods. We combined high-resolution SoHO/MDI magnetograms with TRACE observations taken in the 1216 Å channel to analyze the temporal evolution of an emerging small-scale magnetic loop and its traces in the chromosphere.

Results. We find signatures of flux emergence very close to the edge of a supergranular network boundary located at disk center. The new emerging flux appeared first in the MDI magnetograms in form of an asymmetric bipolar element, i.e., the patch with negative polarity is roughly twice as weak as the corresponding patch with opposite polarity. The average values of magnetic flux and magnetic flux densities reached 1.6 × 1018 Mx, − 8.5 × 1017 Mx, and 55 Mx cm-2, –30 Mx cm-2, respectively. The spatial distance between the opposite polarity patches of the emerged feature increased from about 2.″5 to 5.″0 during the lifetime of the loop, which was 36 min. A more precise lifetime-estimate of the feature was not possible because of a gap in the temporal sequence of the MDI magnetograms. The chromospheric response to the emerged magnetic dipole occurred ~9 min later than in the photospheric magnetograms. It consisted of a quasi-periodic sequence of time-localized brightenings visible in the 1216 Å TRACE channel for ~14 min that were co-spatial with the axis connecting the two patches of opposite magnetic polarity.

Conclusions. We identify the observed event as a small-scale magnetic loop emerging at photospheric layers that subsequently rose to the chromosphere. We discuss the possibility that the fluctuations detected in the chromospheric emission probably reflect magnetic-field oscillations which propagate to the chromosphere in the form of waves.

The dynamics of eruptive prominences **Review**

Nat **Gopalswamy**

Solar Prominences, edited by J.-C. Vial & O. Engvold, Springer, in press (**2014**), Chapter 15, **File**

Astrophysics and Space Science Library Volume 415, **2015**, pp 381-410

http://arxiv.org/pdf/1407.2594v1.pdf

http://link.springer.com/chapter/10.1007/978-3-319-10416-4_15

This chapter discusses the dynamical properties of eruptive prominences in relation to coronal mass ejections (CMEs). The fact that eruptive prominences are a part of CMEs is emphasized in terms of their physical association and kinematics. The continued propagation of prominence material into the heliosphere is illustrated using in-situ observations. The solar-cycle variation of eruptive prominence locations is discussed with a particular emphasis on the rush-to-the-pole (RTTP) phenomenon. One of the consequences of the RTTP phenomenon is polar CMEs, which are shown to be similar to the low-latitude CMEs. This similarity is important because it provides important clues to the mechanism by which CMEs erupt. The nonradial motion of CMEs is discussed, including the deflection by coronal holes that have important space weather consequences. Finally, the implications of the presented observations for the modeling CME modeling are outlined. **1998-01-25, 24-11-2000, 2001-12-20, 2003-02-18, 2003-08-16-19, 2009-05-05, 2009-11-08, 2013-09-29-30, 2012-03-12**,

Prominence Eruptions and Coronal Mass Ejection: A Statistical Study using Microwave Observations

N. **Gopalswamy**1, M. Shimojo2, W. Lu1;3, S. Yashiro1;3, K. Shibasaki2, and R. A. Howard4

File, 2003 , Table

We present the results of a statistical study of a large number of solar prominence events (PEs) observed by the Nobeyama Radioheliograph. We studied the association rate, relative timing and spatial correspondence between PEs and coronal mass ejections (CMEs). We classi_ed the PEs as radial and transverse, depending on whether the prominence moved predominantly in the radial or horizontal direction. The radial events were faster and attained a larger height above the solar surface than the transverse events. Out of the 186 events studied, 152 (82%) were radial events, while only 34 (18%) were transverse events. Comparison with white-light CME data revealed that 134 (72%) PEs were clearly associated with CMEs. We compare our results with those of other studies involving PEs and white light CMEs in order to address the controversy in the rate of association between CMEs and prominence eruptions. We also studied the temporal and spatial relationship between prominence and CME events. The CMEs and PEs seem to start roughly at the same time. There was no solar cycle dependence of the temporal relationship. The spatial relationship was, however, solar cycle dependent. During the solar minimum, the central position angle of the CMEs had a tendency to be o_set closer to the equator as compared to that of the PE, while no such e_ect was seen during solar maximum.

Observational signatures of magnetic reconnection in kink-unstable coronal loops

Mykola **Gordovskyy**

UKSP Nugget #51, Oct **2014**

http://www.uksolphys.org/uksp-nugget/51-observational-signatures-of-magnetic-reconnection-in-twisted-coronal-loops/

What would the flare X-ray emission from a twisted loop look like?

Our numerical models provide two remarkable observational features, which should be observable in reconnecting twisted coronal loops (see [10,11] for more details). Firstly, we predict a 'twisted' pattern in thermal emission (EUV or SXR). However, the twist should be around 2π, i.e. much lower than the critical twist required for kink instability. This is consistent with observations: the twist angle visible in EUV is normally about few π. Secondly, the flaring loop should have expanding cross-section, which should be visible as a gradual increase in the horizontal size of HXR footpoints.

Study of Extreme-ultraviolet Emission and Properties of a Coronal Streamer from PROBA2/SWAP, Hinode/EIS and Mauna Loa Mk4 Observations

F. **Goryaev**1, V. Slemzin1, L. Vainshtein1, and David R. Williams

2014 ApJ 781 100

Wide-field extreme-ultraviolet (EUV) telescopes imaging in spectral bands sensitive to 1 MK plasma on the Sun often observe extended, ray-like coronal structures stretching radially from active regions to distances of 1.5-2 R ⊙, which represent the EUV counterparts of white-light streamers. To explain this phenomenon, we investigated the properties of a streamer observed on **2010 October 20 and 21**, by the PROBA2/SWAP EUV telescope together with the Hinode/EIS (HOP 165) and the Mauna Loa Mk4 white-light coronagraph. In the SWAP 174 Å band comprising the Fe IX-Fe XI lines, the streamer was detected to a distance of 2 R ⊙. We assume that the EUV emission is dominated by collisional excitation and resonant scattering of monochromatic radiation coming from the underlying corona. Below 1.2 R ⊙, the plasma density and temperature were derived from the Hinode/EIS data by a line-ratio method. Plasma conditions in the streamer and in the background corona above 1.2 R ⊙ from the disk center were determined by forward-modeling the emission that best fit the observational data in both EUV and white light. It was found that the plasma in the streamer above 1.2 R ⊙ is nearly isothermal, with a temperature of T = 1.43 ± 0.08 MK. The hydrostatic scale-height temperature determined from the evaluated density distribution was significantly higher (1.72 ± 0.08 MK), which suggests the existence of outward plasma flow along the streamer. We conclude that, inside the streamer, collisional excitation provided more than 90% of the observed EUV emission, whereas, in the background corona, the contribution of resonance scattering became comparable with that of collisions at R 2 R ⊙.

DUAL TRIGGER OF TRANSVERSE OSCILLATIONS IN A PROMINENCE BY EUV FAST AND SLOW CORONAL WAVES: SDO/AIA AND STEREO/EUVI OBSERVATIONS

S. **Gosain**1 and C. Foullon

2012 ApJ 761 103, **File**

We analyze flare-associated transverse oscillations in a quiescent solar prominence on **2010 September 8-9**. Both the flaring active region and the prominence were located near the west limb, with a favorable configuration and viewing angle. The full-disk extreme ultraviolet (EUV) images of the Sun obtained with high spatial and temporal resolution by the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory show flare-associated lateral oscillations of the prominence sheet. The STEREO-A spacecraft, 815 ahead of the Sun-Earth line, provides an on-disk view of the flare-associated coronal disturbances. We derive the temporal profile of the lateral displacement of the prominence sheet by using the image cross-correlation technique. The displacement curve was de-trended and the residual oscillatory pattern was derived. We fit these oscillations with a damped cosine function with a variable period and find that the period is increasing. The initial oscillation period (P 0) is ~28.2 minutes and the damping time (τ D) ~ 44 minutes. We confirm the presence of fast and slow EUV wave components. Using STEREO-A observations, we derive a propagation speed of ~250 km s–1 for the slow EUV wave by applying the time-slice technique to the running difference images. We propose that the prominence oscillations are excited by the fast EUV wave while the increase in oscillation period of the prominence is an apparent effect, related to a phase change due to the slow EUV wave acting as a secondary trigger. We discuss implications of the dual trigger effect for coronal prominence seismology and scaling law studies of damping mechanisms.

Estimation of width and inclination of a filament sheet using He II 304 Å observations by STEREO/EUVI,

Gosain, S. and Schmieder, B.:

Ann. Geophys., 28, 149-153, **2010**

Full Article (PDF, 1142 KB).

The STEREO mission has been providing stereoscopic view of the filament eruptions in EUV wavelengths. The most extended view during filament eruptions is seen in He II 304 Å observations, as the filament spine appears darker and sharper. The projected filament width appears differently when viewed from different angles by STEREO satellites. Here, we present a method for estimating the width and inclination of the filament sheet using He II 304 Å observations by STEREO-A and B satellites from the two viewpoints. The width of the filament sheet, when measured from its feet to its apex, gives estimate of filament height above the chromosphere. **22 May 2008.**

A MULTI-SPACECRAFT VIEW OF A GIANT FILAMENT ERUPTION DURING 2009 SEPTEMBER 26/27

Sanjay **Gosain**1, Brigitte Schmieder2, Guy Artzner3, Sergei Bogachev4, and Tibor Török

2012 ApJ 761 25

We analyze multi-spacecraft observations of a giant filament eruption that occurred during **2009 September 26 and 27.** The filament eruption was associated with a relatively slow coronal mass ejection. The filament consisted of a large and a small part, and both parts erupted nearly simultaneously. Here we focus on the eruption associated with the larger part of the filament. The STEREO satellites were separated by about 117° during this event, so we additionally used SoHO/EIT and CORONAS/TESIS observations as a third eye (Earth view) to aid our measurements. We measure the plane-of-sky trajectory of the filament as seen from STEREO-A and TESIS viewpoints. Using a simple trigonometric relation, we then use these measurements to estimate the true direction of propagation of the filament which allows us to derive the true $R/R_\odot$-time profile of the filament apex. Furthermore, we develop a new tomographic method that can potentially provide a more robust three-dimensional (3D) reconstruction by exploiting multiple simultaneous views. We apply this method also to investigate the 3D evolution of the top part of filament. We expect this method to be useful when SDO and STEREO observations are combined. We then analyze the kinematics of the eruptive filament during its rapid acceleration phase by fitting different functional forms to the height-time data derived from the two methods. We find that for both methods an exponential function fits the rise profile of the filament slightly better than parabolic or cubic functions. Finally, we confront these results with the predictions of theoretical eruption models.

3D evolution of a filament disappearance event observed by STEREO

S. **Gosain**1 · B. Schmieder2 · P. Venkatakrishnan1 · R. Chandra2 · G. Artzner

E-print, Oct 2009, Solar Phys**.**, (**2009**) 259: 13–30, **File**

A filament disappearance event was observed on **22 May 2008** during our recent campaign JOP 178. The filament, situated in the southern hemisphere, showed sinistral chirality consistent with the hemispheric rule. The event was well observed by several observatories in particular by THEMIS. One day before the disappearance, H_ observations showed up and down flows in adjacent locations along the filament, which suggest plasma motions along twisted flux rope. THEMIS and GONG observations show shearing photospheric motions leading to magnetic flux canceling around barbs. STEREO A, B spacecraft with separation angle 52.4 degrees, showed quite different views of this untwisting flux rope in He II 304 °A images. Here, we reconstruct the 3D geometry of the filament during its eruption phase using STEREO EUV He II 304 °A images and find that the filament was highly inclined to the solar normal. The He II 304 °A movies show individual threads, which oscillate and rise to an altitude of about 120 Mm with apparent velocities of about 100 km s−1, during the rapid evolution phase. Finally, as the flux rope expands into the corona, the filament disappears by becoming optically thin to undetectable levels. No CME was detected by STEREO, only a faint CME was recorded by LASCO at the beginning of the disappearance phase at 02:00 UT, which could be due to partial filament eruption. Further, STEREO Fe XII 195 °A images showed bright loops beneath the filament prior to the disappearance phase, suggesting magnetic reconnection below the flux rope.

TRANSIENT CORONAL SIGMOIDS AND ROTATING ERUPTING FLUX ROPES

L. M. **GREEN**1, B. KLIEM2,3, T. T¨O R¨OK1, L. van DRIEL-GESZTELYI1,4,5, and G. D. R. ATTRILL1

E-print, Sept. 2007, File, Solar Phys (**2007**) 246: 365–391, File

To determine the relationship between transient coronal (soft X-ray or EUV) sigmoids and erupting flux ropes, we analyse four events in which a transient sigmoid could be associated with a filament whose apex rotates upon eruption and two further events in which the two phenomena were spatially but not temporally coincident. We find the helicity sign of the erupting field and the direction of filament rotation to be consistent with the conversion of twist into writhe under the ideal

MHD constraint of helicity conservation, thus supporting our assumption of flux rope topology for the rising filament. For positive (negative) helicity the filament apex rotates clockwise (counterclockwise), consistent with the flux rope taking on a reverse (forward) S shape, which is opposite to that observed for the sigmoid. This result is incompatible with two models for sigmoid formation: one identifying sigmoids with upward arching kink-unstable flux ropes and one identifying sigmoids with a current layer between two oppositely sheared arcades. We find instead that the observations agree well with the model by Titov and Démoulin (*Astron. Astrophys.* **351**, 707, 1999), which identifies transient sigmoids with steepened current layers below rising flux ropes.

Absorption Phenomena and a Probable BlastWave in the 13 July 2004 Eruptive Event

V.V. **Grechnev** · A.M. Uralov · V.A. Slemzin · I.M. Chertok · I.V. Kuzmenko · K. Shibasaki

Solar Phys (**2008**) 253: 263–290

We present a case study of the 13 July 2004 solar event, in which disturbances caused by eruption of a filament from an active region embraced a quarter of the visible solar surface. Remarkable are the absorption phenomena observed in the SOHO/EIT 304 Å channel, which were also visible in the EIT 195 Å channel, in the H〈 line, and even in total radio flux records. Coronal and Moreton waves were also observed. Multispectral data allowed reconstructing an overall picture of the event. An explosive filament eruption and related impulsive flare produced a CME and blast shock, both of which decelerated and propagated independently. Coronal and Moreton waves were kinematically close and both decelerated in accordance with an expected motion of a coronal blast shock. The CME did not resemble a classical three-component structure, probably because some part of the ejected mass fell back onto the Sun. Quantitative evaluations from different observations provide close estimates of the falling mass,~ 3×1015 g, which is close to the estimated mass of the CME. The falling material was responsible for the observed large-scale absorption phenomena, in particular, shallow widespread moving dimmings observed at 195 Å. By contrast, deep quasi-stationary dimmings observed in this band near the eruption center were due to plasma density decrease in coronal structures.

Observations of Prominence Eruptions with Two Radioheliographs, SSRT and NoRH

V. V. **Grechnev** et al., PASJ: Publ. Astron. Soc. Japan , 58, 69– , **2006**.

Intensity variations associated with fast sausage modes

M. **Gruszecki**1, V. M. Nakariakov1,2 and T. Van Doorsselaere

A&A 543, A12 (**2012**)

Aims. We determine the dependence of the observed properties of fast magnetoacoustic axisymmetric oscillations (the sausage mode) of a thick and dense flaring coronal loop, modelled by a magnetic cylinder, on the parameters of the equilibrium plasma configuration. The plasma inside and outside the cylinder is of low-beta, and penetrated by a straight magnetic field. The plasma density has a smooth profile across the magnetic field.
Methods. We use three-dimensional ideal magnetohydrodynamic equations to model numerically the development of the perturbations of the cylindrical equilibrium, considering both leaky and trapped regimes.
Results. Short-period sausage oscillations, trapped by the cylinder, are qualitatively consistent with the analytical results obtained in the models of a plasma slab or a cylinder with a step-function transverse profile. The period of trapped sausage oscillations is determined by the ratio of the phase speed, with the value between the internal and external Alfvén speeds, to the wavelength. Longer-period sausage oscillations are leaky, and their decay times are longer for higher density contrasts between the internal and external media. Leaky sausage oscillations have longer periods than trapped sausage oscillations of the same cylinder. In the coronal conditions, sausage oscillations are essentially compressible and transverse, hence produce modulation of the thermal optically thin emission intensity and periodic Doppler broadening of emission lines. However, if the oscillating plasma non-uniformity is poorly spatially resolved, the variation in the emission intensity is weak and proportional to the actual amplitude of the oscillation squared. The latter variation property is connected with the transverse nature of the oscillation, causing the conservation of mass in the transverse cross-section of the oscillating plasma structure.

MHD modeling of coronal loops: the transition region throat

M. **Guarrasi**, F. Reale, S. Orlando, A. Mignone and J. A. Klimchuk

A&A 564, A48 (**2014**)

Context. The expansion of coronal loops in the transition region may considerably influence the diagnostics of the plasma emission measure. The cross-sectional area of the loops is expected to depend on the temperature and pressure, and might be sensitive to the heating rate.
Aims. The approach here is to study the area response to slow changes in the coronal heating rate, and check the current interpretation in terms of steady heating models.
Methods. We study the area response with a time-dependent 2D magnetohydrodynamic (MHD) loop model, including the description of the expanding magnetic field, coronal heating and losses by thermal conduction, and radiation from optically thin plasma. We run a simulation for a loop 50 Mm long and quasi-statically heated to about 4 MK.
Results. We find that the area can change substantially with the quasi-steady heating rate, e.g., by ~40% at 0.5 MK as the loop temperature varies between 1 MK and 4 MK, and, therefore, affects the interpretation of the differential emission measure vs. temperature (DEM(T)) curves.

Lifecycle of a large-scale polar coronal pseudostreamer/cavity system

Chloé **Guennou**1, 2*, Laurel A. Rachmeler3, Daniel B. Seaton3, 4, 5, Frédéric Auchère6
Front. Astron. Space Sci. **2016** | doi: 10.3389/fspas.2016.00014
http://journal.frontiersin.org/article/10.3389/fspas.2016.00014/abstract
We report on an exceptional large-scale coronal pseudostreamer/cavity system in the southern polar region of the solar corona that was visible for approximately a year starting in February 2014. It is unusual to see such a large closed-field structure embedded within the open polar coronal hole. We investigate this structure to document its formation, evolution and eventually its shrinking process using data from both the PROBA2/SWAP and SDO/AIA EUV imagers. In particular, we used EUV tomography to find the overall shape and internal structure of the pseudostreamer and to determine its 3D temperature and density structure using DEM analysis. We found that the cavity temperature is extremely stable with time and is essentially at a similar or slightly hotter temperature than the surrounding pseudostreamer. Two regimes in cavity thermal properties were observed: during the first 5 months of observation, we found lower density depletion and highly multi-thermal plasma, while after the pseudostreamer became stable and slowly shrank, the depletion was more pronounced and the plasma was less multithermal. As the thermodynamic properties are strongly correlated with the magnetic structure, these results provide constraints on both the trigger of CMEs and the processes that maintain cavities stability for such a long lifetime.

On the Physical Nature of the so-Called Prominence Tornadoes Review

Stanislav **Gunár**, Nicolas Labrosse, Manuel Luna, Brigitte Schmieder, Petr Heinzel, Therese A. Kucera, Peter J. Levens, Arturo López Ariste, Duncan H. Mackay & Maciej Zapiór
Space Science Reviews volume 219, Article number: 33 (**2023**)
https://link.springer.com/content/pdf/10.1007/s11214-023-00976-w.pdf
The term ‘tornado’ has been used in recent years to describe several solar phenomena, from large-scale eruptive prominences to small-scale photospheric vortices. It has also been applied to the generally stable quiescent prominences, sparking a renewed interest in what historically was called ‘prominence tornadoes’. This paper carries out an in-depth review of the physical nature of ‘prominence tornadoes’, where their name subconsciously makes us think of violent rotational dynamics. However, after careful consideration and analysis of the published observational data and theoretical models, we conclude that ‘prominence tornadoes’ do not differ in any substantial way from other stable solar prominences. There is simply no unequivocal observational evidence of sustained and coherent rotational movements in quiescent prominences that would justify a distinct category of prominences sharing the name with the well-known atmospheric phenomenon. The visual impression of the column-like silhouettes, the perceived helical motions, or the suggestive Doppler-shift patterns all have a simpler, more likely explanation. They are a consequence of projection effects combined with the presence of oscillations and/or counter-streaming flows. ‘Prominence tornadoes’ are thus just manifestations of the complex nature of solar prominences when observed in specific projections. These coincidental viewing angles, together with the presence of fine-structure dynamics and simple yet profoundly distorting projection effects, may sometimes play havoc with our intuitive understanding of perceived shapes and motions, leading to the incorrect analogy with atmospheric tornadoes. **22-23 Jjun 2011, 24-26 Sep 2011, 14 Sep 2013, 15 Jul 2014**

The influence of Hinode/SOT NFI instrumental effects on the visibility of simulated prominence fine structures in Hα

S. **Gunár**1, J. Jurčák1 and K. Ichimoto2
A&A 629, A118 (**2019**)
https://doi.org/10.1051/0004-6361/201936147
Context. Models of entire prominences with their numerous fine structures distributed within the prominence magnetic field use approximate radiative transfer techniques to visualize the simulated prominences. However, to accurately compare synthetic images of prominences obtained in this way with observations and to precisely analyze

the visibility of even the faintest prominence features, it is important to take into account the influence of instrumental properties on the synthetic spectra and images.
Aims. In the present work, we investigate how synthetic Hα images of simulated prominences are impacted by the instrumental effects induced by the Narrowband Filter Imager (NFI) of the Solar Optical Telescope (SOT) onboard the Hinode satellite.
Methods. To process the synthetic Hα images provided by 3D Whole-Prominence Fine Structure (WPFS) models into SOT-like synthetic Hα images, we take into account the effects of the integration over the theoretical narrow-band transmission profile of NFI Lyot filter, the influence of the stray-light and point spread function (PSF) of Hinode/SOT, and the observed noise level. This allows us to compare the visibility of the prominence fine structures in the SOT-like synthetic Hα images with the synthetic Hα line-center images used by the 3D models and with a pair of Hinode/SOT NFI observations of quiescent prominences.
Results. The comparison between the SOT-like synthetic Hα images and the synthetic Hα line-center images shows that all large and small-scale features are very similar in both visualizations and that the same very faint prominence fine structures can be discerned in both. This demonstrates that the computationally efficient Hα line-center visualization technique can be reliably used for the purpose of visualization of complex 3D prominence models. In addition, the qualitative comparison between the SOT-like synthetic images and prominence observations shows that the 3D WPFS models can reproduce large-scale prominence features rather well. However, the distribution of the prominence fine structures is significantly more diffuse in the observations than in the models and the diffuse intensity areas surrounding the observed prominences are also not present in the synthetic images. We also found that the maximum intensities reached in the models are about twice as high as those present in the observations–an indication that the mass-loading assumed in the present 3D WPFS models might be too large.

Importance of the Hα Visibility and Projection Effects for the Interpretation of Prominence Fine-structure Observations

Stanislav **Gunár**1,2, Jaroslav Dudík1, Guillaume Aulanier2, Brigitte Schmieder2, and Petr Heinzel1
2018 ApJ 867 115
sci-hub.tw/10.3847/1538-4357/aae4e1
We construct a new 3D Whole-prominence Fine-structure (WPFS) model based on a prominence magnetic field configuration designed to qualitatively approximate the morphology of a quiescent prominence observed on **2010 June 22**. The model represents an entire prominence with its numerous fine structures formed by a prominence plasma located in dips in the prominence magnetic field. We use the constructed 3D model and employ a radiative-transfer-based Hαvisualization method to analyze the Hα visibility of prominence fine structures and its effect on the perceived morphology of observed and modeled prominences. We qualitatively compare three techniques used for visualization of modeled prominences—visualizations drawing magnetic dips up to a height of 1 pressure scale height, drawing the full extent of magnetic dips, and the synthetic Hαvisualization—and discuss their suitability for direct comparison between models and observations of prominences and filaments. We also discuss the role of visibility of the prominence fine structures in the estimation of the total height of prominences, which may indicate the height of pre-erupting flux ropes. This parameter is critical for the observational determination of the flux-rope stability. In addition, we employ the WPFS model to assess the effects caused by a projection of the naturally three-dimensional and heterogeneous prominences onto a two-dimensional plane of the sky. We discuss here how the morphological structures of prominences differ when observed in projections from different viewing angles. We also discuss the shapes of the dipped magnetic field lines and the perceived projection of motions of prominence fine structures along such field lines.

Quiescent Prominences in the Era of ALMA. II. Kinetic Temperature Diagnostics

Stanislav **Gunár**1, Petr Heinzel1, Ulrich Anzer2, and Duncan H. Mackay
2018 ApJ 853 21
http://sci-hub.tw/http://iopscience.iop.org/0004-637X/853/1/21/
We provide the theoretical background for diagnostics of the thermal properties of solar prominences observed by the Atacama Large Millimeter/submillimeter Array (ALMA). To do this, we employ the 3D Whole-Prominence Fine Structure (WPFS) model that produces synthetic ALMA-like observations of a complex simulated prominence. We use synthetic observations derived at two different submillimeter/millimeter (SMM) wavelengths—one at a wavelength at which the simulated prominence is completely optically thin and another at a wavelength at which a significant portion of the simulated prominence is optically thick—as if these were the actual ALMA observations. This allows us to develop a technique for an analysis of the prominence plasma thermal properties from such a pair of simultaneous high-resolution ALMA observations. The 3D WPFS model also provides detailed information about the distribution of the kinetic temperature and the optical thickness along any line of sight. We can thus assess whether the measure of the kinetic temperature derived from observations accurately represents the actual kinetic temperature properties of the observed plasma. We demonstrate here that in a given pixel the optical thickness at the wavelength at which the prominence plasma is optically thick needs to be above unity or even larger to achieve a

sufficient accuracy of the derived information about the kinetic temperature of the analyzed plasma. Information about the optical thickness cannot be directly discerned from observations at the SMM wavelengths alone. However, we show that a criterion that can identify those pixels in which the derived kinetic temperature values correspond well to the actual thermal properties in which the observed prominence can be established.

QUIESCENT PROMINENCES IN THE ERA OF ALMA: SIMULATED OBSERVATIONS USING THE 3D WHOLE-PROMINENCE FINE STRUCTURE MODEL

Stanislav **Gunár**1, Petr Heinzel1, Duncan H. Mackay2, and Ulrich Anzer

2016 ApJ 833 141

We use the detailed 3D whole-prominence fine structure model to produce the first simulated high-resolution ALMA observations of a modeled quiescent solar prominence. The maps of synthetic brightness temperature and optical thickness shown in the present paper are produced using a visualization method for synthesis of the submillimeter/millimeter radio continua. We have obtained the simulated observations of both the prominence at the limb and the filament on the disk at wavelengths covering a broad range that encompasses the full potential of ALMA. We demonstrate here extent to which the small-scale and large-scale prominence and filament structures will be visible in the ALMA observations spanning both the optically thin and thick regimes. We analyze the relationship between the brightness and kinetic temperature of the prominence plasma. We also illustrate the opportunities ALMA will provide for studying the thermal structure of the prominence plasma from the cores of the cool prominence fine structure to the prominence–corona transition region. In addition, we show that detailed 3D modeling of entire prominences with their numerous fine structures will be important for the correct interpretation of future ALMA observations of prominences.

Properties of the prominence magnetic field and plasma distributions as obtained from 3D whole-prominence fine structure modeling

S. **Gunár**1 and D. H. Mackay

A&A 592, A60 (**2016**)

Aims. We analyze distributions of the magnetic field strength and prominence plasma (temperature, pressure, plasma β, and mass) using the 3D whole-prominence fine structure model.
Methods. The model combines a 3D magnetic field configuration of an entire prominence, obtained from non-linear force-free field simulations, with a detailed semi-empirically derived description of the prominence plasma. The plasma is located in magnetic dips in hydrostatic equilibrium and is distributed along multiple fine structures within the 3D magnetic model.
Results. We show that in the modeled prominence, the variations of the magnetic field strength and its orientation are insignificant on scales comparable to the smallest dimensions of the observed prominence fine structures. We also show the ability of the 3D whole-prominence fine structure model to reveal the distribution of the prominence plasma with respect to its temperature within the prominence volume. This provides new insights into the composition of the prominence-corona transition region. We further demonstrate that the values of the plasma β are small throughout the majority of the modeled prominences when realistic photospheric magnetic flux distributions and prominence plasma parameters are assumed. While this is generally true, we also find that in the region with the deepest magnetic dips, the plasma β may increase towards unity. Finally, we show that the mass of the modeled prominence plasma is in good agreement with the mass of observed non-eruptive prominences.

3D WHOLE-PROMINENCE FINE STRUCTURE MODELING. II. PROMINENCE EVOLUTION

Stanislav **Gunár**1 and Duncan H. Mackay

2015 ApJ 812 93

We use the new three-dimensional (3D) whole-prominence fine structure model to study the evolution of prominences and their fine structures in response to changes in the underlying photospheric magnetic flux distribution. The applied model combines a detailed 3D prominence magnetic field configuration with a realistic description of the prominence plasma distributed along multiple fine structures. In addition, we utilize an approximate Hα visualization technique to study the evolution of the visible cool prominence plasma both in emission (prominence) and absorption (filament). We show that the initial magnetic field configuration of the modeled prominence is significantly disturbed by the changing position of a single polarity of a magnetic bipole as the bipole is advected toward the main body of the filament. This leads to the creation of a barb, which becomes the dominant feature visible in the synthetic Hα images of both the prominence and filament views. The evolution of the bipole also creates conditions that lead to the disappearance and reappearance of large portions of the main body. We also show that an arch-like region containing a dark void (a bubble) can be naturally produced in the synthetic prominence Hα images. While not visible in terms of the magnetic field lines, it is due to a lack of Hα emission from low-pressure, low-density plasma located in shallow magnetic dips lying along the lines of sight intersecting the dark void. In addition, a quasi-vertical small-scale feature consisting of short and deep dips, piled one above the other, is produced.

3D Whole-Prominence Fine Structure Modeling

Stanislav **Gunár**1 and Duncan H. Mackay

2015 ApJ 803 64

We present the first 3D whole-prominence fine structure model. The model combines a 3D magnetic field configuration of an entire prominence obtained from nonlinear force-free field simulations, with a detailed description of the prominence plasma. The plasma is located in magnetic dips in hydrostatic equilibrium and is distributed along multiple fine structures within the 3D magnetic model. Through the use of a novel radiative transfer visualization technique for the Hα line such plasma-loaded magnetic field model produces synthetic images of the modeled prominence comparable with high-resolution observations. This allows us for the first time to use a single technique to consistently study, in both emission on the limb and absorption against the solar disk, the fine structures of prominences/filaments produced by a magnetic field model.

Magnetic field and radiative transfer modelling of a quiescent prominence⋆

S. **Gunár**1, P. Schwartz3,2, J. Dudík4,5, B. Schmieder6, P. Heinzel2 and J. Jurčák

A&A 567, A123 (**2014**)

Aims. The aim of this work is to analyse the multi-instrument observations of the **June 22, 2010** prominence to study its structure in detail, including the prominence-corona transition region and the dark bubble located below the prominence body.
Methods. We combined results of the 3D magnetic field modelling with 2D prominence fine structure radiative transfer models to fully exploit the available observations.
Results. The 3D linear force-free field model with the unsheared bipole reproduces the morphology of the analysed prominence reasonably well, thus providing useful information about its magnetic field configuration and the location of the magnetic dips. The 2D models of the prominence fine structures provide a good representation of the local plasma configuration in the region dominated by the quasi-vertical threads. However, the low observed Lyman-α central intensities and the morphology of the analysed prominence suggest that its upper central part is not directly illuminated from the solar surface.
Conclusions. This multi-disciplinary prominence study allows us to argue that a large part of the prominence-corona transition region plasma can be located inside the magnetic dips in small-scale features that surround the cool prominence material located in the dip centre. We also argue that the dark prominence bubbles can be formed because of perturbations of the prominence magnetic field by parasitic bipoles, causing them to be devoid of the magnetic dips. Magnetic dips, however, form thin layers that surround these bubbles, which might explain the occurrence of the cool prominence material in the lines of sight intersecting the prominence bubbles.

Non-linear force-free magnetic dip models of quiescent prominence fine structures

S. **Gunár**1,2, D. H. Mackay2, U. Anzer3 and P. Heinzel

A&A 551, A3 (**2013**)

Aims. We use 3D non-linear force-free magnetic field modeling of prominence/filament magnetic fields to develop the first 2D models of individual prominence fine structures based on the 3D configuration of the magnetic field of the whole prominence.
Methods. We use an iterative technique to fill the magnetic dips produced by the 3D modeling with realistic prominence plasma in hydrostatic equilibrium and with a temperature structure that contains the prominence-corona transition region. With this well-defined plasma structure the radiative transfer can be treated in detail in 2D and the resulting synthetic emission can be compared with prominence/filament observations.
Results. Newly developed non-linear force-free magnetic dip models are able to produce synthetic hydrogen Lyman spectra in a qualitative agreement with a range of quiescent prominence observations. Moreover, the plasma structure of these models agrees with the gravity induced prominence fine structure models which have already been shown to produce synthetic spectra in good qualitative agreement with several observed prominences.
Conclusions. We describe in detail the iterative technique which can be used to produce realistic plasma models of prominence fine structures located in prominence magnetic field configurations containing dips, obtained using any kind of magnetic field modeling.

Dynamics of quiescent prominence fine structures analyzed by 2D non-LTE modelling of the Hα line⋆

S. **Gunár**1,2, P. Mein2, B. Schmieder2, P. Heinzel1 and N. Mein

A&A 543, A93 (**2012**)

Aims. We analyze the dynamics of the prominence fine structures of a quiescent prominence observed on April 26, 2007 during a coordinated campaign of several spaceborne and ground-based instruments. We use Lyman spectra observed by SOHO/SUMER and the Hα line spectra obtained by MSDP spectrograph working at the Meudon Solar Tower.
Methods. We employ the 2D multi-thread prominence fine-structure modelling that includes randomly distributed line-of-sight (LOS) velocities of individual threads to derive models producing synthetic Lyman lines in good agreement with the SOHO/SUMER observations. We then use these models to produce synthetic Hα line spectra that we compare with the observed spectra using three statistical parameters: the line integrated intensity, the line full-width at half-maximum (FWHM), and the Doppler velocity derived from shifts of the line profiles.
Results. We demonstrate that the 2D multi-thread models that produce synthetic Lyman spectra in agreement with observations also generate synthetic Hα spectra in good agreement with the observed ones. The statistical analysis of the FWHM and Doppler velocities of the synthetic Hα line profiles show that the overall LOS velocities in the April 26, 2007 prominence at the time of the observations were below 15 km s-1 and in the prominence core were close to 10 km s-1. In combination with the analysis of the Lyman spectra, we determine several physical parameters of the observed prominence fine-structures that show that the **April 26, 2007** prominence had a relatively low-mass weakly magnetized structure. We are also able to impose some constraints on the prominence core temperature, which may be relatively low, with values below 6000 K.
Conclusions. The combination of 2D non-LTE prominence fine-structure modelling with the statistical analysis of the observed and synthetic Lyman and Hα spectra allows us to analyze the influence of the model input parameters and the velocity fields on the synthetic Hα line profiles, thus determine the overall dynamics of the observed prominence as well as the physical parameters of its plasma

Synthetic differential emission measure curves of prominence fine structures

S. **Gunár**1, P. Heinzel1 and U. Anzer2

A&A 528, A47 (**2011)**

Aims. We use 2D single and multi-thread prominence fine-structure models to obtain the synthetic DEM curves. These are then compared with the DEM curves derived from observations.
Methods. We use the temperature and electron density structure resulting from the 2D models and numerically compute the average synthetic DEM curves for different orientations of the threads with respect to the line of sight.
Results. We show that the synthetic DEM curves obtained by 2D modelling are similar to the DEM curves derived from observations of quiescent prominences.
Conclusions. The DEM curves derived from observations, which are most reliable above temperatures of 20 000 K, can be extended towards cool prominence-core temperatures by supplementing them with synthetic DEM values obtained by modelling hydrogen Lyman spectra originating mainly at temperatures below 20 000 K. On the other hand, the observed DEM can constrain the temperature structure of the prominence fine structures above the formation temperatures of the Lyman spectrum.

Influence of the Lower Atmosphere on Wave Heating and Evaporation in Solar Coronal Loops

Mingzhe **Guo**, Timothy Duckenfield, Tom Van Doorsselaere, Konstantinos Karampelas, Gabriel Pelouze, Yuhang gao

ApJL **949** L1 **2023**

https://arxiv.org/pdf/2305.03621.pdf
https://iopscience.iop.org/article/10.3847/2041-8213/acd347/pdf

We model a coronal loop as a three-dimensional magnetic cylinder in a realistic solar atmosphere that extends from the chromosphere to the corona. Kink oscillations, believed ubiquitous in the solar corona, are launched in the loop. Heating is expected due to the dissipation of wave energy at small structures that develop from the Kelvin-Helmholtz instability induced by kink oscillations. Increases in temperature and internal energy can be observed in the coronal counterpart of the driven loop. With the presence of thermal conduction, chromospheric evaporation can also be seen. Although the volume averaged temperature and density changes seem slight (~4% relative to a non-driven loop), the enthalpy flow from the lower atmosphere redistributes the density and temperature in the vertical direction, thus enhancing the dissipation of wave energy in the corona. The efficient heating in the coronal counterpart of the loop can complement the thermal conductive losses shown in the current model and thus maintain the internal energy in the corona.

Prominence fine structures in weakly twisted and highly twisted magnetic flux ropes

J. H. **Guo**, Y. W. Ni, Y. H. Zhou, Y. Guo, B. Schmieder, P. F. Chen

A&A 667, A89 **2022**

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https://www.aanda.org/articles/aa/pdf/2022/11/aa44253-22.pdf
https://doi.org/10.1051/0004-6361/202244253
Many prominences are supported by magnetic flux ropes. One important question is how we can determine whether the flux rope is weakly-twisted or strongly-twisted. In this paper, we attempted to check whether prominences supported by weakly-twisted and strongly-twisted flux ropes can manifest different features so that we might distinguish the two types of magnetic structures by their appearance. We performed pseudo three-dimensional simulations of two magnetic flux ropes with different twists. We found that the resulting two prominences differ in many aspects. The prominence supported by a weakly-twisted flux rope is composed mainly of transient threads, forming high-speed flows inside the prominence. Its horns are evident. Conversely, the one supported by a highly-twisted flux rope consists mainly of stable quasi-stationary threads, including longer independently trapped threads and shorter magnetically connected threads. It is also revealed that the prominence spine deviates from the flux rope axis in the vertical direction and from the photospheric polarity inversion line projected on the solar surface, especially for the weakly-twisted magnetic flux rope. The two types of prominences differ significantly in appearance. It is also suggested that a piling-up of short threads in highly-twisted flux ropes might account for the vertical-like threads in some prominences.

Solar-Filament Detection and Classification Based on Deep Learning

Xulong **Guo**, Yunfei Yang, Song Feng, Xianyong Bai, Bo Liang & Wei Dai
Solar Physics volume 297, Article number: 104 (**2022**)
https://doi.org/10.1007/s11207-022-02019-z
Solar filaments are distinct strip-like structures observed in chromospheric HαHα images. Filament eruptions, flares, and coronal mass ejections (CMEs) can be regarded as the same physical process of releasing magnetic energy at different times and solar atmosphere heights. It is very important to detect filaments for forecasting flares and CMEs. This article proposes a new solar-filament detection and classification method based on CondInst; a deep-learning model. A data set of solar filaments is built, including ten thousand filaments. To distinguish filaments that consist of only a single connected dark region and filaments that are broken into several fragments, the filaments are classified into isolated filaments and non-isolated filaments. The mean precision, recall, APAP, and F1 obtained using the proposed method are 90.83%, 83.88%, 82.86%, and 87.22%, respectively. The results show that the method performs well in detecting and classifying isolated and non-isolated filaments, especially in solving the fragments problem of how to detect a filament that is broken into several fragments. The method also has good performance in handling various images, even with existing uneven brightness or low contrast. The precision of filament masks still needs to be improved in the future.

Formation and Characteristics of Filament Threads in Double-Dipped Magnetic Flux Tubes

Jinhan **Guo**, Yuhao Zhou, Yang Guo, Yiwei Ni, Judy Karpen, Pengfei Chen
ApJ **920** 131 **2021**
https://arxiv.org/pdf/2107.12181.pdf
https://iopscience.iop.org/article/10.3847/1538-4357/ac17e8/pdf
As one of the main formation mechanisms of solar filament formation, the chromospheric evaporation-coronal condensation model has been confirmed by numerical simulations to explain the formation of filament threads very well in flux tubes with single dips. However, coronal magnetic extrapolations indicated that some magnetic field lines might possess more than one dip. It is expected that the formation process would be significantly different in this case compared to a single-dipped magnetic flux tube. In this paper, based on the evaporation-condensation model, we study filament thread formation in double-dipped magnetic flux tubes by numerical simulations. We find that only with particular combinations of magnetic configuration and heating, e.g., concentrated localized heating and a long magnetic flux tube with deep dips, can two threads form and persist in a double-dipped magnetic flux tube. Comparing our parametric survey with observations, we conclude that such magnetically connected threads due to multiple dips are more likely to exist in quiescent filaments than in active-region filaments. Moreover, we find that these threads are usually shorter than independently trapped threads, which might be one of the reasons why quiescent filaments have short threads. These characteristics of magnetically connected threads could also explain barbs and vertical threads in quiescent filaments.

Magnetic Twists of Solar Filaments

Jinhan **Guo**, Yiwei Ni, Ye Qiu, Ze Zhong, Yang Guo, Pengfei Chen
ApJ **917** 81 **2021**
https://arxiv.org/pdf/2107.02580.pdf
https://doi.org/10.3847/1538-4357/ac0cef
Solar filaments are cold and dense materials situated in magnetic dips, which show distinct radiation characteristics compared to the surrounding coronal plasma. They are associated with coronal sheared and twisted magnetic field

lines. However, the exact magnetic configuration supporting a filament material is not easy to be ascertained because of the absence of routine observations of the magnetic field inside filaments. Since many filaments lie above weak-field regions, it is nearly impossible to extrapolate their coronal magnetic structures by applying the traditional methods to noisy photospheric magnetograms, in particular the horizontal components. In this paper, we construct magnetic structures for some filaments with the regularized Biot--Savart laws and calculate their magnetic twists. Moreover, we make a parameter survey for the flux ropes of the Titov-Demoulin-modified model to explore the factors affecting the twist of a force-free magnetic flux rope. It is found that the twist of a force-free flux rope is proportional to its axial length to minor radius ratio, and is basically independent of the overlying background magnetic field strength. Thus, we infer that long quiescent filaments are likely to be supported by more twisted flux ropes than short active-region filaments, which is consistent with observations. **2010-08-07, 2011-06-21, 2011-07-08, 2012-05-05, 2012-05-10**

Reconstructing 3D Magnetic Topology of On-disk Prominence Bubbles from Stereoscopic Observations

Yilin **Guo**, Yijun Hou, Ting Li, Jun Zhang

ApJL **911** L9 **2021**

https://arxiv.org/pdf/2103.07860.pdf
https://iopscience.iop.org/article/10.3847/2041-8213/abee92/pdf
https://doi.org/10.3847/2041-8213/abee92

Bubbles, the semi-circular voids below quiescent prominences (filaments), have been extensively investigated in the past decade. However, hitherto the magnetic nature of bubbles cannot be verified due to the lack of on-disk photospheric magnetic field observations. Here for the first time, we find and investigate an on-disk prominence bubble around a filament barb on **2019 March 18** based on stereoscopic observations from NVST, SDO, and STEREO-A. In high-resolution NVST Hα images, this bubble has a sharp arch-like boundary and a projected width of ∼26 Mm. Combining SDO and STEREO-A images, we further reconstruct 3D structure of the bubble boundary, whose maximum height is ∼15.6 Mm. The squashing factor Q map deduced from extrapolated 3D magnetic fields around the bubble depicts a distinct arch-shaped interface with a height of ∼11 Mm, which agrees well with the reconstructed 3D structure of the observed bubble boundary. Under the interface lies a set of magnetic loops, which is rooted on a surrounding photospheric magnetic patch. To be more persuasive, another on-disk bubble on **2019 June 10** is presented as a supplement. According to these results obtained from on-disk bubble observations, we suggest that the bubble boundary corresponds to the interface between the prominence dips (barb) and the underlying magnetic loops rooted nearby. It is thus reasonable to speculate that the bubble can form around a filament barb below which there is a photospheric magnetic patch.

Kink Oscillations in Solar Coronal Loops with Elliptical Cross-Sections. I. the linear regime

Mingzhe **Guo**, Bo Li, Tom Van Doorsselaere

ApJ **904** 116 **2020**

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The cross sections of solar coronal loops are suggested to be rarely circular. We examine linear kink oscillations in straight, density-enhanced, magnetic cylinders with elliptical cross-sections by solving the three-dimensional magnetohydrodynamic equations from an initial-value-problem perspective. Motivated by relevant eigen-mode analyses, we distinguish between two independent polarizations, one along the major axis (the M-modes) and the other along the minor one (the m-modes). We find that, as happens for coronal loops with circular cross-sections, the apparent damping of the transverse displacement of the loop axis is accompanied by the accumulation of transverse Alfvénic motions and the consequent development of small-scales therein, suggesting the robustness of the concepts of resonant absorption and phase-mixing. In addition, two stages can in general be told apart in the temporal evolution of the loop displacement; a Gaussian time dependence precedes an exponential one. For the two examined density ratios between loops and their surroundings, the periods of the M-modes (m-modes) tend to increase (decrease) with the major-to-minor-half-axis ratio, and the damping times in the exponential stage for the M-modes tend to exceed their m-mode counterparts. This is true for the two transverse profiles we examine. However, the relative magnitudes of the damping times in the exponential stage for different polarizations depend on the specification of the transverse profile and/or the density contrast. The applications of our numerical findings are discussed in the context of coronal seismology.

Wave heating in simulated multi-stranded coronal loops

Mingzhe **Guo**, Tom Van Doorsselaere, Konstantinos Karampelas, Bo Li

ApJ **883** 20 **2019**

https://arxiv.org/pdf/1907.08013.pdf

It has been found that the Kelvin-Helmholtz instability (KHI) induced by both transverse and torsional oscillations in coronal loops can reinforce the effects of wave heating. In this study, we model a coronal loop as a system of individual strands, and we study wave heating effects by considering a combined transverse and torsional driver at the loop footpoint. We deposit the same energy into the multi-stranded loop and an equivalent monolithic loop, and then observe a faster increase in the internal energy and temperature in the multi-stranded model. Therefore, the multi-stranded model is more efficient in starting the heating process. Moreover, higher temperature is observed near the footpoint in the multi-stranded loop and near the apex in the monolithic loop. The apparent heating location in the multi-stranded loop agrees with the previous predictions and observations. Given the differences in the results from our multi-stranded loop and monolithic loop simulations, and given that coronal loops are suggested to be multi-stranded on both theoretical and observational grounds, our results suggest that the multi-strandedness of coronal loops needs to be incorporated in future wave-based heating mechanisms.

Heating effects from driven transverse and Alfvén waves in coronal loops

Mingzhe **Guo**, Tom Van Doorsselaere, Kostas Karampelas, Bo Li, Patrick Antolin, Ineke De Moortel

2018

https://arxiv.org/pdf/1811.07608.pdf

Recent numerical studies revealed that transverse motions of coronal loops can induce the Kelvin-Helmholtz Instability (KHI). This process could be important in coronal heating because it leads to dissipation of energy at small spatial-scale plasma interactions. Meanwhile, small amplitude decayless oscillations in coronal loops have been discovered recently in observations of SDO/AIA. We model such oscillations in coronal loops and study wave heating effects, considering a kink and Alfv{é}n driver separately and a mixed driver at the bottom of flux tubes. Both the transverse and Alfv{é}n oscillations can lead to the KHI. Meanwhile, the Alfv{é}n oscillations established in loops will experience phase mixing. Both processes will generate small spatial-scale structures, which can help the dissipation of wave energy. Indeed, we observe the increase of internal energy and temperature in loop regions. The heating is more pronounced for the simulation containing the mixed kink and Alfv{é}n driver. This means that the mixed wave modes can lead to a more efficient energy dissipation in the turbulent state of the plasma and that the KHI eddies act as an agent to dissipate energy in other wave modes. Furthermore, we also obtained forward modelling results using the FoMo code. We obtained forward models which are very similar to the observations of decayless oscillations. Due to the limited resolution of instruments, neither Alfv{é}n modes nor the fine structures are observable. Therefore, this numerical study shows that Alfv{é}n modes probably can co-exist with kink modes, leading to enhanced heating.

Inferring flare loop parameters with measurements of standing sausage modes

Ming-Zhe **Guo**, Shao-Xia Chen, Bo Li, Li-Dong Xia, Hui Yu

Solar Phys. Volume 291, Issue 3, pp 877-896 **2016**

http://arxiv.org/pdf/1512.03692v1.pdf

Standing fast sausage modes in flare loops were suggested to account for a considerable number of quasi-periodic pulsations (QPPs) in the light curves of solar flares. This study continues our investigation into the possibility to invert the measured periods P and damping times τ of sausage modes to deduce the transverse Alfv\'en time R/vAi, density contrast ρi/ρe, and the steepness of the density distribution transverse to flare loops. A generic dispersion relation (DR) governing linear sausage modes is derived for pressureless cylinders where density inhomogeneity of arbitrary form takes place within the cylinder. We show that in general the inversion problem is under-determined for QPP events where only a single sausage mode exists, be the measurements spatially resolved or unresolved. While R/vAi can be inferred to some extent, the range of possible steepness parameters may be too broad to be useful. However, for spatially resolved measurements where an additional mode is present, it is possible to deduce self-consistently ρi/ρe, the profile steepness, and the internal Alfv\'en speed vAi. We show that at least for a recent QPP event that involves a fundamental kink mode in addition to a sausage one, flare loop parameters are well constrained, even if the specific form of the transverse density distribution remains unknown. We conclude that spatially resolved, multi-mode QPP measurements need to be pursued for inferring flare loop parameters.

MHD Seismology of a Coronal Loop System by the First Two Modes of Standing Kink Waves

Y. **Guo**, R. Erdelyi, A. K. Srivastava, Q. Hao, X. Cheng, P. F. Chen, M. D. Ding, B. N. Dwivedi

ApJ, **799** 151 **2015**

http://arxiv.org/pdf/1411.7095v1.pdf

We report the observation of the first two harmonics of the horizontally polarized kink waves excited in a coronal loop system lying at south-east of AR 11719 on 2013 April 11. The detected periods of the fundamental mode (P_1), its first overtone (P_2) in the northern half, and that in the southern one are 530.2 pm 13.3, 300.4 pm 27.7, and 334.7 pm 22.1 s, respectively. The periods of the first overtone in the two halves are the same considering uncertainties in the measurement. We estimate the average electron density, temperature, and length of the loop system as (5.1 pm 0.8) x 10^8 cm^{-3}, 0.65 pm 0.06 MK, and 203.8 pm 13.8 Mm, respectively. As a zeroth order estimation, the magnetic field strength, B = 8.2 pm 1.0 G, derived by the coronal seismology using the fundamental kink mode matches with that derived by a potential field model. The extrapolation model also shows the asymmetric and nonuniform distribution of the magnetic field along the coronal loop. Using the amplitude profile distributions of both the fundamental mode and its first overtone, we observe that the antinode positions of both the fundamental mode and its first overtone shift towards the weak field region along the coronal loop. The results indicate that the density stratification and the temperature difference effects are larger than the magnetic field variation effect on the period ratio. On the other hand, the magnetic field variation has a greater effect on the eigenfunction of the first overtone than the density stratification does for this case.

MHD Seismology of a Coronal Loop System by the First Two Modes of Standing Kink Waves

Y. **Guo**, R. Erdélyi, A. K. Srivastava, Q. Hao, X. Cheng, P. F. Chen, M. D. Ding, B. N. Dwivedi

ApJ **201**4

http://arxiv.org/pdf/1411.7095v1.pdf

We report the observation of the first two harmonics of the horizontally polarized kink waves excited in a coronal loop system lying at south-east of AR 11719 on **2013 April 11**. The detected periods of the fundamental mode (P1), its first overtone (P2) in the northern half, and that in the southern one are 530.2±13.3, 300.4±27.7, and 334.7±22.1 s, respectively. The periods of the first overtone in the two halves are the same considering uncertainties in the measurement. We estimate the average electron density, temperature, and length of the loop system as (5.1±0.8)×108 cm−3, 0.65±0.06 MK, and 203.8±13.8 Mm, respectively. As a zeroth order estimation, the magnetic field strength, B=8.2±1.0 G, derived by the coronal seismology using the fundamental kink mode matches with that derived by a potential field model. The extrapolation model also shows the asymmetric and nonuniform distribution of the magnetic field along the coronal loop. Using the amplitude profile distributions of both the fundamental mode and its first overtone, we observe that the antinode positions of both the fundamental mode and its first overtone shift towards the weak field region along the coronal loop. The results indicate that the density stratification and the temperature difference effects are larger than the magnetic field variation effect on the period ratio. On the other hand, the magnetic field variation has a greater effect on the eigenfunction of the first overtone than the density stratification does for this case.

Driving Mechanism and Onset Condition of a Confined Eruption

Y. **Guo**1,2,3, M. D. Ding1,2, B. Schmieder3, H. Li4, T. T¨or¨ok3,5, T. Wiegelmann6

E-print, Nov **2010**, ApJL

We study a confined eruption accompanied by an M1.1 flare in solar active region (AR) NOAA 10767 on **2005 May 27**, where a pre-eruptive magnetic flux rope was reported in a nonlinear force-free field (NLFFF) extrapolation. The observations show a strong writhing motion of the erupting structure, suggesting that a flux rope was indeed present and converted some of its twist into writhe in the course of the eruption. Using the NLFFF extrapolation, we calculate the twist of the pre-eruptive flux rope and find that it is in very good agreement with thresholds of the helical kink instability found in numerical simulations. We conclude that the activation and rise of the flux rope were triggered and driven by the instability. Using a potential field extrapolation, we also estimate the height distribution of the decay index of the external magnetic field in the AR one hour prior to the eruption. We find that the decay index stays below the threshold for the torus instability for a significant height range above the erupting flux rope. This provides a possible explanation for the confinement of the eruption to the low corona.

COEXISTING FLUX ROPE AND DIPPED ARCADE SECTIONS ALONG ONE SOLAR FILAMENT

Y. **Guo**1,2, B. Schmieder2, P. D´emoulin2, T. Wiegelmann3, G. Aulanier2, T. T¨or¨ok2, and V. Bommier4

The Astrophysical Journal, 714:343–354, **2010** May; **File**

We compute the three-dimensional magnetic field of an active region in order to study the magnetic configuration of active region filaments. The nonlinear force-free field model is adopted to compute the magnetic field above the photosphere, where the vector magnetic field was observed by THEMIS/MTR on **2005 May 27**. We propose a new method to remove the 180◦ ambiguity of the transverse field. Next, we analyze the implications of the preprocessing of the data by minimizing the total force and torque in the observed vector fields. This step provides a consistent bottom boundary condition for the nonlinear force-free field model. Then, using the optimization method to compute the coronal field, we find a magnetic flux rope along the polarity inversion line. The magnetic flux rope aligns well with part of an Hα filament, while the total distribution of the magnetic dips coincides with the whole Hα filament. This implies that the magnetic field structure in one section of the filament is a flux rope, while the other is a sheared arcade. The arcade induced a left-bearing filament in the magnetic field of negative helicity, which is opposite to the chirality of barbs that a flux rope would induce in a magnetic field of the same helicity sign. The field strength in the center of the flux rope is about 700 G, and the twist of the field lines is ~1.4 turns.

A FLUX ROPE ERUPTION TRIGGERED BY JETS

Juan **Guo**1, Yu Liu2, Hongqi Zhang1, Yuanyong Deng1, Jiaben Lin1, and Jiangtao Su1

Astrophysical Journal, 711:1057–1061, **2010** March

We present an observation of a filament eruption caused by recurrent chromospheric plasma injections (surges/jets) on **2006 July 6**. The filament eruption was associated with an M2.5 two-ribbon flare and a coronal mass ejection (CME). There was a light bridge in the umbra of the main sunspot of NOAA 10898; one end of the filament was terminated at the region close to the light bridge, and recurrent surges were observed to be ejected from the light bridge. The surges occurred intermittently for about 8 hr before the filament eruption, and finally a clear jet was found at the light bridge to trigger the filament eruption. We analyzed the evolutions of the relative darkness of the filament and the loaded mass by the continuous surges quantitatively. It was found that as the occurrence of the surges, the relative darkness of the filament body continued growing for about 3–4 hr, reached its maximum, and kept stable for more than 2 hr until it erupted. If suppose 50% of the ejected mass by the surges could be trapped by the filament channel, then the total loaded mass into the filament channelwill be about 0.57×10^{16} g with a momentum of 0.57×10^{22} g cm s^{-1} by 08:08 UT, which is a non-negligible effect on the stability of the filament. Based on the observations, we present amodel showing the important role that recurrent chromospheric mass injection play in the evolution and eruption of a flux rope. Our study confirms that the surge activities can efficiently supply the necessary material for some filament formation. Furthermore, our study indicates that the continuous mass with momentum loaded by the surge activities to the filament channel could make the filament unstable and cause it to erupt.

Spectroscopic and imaging observations of transient hot and cool loops by IRIS and SDO

Girjesh R. **Gupta**, Sushree S. Nayak

MNRAS Volume 512, Issue 3, Pages 3149–3162 **2022**

https://arxiv.org/pdf/2203.03529

https://doi.org/10.1093/mnras/stac657

Coronal loops are basic building blocks of solar atmosphere and are observed on various length scales. However, their formation mechanism is still unclear. In this paper, we present the spectroscopic and imaging observations of small-scale transients and subsequent formation of transient loops. For the purpose, we have utilized the multi-wavelength observations recorded by AIA and IRIS-SJI, along with spectroscopic measurements provided by IRIS. For the photospheric magnetic field data, we obtained line-of-sight magnetogram data provided by HMI. Small-scale transients are simultaneously observed with several EUV and UV passbands of AIA and IRIS-SJI. HMI magnetogram provides evidence of negative flux cancellations beneath these transients. Differential Emission Measure (DEM) analysis shows that one of the transient attains temperature up to 8 MK whereas another one reaches only up to 0.4 MK. These transients further lead to the formation of small-scale loops with similar temperature distributions, and thus termed as hot and cool loops respectively. During the course of events, IRIS slit was rastering the region and thus provided spectroscopic measurements at both transients and associated loops. This enabled us to perform in-depth investigations of hot and cool loops. Using density sensitive O IV line pair, we obtained average electron densities along the hot and cool loop to be 1011.2 and 1010.8 cm−3 respectively. Energy estimates suggest that flux cancellation can easily power the hot transient whereas is insufficient for cool transient. Life time estimates and magnetic field extrapolation suggest presence of small-scale and fine structures within these loops. Results provide crucial ingredients on the physics of loop formation and involved thermodynamics.

Exploring the damping of Alfvén waves along a long off-limb coronal loop, up to 1.4 R⊙

Girjesh R. **Gupta**, G. Del Zanna, H. E. Mason

A&A 627, A62 **2019**

https://arxiv.org/pdf/1905.08194.pdf

The Alfvén wave energy flux in the corona can be explored using the electron density and velocity amplitude of the waves. The velocity amplitude of Alfvén waves can be obtained from the non-thermal velocity of the spectral line profiles. Previous calculations of the Alfvén wave energy flux with height in active regions and polar coronal holes have provided evidence for the damping of Alfvén waves with height. We present off-limb Hinode EUV imaging spectrometer (EIS) observations of a long coronal loop up to 1.4~R⊙. We have obtained the electron density along the loop and found the loop to be almost in hydrostatic equilibrium. We obtained the temperature using the EM-loci method and found the loop to be isothermal across, as well as along, the loop with a temperature of about 1.37 MK. We significantly improve the estimate of non-thermal velocities over previous studies by using the estimated ion (equal to electron) temperature. Estimates of electron densities are improved using the significant updates of the

CHIANTI v.8 atomic data. More accurate measurements of propagating Alfvén wave energy along the coronal loop and its damping are presented up to distances of 1.4 R⊙, further than have been previously explored. The Alfvén wave energy flux obtained could contribute to a significant part of the coronal losses due to radiation along the loop. **9 May 2007**

Observation and Modeling of Chromospheric Evaporation in a Coronal Loop Related to Active Region Transient Brightening

G. R. **Gupta**, Aveek Sarkar, Durgesh Tripathi

ApJ **2018**

https://arxiv.org/pdf/1803.11172.pdf

Using the observations recorded by Atmospheric Imaging Assembly (AIA) on-board the Solar Dynamics Observatory (SDO), the Interface Region Imaging Spectrograph (IRIS) and the Extreme-ultraviolet Imaging Spectrometer (EIS) and X-Ray Telescope (XRT) both on-board Hinode, we present the evidence of chromospheric evaporation in a coronal loop after the occurrence of two active region transient brightenings (ARTBs) at the two footpoints. The chromospheric evaporation started nearly simultaneously in all the three hot channels of AIA such as 131~{\AA}, 94~{\AA} and 335~{\AA}, which was observed to be temperature dependent, being fastest in the highest temperature channel. The whole loop became fully brightened following the ARTBs after ≈25~s in 131~{\AA}, ≈40~s in 94~{\AA}, and ≈6.5~min in 335~{\AA}. The DEM measurements at the two footpoints (i.e., of two ARTBs) and the loop-top suggest that the plasma attained a maximum temperature of ∼10~MK at all these locations. The spectroscopic observations from IRIS revealed the presence of redshifted emission of ∼20~km~s−1in cooler lines like \ion{C}{2} and \ion{Si}{4} during the ARTBs that was co-temporal with the evaporation flow at the footpoint of the loop. During the ARTBs, the line width of \ion{C}{2} and \ion{Si}{4} increased nearly by a factor of two during the peak emission. Moreover, enhancement in the line width preceded that in the Doppler shift which again preceded enhancement in the intensity. The observed results were qualitatively reproduced by 1-D hydrodynamic simulations where energy was deposited at both the footpoints of a monolithic coronal loop that mimicked the ARTBs identified in the observations. **2014 March 4**

Spectroscopic Observations of a Coronal Loop: Basic Physical Plasma Parameters Along the Full Loop Length

G. R. **Gupta**, Durgesh Tripathi, Helen E. Mason

ApJ **2015**

http://arxiv.org/pdf/1412.7428v1.pdf

Coronal loops are the basic structures of the solar transition region and corona. The understanding of physical mechanism behind the loop heating, plasma flows, and filling are still considered a major challenge in the solar physics. The mechanism(s) should be able to supply mass to the corona from the chromosphere and able to heat the plasma over 1 MK within the small distance of few hundred km from the chromosphere to the corona. This problem makes coronal loops an interesting target for detailed study. In this study, we focus on spectroscopic observations of a coronal loop, observed in its full length, in various spectral lines as recorded by the Extreme-ultraviolet Imaging Spectrometer (EIS) on-board Hinode. We derive physical plasma parameters such as electron density, temperature, pressure, column depth, and filling factors along the loop length from one foot-point to the another. The obtained parameters are used to infer whether the observed coronal loop is over-dense or under-dense with respect to gravitational stratification of the solar atmosphere. These new measurements of physical plasma parameters, from one foot-point to another, provide important constraints on the modeling of the mass and energy balance in the coronal loops. **11 Dec 2010**

Exploring the Prominence-Corona Connection and its Expansion into the Outer Corona Using Total Solar Eclipse Observations

Shadia Rifai **Habbal1**, Huw Morgan2, and Miloslav Druckmüller

2014 ApJ 793 119

Prominences constitute the most complex magnetic structures in the solar corona. The ubiquitous presence of their seemingly confined dense and cool plasma in an otherwise million-degree environment remains a puzzle. Using a decade of white light total solar eclipse observations, we show how these images reveal an intricate relationship between prominences and coronal structures both in their immediate vicinity, known as coronal cavities, and in the extended corona out to several solar radii. Observations of suspended prominences and twisted helical structures spanning several solar radii are central to these findings. The different manifestations of the prominence-corona interface that emerge from this study underscore the fundamental role played by prominences in defining and controlling the complex expansion and dynamic behavior of the solar magnetic field in the neighborhood of magnetic polarity reversal regions. This study suggests that the unraveling of prominences and the outward expansion of the helical twisted field lines linked to them could be the solar origin of twisted magnetic flux ropes detected in interplanetary space, and of the mechanism by which the Sun sheds its magnetic helicity. This work also underscores the likely role of the prominence-corona interface as a source of the slow solar wind.

A DROPLET MODEL OF QUIESCENT PROMINENCE DOWNFLOWS

G. **Haerendel**1 and T. Berger

2011 ApJ 731 82

Observations of quiescent prominences with the Solar Optical Telescope on the Hinode satellite have revealed the ubiquitous existence of downflows forming coherent thin and highly structured vertically oriented threads with velocities between 10 and 20 km s–1. Their widths range between 300 and 500 km. They are often initiated at the top of the visible prominence, but sometimes also at intermediate level. We propose that the downflows are made of plasma packets that squeeze themselves through the dominantly horizontal field under the action of gravity. Their origin is assumed to be hot plasma supplied from either inside or the immediate vicinity of the prominence and condensing at its top. Under compression and further cooling, the matter overflows to the flanks of the prominence dragging its magnetic field with it. Under the increasing action of gravity, vertical structures are forming which eventually disconnect from the field of the inflow channel thus forming finite plasma packets. This process is reminiscent of water flowing over a mountain ridge and breaking up into a multitude of droplets. Like water droplets being subject to air drag, the falling plasma droplets experience a drag force by the horizontal prominence field and assume a steady vertical velocity. This happens via the excitation of Alfvén waves. Lateral confinement by the prominence field determines their spatial extent. The small scales of the droplets and the directional balance of their internal tangled magnetic fields can explain the absence of appreciable vertical components in magnetic field measurements. On the basis of the observed width and vertical speed of the downflows and by adopting a prominence field of about 8 G, we derive central density and temperature of the droplets, which turn out to be quite consistent with known prominence characteristics. In the formulation of the drag force a dimensionless "magnetic drag coefficient" has been introduced with a value well below unity.

Are Nonthermal Velocities in Active Region Coronal Loops Anisotropic?

Michael **Hahn**1, Mahboubeh Asgari-Targhi2, and Daniel Wolf Savin1

2023 ApJ 953 3

https://iopscience.iop.org/article/10.3847/1538-4357/acdfd2/pdf

We have measured line widths in active region coronal loops in order to determine whether the nonthermal broadening is anisotropic with respect to the magnetic field direction. These nonthermal velocities are caused by unresolved fluid motions. Our analysis method combines spectroscopic data and a magnetic field extrapolation. We analyzed spectra from the Extreme Ultraviolet Imaging Spectrometer on Hinode. A differential emission measure analysis showed that many spectral lines that are commonly considered to be formed in the active region have a substantial contribution from the background quiet Sun. From these spectra we identified lines whose emission was dominated by the active region loops rather than background sources. Using these lines, we constructed maps of the nonthermal velocity. With data from the Helioseismic Magnetic Imager on the Solar Dynamics Observatory and the Coronal Modeling System nonlinear force-free magnetic field reconstruction code, we traced several of the magnetic field lines through the active region. Comparing the spectroscopic and magnetic data, we looked for correlations of the nonthermal velocity with the viewing angle between the line of sight and the magnetic field. We found that nonthermal velocities show a weak anticorrelation with the viewing angle. That is, the tendency is for the nonthermal velocity to be slightly larger in the parallel direction. This parallel broadening may be due to acoustic waves or unresolved parallel flows. **2011 April 19**

Statistical Study of the Magnetic Field Orientation in Solar Filaments

Yoichiro **Hanaoka**, Takashi Sakurai

2017 *ApJ* **851** 130

https://arxiv.org/pdf/1711.07735.pdf

We have carried out a statistical study of the average orientation of the magnetic field in solar filaments with respect to their axes for more than 400 samples, based on data taken with daily full-Sun, full-Stokes spectropolarimetric observations using the He I 1083.0 nm line. The major part of the samples are the filaments in the quiet areas, but those in the active areas are included as well. The average orientation of the magnetic field in filaments shows a systematic property depending on the hemisphere; the direction of the magnetic field in filaments in the northern (southern) hemisphere mostly deviates clockwise (counterclockwise) from their axes, which run along the magnetic polarity inversion line. The deviation angles of the magnetic field from the axes, are concentrated between 10--30 deg. This hemispheric pattern is consistent with that revealed for chirality of filament barbs, filament channels and for other solar features found to possess chirality. For some filaments it was confirmed that their magnetic field direction is locally parallel to their structure seen in Halpha images. Our results for the first time confirmed this hemispheric pattern with the direct observation of the magnetic field in filaments. Interestingly, the filaments which show the opposite magnetic field deviation to the hemispheric pattern, are in many cases found above the polarity inversion line whose ambient photospheric magnetic field has the polarity alignment being opposite to that of active regions following the Hale-Nicholson law. **2014 November 23, 2015 October 27.**

Automated Detection Methods for Solar Activities and an Application for Statistic Analysis of Solar Filament

Q. Hao, P. F. Chen, C. Fang

Proceedings IAU Symposium No. 340, **2018**

https://arxiv.org/pdf/1804.03320.pdf

With the rapid development of telescopes, both temporal cadence and the spatial resolution of observations are increasing. This in turn generates vast amount of data, which can be efficiently searched only with automated detections in order to derive the features of interest in the observations. A number of automated detection methods and algorithms have been developed for solar activities, based on the image processing and machine learning techniques. In this paper, after briefly reviewing some automated detection methods, we describe our efficient and versatile automated detection method for solar filaments. It is able not only to recognize filaments, determine the features such as the position, area, spine, and other relevant parameters, but also to trace the daily evolution of the filaments. It is applied to process the full disk H-alpha data observed in nearly three solar cycles, and some statistic results are presented.

Statistical Analysis of Filament Features Based on the Hα Solar Images from 1988 to 2013 by Computer Automated Detection Method

Q. **Hao**, C. Fang, W. Cao, P. F. Chen

ApJS **221** 33 **2015**

http://arxiv.org/pdf/1511.04692v1.pdf

We improve our filament automated detection method which was proposed in our previous works. It is then applied to process the full disk Hα data mainly obtained by Big Bear Solar Observatory (BBSO) from 1988 to 2013, spanning nearly 3 solar cycles. The butterfly diagrams of the filaments, showing the information of the filament area, spine length, tilt angle, and the barb number, are obtained. The variations of these features with the calendar year and the latitude band are analyzed. The drift velocities of the filaments in different latitude bands are calculated and studied. We also investigate the north-south (N-S) asymmetries of the filament numbers in total and in each subclass classified according to the filament area, spine length, and tilt angle. The latitudinal distribution of the filament number is found to be bimodal. About 80% of all the filaments have tilt angles within [0{\deg}, 60{\deg}]. For the filaments within latitudes lower (higher) than 50{\deg} the northeast (northwest) direction is dominant in the northern hemisphere and the southeast (southwest) direction is dominant in the southern hemisphere. The latitudinal migrations of the filaments experience three stages with declining drift velocities in each of solar cycles 22 and 23, and it seems that the drift velocity is faster in shorter solar cycles. Most filaments in latitudes lower (higher) than 50{\deg} migrate toward the equator (polar region). The N-S asymmetry indices indicate that the southern hemisphere is the dominant hemisphere in solar cycle 22 and the northern hemisphere is the dominant one in solar cycle 23. ftp://ftp.bbso.njit.edu/pub/archive

Can We Determine the Filament Chirality by the Filament Footpoint Location or the Barb-bearing?

Q. **Hao**, Y. Guo, C. Fang, P. F. Chen, W. Cao

RAA **2015**

http://arxiv.org/pdf/1506.08490v1.pdf

We attempt to propose a method for automatically detecting the solar filament chirality and barb bearing. We first introduce the unweighted undirected graph concept and adopt the Dijkstra shortest-path algorithm to recognize the filament spine. Then, we use the polarity inversion line (PIL) shift method for measuring the polarities on both sides of the filament, and employ the connected components labeling method to identify the barbs and calculate the angle between each barb and the spine to determine the bearing of the barbs, i.e., left or right. We test the automatic detection method with H-alpha filtergrams from the Big Bear Solar Observatory (BBSO) H-alpha archive and magnetograms observed with the Helioseismic and Magnetic Imager (HMI) on board the Solar Dynamics Observatory (SDO). Four filaments are automatically detected and illustrated to show the results. The barbs in different parts of a filament may have opposite bearings. The filaments in the southern hemisphere (northern hemisphere) mainly have left-bearing (right-bearing) barbs and positive (negative) magnetic helicity, respectively. The tested results demonstrate that our method is efficient and effective in detecting the bearing of filament barbs. It is demonstrated that the conventionally believed one-to-one correspondence between filament chirality and barb bearing is not valid. The correct detection of the filament axis chirality should be done by combining both imaging morphology and magnetic field observations. **2011 Oct 12, 2012 Aug 03, 2013 Feb 18, 2013 May 31**

Developing an Advanced Automated Method for Solar Filament Recognition and Its Scientific Application to a Solar Cycle of MLSO Hα Data

Q. **Hao**, C. Fang, P. F. Chen

Solar Physics, September **2013**, Volume 286, Issue 2, pp 385-404

We developed a method to automatically detect and trace solar filaments in Hα full-disk images. The program is able not only to recognize filaments and determine their properties, such as the position, the area, the spine, and other relevant parameters, but also to trace the daily evolution of the filaments. The program consists of three steps: First, preprocessing is applied to correct the original images; second, the Canny edge-detection method is used to detect filaments; third, filament properties are recognized through morphological operators. To test the algorithm, we successfully applied it to observations from the Mauna Loa Solar Observatory (MLSO). We analyzed Hα images obtained by the MLSO from 1998 to 2009 and obtained a butterfly diagram of filaments. This shows that the latitudinal migration of solar filaments has three trends in Solar Cycle 23: The drift velocity was fast from 1998 to the solar maximum, after which it became relatively slow. After 2006, the migration became divergent, signifying the solar minimum. About 60 % of the filaments with latitudes higher than 50∘ migrate toward the polar regions with relatively high velocities, and the latitudinal migrating speeds in the northern and the southern hemispheres do not differ significantly in Solar Cycle 23.

The Impact of a Filament Eruption on Nearby High-lying Cool Loops

L. K. **Harra**1, S. A. Matthews1, D. M. Long1, G. A. Doschek2, and B. De Pontieu

2014 ApJ 792 93

http://fr.arxiv.org/pdf/1409.0377v1

http://arxiv.org/pdf/1409.0377v1.pdf

The first spectroscopic observations of cool Mg II loops above the solar limb observed by NASA's Interface Region Imaging Spectrograph (IRIS) are presented. During the observation period, IRIS is pointed off-limb, allowing the observation of high-lying loops, which reach over 70 Mm in height. Low-lying cool loops were observed by the IRIS slit-jaw camera for the entire four-hour observing window. There is no evidence of a central reversal in the line profiles, and the Mg II h/k ratio is approximately two. The Mg II spectral lines show evidence of complex dynamics in the loops with Doppler velocities reaching ±40 km s–1. The complex motions seen indicate the presence of multiple threads in the loops and separate blobs. Toward the end of the observing period, a filament eruption occurs that forms the core of a coronal mass ejection. As the filament erupts, it impacts these high-lying loops, temporarily impeding these complex flows, most likely due to compression. This causes the plasma motions in the loops to become blueshifted and then redshifted. The plasma motions are seen before the loops themselves start to oscillate as they reach equilibrium following the impact. The ratio of the Mg h/k lines also increases following the impact of the filament. 26-Oct-13

Chromospheric Magnetic Field Measurements in a Flare and an Active Region Filament

J. W. **Harvey**

Solar Physics, Volume 280, Number 1 (**2012**), 69-81

Intensity (I) and circular polarization (V) spectra using the 854.2 nm line of Ca ii with 3.65 pm spectral and 1 arcsecond spatial sampling were obtained with the SOLIS vector spectromagnetograph on **8 November 2011**. An active region filament showing Doppler shifts as large as 50 km s−1 and an unrelated C1.8 flare were observed. Line-of-sight flux density estimates of the magnetic field (BLOS) were mapped as a function of wavelength in both of these features using the weak-field Zeeman-splitting approximation that V∝dI/dλ. The filament had a large amount of structure in intensity and velocity but remarkably little BLOS structure, which varied smoothly from 35 to 55 G (gauss). Two flare emission kernels showed average BLOS values of 415 and −215 G, about 84 % of the underlying photospheric fields. Counter to this modest strength decrease with increasing height, in nearly all parts of the brighter flare kernel there appears to be a substantial gradient of BLOS over the heights corresponding to the core of the 854.2 nm line. This variation, if verified, may be related to compression of the chromosphere associated with flare-induced evaporation. Alternatively, it might be a spurious result if the profile of the line core is narrowed in the magnetic part of the flare kernel. The results presented here are generally similar to previous, rather sparse observations. Observations of the type reported here are made daily and could be used to greatly increase knowledge about the chromospheric magnetic field in active solar features.

ALMA as a prominence thermometer: First observations

Petr **Heinzel**, Arkadiusz Berlicki, Miroslav Bárta, Paweł Rudawy, Stanislav Gunár, Nicolas Labrosse, Krzysztof Radziszewski

ApJL **927** L29 **2022**

https://arxiv.org/pdf/2202.12761.pdf

https://iopscience.iop.org/article/10.3847/2041-8213/ac588f/pdf

We present first prominence observations obtained with ALMA in Band 3 at the wavelength of 3 mm. High-resolution observations have been coaligned with the MSDP Hα data from Wroclaw-Bialków large coronagraph at similar spatial resolution. We analyze one particular co-temporal snapshot, first calibrating both ALMA and MSDP data and then demonstrating a reasonable correlation between both. In particular we can see quite similar fine-structure patterns in both ALMA brightness temperature maps and MSDP maps of Hα intensities. Using ALMA we intend to derive the prominence kinetic temperatures. However, having current observations only in one band, we use an independent diagnostic constraint which is the Hα line integrated intensity. We develop an inversion code and show that it can provide realistic temperatures for brighter parts of the prominence where one gets a unique solution, while within faint structures such inversion is ill conditioned. In brighter parts ALMA serves as a prominence thermometer, provided that the optical thickness in Band 3 is large enough. In order to find a relation between brightness and kinetic temperatures for a given observed Hα intensity, we constructed an extended grid of non-LTE prominence models covering a broad range of prominence parameters. We also show the effect of the plane-of-sky filling factor on our results. **April 19, 2018,**

Fast approximate radiative transfer method for visualizing the fine structure of prominences in the hydrogen Hα line

P. **Heinzel**1,3, S. Gunár2† and U. Anzer

A&A 579, A16 (**2015**)

Aims. We present a novel approximate radiative transfer method developed to visualize 3D whole-prominence models with multiple fine structures using the hydrogen Hα spectral line.
Methods. This method employs a fast line-of-sight synthesis of the Hα line profiles through the whole 3D prominence volume and realistically reflects the basic properties of the Hα line formation in the cool and low-density prominence medium. The method can be applied both to prominences seen above the limb and filaments seen against the disk.
Results. We provide recipes for the use of this method for visualizing the prominence or filament models that have multiple fine structures. We also perform tests of the method that demonstrate its accuracy under prominence conditions.
Conclusions. We demonstrate that this fast approximate radiative transfer method provides realistic synthetic Hα intensities useful for a reliable visualization of prominences and filaments. Such synthetic high-resolution images of modeled prominences/filaments can be used for a direct comparison with high-resolution observations.

On the Visibility of Prominence Fine Structures at Radio Millimeter Wavelengths

P. **Heinzel**, A. Berlicki, M. Bárta, M. Karlický, P. Rudawy

Solar Physics **2015**

Prominence temperatures have so far mainly been determined by analyzing spectral line shapes, which is difficult when the spectral lines are optically thick. The radio spectra in the millimeter range offer a unique possibility to measure the kinetic temperature. However, studies in the past used data with insufficient spatial resolution to resolve the prominence fine structures. The aim of this article is to predict the visibility of prominence fine structures in the submillimeter/millimeter (SMM) domain, to estimate their brightness temperatures at various wavelengths, and to demonstrate the feasibility and usefulness of future high-resolution radio observations of solar prominences with ALMA (Atacama Large Millimeter-submillimeter Array). Our novel approach is the conversion of Hα coronagraphic images into microwave spectral images. We show that the spatial variations of the prominence brightness both in the Hα line and in the SMM domain predominantly depend on the line-of-sight emission measure of the cool plasma, which we derive from the integrated intensities of the observed Hα line. This relation also offers a new possibility to determine the SMM optical thickness from simultaneous Hα observations with high resolution. We also describe how we determine the prominence kinetic temperature from SMM spectral images. Finally, we apply the ALMA image-processing software Common Astronomy Software Applications (CASA) to our simulated images to assess what ALMA would detect at a resolution level that is similar to the coronagraphic Hα images used in this study. Our results can thus help in preparations of first ALMA prominence observations in the frame of science and technical verification tests.

Understanding the Mg II and Hα Spectra in a Highly Dynamical Solar Prominence

P. **Heinzel**1, B. Schmieder2, N. Mein2, and S. Gunár

2015 ApJ 800 L13

Mg ii h and k and Hα spectra in a dynamical prominence have been obtained along the slit of the Interface Region Imaging Spectrograph (IRIS) and with the Meudon Multi-channel Subtractive Double Pass spectrograph on **2013 September 24**, respectively. Single Mg ii line profiles are not much reversed, while at some positions along the IRIS slit the profiles show several discrete peaks that are Doppler-shifted. The intensity of these peaks is generally decreasing with their increasing Doppler shift. We interpret this unusual behavior as being due to the Doppler dimming effect. We discuss the possibility to interpret the unreversed single profiles by using a two-dimensional (2D) model of the entire prominence body with specific radiative boundary conditions. We have performed new 2D isothermal–isobaric modeling of both Hα and Mg ii lines and show the ability of such models to account for the line profile variations as observed. However, the Mg ii line-center intensities require the model with a temperature increase toward the prominence boundary. We show that even simple one-dimensional (1D) models with a prominence-to-corona transition region (PCTR) fit the observed Mg ii and Hα lines quite well, while the isothermal–isobaric models (1D or 2D) are inconsistent with simultaneous observations in the Mg ii h and k and Hα lines, meaning that the Hα line provides a strong additional constraint on the modeling. IRIS far-UV detection of the C ii lines in this prominence seems to provide a direct constraint on the PCTR part of the model.

On the formation of Mg ii h and k lines in solar prominences

P. **Heinzel**1,2, J.-C. Vial3 and U. Anzer

A&A 564, A132 (**2014**)

Aims. With the recent launch of the IRIS mission, it has become urgent to develop the spectral diagnostics using the Mg ii resonance h and k lines. In this paper, we aim to demonstrate the behavior of these lines under various prominence conditions. Our results serve as a basis for analysis of new IRIS data and for more sophisticated prominence modeling.
Methods. For this exploratory work, we use a canonical 1D prominence-slab model, which is isobaric and may have three different temperature structures: isothermal, PCTR-like (prominence-corona transition region), and consistent with the radiative equilibrium. The slabs are illuminated by a realistic incident solar radiation obtained from the UV observations. A five-level plus continuum Mg ii model atom is used to solve the full NLTE problem of the radiative transfer. We use the numerical code based on the ALI techniques and apply the partial frequency redistribution for both Mg ii resonance lines. We also use the velocity-dependent boundary conditions to study the effect of Doppler dimming in the case of moving prominences. Finally, the relaxation technique is used to compute a grid of models in radiative equilibrium.
Results. We computed the Mg ii h and k line profiles that are emergent from prominence-slab models and show their dependence on kinetic temperature, gas pressure, geometrical extension, and microturbulent velocity. By increasing the line opacity, significant departures from the complete frequency redistribution take place in the line wings. Models with a PCTR temperature structure show that Mg ii becomes ionized to Mg iii in the temperature range between roughly 15 000 and 30 000 K. Doppler dimming is significant for Mg ii resonance lines. At the velocity 300 km s-1, the line intensity decreases to about 20% of the value for static prominences. Finally, we demonstrate the role of Mg ii h and k radiation losses on the prominence energy balance. Their dominant role is at lower pressures, while the losses due to hydrogen and Ca ii dominate at higher pressures.

Synthetic hydrogen spectra of prominence oscillations

P. **Heinzel**1, M. Zapiór1,2, R. Oliver2 and J. L. Balleste

A&A 562, A103 (**2014**)

Context. Prominence oscillations have been mostly detected using Doppler velocity, although there are also claimed detections by means of periodic variations in half-width or line intensity. However, scarce observational evidence exists about simultaneous detection of oscillations in several spectral indicators.
Aims. Our main aim here is to explore the relationship between spectral indicators, such as Doppler shift, line intensity, and line half-width, and the linear perturbations excited in a simple prominence model.
Methods. Our equilibrium background model consists of a bounded, homogeneous slab, which is permeated by a transverse magnetic field, having prominence-like physical properties. Assuming linear perturbations, the dispersion relation for fast and slow modes has been derived, as well as the perturbations for the different physical quantities. These perturbations have been used as the input variables in a one-dimensional radiative transfer code, which calculates the full spectral profile of the hydrogen Hα and Hβ lines.
Results. We have found that different oscillatory modes produce spectral indicator variations in different magnitudes. Detectable variations in the Doppler velocity were found for the fundamental slow mode only. Substantial variations in the Hβ line intensity were found for specific modes. Other modes lead to lower and even undetectable parameter variations.
Conclusions. To perform prominence seismology, analysis of the Hα and Hβ spectral line parameters could be a good tool to detect and identify oscillatory modes.

Radiative equilibrium in solar prominences reconsidered

P. **Heinzel**1,2 and U. Anzer2,1

A&A 539, A49 (**2012**)

Aims. We reconsider the question which kinetic temperatures can lead to prominence configurations that are in radiative equilibrium. We compare these temperatures to those from other calculations.

Methods. For this purpose we solved the full non-LTE radiative-transfer problem for a gas consisting of hydrogen, helium and calcium. We used simple isobaric 1D slabs and began with isothermal models. Then we solved the radiative-relaxation problem and determined the radiative-equilibrium conditions within the whole slab.
Results. By adding the calcium radiative losses, we found that these equilibrium temperatures are considerably lower than those obtained for a pure hydrogen gas. This is because the newly calculated CaII line losses appear to play a significant role in the energy balance, similar to chromospheric conditions. The equilibrium temperatures obtained span the range between 4400−9500 K, depending on the gas pressure and slab thickness.

Hinode, TRACE, SOHO, and Ground-based Observations of a Quiescent Prominence

P. **Heinzel**, B. Schmieder, F. Farnik, P. Schwartz, N. Labrosse, P. Kotrc,
U. Anzer, G. Molodij, A. Berlicki, E. E. DeLuca, L. Golub, T. Watanabe,
and T. Berger

The Astrophysical Journal, Vol. 686, No. 2
http://www.journals.uchicago.edu/doi/abs/10.1086/591018

A quiescent prominence was observed by several instruments on 2007 April 25. The temporal evolution was recorded in H_ by the Hinode SOT, in X-rays by the HinodeXRT, and in the 195 8 channel by TRACE.Moreover, ground-based observatories (GBOs) provided calibrated H_ intensities. Simultaneous extreme-UV (EUV) data were also taken by the Hinode EIS and SOHO SUMER and CDS instruments. Here we have selected the SOT H_ image taken at 13:19 UT, which nicely shows the prominence fine structure.We compare this image with cotemporaneous ones taken by the XRT and TRACE and show the intensity variations along several cuts parallel to the solar limb. EIS spectra were obtained about half an hour later. Dark prominence structure clearly seen in the TRACE and EIS 195 8 images is due to the prominence absorption in H i, He i, and He ii resonance continua plus the coronal emissivity blocking due to the prominence void (cavity). The void clearly visible in the XRT images is entirely due to X-ray emissivity blocking.We use TRACE, EIS, and XRT data to estimate the amount of absorption and blocking. The H_integrated intensities independently provide us with an estimate of the H_ opacity, which is related to the opacity of resonance continua as follows from the non-LTE radiative-transfer modeling. However, spatial averaging of the H_and EUV data have quite different natures, which must be taken into account when evaluating the true opacities. We demonstrate this important effect here for the first time. Finally, based on this multiwavelength analysis, we discuss the determination of the column densities and the ionization degree of hydrogen in the prominence.

Damped large amplitude transverse oscillations in an EUV solar prominence, triggered by large-scale transient coronal waves

J. **Hershaw**1, C. Foullon1, V. M. Nakariakov1,2 and E. Verwichte

A&A 531, A53 (**2011**), **File**

Aims. We investigate two successive trains of large amplitude transverse oscillations in an arched EUV prominence, observed with SoHO/EIT on the north-east solar limb on **30 July 2005**. The oscillatory trains are triggered by two large scale coronal waves, associated with an X-class and a C-class flare occurring in the same remote active region.
Methods. The oscillations are tracked within rectangular slits parallel to the solar limb at different heights, which are taken to move with the apparent height profile of the prominence to account for solar rotation. Time series for the two prominence arch legs are extracted using Gaussian fitting on the 195 Å absorption features, and fitted to a damped cosine curve to determine the oscillatory parameters.
Results. Differing energies of the two triggering flares and associated waves are found to agree with the velocity amplitudes, of 50.6 ± 3.2 and 15.9 ± 8.0 km s-1 at the apex, for the first and second oscillatory trains respectively, as estimated in the transverse direction. The period of oscillation is similar for both trains, with an average of 99 ± 11 min, indicating a characteristic frequency as predicted by magnetohydrodynamics. Increasing velocity amplitude with height during the first oscillatory train, and in-phase starting motions of the two legs regardless of height, for each train, demonstrate that the prominence exhibits a global kink mode to a first approximation. However, discrepancies between the oscillatory characteristics of the two legs and an apparent dependence of period upon height, suggest that the prominence actually oscillates as a collection of separate but interacting threads. Damping times of around two to three cycles are observed. Combining our results with those of previously analysed loop oscillations, we find an approximately linear dependence of damping time upon period for kink oscillations, supporting resonant absorption as the damping mechanism despite limitations in testing this theory.

Observation of bi-directional jets in a prominence⋆

A. **Hillier**1 and V. Polito2,3

A&A 651, A60 (**2021**)
https://www.aanda.org/articles/aa/pdf/2021/07/aa35774-19.pdf
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Quiescent prominences host a large range of flows, many driven by buoyancy, which lead to velocity shear. The presence of these shear flows could bend and stretch the magnetic field resulting in the formation of current sheets which can lead to magnetic reconnection. Though this has been hypothesised to occur in prominences, with some observations that are suggestive of this process, clear evidence has been lacking. In this paper we present observations performed on **June 30, 2015** using the Interface Region Imaging Spectrograph Si IV and Mg II slit-jaw imagers of two bi-directional jets that occur inside the body of the prominence. Such jets are highly consistent with what would be expected from magnetic reconnection theory. Using this observation, we estimate that the prominence under study has an ambient field strength in the range of 4.5−9.2 G with 'turbulent' field strengths of 1 G. Our results highlight the ability of gravity-driven flows to stretch and fold the magnetic field of the prominence, implying that locally, the quiescent prominence field can be far from a static, force-free magnetic field.

Coronal cooling as a result of mixing by the nonlinear Kelvin--Helmholtz instability

Andrew **Hillier**, Inigo Arregui

ApJ **2019**

https://arxiv.org/pdf/1909.11351.pdf

Recent observations show cool, oscillating prominence threads fading when observed in cool spectral lines and appearing in warm spectral lines. A proposed mechanism to explain this evolution is that the threads were heated by turbulence driven by the Kelvin--Helmholtz instability that developed as a result of wave-driven shear flows on the surface of the thread. As the Kelvin--Helmholtz instability is an instability that works to mix the fluids, in the solar corona it can be expected to work by mixing the cool prominence material with that of the hot corona to form a warm boundary layer. In this paper we develop a simple phenomenological model of nonlinear Kelvin--Helmholtz mixing, using it to determine the characteristic density and temperature of the mixing layer, which for the case under study with constant pressure across the two fluids are ρmixed=ρ1ρ2−−−−√ and Tmixed=T1T2−−−−√. One result from the model is that it provides an accurate, as determined by comparison with simulation results, determination of the kinetic energy in the mean velocity field. A consequence of this is that the magnitude of turbulence, and with it the energy that can be dissipated on fast time-scales, as driven by this instability can be determined. For the prominence-corona system, the mean temperature rise possible from turbulent heating is estimated to be less than 1\% of the characteristic temperature (which is found to be 105\,K). These results highlight that mixing, and not heating, are likely to be the cause of the observed transition between cool to warm material in Okamoto et. al (2015). One consequence of this result is that the mixing creates a region with higher radiative loss rates on average than either of the original fluids, meaning that this instability could contribute a net loss of thermal energy from the corona, i.e. coronal cooling.

The magnetic Rayleigh–Taylor instability in solar prominences Review

Andrew **Hillier**

Reviews of Modern Plasma Physics December **2018**, 2:1

https://link.springer.com/content/pdf/10.1007%2Fs41614-017-0013-2.pdf

The magnetic Rayleigh–Taylor instability is a fundamental instability of many astrophysical systems, and recent observations are consistent with this instability developing in solar prominences. Prominences are cool, dense clouds of plasma that form in the solar corona that display a wide range of dynamics of a multitude of spatial and temporal scales, and two different phenomena that have been discovered to occur in prominences can be understood as resulting from the Rayleigh–Taylor instability. The first is that of plumes that rise through quiescent prominences from low density bubbles that form below them. The second is that of a prominence eruption that fragments as the material falls back to the solar surface. To identify these events as the magnetic Rayleigh–Taylor instability, a wide range of theoretical work, both numerical and analytical has been performed, though alternative explanations do exist. For both of these sets of observations, determining that they are created by the magnetic Rayleigh–Taylor instability has meant that the linear instability conditions and nonlinear dynamics can be used to make estimates of the magnetic field strength. There are strong connections between these phenomena and those in a number of other astro, space and plasma systems, making these observations very important for our understanding of the role of the Rayleigh–Taylor instability in magnetised systems. **30 November 2006 , 8 February 2007, 8 August 2007, 16 August 2007 , 3 October 2007 , 29 September 2008, 22 June 2010, 7 June 2011, 27 January 2012**

Observations of the Kelvin-Helmholtz instability driven by dynamic motions in a solar prominence

Andrew **Hillier**, Vanessa Polito

ApJL **864** L10 **2018**

https://arxiv.org/pdf/1808.02286.pdf

http://sci-hub.tw/http://iopscience.iop.org/article/10.3847/2041-8213/aad9a5/meta

Prominences are incredibly dynamic across the whole range of their observable spatial scales, with observations revealing gravity-driven fluid instabilities, waves, and turbulence. With all these complex motions, it would be expected that instabilities driven by shear in the internal fluid motions would develop. However, evidence of these have been lacking. Here we present the discovery in a prominence, using observations from the Interface Region Imaging Spectrograph (IRIS), of a shear flow instability, the Kelvin-Helmholtz sinusoidal-mode of a fluid channel, driven by flows in the prominence body. This finding presents a new mechanism through which we can create turbulent motions from the flows observed in quiescent prominences. The observation of this instability in a prominence highlights their great value as a laboratory for understanding the complex interplay between magnetic fields and fluid flows that play a crucial role in a vast range of astrophysical systems. **30 June 2015**

Investigating prominence turbulence with Hinode SOT Dopplergrams

Andrew **Hillier**, Takeshi Matsumoto, Kiyoshi Ichimoto

A&A 597, A111 **2017**

https://arxiv.org/pdf/1610.08281v1.pdf

Quiescent prominences host a diverse range of flows, including Rayleigh-Taylor instability driven upflows and impulsive downflows, and so it is no surprise that turbulent motions also exist. As prominences are believed to have a mean horizontal guide field, investigating any turbulence they host could shed light on the nature of MHD turbulence in a wide range of astrophysical systems. In this paper we have investigated the nature of the turbulent prominence motions using structure function analysis on the velocity increments estimated from Hα Dopplergrams constructed with observational data from Hinode SOT. The pdf of the velocity increments shows that as we look at increasingly small spatial separations the distribution displays greater departure from a reference Gaussian distribution, hinting at intermittency in the velocity field. Analysis of the even order structure functions for both the horizontal and vertical separations showed the existence of two distinct regions displaying different exponents of the power law with the break in the power law at approximately 2000km. We hypothesise this to be a result of internal turbulence excited in the prominence by the dynamic flows of the system found at this spatial scale. We found that the scaling exponents of the p-th order structure functions for these two regions generally followed the p/2 (smaller scales) and p/4 (larger scales) laws that are the same as those predicted for weak MHD turbulence and Kraichnan-Iroshnikov turbulence respectively. However, the existence of the p/4 scaling at larger scales than the p/2 scaling is inconsistent with the increasing nonlinearity expected in MHD turbulence. Estimating the heating from the turbulent energy dissipation showed that this turbulent heating would be very inefficient, but that the mass diffusion through turbulence driven reconnection was of the order of 10^{10}cm^2/ s^{-1}. This is of similar order to that of the expected value of the ambipolar diffusion and a few orders of magnitude greater than Ohmic diffusion for a quiescent prominence.

A Statistical Study of Transverse Oscillations in a Quiescent Prominence

A. **Hillier**1, R. J. Morton2, and R. Erdély

2013 ApJ 779 L16

The launch of the Hinode satellite has allowed for seeing-free observations at high-resolution and high-cadence making it well suited to study the dynamics of quiescent prominences. In recent years it has become clear that quiescent prominences support small-amplitude transverse oscillations, however, sample sizes are usually too small for general conclusions to be drawn. We remedy this by providing a statistical study of transverse oscillations in vertical prominence threads. Over a 4 hr period of observations it was possible to measure the properties of 3436 waves, finding periods from 50 to 6000 s with typical velocity amplitudes ranging between 0.2 and 23 km s–1. The large number of observed waves allows the determination of the frequency dependence of the wave properties and derivation of the velocity power spectrum for the transverse waves. For frequencies less than 7 mHz, the frequency dependence of the velocity power is consistent with the velocity power spectra generated from observations of the horizontal motions of magnetic elements in the photosphere, suggesting that the prominence transverse waves are driven by photospheric motions. However, at higher frequencies the two distributions significantly diverge, with relatively more power found at higher frequencies in the prominence oscillations. These results highlight that waves over a large frequency range are ubiquitous in prominences, and that a significant amount of the wave energy is found at higher frequency.

ON THE SUPPORT OF SOLAR PROMINENCE MATERIAL BY THE DIPS OF A CORONAL FLUX TUBE

Andrew **Hillier**1 and Adriaan van Ballegooijen

2013 ApJ 766 126

The dense prominence material is believed to be supported against gravity through the magnetic tension of dipped coronal magnetic field. For quiescent prominences, which exhibit many gravity-driven flows, hydrodynamic forces are likely to play an important role in the determination of both the large- and small-scale magnetic field distributions. In this study, we present the first steps toward creating a three-dimensional magneto-hydrostatic prominence model where the prominence is formed in the dips of a coronal flux tube. Here 2.5D equilibria are created by adding mass to an initially force-free magnetic field, then performing a secondary magnetohydrodynamic relaxation. Two inverse polarity magnetic field configurations are studied in detail, a simple o-point configuration with a ratio of the horizontal field (B_x) to the axial field (B_y) of 1:2 and a more complex model that also has an x-point with a ratio of 1:11. The models show that support against gravity is either by total pressure or tension, with only tension support resembling observed quiescent prominences. The o-point of the coronal flux tube was pulled down by the prominence material, leading to compression of the magnetic field at the base of the prominence. Therefore, tension support comes from the small curvature of the compressed magnetic field at the bottom and the larger curvature of the stretched magnetic field at the top of the prominence. It was found that this method does not guarantee convergence to a prominence-like equilibrium in the case where an x-point exists below the prominence flux tube. The results imply that a plasma β of ~0.1 is necessary to support prominences through magnetic tension.

DETERMINATION OF PROMINENCE PLASMA β FROM THE DYNAMICS OF RISING PLUMES

Andrew **Hillier**1, Richard Hillier2, and Durgesh Tripathi

2012 ApJ 761 106

Observations by the Hinode satellite show in great detail the dynamics of rising plumes, dark in chromospheric lines, in quiescent prominences that propagate from large (~10 Mm) bubbles that form at the base of the prominences. These plumes present a very interesting opportunity to study magnetohydrodynamic (MHD) phenomena in quiescent prominences, but obstacles still remain. One of the biggest issues is that of the magnetic field strength, which is not easily measurable in prominences. In this paper we present a method that may be used to determine a prominence's plasma β when rising plumes are observed. Using the classic fluid dynamic solution for flow around a circular cylinder with an MHD correction, the compression of the prominence material can be estimated. This has been successfully confirmed through simulations; application to a prominence gave an estimate of the plasma β as $\beta = 0.47 \pm 0.079$ to 1.13 ± 0.080 for the range $\gamma = 1.4$-1.7. Using this method it may be possible to estimate the plasma β of observed prominences, therefore helping our understanding of a prominence's dynamics in terms of MHD phenomena.

NUMERICAL SIMULATIONS OF THE MAGNETIC RAYLEIGH-TAYLOR INSTABILITY IN THE KIPPENHAHN-SCHLÜTER PROMINENCE MODEL. I. FORMATION OF UPFLOWS

Andrew **Hillier**1, Thomas Berger2, Hiroaki Isobe1,3 and Kazunari Shibata

2012 ApJ 746 120

The launch of the Hinode satellite led to the discovery of rising plumes, dark in chromospheric lines, that propagate from large (~10 Mm) bubbles that form at the base of quiescent prominences. The plumes move through a height of approximately 10 Mm while developing highly turbulent profiles. The magnetic Rayleigh-Taylor instability was hypothesized to be the mechanism that drives these flows. In this study, using three-dimensional (3D) MHD simulations, we investigate the nonlinear stability of the Kippenhahn-Schlüter prominence model for the interchange mode of the magnetic Rayleigh-Taylor instability. The model simulates the rise of a buoyant tube inside the quiescent prominence model, where the interchange of magnetic field lines becomes possible at the boundary between the buoyant tube and the prominence. Hillier et al. presented the initial results of this study, where upflows of constant velocity (maximum found 6 km s–1) and a maximum plume width 1.5 Mm which propagate through a height of approximately 6 Mm were found. Nonlinear interaction between plumes was found to be important for determining the plume dynamics. In this paper, using the results of ideal MHD simulations, we determine how the initial parameters for the model and buoyant tube affect the evolution of instability. We find that the 3D mode of the magnetic Rayleigh-Taylor instability grows, creating upflows aligned with the magnetic field of constant velocity (maximum found 7.3 km s–1). The width of the upflows is dependent on the initial conditions, with a range of 0.5-4 Mm which propagate through heights of 3-6 Mm. These results are in general agreement with the observations of the rising plumes.

NUMERICAL SIMULATIONS OF THE MAGNETIC RAYLEIGH-TAYLOR INSTABILITY IN THE KIPPENHAHN-SCHLÜTER PROMINENCE MODEL

Andrew **Hillier**1, Hiroaki Isobe1,3, Kazunari Shibata1 and Thomas Berger

2011 ApJ 736 L1

The launch of the Hinode satellite has allowed unprecedented high-resolution, stable images of solar quiescent prominences to be taken over extended periods of time. These new images led to the discovery of dark upflows that propagated from the base of prominences, developing highly turbulent profiles. As yet, how these flows are driven is not fully understood. To study the physics behind these phenomena, we use three-dimensional magnetohydrodynamic simulations to investigate the nonlinear stability of the Kippenhahn-Shlüter prominence model to the magnetic Rayleigh-Taylor instability. The model simulates the rise of a buoyant tube inside a quiescent prominence, where the upper boundary between the tube and prominence model is perturbed to excite the interchange of magnetic field lines. We found upflows of constant velocity (maximum found 6 km s–1) and a maximum plume width 1500 km which propagate through a height of approximately 6 Mm in the no guide field case. The case with the strong guide field (initially $B_y = 2B_x$) results in a large plume that rises through the prominence model at ~5 km s–1 with width ~900 km (resulting in width of 2400 km when viewed along the axis of the prominence), reaching a height of ~3.1 Mm. In both cases, nonlinear processes were important for determining plume dynamics.

Do Coronal Loops Oscillate in Isolation?

Bradley W. **Hindman**, Rekha Jain

ApJ **921** 29 **2021**

https://arxiv.org/pdf/2108.04362.pdf

https://doi.org/10.3847/1538-4357/ac1a16

Images of the solar corona by extreme-ultraviolet (EUV) telescopes reveal elegant arches of glowing plasma that trace the corona's magnetic field. Typically, these loops are preferentially illuminated segments of an arcade of vaulted field lines and such loops are often observed to sway in response to nearby solar flares. A flurry of observational and theoretical effort has been devoted to the exploitation of these oscillations with the grand hope that seismic techniques might be used as probes of the strength and structure of the corona's magnetic field. The commonly accepted viewpoint is that each visible loop oscillates as an independent entity and acts as a one-dimensional (1D) wave cavity for magnetohydrodynamic (MHD) kink waves. We argue that for many events, this generally accepted model for the wave cavity is fundamentally flawed. In particular, the 3D magnetic arcade in which the bright loop resides participates in the oscillation. Thus, the true wave cavity is larger than the individual loop and inherently multidimensional. We derive the skin depth of the near-field response for an oscillating loop and demonstrate that most loops are too close to other magnetic structures to oscillate in isolation. Further, we present a simple model of a loop embedded within an arcade and explore how the eigenmodes of the arcade and the eigenmodes of the loop become coupled. In particular, we discuss how distinguishing between these two types of modes can be difficult when the motions within the arcade are often invisible.

EIGENMODES OF THREE-DIMENSIONAL MAGNETIC ARCADES IN THE SUN'S CORONA

Bradley W. **Hindman**1 and Rekha Jain

2015 ApJ 814 105

We develop a model of coronal-loop oscillations that treats the observed bright loops as an integral part of a larger three-dimensional (3D) magnetic structure comprised of the entire magnetic arcade. We demonstrate that magnetic arcades within the solar corona can trap MHD fast waves in a 3D waveguide. This is accomplished through the construction of a cylindrically symmetric model of a magnetic arcade with a potential magnetic field. For a magnetically dominated plasma, we derive a governing equation for MHD fast waves and from this equation we show that the magnetic arcade forms a 3D waveguide if the Alfvén speed increases monotonically beyond a fiducial radius. Both magnetic pressure and tension act as restoring forces, instead of just tension as is generally assumed in 1D models. Since magnetic pressure plays an important role, the eigenmodes involve propagation both parallel and transverse to the magnetic field. Using an analytic solution, we derive the specific eigenfrequencies and eigenfunctions for an arcade possessing a discontinuous density profile. The discontinuity separates a diffuse cylindrical cavity and an overlying shell of denser plasma that corresponds to the bright loops. We emphasize that all of the eigenfunctions have a discontinuous axial velocity at the density interface; hence, the interface can give rise to the Kelvin–Helmholtz instability. Further, we find that all modes have elliptical polarization with the degree of polarization changing with height. However, depending on the line of sight, only one polarization may be clearly visible.

An Interpretation of Flare-induced and Decayless Coronal-loop Oscillations as Interference Patterns

Bradley W. **Hindman**1 and Rekha Jain

2014 ApJ 784 103

We present an alternative model of coronal-loop oscillations, which considers that the waves are trapped in a two-dimensional waveguide formed by the entire arcade of field lines. This differs from the standard one-dimensional model which treats the waves as the resonant oscillations of just the visible bundle of field lines. Within the framework of our two-dimensional model, the two types of oscillations that have been observationally identified, flare-induced waves and "decayless" oscillations, can both be attributed to MHD fast waves. The two components of the signal differ only because of the duration and spatial extent of the source that creates them. The flare-induced waves are generated by strong localized sources of short duration, while the decayless background can be excited by a continuous, stochastic source. Further, the oscillatory signal arising from a localized, short-duration source can be interpreted as a pattern of interference fringes produced by waves that have traveled diverse routes of various pathlengths through the waveguide. The resulting amplitude of the fringes slowly decays in time with an inverse square root dependence. The details of the interference pattern depend on the shape of the arcade and the spatial variation of the Alfvén speed. The rapid decay of this wave component, which has previously been attributed to physical damping mechanisms that remove energy from resonant oscillations, occurs as a natural consequence of the interference process without the need for local dissipation.

Equilibrium Models of Coronal Loops That Involve Curvature and Buoyancy

Bradley W. **Hindman**1 and Rekha Jain

2013 ApJ 778 174

We construct magnetostatic models of coronal loops in which the thermodynamics of the loop is fully consistent with the shape and geometry of the loop. This is achieved by treating the loop as a thin, compact, magnetic fibril that is a small departure from a force-free state. The density along the loop is related to the loop's curvature by requiring that the Lorentz force arising from this deviation is balanced by buoyancy. This equilibrium, coupled with hydrostatic balance and the ideal gas law, then connects the temperature of the loop with the curvature of the loop without resorting to a detailed treatment of heating and cooling. We present two example solutions: one with a spatially invariant magnetic Bond number (the dimensionless ratio of buoyancy to Lorentz forces) and the other with a constant radius of the curvature of the loop's axis. We find that the density and temperature profiles are quite sensitive to curvature variations along the loop, even for loops with similar aspect ratios.

An MHD avalanche model of multi-threaded coronal loop

A. W. **Hood**, P. J. Cargill, P. K. Browning, K. V. Tam

2016 ApJ 817 5

http://arxiv.org/pdf/1512.00628v1.pdf

For the first time, we demonstrate how an MHD avalanche might occur in a multi-threaded coronal loop. Considering 23 non-potential magnetic threads within a loop, we use 3D MHD simulations to show that only one thread needs to be unstable in order to start an avalanche even when the others are below marginal stability. This has significant implications for coronal heating in that it provides for energy dissipation with a trigger mechanism. The instability of the unstable thread follows the evolution determined in many earlier investigations. However, once one stable thread is disrupted, it coalesces with a neighbouring thread and this process disrupts other nearby threads. Coalescence with these disrupted threads then occurs leading to the disruption of yet more threads as the avalanche develops. Magnetic energy is released in discrete bursts as the surrounding stable threads are disrupted. The volume integrated heating, as a function of time, shows short spikes suggesting that the temporal form of the heating is more like that of \textit{nanoflares} than of constant heating.

Formation of solar quiescent coronal loops through magnetic reconnection in an emerging active region

Zhenyong **Hou**, Hui Tian, Hechao Chen, Xiaoshuai Zhu, Zhenghua Huang, Xianyong Bai, Jiansen He, Yongliang Song, Lidong Xia

ApJ **915** 39 **2021**

https://arxiv.org/pdf/2105.03199.pdf

https://doi.org/10.3847/1538-4357/abff60

Coronal loops are building blocks of solar active regions. However, their formation mechanism is still not well understood. Here we present direct observational evidence for the formation of coronal loops through magnetic reconnection as new magnetic fluxes emerge into the solar atmosphere. Extreme-ultraviolet observations of the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO) clearly show the newly formed loops following magnetic reconnection within a plasma sheet. Formation of the loops is also seen in the h{\alpha} line-core images taken by the New Vacuum Solar Telescope. Observations from the Helioseismic and Magnetic Imager onboard SDO show that a positive-polarity flux concentration moves towards a negative-polarity one with a speed of ~0.4 km/s, before the formation of coronal loops. During the loop formation process, we found signatures of flux cancellation and subsequent enhancement of the transverse field between the two polarities. The three-dimensional magnetic field structure reconstructed through a magnetohydrostatic model shows field lines consistent with the loops in AIA images. Numerous bright blobs with an average width of 1.37 Mm appear intermittently in the plasma sheet and move upward with a projected velocity of ~114 km/s. The temperature, emission measure and density of these blobs are about 3 MK, 2.0x10^(28) cm^(-5) and 1.2x10^(10) cm^(-3), respectively. A power spectral analysis of these blobs indicates that the observed reconnection is likely not dominated by a turbulent process. We have also identified flows with a velocity of 20 to 50 km/s towards the footpoints of the newly formed coronal loops. **2020 October 26**

Observations of upward propagating waves in the transition region and corona above Sunspots

Zhenyong **Hou**, Zhenghua Huang, Lidong Xia, Bo Li, Hui Fu

ApJ **2018**

https://arxiv.org/pdf/1801.07515.pdf

We present observations of persistent oscillations of some bright features in the upper-chromosphere/transition-region above sunspots taken by IRIS SJ 1400 {\AA} and upward propagating quasi-periodic disturbances along coronal loops rooted in the same region taken by AIA 171 {\AA} passband. The oscillations of the features are cyclic oscillatory motions without any obvious damping. The amplitudes of the spatial displacements of the oscillations are about 1 ″. The apparent velocities of the oscillations are comparable to the sound speed in the chromosphere, but the upward motions are slightly larger than that of the downward. The intensity variations can take 24-53% of the background, suggesting nonlinearity of the oscillations. The FFT power spectra of the oscillations show dominant peak at a period of about 3 minutes, in consistent with the omnipresent 3 minute oscillations in sunspots. The amplitudes of the intensity variations of the upward propagating coronal disturbances are 10-15% of the background. The coronal disturbances have a period of about 3 minutes, and propagate upward along the coronal loops with apparent velocities in a range of 30-80 km/s. We propose a scenario that the observed transition region oscillations are powered continuously by upward propagating shocks, and the upward propagating coronal disturbances can be the recurrent plasma flows driven by shocks or responses of degenerated shocks that become slow magnetic-acoustic waves after heating the plasma in the coronal loops at their transition-region bases.
2014 February 16, 2016 June 21

Measuring an Eruptive Prominence at Large Distances from the Sun. I. Ionization and Early Evolution

T. A. **Howard**
2015 ApJ 806 175
Measurements of Hα emission within an eruptive solar prominence are presented, using white light polarization properties as a proxy for the presence of Hα in the STEREO COR1 and COR2 coronagraphs. The transition from Hα emission to Thomson scattering radiance serves as an indicator of the ionization of the prominence, and I discuss the physical implications regarding the behavior of the neutrals and ions, and also for the measurement of coronal mass ejection properties using the Thomson scattering assumption. I find that the prominence has a high concentration of neutrals at around two solar radii that gradually exhibit ionization characteristics at it moves away from the Sun. The prominence reaches complete ionization, or at least a state where the Thomson-scattered brightness dominates, by the time it reaches around seven solar radii. This is consistent with predictions inferred from direct Hα measurements made from earlier studies in the 1980s and with the predicted ionization rate of neutral hydrogen near solar maximum. These results pave the way for an accompanying paper that reports on measurements of the prominence at large distances from the Sun using the assumptions verified here.

Magnetic reconnection and the Kelvin-Helmholtz instability in the solar corona

Thomas **Howson**, Ineke De Moortel, David Pontin
A&A **2021**
https://arxiv.org/pdf/2109.15019.pdf
Context. The magnetic Kelvin-Helmholtz instability (KHI) has been proposed as a means of generating magnetohydrodynamic turbulence and encouraging wave energy dissipation in the solar corona, particularly within transversely oscillating loops. Aims. Our goal is to determine whether the KHI encourages magnetic reconnection in oscillating flux tubes in the solar corona. This will establish whether the instability enhances the dissipation rate of energy stored in the magnetic field. Methods. We conducted a series of three-dimensional magnetohydrodynamic simulations of the KHI excited by an oscillating velocity shear. We investigated the effects of numerical resolution, field line length, and background currents on the growth rate of the KHI and on the subsequent rate of magnetic reconnection. Results. The KHI is able to trigger magnetic reconnection in all cases, with the highest rates occurring during the initial growth phase. Reconnection is found to occur preferentially along the boundaries of Kelvin-Helmholtz vortices, where the shear in the velocity and magnetic fields is greatest. The estimated rate of reconnection is found to be lowest in simulations where the KHI growth rate is reduced. For example, this is the case for shorter field lines or due to shear in the background field. Conclusions. In non-ideal regimes, the onset of the instability causes the local reconnection of magnetic field lines and enhances the rate of coronal wave heating. However, we found that if the equilibrium magnetic field is sheared across the Kelvin-Helmholtz mixing layer, the instability does not significantly enhance the rate of reconnection of the background field, despite the free energy associated with the non-potential field.

Energetics of the Kelvin-Helmholtz instability induced by transverse waves in twisted coronal loops

Thomas **Howson**, Ineke De Moortel, Patrick Antolin
2017 A&A 607, A77
https://arxiv.org/pdf/1708.04124.pdf
Aims: We quantify the effects of twisted magnetic fields on the development of the magnetic Kelvin-Helmholtz instability (KHI) in transversely oscillating coronal loops. Methods: We modelled a fundamental standing kink

mode in a straight, density-enhanced magnetic flux tube using the magnetohydrodynamics code, Lare3d. In order to evaluate the impact of an azimuthal component of the magnetic field, various degrees of twist were included within the flux tube's magnetic field. Results: The process of resonant absorption is only weakly affected by the presence of a twisted magnetic field. However, the subsequent evolution of the KHI is sensitive to the strength of the azimuthal component of the field. Increased twist values inhibit the deformation of the loop's density profile, which is associated with the growth of the instability. Despite this, much smaller scales in the magnetic field are generated when there is a non-zero azimuthal component present. Hence, the instability is more energetic in cases with (even weakly) twisted fields. Field aligned flows at the loop apex are established in a twisted regime once the instability has formed. Conclusions: The KHI may have implications for wave heating in the solar atmosphere due to the creation of small length scales and the generation of a turbulent regime. Whilst magnetic twist does suppress the development of the vortices associated with the instability, the formation of the KHI in a twisted regime will be accompanied by greater Ohmic dissipation due to the larger currents that are produced, even if only weak twist is present. The presence of magnetic twist will likely make the instability more difficult to detect in the corona, but will enhance its contribution to heating the solar atmosphere.

The effects of resistivity and viscosity on the Kelvin-Helmholtz instability in oscillating coronal loops

Thomas **Howson**, Ineke De Moortel, Patrick Antolin
A&A 602, A74 **2017**
https://arxiv.org/pdf/1703.02423.pdf
Aims - Investigate the effects of resistivity and viscosity on the onset and growth of the Kelvin-Helmholtz instability (KHI) in an oscillating coronal loop. Methods - We modelled a standing kink wave in a density-enhanced loop with the three dimensional (3-D), resistive magnetohydrodynamics code, Lare3d. We conducted a parameter study on the viscosity and resistivity coefficients to examine the effects of dissipation on the KHI. Results - Enhancing the viscosity and resistivity acts to suppress the KHI. Larger values delay the formation of the instability and, in some cases, prevent the onset completely. This leads to the earlier onset of heating for smaller values of the transport coefficients. We note that viscosity has a greater effect on the development of the KHI than resistivity. Furthermore, when using anomalous resistivity, the Ohmic heating rate associated with the KHI may be greater than that associated with the phase mixing that occurs in an instability-suppressed regime (using uniform resistivity). Conclusions - From our study, it is clear that the heating rate crucially depends on the formation of small length scales (influenced by the numerical resolution) as well as the values of resistivity and viscosity. As larger values of the transport coefficients suppress the KHI, the onset of heating is delayed but the heating rate is larger. As increased numerical resolution allows smaller length scales to develop, the heating rate will be higher even for the same transport coefficients.

Formation and Dynamics in an Observed Preeruptive Filament

Jing **Huang**1,2,3, Yin Zhang1,2, Baolin Tan1,2,3, Xianyong Bai1,2,3, Leping Li , +++
2023 ApJL 958 L13
https://iopscience.iop.org/article/10.3847/2041-8213/ad083e/pdf
The formation of filaments/prominences is still a debated topic. Many different processes have been proposed: levitation, injection of cool plasma, merging filaments, and cooling plasma in hot loops. We take the opportunity to make a multiwavelength analysis of the formation of an active-region filament, combining several UV and EUV observations including the new Ne vii 465 Å filtergrams provided by the Solar Upper Transition Region Imager on board the Space Advanced Technology satellite. The filament is mainly observed at the limb for 3 hr. It is progressively formed through a series of stages, including emergence and cooling of hot loops, reconnection between small filaments, material transfer in a large filament channel, and reconnection between filaments and emerged hot loops. From the observations at 465 Å, we find that the new-formed filaments show bright structures as in 304 Å, while the long-lived stable filaments display dark morphology as in 211 Å. This suggests that the plasma around 0.5 MK would be an essential component of new-formed filaments and the material temperature in filaments would be variable during their evolution. The filament formed by the recombination of two filaments and an emerged hot loop finally erupts. After reconnection, the final filament shows a highly twisted structure of both bright and dark strands, which is surrounded by several weak and dispersive looplike structures. This eruptive filament has a complex multichannel topology and covers a wide range of temperatures. **2022 September 23**

A unified model of solar prominence formation

C. J. **Huang**, J. H. Guo, Y. W. Ni, A. A. Xu, P. F. Chen
2021 *ApJL* **913** L8
https://arxiv.org/pdf/2104.13546
https://doi.org/10.3847/2041-8213/abfbe0
Several mechanisms have been proposed to account for the formation of solar prominences or filaments, among which direct injection and evaporation-condensation models are the two most popular ones. In the direct injection

model, cold plasma is ejected from the chromosphere into the corona along magnetic field lines; In the evaporation-condensation model, the cold chromospheric plasma is heated to over a million degrees and is evaporated into the corona, where the accumulated plasma finally reaches thermal instability or non-equilibrium so as to condensate to cold prominences. In this paper, we try to unify the two mechanisms: The essence of filament formation is the localized heating in the chromosphere. If the heating happens in the lower chromosphere, the enhanced gas pressure pushes the cold plasma in the upper chromosphere to move up to the corona, such a process is manifested as the direct injection model. If the heating happens in the upper chromosphere, the local plasma is heated to million degrees, and is evaporated into the corona. Later, the plasma condensates to form a prominence. Such a process is manifested as the evaporation-condensation model. With radiative hydrodynamic simulations we confirmed that the two widely accepted formation mechanisms of solar prominences can really be unified in such a single framework. A particular case is also found where both injection and evaporation-condensation processes occur together.

Transition Region Loops in the Very Late Phase of Flux Emergence in IRIS Sit-and-stare Observations

Zhenghua **Huang**, Bo Li, Lidong Xia, MiJie Shi, Hui Fu, and Zhenyong Hou
2019 ApJ 887 221
https://doi.org/10.3847/1538-4357/ab5523
Loops are one of the fundamental structures that trace the geometry of the magnetic field in the solar atmosphere. Their evolution and dynamics provide a crucial proxy for studying how the magnetized structures are formed and heated in the solar atmosphere. Here, we report on spectroscopic observations of a set of transition-region loops taken by the Interface Region Imaging Spectrograph (IRIS) at Si iv 1394 Å in the sit-and-stare mode. The loops are corresponding to the flux emergence at its very late phase when the emerged magnetic features in the photosphere have fully developed. We find the transition-region loops are still expanding and moving upward with a velocity of a few kilometers per second ($\lesssim$10 km s−1) at this stage. The expansion of the loops leads to interactions between the loops themselves and with the ambient field, which can drive magnetic reconnection evidenced by multiple intense brightenings, including transition-region explosive events and IRIS bombs in the footpoint region associated with the moving polarity. A set of quasi-periodic brightenings with a period of about 130 s is found at the loop apex, from which the Si iv 1394 Å profiles are significantly non-Gaussian with enhancements at both blue and red wings at Doppler velocities of about 50 km s−1. We suggest that the transition-region loops in the very late phase of flux emergence can be powered by heating events generated by the interactions between the expanding loops and the ambient fields and also by (quasi-)periodic processes, such as oscillation-modulated braiding reconnection.

Magnetic loops above a small flux-emerging region observed by IRIS, Hinode and SDO

Zhenghua **Huang**
ApJ **869** 175 **2018**
https://arxiv.org/pdf/1811.03219.pdf
I report on observations of a set of magnetic loops above a region with late-phase flux emergence taken by IRIS, Hinode and SDO. The loop system consists of many transition region loop threads with size of 5--12\arcsec\ in length and ∼0.5\arcsec in width and coronal loops with similar length and ∼2\arcsec width. Although the loop system consists of threads with different temperatures, most individual loop thread have temperature in a narrow range. In the middle of the loop system, it shows clear systematic blue-shifts of about 10\,\kms\ in the transition region that is consistent with a flux emerging picture, while red-shifts of about 10\,\kms\ in the corona is observed. The nonthermal velocity of the loop system are smaller than the surrounding region in the transition region but are comparable in the corona. The electron densities of the coronal counterpart of the loop system range from 1×109\,cm−3 to 4×109\,cm−3. Electron density of a transition region loop is also measured and found to be about 5×1010\,cm−3, a magnitude larger than that in the coronal loops. In agreement with imaging data, the temperature profiles derived from the differential emission measurement technique confirms that some of the loops have been heated to corona. Our observations indicate that the flux emergence in its late phase is much different from that at the early stage. While the observed transition region is dominated by emerging flux, these emerging loops could be heated to corona and the heatings (if via nonthermal processes) most likely take place only after they reaching the transition region or lower corona. **August 26 2017**

Cool transition region loops observed by the Interface Region Imaging Spectrograph

Zhenghua **Huang**, Lidong Xia, Bo Li, Maria S. Madjarska
ApJ 810(1) 46 **2015**
http://arxiv.org/pdf/1507.07594v1.pdf
We report on the first Interface Region Imaging Spectrograph (IRIS) study of cool transition region loops. This class of loops has received little attention in the literature. A cluster of such loops was observed on the solar disk in active region NOAA11934, in the Si IV 1402.8 \AA\ spectral raster and 1400 \AA\ slit-jaw (SJ) images. We divide the

loops into three groups and study their dynamics and interaction. The first group comprises relatively stable loops, with 382--626\,km cross-sections. Observed Doppler velocities are suggestive of siphon flows, gradually changing from -10 km/s at one end to 20 km/s at the other end of the loops. Nonthermal velocities from 15 to 25 km/s were determined. These physical properties suggest that these loops are impulsively heated by magnetic reconnection occurring at the blue-shifted footpoints where magnetic cancellation with a rate of 1015Mx/s is found. The released magnetic energy is redistributed by the siphon flows. The second group corresponds to two footpoints rooted in mixed-magnetic-polarity regions, where magnetic cancellation occurred at a rate of 1015 Mx/s and line profiles with enhanced wings of up to 200 km/s were observed. These are suggestive of explosive-like events. The Doppler velocities combined with the SJ images suggest possible anti-parallel flows in finer loop strands. In the third group, interaction between two cool loop systems is observed. Evidence for magnetic reconnection between the two loop systems is reflected in the line profiles of explosive events, and a magnetic cancellation rate of 3×1015 Mx/s observed in the corresponding area. The IRIS observations have thus opened a new window of opportunity for in-depth investigations of cool transition region loops. Further numerical experiments are crucial for understanding their physics and their role in the coronal heating processes. **2013 December 27**

The Effect of Thermal Misbalance on Slow Magnetoacoustic Waves in a Partially Ionized Prominence-Like Plasma

M. H. **Ibañez** & J. L. Ballester

Solar Physics volume 297, Article number: 144 (**2022**)

https://doi.org/10.1007/s11207-022-02071-9

https://link.springer.com/content/pdf/10.1007/s11207-022-02071-9.pdf

Solar prominences are partially ionized plasma structures embedded in the solar corona. Ground- and space-based observations have confirmed the presence of oscillatory motions in prominences, which have been interpreted in terms of standing or propagating MHD waves. Some of these observations suggest that slow magnetoacoustic waves could be responsible for these oscillations and have provided us with evidence about their damping/amplification with very small ratios between damping/amplifying times and periods, which have been difficult to explain from a theoretical point of view. Here we investigate the temporal behavior of non-adiabatic, slow, magnetoacoustic waves when a heating–cooling misbalance is present. The influence of optically thin losses and of a general heating term, in which density and temperature dependence can be modified, as well as the effect of partial ionization have been considered. Furthermore, a tentative example of how, using observational data, the observed ratio between damping/amplifying times and periods could be matched with those theoretically obtained is shown. In summary, different combinations of radiative losses, heating mechanisms, and typical wavenumbers, together with the effect of partial ionization, could provide a theoretical tool able to reproduce observational results on small-amplitude oscillations in prominences.

On the Frequency Drift of Coronal Loop's Fast Kink Oscillation: Effects of Quasi-static Evolution in Loop Density

Hongbo **li**1,2, Hengqiang Feng1, Yuandeng Shen3, Zhanjun Tian1, Guoqing Zhao1, Ake Zhao1, and Yan Zhao1

2021 ApJ 922 224

https://iopscience.iop.org/article/10.3847/1538-4357/ac32bf/pdf

https://doi.org/10.3847/1538-4357/ac32bf

Although the fast kink oscillation, as one of a few fundamental modes in coronal seismology, has received a lot of attention over the past two decades, observations of its frequency drift remain elusive. There is evidence that this phenomenon is related to the quasi-static evolution of loop density. We therefore consider analytically the effects of a quasi-static density evolution on the fast kink oscillation of coronal loops. From the analyses, we determine explicitly the analytic dependence of the oscillation period/frequency and amplitude on the evolving density of the oscillatory loop. The findings can well reconcile several key characters in some frequency drift observations, which are not understood. Models of fast kink oscillation in the thermal dynamic loop are also established to investigate the present effects in more detail. Our findings not only show us a possible explanation for the frequency drift of the coronal loop's fast kink oscillation, but also a full new energy transformation mechanism where the internal energy and the kinetic energy of an oscillating coronal loop can be interchanged directly by the interaction of the loop's oscillation and its density evolution, which we suggest may provide a new clue for the energy processes associated with a thermodynamic resonator in the space magnetic plasma.

Energy release from a stream of infalling prominence debris on 2011 September 7-8

Andrew R. **Inglis**, Holly R. Gilbert, Leon Ofman

ApJ **2017**

https://arxiv.org/pdf/1708.01555.pdf

In recent years high-resolution and high-cadence EUV imaging has revealed a new phenomenon, impacting prominence debris, where prominence material from failed or partial eruptions can impact the lower atmosphere and

release energy. We report a clear example of energy release and EUV brightening due to infalling prominence debris that occurred on **2011 September 7-8**.
Subsequently, a semi-continuous stream of this material was observed to return to the solar surface with a velocity v > 150 km/s, impacting a region remote from the original active region between 00:20 - 00:40 UT on 2011 September 8. Using SDO/AIA, the differential emission measure of the plasma was estimated throughout this brightening event. We found that the radiated energy of the impacted plasma was L ~ 10^27 ergs, while the thermal energy peaked at ~ 10^28 ergs. From this we were able to determine the mass content of the debris to be in the range 2x10^14 < m < 2x10^15 g. Given typical prominence masses, the likely debris mass is towards the lower end of this range. This clear example of a prominence debris event shows that significant energy release takes place during these events, and that such impacts may be used as a novel diagnostic tool for investigating prominence material properties.

Break up of returning plasma after the 7 June 2011 filament eruption by Rayleigh-Taylor instabilities⋆

D. E. **Innes**1, R. H. Cameron1, L. Fletcher2, B. Inhester1 and S. K. Solanki1

A&A 540, L10 (**2012**)

Context. A prominence eruption on **7 June 2011** produced spectacular curtains of plasma falling through the lower corona. At the solar surface they created an incredible display of extreme ultraviolet brightenings.
Aims. To identify and analyze some of the local instabilities which produce structure in the falling plasma.
Methods. The structures were investigated using SDO/AIA 171 Å and 193 Å images in which the falling plasma appeared dark against the bright coronal emission.
Results. Several instances of the Rayleigh-Taylor instability were investigated. In two cases the Alfvén velocity associated with the dense plasma could be estimated from the separation of the Rayleigh-Taylor fingers. A second type of feature, which has the appearance of self-similar branching horns was discussed.

Automated techniques for the analysis of magnetic field inversion in filaments with the Solar Feature Catalogue.

S.S. **Ipson**, V.V. Zharkova, S. Zharkov, A.K. Benkhalil, J. Aboudarham, N. Fuller.

Advances in Space Research, Volume 43, Issue 2, 15 January **2009**, Pages 282-291; **File**.

We present an automated comparison of magnetic field inversion line maps from SOHO/MDI magnetograms with solar filament data from the Solar Feature Catalogue created as part of the European Grid of Solar Observations project. The Euclidean distance transform and connected component labelling are used to identify nearest neighbour filament skeletons and inversion lines. Several filament-inversion line characteristics are defined and used to automate the decision whether a particular filament/inversion line pair is suitable for quantitative comparison of orientation and separation. The technique is tested on a total of 207 filaments from four H_α images, and the distributions of angles and distances between filament skeletons and LOS magnetic inversion lines are presented for six degrees of magnetic field smoothing. The results show the approach is robust and can be applied for a statistical analysis of magnetic field in filaments.

Large-Amplitude Oscillation of an Erupting Filament as Seen in EUV, Hα, and Microwave Observations

H. **Isobe** · D. Tripathi · A. Asai · R. Jain

Solar Phys (**2007**) 246: 89–99, File

We present multiwavelength observations of a large-amplitude oscillation of a
polar-crown filament on **15 October 2002**, which has been reported by Isobe and Tripathi
(*Astron. Astrophys.* **449**, L17, 2006). The oscillation occurred during the slow rise
(≈ 1 kms^{-1}) of the filament. It completed three cycles before sudden acceleration and eruption.
The oscillation and following eruption were clearly seen in observations recorded by
the Extreme-Ultraviolet Imaging Telescope (EIT) onboard the *Solar and Heliospheric Observatory*
(SOHO). The oscillation was seen only in a part of the filament, and it appears
to be a standing oscillation rather than a propagating wave. The amplitudes of velocity and
spatial displacement of the oscillation in the plane of the sky were about 5 kms^{-1} and
15 000 km, respectively. The period of oscillation was about two hours and did not change
significantly during the oscillation. The oscillation was also observed in Hα by the Flare
Monitoring Telescope at the Hida Observatory. We determine the three-dimensional motion
of the oscillation from the Hα wing images. The maximum line-of-sight velocity was estimated
to be a few tens of kilometers per second, although the uncertainty is large owing
to the lack of line-profile information. Furthermore, we also identified the spatial displacement

of the oscillation in 17-GHz microwave images from Nobeyama Radio Heliograph (NoRH). The filament oscillation seems to be triggered by magnetic reconnection between a filament barb and nearby emerging magnetic flux as was evident from the MDI magnetogram observations. No flare was observed to be associated with the onset of the oscillation. We also discuss possible implications of the oscillation as a diagnostic tool for the eruption mechanisms. We suggest that in the early phase of eruption a part of the filament lost its equilibrium first, while the remaining part was still in an equilibrium and oscillated.

Large-amplitude oscillations of a polar crown filament in the pre-eruption phase

Isobe, H., Tripathi, D.:
2006, *Astron. Astrophys.* **449**, L17., File
15 October 2002,

Fundamental-Mode Oscillations of Two Coronal Loops within a Solar Magnetic Arcade

Rekha **Jain**, Ram A. Maurya, B. W. Hindman
2015 ApJL 804 L19
http://arxiv.org/pdf/1504.07822v1.pdf

Fundamental-Mode Oscillations of Two Coronal Loops within a Solar Magnetic Arcade

Rekha **Jain**, Ram A. Maurya, B. W. Hindman
2015
http://arxiv.org/pdf/1504.07822v1.pdf

We analyse intensity variations, as measured by the Atmospheric Imaging Assembly (AIA) in the 171 {\AA} passband, in two coronal loops embedded within a single coronal magnetic arcade. We detect oscillations in the fundamental mode with periods of roughly 2 minutes and decay times of 5 minutes. The oscillations were initiated by interaction of the arcade with a large wavefront issuing from a flare site. Further, the power spectra of the oscillations evince signatures consistent with oblique propagation to the field lines and for the existence of a 2-D waveguide instead of a 1-D one. **6 September 2011**

What can be learned from the seismology of a coronal loop using only a handful of frequencies?

R. **Jain**1 and B. W. Hindman
A&A 545, A138 (**2012**)

Context. Transverse oscillating loops in the solar corona have been observed and the frequencies for a couple of low-order modes measured. These frequencies have been used as a diagnostic tool to investigate the internal properties of such oscillating loops. In particular, the density and magnetic field profiles along the loop are estimated by comparing the measured frequencies with those of a reference model. In this paper, we argue that only the kink speed may be assessed directly and there is no diagnostic capability for density or magnetic field independent of the wave speed. Further, with just a handful of measured frequencies available, only broad spatial averages of the kink speed may be obtained. We demonstrate using a frequency inversion procedure that with only two frequencies as inputs, at best one can assess the mean and the contrast of the kink speed along the loop. One requires access to the frequencies of many mode orders to perform inversions that offer kink speed determinations with high spatial resolution.
Aims. We suggest a rigorous mathematical formalism that describes the information content of the measured mode frequencies and we present a method to infer the kink speed within a coronal loop by inverting those frequencies.
Methods. We consider a single magnetic coronal loop and by using perturbation theory, relate its eigenfrequencies to the loop's physical properties.
Results. We derive the sensitivity kernels that describe how each eigenfrequency contain the information about the kink speed and density along the loop.
Conclusions. We conclude that the eigenfrequencies contain information primarily about the kink speed, and do not strongly depend on the density. Therefore, all loop models with the same kink speed profile (but different density and magnetic field profiles) are seismically indistinguishable. To acheive the spatial resolution neccessary to uncover the non-uniform nature of the coronal loop, it is necessary to do inversion of many measured frequencies. Making inferences about the density stratification and magnetic field varying along the loop requires supplemental observations that are non-seismic in nature.

Statistical analysis of UV spectra of a quiescent prominence observed by IRIS

S. **Jejčič**, P. Schwartz, P. Heinzel, M. Zapiór, S. Gunár

A&A 618, A88 **2018**
https://arxiv.org/pdf/1807.05767.pdf
The paper analyzes the structure and dynamics of a quiescent prominence that occurred on **October 22, 2013**. We aim to determine the physical characteristics of the observed prominence using MgII k and h, CII (1334 and 1336 A), and SiIV (1394 A) lines observed by IRIS. We employed the 1D non-LTE modeling of MgII lines assuming static isothermal-isobaric slabs. We selected a large grid of models with realistic input parameters and computed synthetic MgII lines. The method of Scargle periodograms was used to detect possible prominence oscillations. We analyzed 2160 points of the observed prominence in five different sections along the slit averaged over ten pixels due to low signal to noise ratio in the CII and SiIV lines. We computed the integrated intensity for all studied lines, while the central intensity and reversal ratio was determined only for both MgII and CII 1334 lines. We plotted several correlations: time evolution of the integrated intensities and central intensities, scatter plots between all combinations of line integrated intensities, and reversal ratio as a function of integrated intensity. We also compared MgII observations with the models. Results show that more than two-thirds of MgII profiles and about one-half of CII 1334 profiles are reversed. Profiles of SiIV are generally unreversed. The MgII and CII lines are optically thick, while the SiIV line is optically thin. The studied prominence shows no global oscillations in the MgII and CII lines. Therefore, the observed time variations are caused by random motions of fine structures with velocities up to 10 km/s. The observed average ratio of MgII k to MgII h line intensities can be used to determine the prominence's characteristic temperature. Certain disagreements between observed and synthetic line intensities of MgII lines point to the necessity of using more complex 2D multi-thread modeling in the future.

Visibility of Prominences Using the He i D3 Line Filter on the PROBA-3/ASPIICS Coronagraph

S. **Jejčič**, P. Heinzel, N. Labrosse, A. N. Zhukov, A. Bemporad, S. Fineschi, S. Gunár
Solar Physics February **2018**, 293:33
We determine the optimal width and shape of the narrow-band filter centered on the He i D3 line for prominence and coronal mass ejection (CME) observations with the ASPIICS (Association of Spacecraft for Polarimetric and Imaging Investigation of the Corona of the Sun) coronagraph onboard the PROBA-3 (Project for On-board Autonomy) satellite, to be launched in 2020. We analyze He i D3 line intensities for three representative non-local thermal equilibrium prominence models at temperatures 8, 30, and 100 kK computed with a radiative transfer code and the prominence visible-light (VL) emission due to Thomson scattering on the prominence electrons. We compute various useful relations at prominence line-of-sight velocities of 0, 100, and 300 km s−1 for 20 Å wide flat filter and three Gaussian filters with a full-width at half-maximum (FWHM) equal to 5, 10, and 20 Å to show the relative brightness contribution of the He i D3 line and the prominence VL to the visibility in a given narrow-band filter. We also discuss possible signal contamination by Na i D1 and D2 lines, which otherwise may be useful to detect comets. Our results mainly show that i) an optimal narrow-band filter should be flat or somewhere between flat and Gaussian with an FWHM of 20 Å in order to detect fast-moving prominence structures, ii) the maximum emission in the He i D3 line is at 30 kK and the minimal at 100 kK, and iii) the ratio of emission in the He i D3 line to the VL emission can provide a useful diagnostic for the temperature of prominence structures. This ratio is up to 10 for hot prominence structures, up to 100 for cool structures, and up to 1000 for warm structures.

Multi-Wavelength Eclipse Observations of a Quiescent Prominence

S. **Jejčič**, P. Heinzel, M. Zapiór, M. Druckmüller, S. Gunár, P. Kotrč
Solar Physics, July **2014**, Volume 289, Issue 7, pp 2487-2501
We construct the maps of temperatures, geometrical thicknesses, electron densities and gas pressures in a quiescent prominence. For this we use the RGB signal of the prominence visible-light emission detected during the total solar eclipse of **1 August 2008** in Mongolia and quasi-simultaneous Hα spectra taken at Ondřejov Observatory. The method of disentangling the electron density and geometrical (effective) thickness was described by Jejčič and Heinzel (Solar Phys. 254, 89 – 100, 2009) and is used here for the first time to analyse the spatial variations of prominence parameters. For the studied prominence we obtained the following range of parameters: temperature 6000 – 15 000 K, effective thickness 200 – 15000 km, electron density 5×109 – 1011 cm−3 and gas pressure 0.02 – 0.2 dyn cm−2 (assuming a fixed ionisation degree n p/n H=0.5). The electron density increases towards the bottom of the prominence, which we explain by an enhanced photoionisation due to the incident solar radiation. To confirm this, we construct a two-dimensional radiative-transfer model with realistic prominence illumination.

Transverse oscillations of a double-strutured solar filament

P. **Jelínek**, M. Karlický, V. V. Smirnova, A. A. Solov'ev
A&A, 637, A42 **2020**
https://www.aanda.org/articles/aa/pdf/forth/aa36836-19.pdf

https://www.aanda.org/articles/aa/pdf/2020/05/aa36836-19.pdf
Aims. We study the transverse os illations of a double-stru tured solar lament. Methods. We modelled the lament numeri ally via a 2-D magnetohydrodynami (MHD) model, in whi h we solved a full set of time-dependent MHD equations by means of the FLASH ode, using the adaptive mesh re nement (AMR) method. We used the wavelet analysis method as a diagnosti tool for analysing periods in simulated os illations. Results. We present a model of a solar filament ombined with semi-empiri al C7 model of the quiet solar atmosphere. This model is an alternative model of a filament based on the magnetostati solution of MHD equations. We find that this double-stru tured filament os illates with two di erent eigen frequen ies. The ratio is approximately 1.75 (~ 7.4 min/~ 4.2 min), whi h is hara teristi for this type of lament model. To show the details of these os illations we present a time evolution of the plasma density, temperature, plasma beta parameter, and the ratio of gravity to magneti pressure taken along the verti al axis of the filament at x = 0. The periods found by numeri al simulations are then dis ussed in omparison with those observed.

The Bright Rim Prominences according to 2.5D Radiative Transfer
Jack M. **Jenkins**, Christopher M. J. Osborne, Ye Qiu, Rony Keppens, Chuan Li
ApJL **964** L34 **2024**
https://arxiv.org/pdf/2403.09931.pdf
https://iopscience.iop.org/article/10.3847/2041-8213/ad3423/pdf
Solar prominences observed close to the limb commonly include a bright feature that, from the perspective of the observer, runs along the interface between itself and the underlying chromosphere. Despite several idealised models being proposed to explain the underlying physics, a more general approach remains outstanding. In this manuscript we demonstrate as a proof-of-concept the first steps in applying the Lightweaver radiative transfer framework's 2.5D extension to a `toy' model prominence + VAL3C chromosphere, inspired by recent 1.5D experiments that demonstrated a significant radiative chromosphere--prominence interaction. We find the radiative connection to be significant enough to enhance both the electron number density within the chromosphere, as well as its emergent intensity across a range of spectral lines in the vicinity of the filament absorption signature. Inclining the viewing angle from the vertical, we find these enhancements to become increasingly asymmetric and merge with a larger secondary enhancement sourced directly from the prominence underside. In wavelength, the enhancements are then found to be the largest in both magnitude and horizontal extent for the spectral line cores, decreasing into the line wings. Similar behaviour is found within new Chinese Hα Solar Explorer (CHASE)/Hα Imaging Spectrograph (HIS) observations, opening the door for subsequent statistical confirmations of the theoretical basis we develop here.

1.5D NLTE spectral synthesis of a 3D filament/prominence simulation
J. M. **Jenkins**, C. M. J. Osborne, R. Keppens
A&A 670, A179 **2022**
https://arxiv.org/pdf/2211.14869.pdf
https://www.aanda.org/articles/aa/pdf/2023/02/aa44868-22.pdf
Aims. We here demonstrate how the recently developed Lightweaver framework makes non-LTE (NLTE) spectral synthesis feasible on a new 3D ab-initio magnetohydrodynamic (MHD) filament/prominence simulation, in a post-processing step. Methods. We clarify the need to introduce filament/prominent-specific Lightweaver boundary conditions that accurately model incident chromospheric radiation, and include a self-consistent and smoothly varying limb darkening function. Results. Progressing from isothermal/isobaric models to the self-consistently generated stratifications within a fully 3D MHD filament/prominence simulation, we find excellent agreement between our 1.5D non local thermodynamic equilibrium Lightweaver synthesis and a popular Hydrogen H{\alpha} proxy. We compute additional lines including Ca~\textsc{ii} 8542 alongside the more optically-thick Ca~\textsc{ii} H&K & Mg~\textsc{ii} h&k lines, for which no comparable proxy exists, and explore their formation properties within filament/prominence atmospheres. Conclusions. The versatility of the Lightweaver framework is demonstrated with this extension to 1.5D filament/prominence models, where each vertical column of the instantaneous 3D MHD state is spectrally analysed separately, without accounting for (important) multi-dimensional radiative effects. The general agreement found in the line core contrast of both observations and the Lightweaver-synthesised simulation further validates the current generation of solar filaments/prominences models constructed numerically with MPI-AMRVAC.

Prominence formation by levitation-condensation at extreme resolutions
Jack **Jenkins**, Rony Keppens
A&A 646, A134 (**2021**)
https://arxiv.org/pdf/2011.13428.pdf
https://doi.org/10.1051/0004-6361/202039630
Prominences in the solar atmosphere represent an intriguing and delicate balance of forces and thermodynamics in an evolving magnetic topology. How this relatively cool material comes to reside at coronal heights, and what drives

its evolution prior to, during, and after its appearance remains an area full of open questions. We deliberately focus on the levitation-condensation scenario, where a coronal flux rope forms and eventually demonstrates in-situ condensations, revisiting it at extreme resolutions down to order 6 km in scale. We perform grid-adaptive numerical simulations in a 2.5D translationally invariant setup, where we can study the distribution of all metrics involved in advanced magnetohydrodynamic stability theory for nested flux rope equilibria. We quantify in particular Convective Continuum Instability (CCI), Thermal Instability (TI), baroclinicity, and mass-slipping metrics within a series of numerical simulations of prominences formed via levitation-condensation. Overall, we find that the formation and evolution of prominence condensations happens in a clearly defined sequence regardless of resolution or background field strength between 3 and 10 Gauss. The CCI governs the slow evolution of plasma prior to the formation of distinct condensations found to be driven by the TI. Evolution of the condensations towards the topological dips of the magnetic flux rope is a consequence of these condensations forming initially outside of pressure balance with their surroundings. From the baroclinicity distributions, smaller-scale rotational motions are inferred within forming and evolving condensations. Upon the complete condensation of a prominence `monolith', the slow descent of this plasma towards lower heights appears consistent with the mass-slippage mechanism driven by episodes of both local current diffusion and magnetic reconnection.

Prominence and coronal rain formation by steady versus stochastic heating and how we can relate it to observations

V. **Jerčić** (1), J. M. Jenkins (1), R. Keppens (1)

A&A 688, A145 **2024**
https://arxiv.org/pdf/2406.02955

Prominences and coronal rain are two forms of coronal condensations for which we still lack satisfactory details on the formation pathways and conditions under which the two come to exist. We compared prominences that formed via a steady versus stochastic type of heating. We performed 2.5D simulations using the open-source MPI-AMRVAC code. To further extend the work and allow for future direct comparison with observations, we used Lightweaver to form spectra of the filament view of our steady case prominence. With that, we analysed a reconnection event that shares certain characteristics with nanojets. We show how different forms of localised heating that induce thermal instability result in prominences with different properties. The steady form of heating results in prominence with a clear vertical structure stretching across the magnetic field lines. On the other hand, stochastic heating produces many threads that predominantly have a horizontal motion along the field lines. In the steady heating case, the prominence is relatively static; however, there is evidence of reconnection happening almost the entire time the prominence is present. In the case of stochastic heating, the threads are highly dynamic, with them also exhibiting a form of transverse oscillation (strongly resembling the decayless type). The fact that the threads in the stochastic heating case are constantly moving along the field lines suppresses any conditions for reconnection. It, therefore, appears that, to first order, the choice of heating prescription defines whether the prominence-internal dynamics are oriented vertically or horizontally. We closely inspected a sample reconnection event and computed the synthetic optically thick radiation using the open-source Lightweaver radiative transfer framework.

Dynamic formation of multi-threaded prominences in arcade configurations

V. **Jerčić** (1), R. Keppens (1)

A&A 670, A64 **2023**
https://arxiv.org/pdf/2212.08537.pdf
https://www.aanda.org/articles/aa/pdf/2023/02/aa45067-22.pdf

With this study, we aim to understand the nature of prominences, governed by their formation process. We use a state-of-the-art threaded prominence model within a dipped magnetic arcade. The non-ideal magnetohydrodynamic (MHD) equations are solved using the open-source MPI-AMRVAC MHD toolkit. Unlike many previous 1D models, we study the full 2D dynamics in a fixed-shaped arcade. This allows for sideways field deformations and cross-field thermodynamic coupling. To achieve a realistic setup we consider field-aligned thermal conduction, radiative cooling and heating, wherein the latter combines a steady background and a localized stochastic component. The stochastic component simulates energy pulses localized in time and space at the footpoints of the magnetic arcade. We vary the height and amplitude of the localized heating and observe how it influences the prominence, its threads, and its overall dynamics. We show the importance of random localized heating in the evolution of prominences and their threaded structure. Random heating strongly influences the morphology of the prominence threaded structure, the area, the mass the threads reach, their minimum temperature and their average density. More importantly, the strength of the localized heating plays a role in maintaining the balance between condensation and draining, affecting the general prominence stability. Stronger sources form condensations faster and result in larger and more massive prominences. We show how the condensation rates scale with the amplitude of the heating inputs and quantify how these rates match with values from observations. We detail how stochastic sources determine counterstreaming flows and oscillations of prominence threads.

Multi-threaded prominence oscillations triggered by a coronal shock wave

V. **Jerčić**, R. Keppens, Y. Zhou

A&A 658, A58 **2022**
https://arxiv.org/pdf/2111.09019.pdf
https://www.aanda.org/articles/aa/pdf/2022/02/aa42127-21.pdf
https://doi.org/10.1051/0004-6361/202142127

In this work, we study the causal relations between a localised energy release and a remote prominence oscillation, where the prominence has a realistic thread-like structure. We used an open source magnetohydrodynamic (MHD) code known as MPI-AMRVAC to create a multithreaded prominence body. We introduced an additional energy source from which a shock wave originates, thereby inducing prominence oscillation. We studied two cases with different source amplitudes to analyze its effect on the oscillations. Our results show that the frequently used pendulum model does not suffice to fully estimate the period of the prominence oscillation, in addition to showing that the influence of the source and the thread-like prominence structure needs to be taken into account. Repeated

reflections and transmissions of the initial shock wave occur at the specific locations of multiple high-temperature and high-density gradients in the domain. This includes the left and right transition region (TR) located at the footpoints of the magnetic arcade, as well as the various transition regions between the prominence and the corona (PCTR). This results in numerous interferences of compressional waves. They contribute to the restoring forces of the oscillation, causing the period to deviate from the expected pendulum model, in addition to leading to differences in attributed damping or even growth in amplitude between the various threads. Along with the global longitudinal motion that result from the shock impact, small-scale transverse oscillations are also evident. Multiple high-frequency oscillations represent the propagation of magnetoacoustic waves. The damping we see is linked to the conversion of energy and its exchange with the surrounding corona. Our simulations demonstrate the exchange of energy between different threads and their different modes of oscillation.

OBSERVATIONS OF THE FAILED ERUPTION OF A FILAMENT

Haisheng **Ji**,1,2 Haimin Wang,1 Edward J. Schmahl,3 Y.-J. Moon,1,4 and Yunchun Jiang1

Astrophysical Journal, 595:L135–L138, **2003; File**

We have observed the fine temporal and spatial structure of a filament eruption on 2002 May 27 following an M2-class flare. Our observations at Big Bear Solar Observatory were made at the wavelength of Ha 1.3 A° , with a cadence of 40 ms. The event was also observed by the *Reuven Ramaty High Energy Solar Spectroscopic Imager* (*RHESSI*) at X-ray energies from 3 to 50 keV and by the *Transition Region and Coronal Explorer* (*TRACE*) in poFe xii 195 A° . The event appears to be a "failed eruption," as the filament material, seen in absorption by *TRACE*, first accelerated then decelerated as it approached its peak height of ~ km while 4 8#10 the filament threads drained back to the Sun. The fact that the eruption did not lead to a coronal mass ejection indicates that the coronal magnetic field near ~ km did not open during the flare. The height-time curve 4 8#10 obtained from the *TRACE* 195 A° images during the deceleration phase shows that the deceleration of the filament exceeded the gravitational deceleration by more than a factor of 10, which suggests that the filament material was pulled back by magnetic tension. Also of importance are three sequential but cospatial features—brightenings in EUV, a loop-top hard X-ray emission, and "rupturing" of the Ha filament—that point to a release of energy (and probably magnetic reconnection) above the initial filament's location but well below its terminal height. Reconnection above a filament does not appear in most models, with the notable exception of quadrupolar and "breakout" models. These observations provide evidence that at least two conditions are required for a successful eruption: a reconnection very low in the corona (possibly above the filament) and open or opening fields above that point.

Interaction and Merging of two Sinistral Filaments

Yunchun **Jiang**1, Jiayan Yang1, Haimin Wang2, Haisheng Ji3, Yu Liu1, Haidong Li1, and Jianping Li

2014 ApJ 793 14

In this paper, we report the interaction and subsequent merging of two sinistral filaments (F1 and F2) occurring at the boundary of AR 9720 on **2001 December 6**. The two filaments were close and nearly perpendicular to each other. The interaction occurred after F1 was erupted and the eruption was impeded by a more extended filament channel (FC) standing in the way, in which F2 was embedded. The erupted material ran into FC along its axis, causing F1 and F2 to merge into a single structure that subsequently underwent a large-amplitude to-and-fro motion. A significant plasma heating process was observed in the merging process, making the mixed material largely disappear from the H? passband, but appear in Extreme Ultraviolet Telescope 195?? images for a while. These observations can serve as strong evidence of merging reconnection between the two colliding magnetic structures. A new sinistral filament was formed along FC after the cooling of the merged and heated material. No coronal mass ejection was observed to be associated with the event; though, the eruption was accompanied by a two-ribbon flare with a separation motion, indicating that the eruption had failed. This event shows that, in addition to overlying magnetic fields, such an interaction is an effective restraint to make a filament eruption fail in this way.

Nonlinear Force-Free Field Extrapolation of a Coronal Magnetic Flux Rope Supporting a Large-Scale Filament from Photospheric Vector Magnetogram

Chaowei **Jiang**, S. T. Wu, Xueshang Feng, Qiang Hu

ApJL, **2014**

http://arxiv.org/pdf/1403.7807v1.pdf

Solar filament are commonly thought to be supported in magnetic dips, in particular, of magnetic flux ropes (FRs). In this Letter, from the observed photospheric vector magnetogram, we implement a nonlinear force-free field (NLFFF) extrapolation of a coronal magnetic FR that supports a large-scale intermediate filament between an active region and a weak polarity region. This result is the first in that current NLFFF extrapolations with presence of FRs are limited to relatively small-scale filaments that are close to sunspots and along main polarity inversion line (PIL) with strong transverse field and magnetic shear, and the existence of a FR is usually predictable. In contrast, the present filament lies along the weak-field region (photospheric field strength $\lesssim$100 G), where the PIL is very fragmented due to small parasitic polarities on both side of the PIL and the transverse field has a low value of signal-to-noise ratio. Thus it represents a far more difficult challenge to extrapolate a large-scale FR in such case. We demonstrate that our CESE--MHD--NLFFF code is competent for the challenge. The numerically reproduced magnetic dips of the extrapolated FR match observations of the filament and its barbs very well, which supports strongly the FR-dip model for filaments. The filament is stably sustained because the FR is weakly twisted and strongly confined by the overlying closed arcades.

PARTIAL SLINGSHOT RECONNECTION BETWEEN TWO FILAMENTS

Yunchun Jiang1, Junchao Hong1,2, Jiayan Yang1, Yi Bi1, Ruisheng Zheng1, Bo Yang1,2, Haidong

Yunchun **Jiang**1, Junchao Hong1,2, Jiayan Yang1, Yi Bi1, Ruisheng Zheng1, Bo Yang1,2, Haidong Li1, and Dan Yang

2013 ApJ 764 68

We present a rare observation of an interaction between two filaments around AR 11358 and AR 11361 on **2011 December 3** that is strongly suggestive of the occurrence of slingshot reconnection. A small elbow-shaped active-region filament (F12) underwent a failed eruption that brought it into contact with a nearby larger, thicker filament (F34). Accompanied by the appearance of complicated internal structures below the erupting F12, its two legs separated away from each other and then connected into F34. This process led the filaments to change their connectivity to form two newly linked filaments, and one of them showed a clear inverse γ-shape. However, the alteration in the filament connectivity was imperfect since F34 is discernible after the eruption. These observations can be interpreted as a partial slingshot reconnection between two filaments that had unequal axial magnetic flux.

SYMPATHETIC FILAMENT ERUPTIONS CONNECTED BY CORONAL DIMMINGS

Yunchun **Jiang**, Jiayan Yang, Junchao Hong, Yi Bi and Ruisheng Zheng

2011 ApJ 738 179, **File?**

We present for the first time detailed observations of three successive, interdependent filament eruptions that occurred one by one within 5 hr from different locations beyond the range of a single active region. The first eruption was observed from an active region and was associated with a coronal mass ejection (CME), during which diffuse and complex coronal dimmings formed, largely extending to the two other filaments located in quiet-Sun regions. Then, both quiescent filaments consecutively underwent the second and third eruptions, while the nearby dimmings were persistent. Comparing the result of a derived coronal magnetic configuration, the magnetic connectivity between the dimmings suggested that they were caused by the joint effect of simple expansion of overlying loop systems forced by the first eruption, as well as by its erupting field interacting or reconnecting with the surrounding magnetic structures. Note that the dimming process in the first eruption indicated a weakening and partial removal of an overlying magnetic field constraint on the two other filaments, and thus one can physically connect these eruptions as sympathetic. It appears that the peculiar magnetic field configuration in our event was largely favorable to the occurrence of sympathetic filament eruptions. Because coronal dimmings are frequent and common phenomena in solar eruptions, especially in CME events, it is very likely that they represent a universal agent that can link consecutive eruptions nearby with sympathetic eruptions.

MAGNETIC INTERACTION: AN ERUPTING FILAMENT AND A REMOTE CORONAL HOLE

Yunchun **Jiang**, Liheng Yang, Kejun Li, and Yuandeng Shen

The Astrophysical Journal, 667: L105–L108, **2007, File**

2004 December 30

For the first time, we present a rare observation of direct magnetic interaction between an erupting filament and a coronal hole (CH). The small active region filament obliquely erupted toward the CH getting in the way, met and interacted with it, and then was deflected back. The erupting filament thus underwent a distinct to-and-fro motion in the visible disk, while the CH was clearly disturbed by the interaction. Brightenings in Hα and EUV and darkenings in He i 10830 °A appeared at the boundaries and in the interior of the CH. This eruption was closely associated with the initiation of a halo-type coronal mass ejection (CME). The direction of the CME, despite being greatly different from that of the initial filament eruption, was consistent with that of the reflected filament. Moreover, when the CME was seen in the limb, the filament was still in the process of the return journey in the visible disk. Therefore, it appears that the large-scale structure of the CME was bounced against and then reflected away from the CH along with the filament, and the eruptive filament represented only a very small part in the CME.

H-alpha Dimming Associated With the Eruption of a Coronal Sigmoid in the Quiet Sun
Yunchun **Jiang** · Huadong Chen · Yuandeng Shen · Liheng Yang · Kejun Li
Solar Phys (**2007**) 240: 77–87
14 August 2001. During the eruption,
coronal bipolar double dimming took place at the regions with opposite magnetic polarities around the two sigmoid ends, but the underlying chromospheric channel did not show observable changes corresponding to the coronal eruption. Different from the erupting coronal sigmoid itself, however, the coronal dimming had a detectable chromosphere counterpart, i.e., Hα dimming. By regarding the sigmoid as a coronal sign for a flux rope, these observations are explained in the framework of the flux rope model of CMEs. The flux rope is possibly deeply rooted in the chromosphere, and the coronal and Hα dimming regions mark its evacuated feet, through which the material is possibly fed to the halo CME.

The Filament Eruption of 1999 March 21 and Its Associated Coronal Dimmings and CME
Yun-Chun **Jiang**, Le-Ping Li and Li-Heng Yang
Chin. J. Astron. Astrophys. Vol. 6 (**2006**), No. 3, 345–353

Filament eruption, flare, coronal dimming and associated partial halo CME on 2001 September 17
Y.C. **Jiang,** L.P. Li, S.Q. Zhao, Q.Y. Li, H.D. Chen, S.L. Ma
New Astronomy, Volume 11, Issue 8, July **2006,** Pages 612-618
Using Hα, EUV, photospheric magnetic field and white-light coronagraph data, we study the eruption of an active-region Hα filament and associated partial-halo type coronal mass ejection (CME) occurring in NOAA AR 9616 on 2001 September 17. Accompanied by an M1.5 flare, the small active-region filament quickly erupted, a quiet-sun region outside the active region intensively darkened so a remote coronal dimming region was formed, and then a long Hα surge developed from the eruption site. During the eruption, remote EUV brightening appeared along the dimming boundary, leaving behind huge EUV loops connecting the eruption source region and the remote EUV brightening. Finally, as a definite indication of the start of CME, a large-scale dark rim appeared to span the eruption region. These observations indicate that a much larger-scale rearrangement of the coronal magnetic fields, eventually represented by the occurrence of the CME, was involved in the eruption of the filament with small spatial scale. The relationship between the filament eruption, flare and coronal dimming is also discussed.

NONLINEAR FORCE-FREE MODELING OF MAGNETIC FIELDS IN A SOLAR FILAMENT
Ju **Jing** 1, Yuan Yuan 1, Thomas Wiegelmann 2, Yan Xu 1, Rui Liu 1 and Haimin Wang
2010 ApJL 719 L56, **File**
We present a striking filament pattern in the nonlinear force-free (NLFF) chromospheric magnetic field of the active region NOAA 10956. The NLFF chromospheric field is extrapolated from the Hinode high-resolution photospheric vector magnetogram using the weighted optimization method. The modeled structure is characterized by a highly sheared field with strong horizontal magnetic components and has a virtually identical shape and location as the filament seen in Hα. The modeled field strength agrees with the recent He I 10830 Å observations by Kuckein et al.. The unequivocal resemblance between the NLFF extrapolation and the Hα observation not only demonstrates the ability of the NLFF field to reproduce chromospheric features, but also provides a valuable diagnostic tool for the filament magnetic fields. **18 May 2007 (related to eruption on 19 May 2007)**

ON THE RELATION BETWEEN FILAMENT ERUPTIONS, FLARES, AND CORONAL MASS EJECTIONS
Ju **Jing**, Vasyl B. Yurchyshyn, Guo Yang, Yan Xu, and Haimin Wang
The Astrophysical Journal, 614:1054–1062, **2004**
Таблица
a statistical study of **106 filament eruptions**, which were automatically detected by a pattern recognition program implemented at Big Bear Solar Observatory using H_ full-disk data from **1999 to 2003**.

The effects of numerical resolution, heating timescales and background heating on thermal non-equilibrium in coronal loops

C. D. **Johnston**, P. J. Cargill, P. Antolin, A. W. Hood, I. De Moortel, S. J. Bradshaw
A&A 625, A149 **2019**
https://arxiv.org/pdf/1904.07287.pdf
Thermal non-equilibrium (TNE) is believed to be a potentially important process in understanding some properties of the magnetically closed solar corona. Through one-dimensional hydrodynamic models, this paper addresses the importance of the numerical spatial resolution, footpoint heating timescales and background heating on TNE. Inadequate transition region (TR) resolution can lead to significant discrepancies in TNE cycle behaviour, with TNE being suppressed in under-resolved loops. A convergence on the periodicity and plasma properties associated with TNE required spatial resolutions of less than 2 km for a loop of length 180 Mm. These numerical problems can be resolved using an approximate method that models the TR as a discontinuity using a jump condition, as proposed by Johnston et al. (2017a,b). The resolution requirements (and so computational cost) are greatly reduced while retaining good agreement with fully resolved results. Using this approximate method we (i) identify different regimes for the response of coronal loops to time-dependent footpoint heating including one where TNE does not arise and (ii) demonstrate that TNE in a loop with footpoint heating is suppressed unless the background heating is sufficiently small. The implications for the generality of TNE are discussed.

PRE-ERUPTION OSCILLATIONS IN THIN AND LONG FEATURES IN A QUIESCENT FILAMENT
Anand D. **Joshi**1,2, Yoichiro Hanaoka1, Yoshinori Suematsu1, Satoshi Morita1, Vasyl Yurchyshyn2,3, and Kyung-Suk Cho
2016 ApJ 833 243
http://sci-hub.cc/doi/10.3847/1538-4357/833/2/243
We investigate the eruption of a quiescent filament located close to an active region. Large-scale activation was observed in only half of the filament in the form of pre-eruption oscillations. Consequently only this half erupted nearly 30 hr after the oscillations commenced. Time-slice diagrams of 171 Å images from the Atmospheric Imaging Assembly were used to study the oscillations. These were observed in several thin and long features connecting the filament spine to the chromosphere below. This study traces the origin of such features and proposes their possible interpretation. Small-scale magnetic flux cancellation accompanied by a brightening was observed at the footpoint of the features shortly before their appearance, in images recorded by the Helioseismic and Magnetic Imager. A slow rise of the filament was detected in addition to the oscillations, indicating a gradual loss of equilibrium. Our analysis indicates that a change in magnetic field connectivity between two neighbouring active regions and the quiescent filament resulted in a weakening of the overlying arcade of the filament, leading to its eruption. It is also suggested that the oscillating features are filament barbs, and the oscillations are a manifestation during the pre-eruption phase of the filaments. **2013 August 14**

Formation of Compound Flux Rope by The Merging of Two Filament Channels, Associated Dynamics and its Stability
Navin Chandra **Joshi**, Tetsuya Magara, Satoshi Inoue
ApJ, **2014**
http://arxiv.org/pdf/1409.1359v1.pdf
We present the observations of compound flux rope formation via merging of two nearby filament channels, associated dynamics and its stability that occurred on **2014 January 1** using multiwavelength data. We have also discussed the dynamics of cool and hot plasma moving along the newly formed compound flux rope. The merging started after the interaction between the southern leg of northward filament and the northern leg of the southward filament at around 01:21 UT and continue until a compound flux rope formed at around 01:33 UT. During the merging the cool filaments plasma heated up and started to move along the both side of the compound flux rope i.e., toward north (approx 265 km/s) and south (approx 118 km/s) from the point of merging. After travelling a distance of approx 150 Mm towards north the plasma become cool and started to returns back towards south (approx 14 km/s) after 02:00 UT. The observations provide an clear example of compound flux rope formation via merging of two different flux ropes and occurrence of flare through tether cutting reconnection. However, the compound flux rope remained stable in the corona and made an confined eruption. The coronal magnetic field decay index measurements revealed that both the filaments and the compound flux rope axis lies within the stability domain (decay index less than 1.5), which may be the possible cause for their stability. The present study also deals with the relationship between the filaments chirality (sinistral) and the helicity (positive) of the surrounding flux rope.

Confined Partial Filament Eruption and its Reformation within a Stable Magnetic Flux Rope

Navin Chandra **Joshi**, Abhishek K. Srivastava, Boris Filippov, Pradeep Kayshap, Wahab Uddin, Ramesh Chandra, Debi Prasad Choudhary, and B. N. Dwivedi
2014 ApJ 787 11
We present observations of a confined partial eruption of a filament on **2012 August 4**, which restores its initial shape within 2 hr after eruption. From the Global Oscillation Network Group Hα observations, we find that the filament plasma turns into dynamic motion at around 11:20 UT from the middle part of the filament toward the northwest direction with an average speed of 105 km s–1. A little brightening underneath the filament possibly shows the signature of low-altitude reconnection below the filament eruptive part. In Solar Dynamics Observatory/Atmospheric Imaging Assembly 171 Å images, we observe an activation of right-handed helically twisted magnetic flux rope that contains the filament material and confines it during its dynamical motion. The motion of cool filament plasma stops after traveling a distance of 215 Mm toward the northwest from the point of eruption. The plasma moves partly toward the right foot point of the flux rope, while most of the plasma returns after 12:20 UT toward the left foot point with an average speed of 60 km s–1 to reform the filament within the same stable magnetic structure. On the basis of the filament internal fine structure and its position relative to the photospheric magnetic fields, we find filament chirality to be sinistral, while the activated enveloping flux rope shows a clear right-handed twist. Thus, this dynamic event is an apparent example of one-to-one correspondence between the filament chirality (sinistral) and the enveloping flux rope helicity (positive). From the coronal magnetic field decay index, n, calculation near the flux rope axis, it is evident that the whole filament axis lies within the domain of stability (i.e., $n < 1$), which provides the filament stability despite strong disturbances at its eastern foot point.

Rapid Formation and Disappearance of a Filament Barb

Anand D. **Joshi**, Nandita Srivastava, Shibu K. Mathew, Sara F. Martin
Solar Physics, November **2013**, Volume 288, Issue 1, pp 191-203
We present observations of an activated quiescent filament obtained in Hα from the high-resolution Dutch Open Telescope (DOT) on **20 August 2010**. The filament developed a barb in 10 min, which disappeared within the next 35 min. A data set from the DOT spanning 2 h was used to analyse this event. Line-of-sight velocity maps were constructed from the Doppler images, which reveal flows in filament spine during this period. Photospheric magnetograms were used from the Helioseismic and Magnetic Imager (HMI) on board the Solar Dynamics Observatory (SDO) to determine the changes in magnetic flux in the region surrounding the barb location. The analysis shows flows in the filament spine towards the barb location preceding its formation, and flows in the barb towards the spine during its disappearance. Magnetograms reveal patches of minority polarity flux close to the end of the barb at its greatest elongation. The flows in the spine and barbs are along numerous threads that compose these typical filament structures. The flows are consistent with field-aligned threads and demonstrate that the replacement time of the mass in barbs, and by inference, in the spine is very rapid.

RHESSI AND TRACE OBSERVATIONS OF MULTIPLE FLARE ACTIVITY IN AR 10656 AND ASSOCIATED FILAMENT ERUPTION

Bhuwan **Joshi**1, Upendra Kushwaha1, K.-S. Cho2, and Astrid M. Veronig
2013 ApJ 771 1
We present Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) and Transition Region and Coronal Explorer (TRACE) observations of multiple flare activity that occurred in the NOAA active region 10656 over a period of 2 hr on **2004 August 18**. Out of four successive flares, three were class C events, and the final event was a major X1.8 solar eruptive flare. The activities during the pre-eruption phase, i.e., before the X1.8 flare, are characterized by three localized episodes of energy release occurring in the vicinity of a filament that produces intense heating along with non-thermal emission. A few minutes before the eruption, the filament undergoes an activation phase during which it slowly rises with a speed of ~12 km s–1. The filament eruption is accompanied by an X1.8 flare, during which multiple hard X-ray (HXR) bursts are observed up to 100-300 keV energies. We observe a bright and elongated coronal structure simultaneously in E(UV) and 50-100 keV HXR images underneath the expanding filament during the period of HXR bursts, which provides strong evidence for ongoing magnetic reconnection. This phase is accompanied by very high plasma temperatures of ~31 MK, followed by the detachment of the prominence from the solar source region. From the location, timing, strength, and spectrum of HXR emission, we conclude that the prominence eruption is driven by the distinct events of magnetic reconnection occurring in the current sheet below the erupting prominence. These multi-wavelength observations also suggest that the localized magnetic reconnections associated with different evolutionary stages of the filament in the pre-eruption phase play an important role in destabilizing the active-region filament through the tether-cutting process, leading to large-scale eruption and X-class flare.

Study of Failed CME Core Associated with Asymmetric Filament Eruption

Joshi, N. C.; Srivastava, A. K.; Filippov, B.; Uddin, W.; Kayshap, P.; Chandra, R.

E-print, April **2013**
http://arxiv.org/abs/1304.6852
We present the multi-wavelength observations of asymmetric filament eruption, associated CME and coronal downflows on **2012 June 17-18** during 20:00-05:00 UT. We use SDO/AIA, STEREO-B/SECCHI observations to understand the filament eruption scenario and its kinematics. While LASCO C2 observations have been analyzed to study the kinematics of the CME and associated downflows. SDO/AIA limb observations show that the filament exhibits whipping like asymmetric eruption. STEREO/EUVI disk observations reveal a two ribbon flare underneath the south-eastern part of the filament that is most probably occurred due to reconnection process in the coronal magnetic field in the wake of the filament eruption. The whipping like filament eruption later gives a slow CME in which the leading edge and the core propagate respectively with the average speed of approx 540 km s-1 and approx 126 km s-1 as observed in the LASCO C2 coronagraph. The CME core formed by the eruptive flux-rope shows the outer coronal downflows with the average speed of approx 56 km s-1 after reaching up to approx4.33 Rsun. Initially, the core decelerates with approx 48 m s-2. The plasma first decelerates gradually up to the height of approx4.33 Rsun and then starts accelerating downward. We suggest a self-consistent model of a magnetic flux rope representing the magnetic structure of the CME core formed by eruptive filament that lost its previous stable equilibrium when reach at a critical height. With some reasonable parameters, and inherent physical conditions the model describes the non-radial ascending motion of the flux rope in the corona, its stopping at some height, and thereafter the downward motion, which are in good agreement with the observations.

KINEMATICS OF TWO ERUPTIVE PROMINENCES OBSERVED BY EUVI/*STEREO*
Anand D. **Joshi** and Nandita Srivastava
Astrophysical Journal, 730:104 (11pp), **2011** April, **File**
Two large northern polar crown prominences that erupted on **2010 April 13 and 2010 August 1** were analyzed using images obtained from the Extreme UltraViolet Imager on the twin *Solar Terrestrial Relations Observatory* spacecraft. Several features along the prominence legs were reconstructed using a stereoscopic reconstruction technique developed by us. The three-dimensional changes exhibited by the prominences can be explained as an interplay between two different motions, namely helical twist in the prominence spine, and overall non-radial equatorward motion of the entire prominence structure. The sense of twist in both the prominences is determined from the changes in latitudes and longitudes of the reconstructed features. The prominences are observed starting from a few hours before the eruption. Increase in height before and during the eruption allowed us to study the kinematics of the prominences in the two phases of eruption, the slow-rise and the fast-eruptive phase. A constant value of acceleration was found for each reconstructed feature in each phase, but it showed a significant change from one leg to the other in both the prominences. The magnitude of acceleration during the eruptive phase is found to be commensurate with the net effect of the two motions stated above.

Automated Detection of Filaments and Their Disappearance Using Full-Disc Hα Images
A. D. Joshi, N. Srivastava and S. K. Mathew
Solar Phys. 262(2), 425-436, **2010**
A new algorithm is presented that automatically detects filaments on the Sun in full-disc Hα images. Pre-processing of Hα images includes corrections for limb darkening and foreshortening. Further, by applying suitable intensity and size thresholds, filaments are extracted, while other solar features, *e.g.* sunspots and plages, are removed. Filament attributes such as their position on the solar disc, total area, length, and number of fragments are determined. In addition, every filament is also labelled with a unique number for identification. The algorithm is capable of following a particular filament through successive images, which allows us to detect their changes and disappearance. We have analysed ten cases of filament eruption from different observatories, and the results obtained are presented. The algorithm will eventually be integrated with an upcoming telescope at the Udaipur Solar Observatory for real-time monitoring of activated/eruptive filaments. This aspect should prove to be of particular importance in studies pertaining to space weather.

GLOBAL DYNAMICS OF SUBSURFACE SOLAR ACTIVE REGIONS
L. **Jouve**1,2, A. S. Brun2,4, and G. Aulanie
2013 ApJ 762 4
We present three-dimensional numerical simulations of a magnetic loop evolving in either a convectively stable or unstable rotating shell. The magnetic loop is introduced into the shell in such a way that it is buoyant only in a certain portion in longitude, thus creating an Ω-loop. Due to the action of magnetic buoyancy, the loop rises and develops asymmetries between its leading and following legs, creating emerging bipolar regions whose characteristics are similar to those of observed spots at the solar surface. In particular, we self-consistently reproduce the creation of tongues around the spot polarities, which can be strongly affected by convection. We further emphasize the presence of ring-shaped magnetic structures around our simulated emerging regions, which we call

"magnetic necklace" and which were seen in a number of observations without being reported as of today. We show that those necklaces are markers of vorticity generation at the periphery and below the rising magnetic loop. We also find that the asymmetry between the two legs of the loop is crucially dependent on the initial magnetic field strength. The tilt angle of the emerging regions is also studied in the stable and unstable cases and seems to be affected both by the convective motions and the presence of a differential rotation in the convective cases.

On the Intermittency of Hot Plasma Loops in the Solar Corona

Philip G. **Judge**1,2 and N. Paul M. Kuin3

2024 ApJ 970 130

https://iopscience.iop.org/article/10.3847/1538-4357/ad5202/pdf

A recent analysis has suggested that the heating of plasma loops in the solar corona depends not just on the Poynting flux but also on processes yet to be identified. This discovery reflects and refines earlier questions such as, Why and how are entire hydromagnetic structures only intermittently loaded with bright coronal plasma? The present work scrutinizes more chromospheric and coronal data, with the aim of finding reproducible observational constraints on coronal heating mechanisms. Six independent scans of chromospheric active-region magnetic fields are investigated and correlated to overlying hot plasma loops. For the first time, the footpoints of over 30 bright plasma loops are thus related to scalar proxies for the Poynting fluxes measured from the upper chromosphere. Although imperfect, the proxies all indicate a general lack of correlation between footpoint Poynting flux and loop brightness. Our findings consolidate the claim that unobserved physical processes are at work, which govern the heating of long-lived coronal loops.

Magnetic field vector ambiguity resolution in a quiescent prominence observed on two following days

T. **Kalewicz**, V. Bommier

A&A 629, A138 **2019**

https://arxiv.org/pdf/1904.01816.pdf

https://www.aanda.org/articles/aa/pdf/2019/09/aa35488-19.pdf

% context {Magnetic field vector measurements are always ambiguous, i.e., two or more field vectors are solutions of the observed polarisation.} % aims {The aim of the present paper is to solve the ambiguity by comparing the ambiguous field vectors obtained in the same prominence observed on two following days. The effect of the solar rotation is to modify the scattering angle of the prominence radiation, which modifies the symmetry of the ambiguous solutions. This method, which is a kind of tomography, was successfully applied in the past to the average magnetic field vector of 20 prominences observed at the Pic-du-Midi. The aim of the present paper is to apply this method to a prominence observed with spatial resolution at the THÉMIS telescope (European site at Izaña, Tenerife Island).} % methods {The magnetic field vector is measured by interpretation of the Hanle effect observed in the \ion{He}{i} D3 5876 \AA\, line, within the horizontal field vector hypothesis for simplicity. The ambiguity is first solved by comparing the two pairs of solutions obtained for a "big pixel" determined by averaging the observed Stokes parameters in a large region at the prominence center. Then, each pixel is disambiguated by selecting the closest solution in a propagation from the prominence center to the prominence boundary.} % results {The results previously obtained on averaged prominences are all recovered: Inverse Polarity, small angle of about −21∘ between the magnetic field vector and the filament long axis, within the Inverse Polarity scheme. The magnetic field strength, of about 6 G, is found to slightly increase with height, as previously observed also. The new result is the observed decreasing with height, of the absolute value of the angle between the magnetic field vector and the filament long axis.} **11 to 17 September 2008**

Impact of Dynamic State on the Mass Condensation Rate of Solar Prominences

Takafumi **Kaneko**, Takaaki Yokoyama

ApJ **869** 136 **2018**

https://arxiv.org/pdf/1811.00828.pdf

sci-hub.tw/10.3847/1538-4357/aaee6f

The interiors of quiescent prominences are filled with turbulent flows. The evolution of upflow plumes, descending pillars, and vortex motions has been clearly detected in high-resolution observations. The Rayleigh-Taylor instability is thought to be a driver of such internal flows. Descending pillars are related to the mass budgets of prominences. There is a hypothesis of dynamic equilibrium where the mass drainage via descending pillars and the mass supply via radiative condensation are balanced to maintain the prominence mass; however, the background physics connecting the two different processes is poorly understood. In this study, we reproduced the dynamic interior of a prominence via radiative condensation and the mechanism similar to the Rayleigh-Taylor instability using a three-dimensional magnetohydrodynamic simulation including optically thin radiative cooling and nonlinear anisotropic thermal conduction. The process to prominence formation in the simulation follows the reconnection-condensation model, where topological change in the magnetic field caused by reconnection leads to radiative condensation. Reconnection is driven by converging motion at the footpoints of the coronal arcade fields. In contrast to the previous model, by randomly changing the speed of the footpoint motion along a polarity inversion line, the dynamic interior of prominence is successfully reproduced. We find that the mass condensation rate of the prominence is enhanced in the case with dynamic state. Our results support the observational hypothesis that the condensation rate is balanced with the mass drainage rate and suggest that a self-induced mass maintenance mechanism exists.

Reconnection-Condensation Model for Solar Prominence Formation

Takafumi **Kaneko**, Takaaki Yokoyama

ApJ **845** 12 **2017**

https://arxiv.org/pdf/1706.10008.pdf

We propose a reconnection-condensation model in which topological change in a coronal magnetic field via reconnection triggers radiative condensation, thereby resulting in prominence formation. Previous observational studies have suggested that reconnection at a polarity inversion line of a coronal arcade field creates a flux rope that can sustain a prominence; however, they did not explain the origin of cool dense plasmas of prominences. Using three-dimensional magnetohydrodynamic simulations including anisotropic nonlinear thermal conduction and optically thin radiative cooling, we demonstrate that reconnection can lead not only to flux rope formation but also to radiative condensation under a certain condition. In our model, this condition is described by the Field length, which is defined as the scale length for thermal balance between radiative cooling and thermal conduction. This critical condition depends weekly on the artificial background heating. The extreme ultraviolet emissions synthesized with our simulation results have good agreement with observational signatures reported in previous studies.

Numerical Study on In-Situ Prominence Formation by Radiative Condensation in the Solar Corona

Takafumi **Kaneko**, Takaaki Yokoyama

ApJ **806** 115 **2015**

http://arxiv.org/pdf/1504.08091v1.pdf

We propose an in-situ formation model for inverse-polarity solar prominence and demonstrate it using self-consistent 2.5-dimensional magnetohydrodynamics simulations, including thermal conduction along magnetic fields and optically thin radiative cooling. The model enables us to form cool dense plasma clouds inside a flux rope by radiative condensation, which is regarded as an inverse-polarity prominence. Radiative condensation is triggered by changes in the magnetic topology, i.e., formation of the flux rope from the sheared arcade field, and by thermal imbalance due to the dense plasma trapped inside the flux rope. The flux rope is created by imposing converging and shearing motion on the arcade field. Either when the footpoint motion is in the anti-shearing direction or when heating is proportional to local density, the thermal state inside the flux rope becomes cooling-dominant, leading to radiative condensation. By controlling the temperature of condensation, we investigate the relationship between the temperature and density of prominence and derive a scaling formula for this relationship. This formula suggests that the proposed model reproduce the observed density of prominence, which is 10-100 times larger than the coronal density. Moreover, the time evolution of the extreme ultraviolet emission synthesized by combining our simulation results with the response function of the Solar Dynamics Observatory Atmospheric Imaging Assembly filters agrees with the observed temporal and spatial intensity shift among multi-wavelength during in-situ condensation.

Modelling the magnetic structure of a large-scale horse-shoe-like filament in a decaying and diffuse active region

Kaifeng **Kang**, Yang Guo, Ilia I. Roussev, Rony Keppens, Jun Lin

MNRAS Volume 518, Issue 1, January 2023, Pages 388–404, **2022**

https://arxiv.org/pdf/2211.04842.pdf

https://doi.org/10.1093/mnras/stac3156

A large-scale, horse-shoe-like filament was investigated and the magnetic field around it was reconstructed. This is an intermediate filament (IF) that appeared on the solar disk for the first time at 02:00 UT on **2015 November 7**, and took 8 days to move to the central median on the solar disk. The active region AR 12452 around which the filament occurred was diffuse so that the magnetic field nearby was weak, the average field strength is 106 G. Therefore, the existing approaches to extrapolating the coronal magnetic field and to constructing the filament configuration in the region with strong background field do not work well here. On the basis of the regularized Biot-Savart laws method, we successfully constructed a data-constrained, non-linear force-free field configuration for this IF observed on **2015 November 14**. The overall IF configuration obtained in this way matches well the morphology suggested by a 304~Å\ image taken by the Atmospheric Imaging Assembly on board Solar Dynamics Observatory. Magnetic dips in the configuration were coincident in space with the Hα features of the filament, which is lower in altitude than the features seen in 304~Å. This suggests that the cold plasma fills the lower part of the filament, and hot plasma is situated in the higher region. A quasi-separatrix layer wraps the filament, and both the magnetic field and the electric current are stronger near the inner edge of the filament.

Photospheric Properties of Warm EUV Loops and Hot X-Ray Loops

R. **Kano**1, K. Ueda2, and S. Tsuneta

2014 ApJ 782 L32

We investigate the photospheric properties (vector magnetic fields and horizontal velocity) of a well-developed active region, NOAA AR 10978, using the Hinode Solar Optical Telescope specifically to determine what gives rise to the temperature difference between "warm loops" (1-2 MK), which are coronal loops observed in EUV wavelengths, and "hot loops" (>3 MK), coronal loops observed in X-rays. We found that outside sunspots, the magnetic filling factor in the solar network varies with location and is anti-correlated with the horizontal random velocity. If we accept that the observed magnetic features consist of unresolved magnetic flux tubes, this anti-correlation can be explained by the ensemble average of flux-tube motion driven by small-scale random flows. The observed data are consistent with a flux tube width of ~77 km and horizontal flow at ~2.6 km s–1 with a spatial scale of ~120 km. We also found that outside sunspots, there is no significant difference between warm and hot loops either in the magnetic properties (except for the inclination) or in the horizontal random velocity at their footpoints, which are identified with the Hinode X-Ray Telescope and the Transition Region and Coronal Explorer. The energy flux injected into the coronal loops by the observed photospheric motion of the magnetic fields is estimated to be 2 × 106 erg s–1 cm–2, which is the same for both warm and hot loops. This suggests that coronal properties (e.g., loop length) play a more important role in giving rise to temperature differences of active-region coronal loops than photospheric parameters.

Properties of Magnetic Neutral Line Gradients and Formation of Filaments

Nina V. **Karachik**, Alexei A. Pevtsov

Solar Physics, March **2014**, Volume 289, Issue 3, pp 821-830

http://arxiv.org/pdf/1307.3317v1.pdf

We investigate the gradients of magnetic fields across neutral lines (NLs) and compare their properties for NLs with and without chromospheric filaments. Our results show that there is a range of preferred magnetic field gradients where the filament formation is enhanced. On the other hand, a horizontal gradient of the magnetic field across an NL alone does not appear to be a single factor that determines if a filament will form (or not) in a given location.

Decayless oscillations in 3D coronal loops excited by a power-law driver

Konstantinos **Karampelas**, Tom Van Doorsselaere

A&A **2024**

https://arxiv.org/pdf/2401.01095.pdf

Aims. We studied the manifestation of decayless oscillations in 3D simulations of coronal loops, driven by random motions. Methods. Using the PLUTO code, we ran magnetohydrodynamic (MHD) simulations of a straight gravitationally stratified flux tube, with its footpoints embedded in chromospheric plasma. We consider transverse waves drivers with a horizontally polarised red noise power-law spectrum. Results. Our broadband drivers lead to the excitation of standing waves with frequencies equal to the fundamental standing kink mode and its harmonics. These standing kink oscillations have non-decaying amplitudes, and spectra that depend on the characteristics of the loops, with the latter amplifying the resonant frequencies from the drivers. We thus report for the first time in 3D simulations the manifestation of decayless oscillations from broadband drivers. The spatial and temporal evolution of our oscillation spectra reveals the manifestation of a half harmonic, which exhibits half the frequency of the identified fundamental mode with a similar spatial profile. Our results suggest that this mode is related to the presence of the transition region in our model and could be interpreted as being the equivalent to the fundamental mode of standing sound waves driven on pipes closed at one end. Conclusions. The potential existence of this half harmonic has important implications for coronal seismology, since misinterpreting it for the fundamental mode of the system can lead to false estimations of the average kink speed profile along oscillating loops. Finally, its detection could potentially give us a tool for distinguishing between different excitation and driving mechanisms of decayless oscillations in observations.

Decayless oscillations in 3D coronal loops excited by a power-law driver L6

Konstantinos **Karampelas** and Tom Van Doorsselaere

A&A 681, L6 (**2024**)

https://doi.org/10.1051/0004-6361/202348144

https://www.aanda.org/articles/aa/pdf/2024/01/aa48144-23.pdf

Aims. We studied the manifestation of decayless oscillations in 3D simulations of coronal loops, driven by random motions.

Methods. Using the PLUTO code, we ran magnetohydrodynamic (MHD) simulations of a straight gravitationally stratified flux tube, with its footpoints embedded in chromospheric plasma. We consider transverse waves drivers with a horizontally polarised red noise power-law spectrum.
Results. Our broadband drivers lead to the excitation of standing waves with frequencies equal to the fundamental standing kink mode and its harmonics. These standing kink oscillations have non-decaying amplitudes, and spectra that depend on the characteristics of the loops, with the latter amplifying the resonant frequencies from the drivers. We thus report for the first time in 3D simulations the manifestation of decayless oscillations from broadband drivers. The spatial and temporal evolution of our oscillation spectra reveals the manifestation of a half harmonic, which exhibits half the frequency of the identified fundamental mode with a similar spatial profile. Our results suggest that this mode is related to the presence of the transition region in our model and could be interpreted as being the equivalent to the fundamental mode of standing sound waves driven on pipes closed at one end.
Conclusions. The potential existence of this half harmonic has important implications for coronal seismology, since misinterpreting it for the fundamental mode of the system can lead to false estimations of the average kink speed profile along oscillating loops. Finally, its detection could potentially give us a tool for distinguishing between different excitation and driving mechanisms of decayless oscillations in observations.

Transverse loop oscillations via vortex shedding: a self oscillating process

Konstantinos **Karampelas**, Tom Van Doorsselaere

ApJL **908** L7 **2021**

https://arxiv.org/pdf/2102.03332.pdf

https://doi.org/10.3847/2041-8213/abdc2b

Identifying the underlying mechanisms behind the excitation of transverse oscillations in coronal loops is essential for their role as diagnostic tools in coronal seismology and their potential use as wave heating mechanisms of the solar corona. In this paper, we explore the concept of these transverse oscillations being excited through a self-sustaining process, caused by Alfvénic vortex shedding from strong background flows interacting with coronal loops. We show for the first time in 3D simulations that vortex shedding can generate transverse oscillations in coronal loops, in the direction perpendicular to the flow due to periodic "pushing" by the vortices. By plotting the power spectral density we identify the excited frequencies of these oscillations. We see that these frequencies are dependent both on the speed of the flow, as well as the characteristics of the oscillating loop. This, in addition to the fact that the background flow is constant and not periodic, makes us treat this as a self-oscillating process. Finally, the amplitudes of the excited oscillations are near constant in amplitude, and are comparable with the observations of decay-less oscillations. This makes the mechanism under consideration a possible interpretation of these undamped waves in coronal loops.

Generating Transverse Loop Oscillations through a Steady-flow Driver

Konstantinos **Karampelas** and Tom Van Doorsselaere

2020 ApJL 897 L35

https://doi.org/10.3847/2041-8213/ab9f38

https://arxiv.org/pdf/2007.13402.pdf

In recent years, the decay-less regime of standing transverse oscillations in coronal loops has been the topic of many observational and numerical studies, focusing on their physical characteristics, as well as their importance for coronal seismology and wave heating. However, no definitive answer has yet been given on the driving mechanism behind these oscillations, with most studies focusing on the use of periodic footpoint drivers as a means to excite them. In this paper, our goal is to explore the concept of these standing waves being self-sustained oscillations, driven by a constant background flow. To that end, we use the PLUTO code, to perform 3D magnetohydrodynamic simulations of a gravitationally stratified straight flux tube in a coronal environment, in the presence of a weak flow around the loop, perpendicular to its axis. Once this flow is firmly set up, a transverse oscillation is initiated, dominated by the fundamental kink mode of a standing wave, while the existence of a second harmonic is revealed, with a frequency ratio to the fundamental mode near the observed ones in decay-less oscillations. The presence of vortex shedding is also established in our simulations, which is connected to the "slippery" interaction between the oscillator and its surrounding plasma. We thus present a proof-of-concept of a self-oscillation in a coronal loop, and we propose it as a mechanism that could interpret the observed decay-less transverse oscillations of coronal loops.

Amplitudes and energy fluxes of simulated decayless kink oscillations

K. **Karampelas**, T. Van Doorsselaere, D. J. Pascoe, M. Guo, P. Antolin

Frontiers in Astronomy and Space Sciences (**2019**), 6, 38

https://arxiv.org/pdf/1906.02001.pdf

Recent observations with the Atmospheric Imaging Assembly (AIA) instrument on the SDO spacecraft have revealed the existence of decayless coronal kink oscillations. These transverse oscillations are not connected to any external phenomena like flares or coronal mass ejections, and show significantly lower amplitudes than the externally excited decaying oscillations. Numerical studies have managed to reproduce such decayless oscillations in the form of footpoint driven standing waves in coronal loops, and to treat them as a possible mechanism for wave heating of the solar corona. Our aim is to investigate the correlation between the observed amplitudes of the oscillations and input the energy flux from different drivers. We perform 3D MHD simulations in single, straight, density-enhanced coronal flux tubes for different drivers, in the presence of gravity. Synthetic images at different spectral lines are constructed with the use of the FoMo code. The development of the Kelvin-Helmholtz instability leads to mixing of plasma between the flux tube and the hot corona. Once the KHI is fully developed, the amplitudes of the decayless oscillations show only a weak correlation with the driver strength. We find that low amplitude decayless kink oscillations may correspond to significant energy fluxes of the order of the radiative losses for the Quiet Sun. A clear correlation between the input energy flux and the observed amplitudes from our synthetic imaging data cannot be established. Stronger drivers lead to higher vales of the line width estimated energy fluxes. Finally, estimations of the energy fluxes by spectroscopic data are affected by the LOS angle, favoring combined analysis of imaging and spectroscopic data for single oscillating loops.

Wave heating in gravitationally stratified coronal loops in the presence of resistivity and viscosity⋆

K. **Karampelas**1, T. Van Doorsselaere1 and M. Guo

A&A 623, A53 (**2019**)

https://doi.org/10.1051/0004-6361/201834309

Context. In recent years, coronal loops have been the focus of studies related to the damping of different magnetohydrodynamic (MHD) surface waves and their connection with coronal seismology and wave heating. For a better understanding of wave heating, we need to take into account the effects of different dissipation coefficients such as resistivity and viscosity, the importance of the loop physical characteristics, and the ways gravity can factor into the evolution of these phenomena.

Aims. We aim to map the sites of energy dissipation from transverse waves in coronal loops in the presence and absence of gravitational stratification and to compare ideal, resistive, and viscous MHD.

Methods. Using the PLUTO code, we performed 3D MHD simulations of kink waves in single, straight, density-enhanced coronal flux tubes of multiple temperatures.

Results. We see the creation of spatially expanded Kelvin–Helmholtz eddies along the loop, which deform the initial monolithic loop profile. For the case of driven oscillations, the Kelvin–Helmholtz instability develops despite physical dissipation, unless very high values of shear viscosity are used. Energy dissipation gets its highest values near the apex, but is present all along the loop. We observe an increased efficiency of wave heating once the kinetic energy saturates at the later stages of the simulation and a turbulent density profile has developed.

Conclusions. The inclusion of gravity greatly alters the dynamic evolution of our systems and should not be ignored in future studies. Stronger physical dissipation leads to stronger wave heating in our set-ups. Finally, once the kinetic energy of the oscillating loop starts saturating, all the excess input energy turns into internal energy, resulting in more efficient wave heating.

Simulations of fully deformed oscillating flux tubes

K. **Karampelas**, T. Van Doorsselaere

A&A 610, L9 **2018**

https://arxiv.org/pdf/1801.07657.pdf

In recent years, a number of numerical studies have been focusing on the significance of the Kelvin-Helmholtz instability (KHI) in the dynamics of oscillating coronal loops. This process enhances the transfer of energy into smaller scales, and has been connected with heating of coronal loops, when dissipation mechanisms, such as resistivity, are considered. However, the turbulent layer is expected near the outer regions of the loops. Therefore, the effects of wave heating are expected to be confined to the loop's external layers, leaving their denser inner parts without a heating mechanism. In the current work we aim to study the spatial evolution of wave heating effects from a footpoint driven standing kink wave in a coronal loop. Using the MPI-AMRVAC code, we performed ideal, three dimensional magnetohydrodynamic simulations of footpoint driven transverse oscillations of a cold, straight coronal flux tube, embedded in a hotter environment. We have also constructed forward models for our simulation using the FoMo code. The developed Transverse Wave Induced Kelvin-Helmholtz (TWIKH) rolls expand throughout the tube cross-section, and cover it entirely. This turbulence significantly alters the initial density profile, leading to a fully deformed cross section. As a consequence, the resistive and viscous heating rate both increase over the entire loop cross section. The resistive heating rate takes its maximum values near the footpoints, while the viscous heating rate at the apex. We conclude that even a monoperiodic driver can spread wave heating over the whole loop cross section, potentially providing a heating source in the inner loop region. Despite the loop's fully deformed structure, forward modelling still shows the structure appearing as a loop.

Heating by transverse waves in simulated coronal loops

K. **Karampelas**, T. Van Doorsselaere, P. Antolin

A&A 604, A130 **2017**
https://arxiv.org/pdf/1706.02640.pdf
Recent numerical studies of oscillating flux tubes have established the significance of resonant absorption in the damping of propagating transverse oscillations in coronal loops. The nonlinear nature of the mechanism has been examined alongside the Kelvin-Helmholtz instability, which is expected to manifest in the resonant layers at the edges of the flux tubes. While these two processes have been hypothesized to heat coronal loops through the dissipation of wave energy into smaller scales, the occurring mixing with the hotter surroundings can potentially hide this effect. We aim to study the effects of wave heating from driven and standing kink waves in a coronal loop. Using the MPI-AMRVAC code, we perform ideal, three dimensional magnetohydrodynamic (MHD) simulations of both (a) footpoint driven and (b) free standing oscillations in a straight coronal flux tube, in the presence of numerical resistivity. We have observed the development of Kelvin-Helmholtz eddies at the loop boundary layer of all three models considered here, as well as an increase of the volume averaged temperature inside the loop. The main heating mechanism in our setups was Ohmic dissipation, as indicated by the higher values for the temperatures and current densities located near the footpoints. The introduction of a temperature gradient between the inner tube and the surrounding plasma, suggests that the mixing of the two regions, in the case of hotter environment, greatly increases the temperature of the tube at the site of the strongest turbulence, beyond the contribution of the aforementioned wave heating mechanism.

The 1 October 2001 Eruptive Prominence: Observed and Modeled Structures

Karlický, Marian; Kotrč, Pavel; Kupryakov, Yurij A.
Solar Physics, v. 211, Issue 1, p. 231-240 **(2002).**
Using TRACE 171 Å image observations and Hα spectra and images observed at the Ondřejov Observatory, the October 1, 2001, eruptive prominence is studied. The evolution of this prominence is described and velocities of specific parts of the prominence are determined. It was found that, after the rising phase of the cold loop-like prominence, its upper part expanded and below this expanding part, around one of its legs a `ring' structure, visible in the TRACE images, was formed. Then, at the same place, a tearing of the prominence leg was recognized. Simultaneous spectral observations of this structure reveal a very broad Hα line, which indicates strong turbulent motion at these positions. These processes were accompanied by an expanding Hα envelope. Due to the similarity of the observed `ring' and tearing structures with those modeled by Lau and Finn (1996), the prominence leg tearing is interpreted as a reconnection process between two parallel magnetic ropes having parallel electric currents, but anti-parallel axial magnetic fields.

Forward Modeling of a Pseudostreamer

Nishu **Karna**1, Antonia Savcheva1, Kévin Dalmasse2, Sarah Gibson3, Svetlin Tassev1
2019 ApJ 883 74
https://doi.org/10.3847/1538-4357/ab3c50
In this paper, we present an analysis of a pseudostreamer embedding a filament cavity, observed on **2015 April 18** on the solar southwest limb. We use the flux-rope insertion method to construct nonlinear force-free field (NLFFF) models constrained by observed Solar Dynamics Observatory (SDO)/AIA coronal structures and the SDO/Helioseismic Magnetic Imager photospheric magnetogram. The resulting magnetic field models are forward-modeled to produce synthetic data directly comparable to Mauna Loa Solar Observatory/Coronal Multichannel Polarimeter (CoMP) observations of the intensity and linear polarization of the Fe xiii 1074.7 nm infrared coronal emission line using FORWARD. In addition, we determine the location of quasi-separatrix layers in the magnetic models, producing a Q-map from which the signatures of magnetic null points and separatrices can be identified. An apparent magnetic null observed in linear polarization by CoMP is reproduced by the model and appears in the region of the 2D-projected magnetic null in the Q-map. Further, we find that the height of the CoMP null is better reproduced by our NLFFF model than by the synthetic data we produce with potential-field source-surface models, implying the presence of a flux rope in the northern lobe of the pseudostreamer.

APPEARANCES AND STATISTICS OF CORONAL CAVITIES DURING THE ASCENDING PHASE OF SOLAR CYCLE 24

N. **Karna**, W. D. Pesnell, and J. Zhang
2015 ApJ 810 123
We present a survey of 429 coronal prominence cavities found between 2010 May and 2015 February using the Solar Dynamics Observatory (SDO)/Atmospheric Imaging Assembly limb synoptic maps. We examined correlations between each cavity's height, width, and length. Our findings showed that around 38% of the cavities were prolate, 27% oblate, and 35% circular in shape. The lengths of the cavities ranged from 0.06 to 2.9 {R}⊙ . When a cavity is longer than 1.5 {R}⊙ , it has a narrower height range (0.1"0.3 {R}⊙), whereas when the cavity was shorter than 1.5 {R}⊙ , it had a wider height range (0.07"0.5 {R}⊙). We find that the overall three-dimensional topology of the long, stable cavities can be characterized as a long tube with an elliptical cross section. We also noted that the circular and oblate cavities are longer in length than the prolate cavities. We also studied the

physical mechanisms behind the cavity drift toward the pole and found it to be tied to the meridional flow. Finally, by observing the evolution of the cavity regions using SDO/Helioseismic Magnetic Imager (HMI) surface magnetic field observations, we found that the cavities formed a belt near the polar coronal hole boundary; we call this the cavity belt. Our results showed that the cavity belt migrated toward higher latitude over time and the cavity belt disappeared after the polar magnetic field reversal. This result shows that cavity evolution provides new insight into the solar cycle.

STUDY OF THE 3D GEOMETRIC STRUCTURE AND TEMPERATURE OF A CORONAL CAVITY USING THE LIMB SYNOPTIC MAP METHOD

N. **Karna**, J. Zhang, W. Dean Pesnell, and S. A. Hess Webber

2015 ApJ 810 124

We present the three-dimensional geometric structure and thermal properties of a coronal cavity deduced from limb synoptic maps. The observations are extreme ultraviolet images from the Atmospheric Imager Assembly (AIA) and magnetic images from the Helioseismic Magnetic Imager instruments on board the Solar Dynamics Observatory. We describe a limb synoptic-map method used to effectively identify and measure cavities from annuli of radiance above the solar limb. We find that cavities are best seen in the 211, 193, and 171 " passbands. The prominence associated with each cavity is best seen in the 304 " synoptic maps. We also estimate the thermal properties of the cavity and surrounding plasma by combining the AIA radiances with a differential emission measure analysis. This paper focuses on one long cavity from a catalog of coronal cavities that we are developing. Cavities in this catalog are designated by a coded name using the Carrington Rotation number and position. Cavity C211347177N was observed during Carrington Rotation 2113 at the northwestern limb of the solar disk with an average latitude of 47" N and a central longitude of 177". We showed the following. (1) The cavity is a long tube with an elliptical cross-section with ratios of the length to width and the length to height of 11:1 and 7:1, respectively. (2) The cavity is about 1360 Mm long, or 170? in longitude. (3) It is tilted in latitude. (4) And it is slightly hotter than its surroundings.

Solar prominences: 'double, double ... boil and bubble'

Rony **Keppens**, Chun Xia, Oliver Porth

2015 **806** L13 ApJL

http://arxiv.org/pdf/1505.05268v2.pdf

Observations revealed rich dynamics within prominences, the cool 10,000 K, macroscopic (sizes of order 100 Mm) "clouds" in the million degree solar corona. Even quiescent prominences are continuously perturbed by hot, rising bubbles. Since prominence matter is hundredfold denser than coronal plasma, this bubbling is related to Rayleigh-Taylor instabilities. Here we report on true macroscopic simulations well into this bubbling phase, adopting a magnetohydrodynamic description from chromospheric layers up to 30 Mm height. Our virtual prominences rapidly establish fully non-linear (magneto)convective motions where hot bubbles interplay with falling pillars, with dynamical details including upwelling pillars forming within bubbles. Our simulations show impacting Rayleigh-Taylor fingers reflecting on transition region plasma, ensuring that cool, dense chromospheric material gets mixed with prominence matter up to very large heights. This offers an explanation for the return mass cycle mystery for prominence material. Synthetic views at extreme ultraviolet wavelengths show remarkable agreement with observations, with clear indications of shear-flow induced fragmentations.

The Dynamics of Funnel Prominences

Rony **Keppens**, Chun Xia

ApJ, 789 22, **2014**

http://arxiv.org/pdf/1405.3419v1.pdf

We present numerical simulations in 2.5D settings where large scale prominences form in situ out of coronal condensation in magnetic dips, in close agreement with early as well as recent reporting of `funnel prominences'. Our simulation uses full thermodynamic MHD with anisotropic thermal conduction, optically thin radiative losses, and parametrized heating as main ingredients to establish a realistic arcade configuration from chromosphere to corona. The chromospheric evaporation from especially transition region heights ultimately causes thermal instability and we witness the growth of a prominence suspended well above the transition region, continuously gaining mass and cross-sectional area. Several hours later, the condensation has grown into a structure connecting the prominence-corona transition region with the underlying transition region, and a continuous downward motion from the accumulated mass represents a drainage that matches observational findings. A more dynamic phase is found as well, with coronal rain, induced wave trains, and even a reconnection event when the core prominence plasma weighs down the fieldlines until a fluxrope gets formed. The upper part of the prominence is then trapped in a fluxrope structure, and we argue for its violent kink-unstable eruption as soon as the (ignored) length dimension would allow for ideal kink deformations.

Observational detection of drift velocity between ionized and neutral species in solar prominences

Elena **Khomenko**, Manuel Collados, Antonio J. Diaz

ApJ 823 132 **2016**

http://arxiv.org/pdf/1604.01177v1.pdf

We report a detection of differences in ion and neutral velocities in prominences using high resolution spectral data obtained in **11 September 2012** at the German Vacuum Tower Telescope (Observatorio del Teide, Tenerife). A time series of scans of a small portion of a solar prominence was obtained simultaneously with a high cadence using the lines of two elements with different ionization states, namely the CaII 8542 A and the HeI 10830 A. Displacements, widths and amplitudes of both lines were carefully compared to extract dynamical information about the plasma. Many dynamical features are detected, such as counterstreaming flows, jets and propagating waves. In all the cases we find very strong correlation between the parameters extracted from the lines of both elements, confirming that both trace the same plasma. Nevertheless, we also find short-lived transients where this correlation is lost. These transients are associated with the ion-neutral drift velocities of the order of several hundred m/s. The patches of non-zero drift velocity show coherence on time-distance diagrams.

Rayleigh-Taylor instability in prominences from numerical simulations including partial ionization effects

E. **Khomenko**, A. Diaz, A. de Vicente, M. Collados, M. Luna

A&A, 565, A45, **2014**

http://arxiv.org/pdf/1403.4530v1.pdf

We study the Rayleigh-Taylor instability (RTI) at a prominence-corona transition region in a non-linear regime. Our aim is to understand how the presence of neutral atoms in the prominence plasma influences the instability growth rate, and the evolution of velocity, magnetic field vector and thermodynamic parameters of turbulent drops. We perform 2.5D numerical simulations of the instability initiated by a multi-mode perturbation at the corona-prominence interface using a single-fluid MHD approach including a generalized Ohm's law. The initial equilibrium configuration is purely hydrostatic and contains a homogeneous horizontal magnetic field forming an angle with the direction in which the plasma is perturbed. We analyze simulations with two different orientations of the magnetic field. For each field orientation we compare two simulations, one for the pure MHD case, and one including the ambipolar diffusion in the Ohm's law (AD case). Other than that, both simulations for each field orientation are identical. The numerical results in the initial stage of the instability are compared with the analytical linear calculations. We find that the configuration is always unstable in the AD case. The growth rate of the small-scale modes in the non-linear regime is up to 50% larger in the AD case than in the purely MHD case and the average velocities of flows are a few percent larger. Significant drift momenta are found at the interface between the coronal and the prominence material at all stages of the instability, produced by the faster downward motion of the neutral component with respect to the ionized component. The differences in temperature of the bubbles between the ideal and non-ideal case are also significant, reaching 30%. There is an asymmetry between large rising bubbles and small-scale down flowing fingers, favoring the detection of upward velocities in observations.

Propagating Disturbances in Coronal Loops: A Detailed Analysis of Propagation Speeds

G. **Kiddie**, I. De Moortel, G. Del Zanna, S. W. McIntosh and I. Whittaker

Solar Physics, Volume 279, Number 2 (**2012**), 427-452

Quasi-periodic disturbances have been observed in the outer solar atmosphere for many years. Although first interpreted as upflows (Schrijver et al., Solar Phys. 187, 261, 1999), they have been widely regarded as slow magneto-acoustic waves, due to their observed velocities and periods. However, recent observations have questioned this interpretation, as periodic disturbances in Doppler velocity, line width, and profile asymmetry were found to be in phase with the intensity oscillations (De Pontieu and McIntosh, Astrophys. J. 722, 1013, 2010; Tian, McIntosh, and De Pontieu, Astrophys. J. Lett. 727, L37, 2011), suggesting that the disturbances could be quasi-periodic upflows. Here we conduct a detailed analysis of the velocities of these disturbances across several wavelengths using the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO). We analysed 41 examples, including both sunspot and non-sunspot regions of the Sun. We found that the velocities of propagating disturbances (PDs) located at sunspots are more likely to be temperature dependent, whereas the velocities of PDs at non-sunspot locations do not show a clear temperature dependence. This suggests an interpretation in terms of slow magneto-acoustic waves in sunspots but the nature of PDs in non-sunspot (plage) regions remains unclear. We also considered on what scale the underlying driver is affecting the properties of the PDs. Finally, we found that removing the contribution due to the cooler ions in the 193 Å wavelength suggests that a substantial part of the 193 Å emission of sunspot PDs can be attributed to the cool component of 193 Å.

MASS COMPOSITION IN PRE-ERUPTION QUIET SUN FILAMENTS

Gary **Kilper**1, Holly Gilbert1,2, and David Alexander1

The Astrophysical Journal, 704:522–530, **2009** October; **File**

Filament eruptions are extremely important phenomena due to their association with coronal mass ejections and their effects on space weather. Little is known about the filament mass and composition in the eruption process, since most of the related research has concentrated on the evolution and disruption of the magnetic field. Following up on our previous work, we present here an analysis of nineteen quiet Sun filament eruptions observed by Mauna Loa Solar Observatory in H*α* and He i 10830 Å that has identified a compositional precursor common to all of these eruptions. There is a combined trend of an apparent increase in the homogenization of the filament mass composition, with concurrent increases in absorption in H*α* and He i and in the level of activity, all starting at least one day prior to eruption. This finding suggests that a prolonged period of mass motions, compositional mixing, and possibly even extensive mass loading is occurring during the build up of these eruptions.

STEREO observations of interplanetary coronal mass ejections and prominence deflection during solar minimum period

E. K. J. **Kilpua**[1], J. Pomoell[1], A. Vourlidas[3], R. Vainio[1], J. Luhmann[2], Y. Li[2], P. Schroeder[2], A. B. Galvin[4], and K. Simunac

Ann. Geophys., 27, 4491-4503, **2009**, **File**

www.ann-geophys.net/27/4491/2009/

In this paper we study the occurrence rate and solar origin of interplanetary coronal mass ejections (ICMEs) using data from the two Solar TErrestrial RElation Observatory (STEREO) and the Wind spacecraft. We perform a statistical survey of ICMEs during the late declining phase of solar cycle 23. Observations by multiple, well-separated spacecraft show that even at the time of extremely weak solar activity a considerable number of ICMEs were present in the interplanetary medium. Soon after the beginning of the STEREO science mission in January 2007 the number of ICMEs declined to less than one ICME per month, but in late 2008 the ICME rate clearly increased at each spacecraft although no apparent increase in the number of coronal mass ejections (CMEs) occurred. We suggest that the near-ecliptic ICME rate can increase due to CMEs that have been guided towards the equator from their high-latitude source regions by the magnetic fields in the polar coronal holes.

We consider two case studies to highlight the effects of the polar magnetic fields and CME deflection taking advantage of STEREO observations when the two spacecraft were in the quadrature configuration (i.e. separated by about 90 degrees). We study in detail the solar and interplanetary consequences of two CMEs that both originated from high-latitude source regions on **2 November 2008**. The first CME was slow (radial speed 298 km/s) and associated with a huge polar crown prominence eruption. The CME was guided by polar coronal hole fields to the equator and it produced a clear flux rope ICME in the near-ecliptic solar wind. The second CME (radial speed 438 km/s) originated from an active region 11007 at latitude 35° N. This CME propagated clearly north of the first CME and no interplanetary consequences were identified. The two case studies suggest that slow and elongated CMEs have difficulties overcoming the straining effect of the overlying field and as a consequence they are guided by the polar coronal fields and cause in-situ effects close to the ecliptic plane. The 3-D propagation directions and CME widths obtained by using the forward modelling technique were consistent with the solar and in-situ observations.

Table 1. *ICMEs identified from the solar wind measurements by STA (A), STB (B) and Wind (W).*

Detection of supersonic downflows and associated heating events in the transition region above sunspots

L. **Kleint**, P. Antolin, H. Tian, P. Judge, P. Testa, B. De Pontieu, J. Martínez-Sykora, K. K. Reeves, J. P. Wuelser, S. McKillop, S. Saar, M. Carlsson, P. Boerner, N. Hurlburt, J. Lemen, T. D. Tarbell, A. Title, L. Golub, V. Hansteen, S. Jaeggli, C. Kankelborg

ApJL, 789 L42, **2014**

http://arxiv.org/pdf/1406.6816v1.pdf

IRIS data allow us to study the solar transition region (TR) with an unprecedented spatial resolution of 0.33 arcsec. On **2013 August 30**, we observed bursts of high Doppler shifts suggesting strong supersonic downflows of up to 200 km/s and weaker, slightly slower upflows in the spectral lines Mg II h and k, C II 1336 \AA, Si IV 1394 \AA, and 1403 \AA, that are correlated with brightenings in the slitjaw images (SJIs). The bursty behavior lasts throughout the 2 hr observation, with average burst durations of about 20 s. The locations of these short-lived events appear to be the umbral and penumbral footpoints of EUV loops. Fast apparent downflows are observed along these loops in the SJIs and in AIA, suggesting that the loops are thermally unstable. We interpret the observations as cool material falling from coronal heights, and especially coronal rain produced along the thermally unstable loops, which leads to an increase of intensity at the loop footpoints, probably indicating an increase of density and temperature in the TR. The rain speeds are on the higher end of previously reported speeds for this phenomenon, and possibly higher than the free-fall velocity along the loops. On other observing days, similar bright dots are sometimes aligned into ribbons, resembling small flare ribbons. These observations provide a first insight into small-scale heating events in sunspots in the TR.

UNUSUAL FILAMENTS INSIDE THE UMBRA

L. **Kleint**1 and A. Sainz Dalda

2013 ApJ 770 74

We analyze several unusual filamentary structures which appeared in the umbra of one of the sunspots in **AR 11302**. They do not resemble typical light bridges in morphology or in evolution. We analyze data from SDO/HMI to investigate their temporal evolution, Hinode/SP for photospheric inversions, IBIS for chromospheric imaging, and SDO/AIA for the overlying corona. Photospheric inversions reveal a horizontal, inverse Evershed flow along these structures, which we call umbral filaments. Chromospheric images show brightenings and energy dissipation, while coronal images indicate that bright coronal loops seem to end in these umbral filaments. These rapidly evolving features do not seem to be common, and are possibly related to the high flare-productivity of the active region. Their analysis could help to understand the complex evolution of active regions.

Cross Sections of Coronal Loop Flux Tubes

James A. **Klimchuk**, Craig E. DeForest

ApJ **900** 167 **2020**

https://arxiv.org/ftp/arxiv/papers/2007/2007.15085.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/abab09/pdf

Coronal loops reveal crucial information about the nature of both coronal magnetic fields and coronal heating. The shape of the corresponding flux tube cross section and how it varies with position are especially important properties. They are a direct indication of the expansion of the field and of the cross-field spatial distribution of the heating. We have studied 20 loops using high spatial resolution observations from the first flight of the Hi-C rocket experiment, measuring the intensity and width as a function of position along the loop axis. We find that intensity and width tend to either be uncorrelated or to have a direct dependence, such that they increase or decrease together. This implies that the flux tube cross sections are approximately circular under the assumptions that the tubes have non-negligible twist and that the plasma emissivity is approximately uniform along the magnetic field. The shape need not be a perfect circle and the emissivity need not be uniform within the cross section, but sub-resolution patches of emission must be distributed quasi-uniformly within an envelope that has an aspect ratio of order unity. This raises questions about the suggestion that flux tubes expand with height, but primarily in the line-of-sight direction so that the corresponding (relatively noticeable) loops appear to have roughly uniform width, a long-standing puzzle. It also casts doubt on the idea that most loops correspond to simple warped sheets, although we leave open the possibility of more complex manifold structures. **2012 July 11**

The Distinction Between Thermal Nonequilibrium and Thermal Instability

James A. **Klimchuk**

Solar Phys. **294**, Article number: 173 **2019**

https://arxiv.org/ftp/arxiv/papers/1911/1911.11849.pdf

https://link.springer.com/content/pdf/10.1007/s11207-019-1562-z.pdf

For some forms of steady heating, coronal loops are in a state of thermal nonequilibrium and evolve in a manner that includes accelerated cooling, often resulting in the formation of a cold condensation. This is frequently confused with thermal instability, but the two are in fact fundamentally different. We explain the distinction and discuss situations where they may be interconnected. Large-amplitude perturbations, perhaps associated with MHD waves, likely play a role in explaining phenomena that have been attributed to thermal nonequilibrium but also seem to require cross-field communication.

CAN THERMAL NONEQUILIBRIUM EXPLAIN CORONAL LOOPS?

James A. **Klimchuk**, Judy T. Karpen, and Spiro K. Antiochos

Astrophysical Journal, 714:1239–1248, **2010** May

Any successful model of coronal loops must explain a number of observed properties. For warm (~1 MK) loops, these include (1) excess density, (2) flat temperature profile, (3) super-hydrostatic scale height, (4) unstructured intensity profile, and (5) 1000–5000 s lifetime. We examine whether thermal nonequilibrium can reproduce the observations by performing hydrodynamic simulations based on steady coronal heating that decreases exponentially with height. We consider both monolithic and multi-stranded loops. The simulations successfully reproduce certain aspects of the observations, including the excess density, but each of them fails in at least one critical way. Monolithic models have far too much intensity structure, while multi-strand models are either too structured or too long-lived. Our results appear to rule out the widespread existence of heating that is both highly concentrated low in the corona and steady or quasi-steady (slowly varying or impulsive with a rapid cadence). Active regions would have a very different appearance if the dominant heating mechanism had these properties. Thermal nonequilibrium may nonetheless play an important role in prominences and catastrophic cooling events (e.g., coronal rain) that occupy a small fraction of the coronal volume. However, apparent inconsistencies between the models and observations of cooling events have yet to be understood.

Filament Channel Formation Via Magnetic Helicity Condensation

Kalman J. **Knizhnik**, Spiro K. Antiochos, C. Richard DeVore

ApJ **809** 137 **201**4

http://arxiv.org/pdf/1411.5396v1.pdf

A major unexplained feature of the solar atmosphere is the accumulation of magnetic shear, in the form of filament channels, at photospheric polarity inversion lines (PILs). In addition to free energy, this shear also represents magnetic helicity, which is conserved under reconnection. In this paper, we address the problem of filament channel formation and show how they acquire their shear and magnetic helicity. The results of 3D simulations using the Adaptively Refined Magnetohydrodynamics Solver (ARMS) are presented that support the model of filament channel formation by magnetic helicity condensation developed by \citet{Antiochos13}. We consider the supergranular twisting of a quasi-potential flux system that is bounded by a PIL and contains a coronal hole (CH). The magnetic helicity injected by the small-scale photospheric motions is shown to inverse-cascade up to the largest allowable scales that define the closed flux system: the PIL and the CH. This process produces field lines that are both sheared and smooth, and are sheared in opposite senses at the PIL and the CH. The accumulated helicity and shear flux are shown to be in excellent quantitative agreement with the helicity-condensation model. We present a detailed analysis of the simulations, including comparisons of our analytical and numerical results, and discuss their implications for observations.

The relationship between coronal fan structures and oscillations above faculae regions

N. I. **Kobanov**, A. A. Chelpanov

Astronomy Reports, April **2014**, Volume 58, Issue 4, pp 272-279

Astronomicheskii Zhurnal, **2014**, Vol. 91, No. 4, pp. 332–340.

The power spectra of radial-velocity and intensity oscillations are analyzed using ground-based (the Si I 10 827 Å and He I 10 830 Å lines) and Solar Dynamics Observatory (the Fe I 6173, 1700 Å, He II 304 Å, and Fe IX 171 Å lines) data, with the aim of searching for frequency modes that most efficiently penetrate into the solar corona from the lower layers of solar faculae. Analysis of the spatial distribution of the oscillation power at various heights indicates that fan structures in the corona (at the height of the 171 Å emission) are better reproduced at frequencies of 1–1.5 mHz. This means that oscillations with periods of 10–15 min dominate in coronal loops above faculae regions. The five-minute oscillations that universally dominate in radial-velocity measurements in low layers of faculae are appreciable in coronal loops only in individual compact fragments.

Damping of coronal oscillations in self-consistent 3D radiative magnetohydrodynamics simulations of the solar atmosphere⋆

P. **Kohutova**1,2, P. Antolin3, M. Szydlarski1,2 and M. Carlsson1,2

A&A 676, A32 (**2023**)

https://www.aanda.org/articles/aa/pdf/2023/08/aa46671-23.pdf

Context. Oscillations are abundant in the solar corona. Coronal loop oscillations are typically studied using highly idealised models of magnetic flux tubes. In order to improve our understanding of coronal oscillations, it is necessary to consider the effect of a realistic magnetic field topology and the density structuring.

Aims. We analyse the damping of coronal oscillations using a self-consistent 3D radiation-magnetohydrodynamics simulation of the solar atmosphere spanning from the convection zone into the corona, the associated oscillation dissipation and heating, and finally, the physical processes that cause the damping and dissipation. The simulated corona that forms in this model does not depend on any prior assumptions about the shape of the coronal loops.

Methods. We analysed the evolution of a bundle of magnetic loops by tracing the magnetic field.

Results. We find that the bundle of magnetic loops shows damped transverse oscillations in response to perturbations in two separate instances, with oscillation periods of 177 s and 191 s, velocity amplitudes of 10 km s−1 and 16 km s−1, and damping times of 176 s and 198 s. The coronal oscillations lead to the development of velocity shear in the simulated corona, which results in the formation of vortices seen in the velocity field that are caused by the Kelvin-Helmholtz instability. This contributes to the damping and dissipation of the transverse oscillations.

Conclusions. The oscillation parameters and evolution we observed are in line with the values that are typically seen in observations of coronal loop oscillations. The dynamic evolution of the coronal loop bundle suggests that the models of monolithic and static coronal loops with constant lengths might need to be re-evaluated by relaxing the assumption of highly idealised wave guides.

Self-consistent 3D radiative MHD simulations of coronal rain formation and evolution

P. **Kohutova**, P. Antolin, A. Popovas, M. Szydlarski, V. H. Hansteen

A&A **2020**

https://arxiv.org/pdf/2005.03317.pdf

Coronal rain consists of cool and dense plasma condensations formed in coronal loops as a result of thermal instability. Previous numerical simulations of thermal instability and coronal rain formation have relied on artificially adding a coronal heating term to the energy equation. To reproduce large-scale characteristics of the corona, using more realistic coronal heating prescription is necessary. We analyse coronal rain formation and evolution in a 3-dimensional radiative magnetohydrodynamic simulation spanning from convection zone to corona which is self-consistently heated by magnetic field braiding as a result of convective motions. We investigate the spatial and temporal evolution of energy dissipation along coronal loops which become thermally unstable. Ohmic dissipation in the model leads to the heating events capable of inducing sufficient chromospheric evaporation into the loop to trigger thermal instability and condensation formation. The cooling of the thermally unstable plasma occurs on timescales comparable to the duration of the individual impulsive heating events. The impulsive heating has sufficient duration to trigger thermal instability in the loop but does not last long enough to lead to coronal rain limit cycles. We show that condensations can either survive and fall into the chromosphere or be destroyed by strong bursts of Joule heating associated with a magnetic reconnection events. In addition, we find that condensations can also form along open magnetic field lines.

Formation of coronal rain triggered by impulsive heating associated with magnetic reconnection⋆

P. **Kohutova**1,2, E. Verwichte3 and C. Froment

A&A 630, A123 (**2019**)

https://doi.org/10.1051/0004-6361/201936253

Context. Coronal rain consists of cool plasma condensations formed in coronal loops as a result of thermal instability. The standard models of coronal rain formation assume that the heating is quasi-steady and localised at the coronal loop footpoints.

Aims. We present an observation of magnetic reconnection in the corona and the associated impulsive heating triggering formation of coronal rain condensations.

Methods. We analyse combined SDO/AIA and IRIS observations of a coronal rain event following a reconnection between threads of a low-lying prominence flux rope and surrounding coronal field lines.

Results. The reconnection of the twisted flux rope and open field lines leads to a release of magnetic twist. Evolution of the emission of one of the coronal loops involved in the reconnection process in different AIA bandpasses suggests that the loop becomes thermally unstable and is subject to the formation of coronal rain condensations following the reconnection and that the associated heating is localised in the upper part of the loop leg.

Conclusions. In addition to the standard models of thermally unstable coronal loops with heating localised exclusively in the footpoints, thermal instability and subsequent formation of condensations can be triggered by the impulsive heating associated with magnetic reconnection occurring anywhere along a magnetic field line.

Tracking Filament Evolution in the Low Solar Corona Using Remote Sensing and In Situ Observations

Manan **Kocher**, Enrico Landi, and Susan. T. Lepri

2018 ApJ 860 51

In the present work, we analyze a filament eruption associated with an interplanetary coronal mass ejection that arrived at L1 on **2011 August 5**. In multiwavelength Solar Dynamic Observatory/Advanced Imaging Assembly (AIA) images, three plasma parcels within the filament were tracked at high cadence along the solar corona. A novel absorption diagnostic technique was applied to the filament material traveling along the three chosen trajectories to compute the column density and temperature evolution in time. Kinematics of the filamentary material were estimated using STEREO/Extreme Ultraviolet Imager and STEREO/COR1 observations. The Michigan Ionization Code used inputs of these density, temperature, and speed profiles for the computation of ionization profiles of the filament plasma. Based on these measurements, we conclude that the core plasma was in near ionization equilibrium, and the ionization states were still evolving at the altitudes where they were visible in absorption in

AIA images. Additionally, we report that the filament plasma was heterogeneous, and the filamentary material was continuously heated as it expanded in the low solar corona.

First direct observation of a torsional Alfvén oscillation at coronal heights

P. **Kohutova**, E. Verwichte, C. Froment

A&A 633, L6 (**2020**)

https://arxiv.org/pdf/1912.03954.pdf

https://www.aanda.org/articles/aa/pdf/2020/01/aa37144-19.pdf

Torsional Alfvén waves are promising candidates for transport of energy across different layers of the solar atmosphere and have been theoretically predicted for decades. Previous detections of Alfvén waves so far have however mostly relied on indirect signatures. We present a first direct observational evidence of a fully resolved torsional Alfvén oscillation of a large-scale structure occurring at coronal heights. We analyse IRIS imaging and spectral observation of a surge resulting from magnetic reconnection between active region prominence threads and surrounding magnetic fieldlines. The IRIS spectral data provides clear evidence of an oscillation in the line-of-sight velocity with a 180° phase difference between the oscillation signatures at opposite edges of the surge flux tube. This together with an alternating tilt in the Si IV and Mg II k spectra across the flux tube and the trajectories traced by the individual threads of the surge material provides clear evidence of torsional oscillation of the flux tube. Our observation shows that magnetic reconnection leads to the generation of large-scale torsional Alfvén waves. **9 December 2015**

Excitation of vertical coronal loop oscillations by impulsively driven flows

P. **Kohutova** and E. Verwichte

A&A 613, L3 (**2018**)

https://www.aanda.org/articles/aa/pdf/2018/05/aa32656-18.pdf

Context. Flows of plasma along a coronal loop caused by the pressure difference between loop footpoints are common in the solar corona.

Aims. We aim to investigate the possibility of excitation of loop oscillations by an impulsively driven flow triggered by an enhanced pressure in one of the loop footpoints.

Methods. We carry out 2.5D magnetohydrodynamic (MHD) simulations of a coronal loop with an impulsively driven flow and investigate the properties and evolution of the resulting oscillatory motion of the loop.

Results. The action of the centrifugal force associated with plasma moving at high speeds along the curved axis of the loop is found to excite the fundamental harmonic of a vertically polarised kink mode. We analyse the dependence of the resulting oscillations on the speed and kinetic energy of the flow.

Conclusions. We find that flows with realistic speeds of less than 100 km s^{-1} are sufficient to excite oscillations with observable amplitudes. We therefore propose plasma flows as a possible excitation mechanism for observed transverse loop oscillations.

Excitation of vertical coronal loop oscillations by plasma condensations

P. **Kohutova** and E. Verwichte

A&A 606, A120 (**2017**)

https://www.aanda.org/articles/aa/pdf/2017/10/aa31417-17.pdf

Context. Coronal rain composed of downfalling cool plasma condensations occurs in thermally unstable loops as a consequence of catastrophic cooling. Such loops contain significant quantities of dense plasma out of hydrostatic equilibrium. Transverse oscillations traced by coronal rain blobs are often observed in rainy loops.

Aims. We aim to investigate the possibility of excitation of loop oscillations by the presence of condensation plasma.

Methods. We carried out 2.5D magnetohydrodynamic simulations of a coronal loop containing a cool and a dense condensation region near the loop apex and investigated the properties and evolution of the resulting oscillatory motion of the loop.

Results. The presence of dense condensation region at the apex of the coronal loop is found to excite fundamental harmonic of a vertically polarised kink mode. As the condensations fall towards the loop footpoints under the influence of gravity, the fundamental mode period decreases as a result of the change in distribution of mass along the loop.

Conclusions. We propose coronal rain as a possible excitation mechanism for transverse loop oscillations.

Dynamics of plasma condensations in a gravitationally stratified coronal loop A23

P. **Kohutova** and E. Verwichte

A&A 602, A23 (**2017**)

https://www.aanda.org/articles/aa/pdf/2017/06/aa29912-16.pdf
Context. Coronal rain composed of cool plasma condensations falling from coronal heights is a phenomenon occurring in footpoint-heated coronal loops as a result of thermal instability. High-resolution coronal rain observations suggest that condensations move with less than free-fall speed and can sometimes undergo longitudinal oscillations.
Aims. We investigate the evolution and dynamics of plasma condensations in a gravitationally stratified coronal loop.
Methods. We carried out 2.5 dimensional magnetohydrodynamic simulations of a cool plasma condensation in a gravitationally stratified coronal loop and analysed its evolution, kinematics, and the evolution of the forces acting on the condensation. We further propose a one-dimensional analytical model of the condensation dynamics.
Results. The motion of plasma condensations is found to be strongly affected by the pressure of the coronal loop plasma. Maximum downward velocities are in agreement with recent coronal rain observations. A high coronal magnetic field or low condensation mass can lead to damped oscillatory motion of the condensations that are caused by the pressure gradient force and magnetic tension force that results from bending of the magnetic field in the lower part of the coronal loop. Period and damping scaling time of the oscillatory motion seen in the simulations are consistent with values predicted by the model.
Conclusions. The combined effect of pressure gradients in the coronal loop plasma and magnetic tension force that results from changes in magnetic field geometry can explain observed sub-ballistic motion and longitudinal oscillations of coronal rain.

ANALYSIS OF CORONAL RAIN OBSERVED BY IRIS,HINODE/SOT, AND SDO/AIA: TRANSVERSE OSCILLATIONS, KINEMATICS, AND THERMAL EVOLUTION

P. **Kohutova** and E. Verwichte
2016 ApJ 827 39
Coronal rain composed of cool plasma condensations falling from coronal heights along magnetic field lines is a phenomenon occurring mainly in active region coronal loops. Recent high-resolution observations have shown that coronal rain is much more common than previously thought, suggesting its important role in the chromosphere-corona mass cycle. We present the analysis of MHD oscillations and kinematics of the coronal rain observed in chromospheric and transition region lines by the Interface Region Imaging Spectrograph (IRIS), the Hinode Solar Optical Telescope (SOT), and the Solar Dynamics Observatory (SDO)Atmospheric Imaging Assembly (AIA). Two different regimes of transverse oscillations traced by the rain are detected: small-scale persistent oscillations driven by a continuously operating process and localized large-scale oscillations excited by a transient mechanism. The plasma condensations are found to move with speeds ranging from few km s^{-1} up to 180 km s^{-1} and with accelerations largely below the free-fall rate, likely explained by pressure effects and the ponderomotive force resulting from the loop oscillations. The observed evolution of the emission in individual SDO/AIA bandpasses is found to exhibit clear signatures of a gradual cooling of the plasma at the loop top. We determine the temperature evolution of the coronal loop plasma using regularized inversion to recover the differential emission measure (DEM) and by forward modeling the emission intensities in the SDO/AIA bandpasses using a two-component synthetic DEM model. The inferred evolution of the temperature and density of the plasma near the apex is consistent with the limit cycle model and suggests the loop is going through a sequence of periodically repeating heating-condensation cycles.

Kinematics and helicity evolution of a loop-like eruptive prominence ⋆

K. **Koleva**[1], M. S. Madjarska[2], P. Duchlev[1], C. J. Schrijver[5], J.-C. Vial[3,4], E. Buchlin[3,4] and M. Dechev
E-print, 14 Feb 2012; A&A 540, A127 (**2012**)
Aims. We aim at investigating the morphology as well as kinematic and helicity evolution of a loop-like prominence during its eruption.
Methods. We used multi-instrument observations from AIA/SDO, EUVI/STEREO and LASCO/SoHO. The kinematic, morphological, geometrical, and helicity evolution of a loop-like eruptive prominence were studied in the context of the magnetic flux rope model of solar prominences.
Results. The prominence eruption evolved as a height-expanding twisted loop with both legs anchored in the chromosphere of a plage area. The eruption process consisted of a prominence activation, acceleration, and a phase of constant velocity. The prominence body was composed of counter-clockwise twisted threads around the main prominence axis. The twist during the eruption was estimated at 6π (3 turns). The prominence reached a maximum height of 526 Mm before contracting to its primary location and was partially reformed in the same place two days after the eruption. This ejection, however, triggered a coronal mass ejection (CME) observed in LASCO C2. The prominence was located in the northern periphery of the CME magnetic field configuration and, therefore, the background magnetic field was asymmetric with respect to the filament position. The physical conditions of the falling plasma blobs were analysed with respect to the prominence kinematics.

Conclusions. The same sign of the prominence body twist and writhe, as well as the amount of twisting above the critical value of 2π after the activation phase indicate that possibly conditions for kink instability were present. No signature of magnetic reconnection was observed anywhere in the prominence body and its surroundings. The filament/prominence descent following the eruption and its partial reformation at the same place two days later suggest a confined type of eruption. The asymmetric background magnetic field possibly played an important role in the failed eruption. **between 17:30 UT and 19:30 UT on 2010 March 30**

Behaviour of oscillations in loop structures above active regions

D.Y. **Kolobov**, N.I. Kobanov, A.A. Chelpanov, A.A. Kochanov, S.A. Anfinogentov, S.A. Chupin, I.I. Myshyakov, V.E. Tomin

Advances in Space Research Volume 56, Issue 12, 15 December **2015**, Pages 2760–2768

http://www.sciencedirect.com/science/article/pii/S0273117715003403

http://arxiv.org/pdf/1505.02857v1.pdf

In this study we combine the multiwavelength ultraviolet -- optical (Solar Dynamics Observatory, SDO) and radio (Nobeyama Radioheliograph, NoRH) observations to get further insight into space-frequency distribution of oscillations at different atmospheric levels of the Sun. We processed the observational data on NOAA 11711 active region and found oscillations propagating from the photospheric level through the transition region upward into the corona. The power maps of low-frequency (1--2 mHz) oscillations reproduce well the fan-like coronal structures visible in the Fe ix 171A line. High frequency oscillations (5--7 mHz) propagate along the vertical magnetic field lines and concentrate inside small-scale elements in the umbra and at the umbra-penumbra boundary. We investigated the dependence of the dominant oscillation frequency upon the distance from the sunspot barycentre to estimate inclination of magnetic tubes in higher levels of sunspots where it cannot be measured directly, and found that this angle is close to 40 degrees above the umbra boundaries in the transition region. **2013 April 6**

Damping of slow magnetoacoustic oscillations by the misbalance between heating and cooling processes in the solar corona

D. Y. **Kolotkov**1?, V. M. Nakariakov1, 2 , and D. I. Zavershinskii3, 4

A&A **2019**

https://warwick.ac.uk/fac/sci/physics/research/cfsa/people/kolotkov/eprints/kolotkov_aanda_slow_r2.pdf

Context. Rapidly decaying slow magnetoacoustic waves are regularly observed in the solar coronal structures, offering a promising tool for a seismological diagnostics of the coronal plasma, including its thermodynamical properties. Aims. The effect of damping of standing slow magnetoacoustic oscillations in the solar coronal loops is investigated accounting for the field-aligned thermal conductivity and a wave-induced misbalance between radiative cooling and some unspecified heating rates. Methods. The non-adiabatic terms were allowed to be arbitrarily large, corresponding to the observed values. The thermal conductivity was taken in its classical form, and a power-law dependence of the heating function on the density and temperature was assumed. The analysis was conducted in the linear regime and in the infinite magnetic field approximation. Results. The wave dynamics is found to be highly sensitive to the characteristic time scales of the thermal misbalance. Depending on certain values of the misbalance time scales three regimes of the wave evolution were identified, namely the regime of a suppressed damping, enhanced damping where the damping rate drops down to the observational values, and acoustic over-stability. The specific regime is determined by the dependences of the radiative cooling and heating functions on thermodynamical parameters of the plasma in the vicinity of the perturbed thermal equilibrium. Conclusions. The comparison of the observed and theoretically derived decay times and oscillation periods allows us to constrain the coronal heating function. For typical coronal parameters, the observed properties of standing slow magnetoacoustic oscillations could be readily reproduced with a reasonable choice of the heating function.

Finite amplitude transverse oscillations of a magnetic rope

Dmitrii Y. **Kolotkov**, Giuseppe Nistico, George Rowlands, Valery M. Nakariakov

Journal of Atmospheric and Solar-Terrestrial Physic 172, 40-52 **2018**

https://arxiv.org/pdf/1803.05195.pdf

The effects of finite amplitudes on the transverse oscillations of a quiescent prominence represented by a magnetic rope are investigated in terms of the model proposed by Kolotkov et al. 2016. We consider a weakly nonlinear case governed by a quadratic nonlinearity, and also analyse the fully nonlinear equations of motion. We treat the prominence as a massive line current located above the photosphere and interacting with the magnetised dipped environment via the Lorentz force. In this concept the magnetic dip is produced by two external current sources located at the photosphere. Finite amplitude horizontal and vertical oscillations are found to be strongly coupled between each other. The coupling is more efficient for larger amplitudes and smaller attack angles between the direction of the driver and the horizontal axis. Spatial structure of oscillations is represented by Lissajous-like curves with the limit cycle of a hourglass shape, appearing in the resonant case, when the frequency of the vertical mode is twice the horizontal mode frequency. A metastable equilibrium of the prominence is revealed, which is stable for small amplitude displacements, and becomes horizontally unstable, when the amplitude exceeds a threshold value. The maximum oscillation amplitudes are also analytically derived and analysed. Typical oscillation periods are determined by the oscillation amplitude, prominence current, its mass and position above the photosphere, and the parameters of the magnetic dip. The main new effects of the finite amplitude are the coupling of the horizontally and vertically polarised transverse oscillations (i.e. the lack of a simple, elliptically polarised regime) and the presence of metastable equilibria of prominences.

Transverse oscillations and stability of prominences in a magnetic field dip

D.Y. **Kolotkov**, G. Nistico and V.M. Nakariakov

A&A 590, A120 **2016**

Aims. We developed an analytical model of the global transverse oscillations and mechanical stability of a quiescent prominence in the magnetised environment with a magnetic field dip that accounts for the mirror current effect.
Methods. The model is based on the interaction of line currents through the Lorentz force. Within this concept the prominence is treated as a straight current-carrying wire, and the magnetic dip is provided by two photospheric current sources.
Results. Properties of both vertical and horizontal oscillations are determined by the value of the prominence current, its density and height above the photosphere, and the parameters of the magnetic dip. The prominence can be stable in both horizontal and vertical directions simultaneously when the prominence current dominates in the system and its height is less than the half-distance between the photospheric sources.

Spectral Characteristics of the He i D3 Line in a Quiescent Prominence Observed by THEMIS

Július **Koza**, Ján Rybák Peter Gömöry, Matúš Kozák, Arturo López Ariste

Solar Physics August **2017**, 292:98

https://arxiv.org/pdf/1712.09255.pdf

We analyze the observations of a quiescent prominence acquired by the Téléscope Heliographique pour l'Étude du Magnetisme et des Instabilités Solaires (THEMIS) in the He i 5876 Å (He i D3) multiplet aiming to measure the spectral characteristics of the He i D3profiles and to find for them an adequate fitting model. The component characteristics of the He i D3 Stokes I profiles are measured by the fitting system by approximating them with a double Gaussian. This model yields an He i D3 component peak intensity ratio of 5.5±0.45.5±0.4, which differs from the value of 8 expected in the optically thin limit. Most of the measured Doppler velocities lie in the interval ± 5 km s−1, with a standard deviation of ± 1.7 km s−1around the peak value of 0.4 km s−1. The wide distribution of the full-width at half maximum has two maxima at 0.25 Å and 0.30 Å for the He i D3 blue component and two maxima at 0.22 Å and 0.31 Å for the red component. The width ratio of the components is 1.04±0.181.04±0.18. We show that the double-Gaussian model systematically underestimates the blue wing intensities. To solve this problem, we invoke a two-temperature multi-Gaussian model, consisting of two double-Gaussians, which provides a better representation of He i D3 that is free of the wing intensity deficit. This model suggests temperatures of 11.5 kK and 91 kK, respectively, for the cool and the hot component of the target prominence. The cool and hot components of a typical He i D3 profile have component peak intensity ratios of 6.6 and 8, implying a prominence geometrical width of 17 Mm and an optical thickness of 0.3 for the cool component, while the optical thickness of the hot component is negligible. These prominence parameters seem to be realistic, suggesting the physical adequacy of the multi-Gaussian model with important implications for interpreting He i D3 spectropolarimetry by current inversion codes.
2-4 August 2014

ANALYSIS OF ERUPTING SOLAR PROMINENCES IN TERMS OF AN UNDERLYING FLUX-ROPE CONFIGURATION

Jonathan **Krall** and Alphonse C.

The Astrophysical Journal, 663:1354Y1362, 2007

Data from four solar prominence eruptions are analyzed so as to examine the flux-rope configuration at the onset of eruption and to test specific aspects of an analytic flux-rope model of solar eruptions. The model encompasses both prominence eruptions and coronal mass ejections (CMEs) as generic elements of a typical erupting flux-rope structure.
This analysis further suggests that the onset of eruption is associated with a situation in which the underlying flux-rope geometry maximizes the outward magnetic ''hoop'' force.

On the Asymmetric Longitudinal Oscillations of a Pikelner's Model Prominence

J. **Kraskiewicz**, K. Murawski, A. Solov'ev, A.K. Srivastava
Solar Physics Vol. 291, Issue 2 **2016** **Open Access**
http://arxiv.org/pdf/1601.04792v1.pdf
We present analytical and numerical models of a normal-polarity quiescent prominence that are based on the model of Pikelner (Solar Phys. 1971, 17, 44). We derive the general analytical expressions for the two-dimensional equilibrium plasma quantities such as the mass density and a gas pressure, and we specify magnetic-field components for the prominence, which corresponds to a dense and cold plasma residing in the dip of curved magnetic-field lines. With the adaptation of these expressions, we solve numerically the 2D, nonlinear, ideal MHD equations for a Pikelner's model of a prominence that is initially perturbed by reducing the gas pressure at the dip of magnetic-field lines. Our findings reveal that as a result of pressure perturbations the prominence plasma starts evolving in time and this leads to the antisymmetric magnetoacoustic--gravity oscillations as well as to the mass-density growth at the magnetic dip, and the magnetic-field lines subside there. This growth depends on the depth of magnetic dip. For a shallower dip, less plasma is condensed and vice-versa. We conjecture that the observed long-period magnetoacoustic-gravity oscillations in various prominence systems are in general the consequence of the internal pressure perturbations of the plasma residing in equilibrium at the prominence dip.

Modeling of Condensations in Coronal Loops Produced by Impulsive Heating

Therese A. **Kucera**, James A. Klimchuk, Manuel Luna
ApJ **2024**
https://arxiv.org/pdf/2402.06799.pdf
We present the results of models of impulsively heated coronal loops using the 1-D hydrodynamic Adaptively Refined Godunov Solver (ARGOS) code. The impulsive heating events (which we refer to as "nanoflares") are modeled by discrete pulses of energy along the loop. We explore the occurrence of cold condensations due to the effective equivalent of thermal non-equilibrium (TNE) in loops with steady heating, and examine its dependence on nanoflare timing and intensity and also nanoflare location along the loop, including randomized distributions of nanoflares. We find that randomizing nanoflare distributions, both in time/intensity and location, diminishes the likelihood of condensations as compared to distributions with regularly occurring nanoflares with the same average properties. The usual criteria that condensations are favored for heating near loop footpoints and with high cadences are more strict for randomized (as opposed to regular) nanoflare distributions, and for randomized distributions the condensations stay in the loop for a shorter amount of time. That said, condensations can sometimes occur in cases where the average values of parameters (frequency or location) are beyond the critical limits above which condensations do not occur for corresponding steady, non-randomized values of those parameters. These properties of condensations occurring due to randomized heating can be used in the future to investigate diagnostics of coronal heating mechanisms.

Comparison of Two Methods for Deriving the Magnetic Field in a Filament Channel

T. A. **Kucera**1, M. Luna2, T. Török3, K. Muglach1,4, J. T. Karpen1, C. Downs3, X. Sun5, B. J. Thompson1, and H. R. Gilbert6
2022 ApJ 940 34
https://iopscience.iop.org/article/10.3847/1538-4357/ac9377/pdf
Understanding the magnetic structure of filament channels is difficult but essential for identifying the mechanism (s) responsible for solar eruptions. In this paper we characterize the magnetic field in a well-observed filament channel with two independent methods, prominence seismology and magnetohydrodynamics flux-rope modeling, and compare the results. In 2014 May and June, active region 12076 exhibited a complex of filaments undergoing repeated oscillations over the course of 12 days. We measure the oscillation periods in the region with both Global Oscillation Network Group Hα and Solar Dynamics Observatory (SDO) Advanced Imaging Assembly EUV images, and then utilize the pendulum model of large-amplitude longitudinal oscillations to calculate the radius of curvature of the fields supporting the oscillating plasma from the derived periods. We also employ the regularized Biot–Savart laws formalism to construct a flux-rope model of the field of the central filament in the region based on an SDO Helioseismic and Magnetic Imager magnetogram. We compare the estimated radius of curvature, location, and angle of the magnetic field in the plane of the sky derived from the observed oscillations with the corresponding magnetic-field properties extracted from the flux-rope model. We find that the two models are broadly consistent, but detailed comparisons of the model and specific oscillations often differ. Model observation comparisons such as these are important for advancing our understanding of the structure of filament channels. **26 May-1 Jun 2014**

Spectroscopic Constraints on the Cross-sectional Asymmetry and Expansion of Active Region Loops

T. A. **Kucera**1, P. R. Young1,2, J. A. Klimchuk1, and C. E. DeForest3
2019 ApJ 885 7
sci-hub.se/10.3847/1538-4357/ab449e

We explore the constraints that can be placed on the dimensions of coronal loops out of the plane of the sky by utilizing spectroscopic observations from the Hinode/EUV Imaging Spectrometer (EIS). The usual assumption is that loop cross sections are circular. Changes in intensity are assumed to be the result of changing density, filling factor, and/or point of view. In this work we instead focus on the possibility that the loop dimensions may be changing along the line of sight while the filling factor remains constant. We apply these ideas to two warm ($5.5 \lesssim \log T(\mathrm{K}) < 6.2$) loops observed by EIS in Active Region 11150 on 2011 February 6 with supporting observations from Solar Dynamics Observatory's Atmospheric Imaging Assembly and the Solar TErrestrial RElations Observatory-A's Extreme Ultraviolet Imager. Our results are generally consistent with nonexpanding loops but could also allow linear expansions of up to a factor of 2.5 along a 40 Mm section of one loop and up to a factor of 3.9 in another loop, both under the assumption that the filling factor is constant along the loop. Expansions in the plane of the sky over the same sections of the loops are 1.5 or less. For a filling factor of 1, the results of the analysis are consistent with circular cross sections but also with aspect ratios of 2 or greater. Count rate statistics are an important part of the uncertainties, but the results are also significantly dependent on radiometric calibration of EIS and the selection of the loop backgrounds.

Motions in Prominence Barbs Observed on the Solar Limb

T. A. **Kucera**1, L. Ofman1,2,3, and T. D. Tarbell

2018 ApJ 859 121

https://iopscience.iop.org/article/10.3847/1538-4357/aabe90/pdf

We analyze and discuss an example of prominence barbs observed on the limb on **2016 January 7** by the Hinode/Solar Optical Telescope in Ca ii and Hα, the Interface Region Imaging Spectrograph, with slit jaw images and Mg ii spectral data, and the Solar Dynamics Observatory's Atmospheric Imaging Assembly. In the recent literature there has been a debate concerning whether these features, sometimes referred to as "tornadoes," are rotating. Our data analysis provides no evidence for systematic rotation in the barbs. We do find line-of-sight motions in the barbs that vary with location and time. We also discuss observations of features moving along the barbs. These moving features are elongated parallel to the solar limb and tend to come in clusters of features moving along the same or similar paths in the plane of the sky during a period of 10 minutes to an hour, moving toward or away from the limb. The motion may have a component along the line of sight as well. The spectral data indicate that the features are Doppler shifted. We discuss possible explanations for these features.

Derivations and Observations of Prominence Bulk Motions and Mass **Review**

T.A. **Kucera**

in Solar Prominences, eds. J.-C. Vial and O. Engvold, Springer, p. 79, **2015**

http://arxiv.org/pdf/1502.00653v1.pdf

In this chapter we review observations and techniques for measuring both bulk flows in prominences and prominence mass. Measuring these quantities is essential to development and testing of models discussed throughout this book. Prominence flows are complex and various, ranging from the relatively linear flows along prominence spines to the complex, turbulent patterns exhibited by hedgerow prominences. Techniques for measuring flows include time slice and optical flow techniques used for motions in the plane of the sky and the use of spectral line profiles to determine Doppler velocities along the line of sight. Prominence mass measurement is chiefly done via continuum absorption measurements, but mass has also been estimated using cloud modeling and white light measurements. **2010 August 11**

Mass Flows in a Prominence Spine as Observed in EUV

T. A. **Kucera**1, H. R. Gilbert1, and J. T. Karpen

2014 ApJ 790 68

We analyze a quiescent prominence observed by the Solar Dynamics Observatory's Atmospheric Imaging Assembly (AIA) with a focus on mass and energy flux in the spine, measured using Lyman continuum absorption. This is the first time this type of analysis has been applied with an emphasis on individual features and fluxes in a quiescent prominence. The prominence, observed on **2010 September 28**, is detectable in most AIA wavebands in absorption and/or emission. Flows along the spine exhibit horizontal bands 5"-10" wide and kinetic energy fluxes on the order of a few times 105 erg s–1cm–2, consistent with quiet sun coronal heating estimates. For a discrete moving feature we estimate a mass of a few times 1011 g. We discuss the implications of our derived properties for a model of prominence dynamics, the thermal non-equilibrium model.

TEMPERATURE AND EXTREME-ULTRAVIOLET INTENSITY IN A CORONAL PROMINENCE CAVITY AND STREAMER

T. A. **Kucera**1, S. E. Gibson2, D. J. Schmit2,3, E. Landi4, and D. Tripathi

2012 ApJ 757 73

We analyze the temperature and EUV line emission of a coronal cavity and surrounding streamer in terms of a morphological forward model. We use a series of iron line ratios observed with the Hinode Extreme-ultraviolet Imaging Spectrograph (EIS) on **2007 August 9** to constrain temperature as a function of altitude in a morphological forward model of the streamer and cavity. We also compare model predictions to the EIS EUV line intensities and polarized brightness (pB) data from the Mauna Loa Solar Observatory (MLSO) Mark 4 K-coronameter. This work builds on earlier analysis using the same model to determine geometry of and density in the same cavity and streamer. The fit to the data with altitude-dependent temperature profiles indicates that both the streamer and cavity have temperatures in the range 1.4-1.7 MK. However, the cavity exhibits substantial substructure such that the altitude-dependent temperature profile is not sufficient to completely model conditions in the cavity. Coronal prominence cavities are structured by magnetism so clues to this structure are to be found in their plasma properties. These temperature substructures are likely related to structures in the cavity magnetic field. Furthermore, we find that the model overestimates the EUV line intensities by a factor of 4-10, without overestimating pB. We discuss this difference in terms of filling factors and uncertainties in density diagnostics and elemental abundances.

AN OBSERVATION OF LOW-LEVEL HEATING IN AN ERUPTING PROMINENCE

T. A. **Kucera** and E. Landi

The Astrophysical Journal, 673:611–620, **2008**

http://www.journals.uchicago.edu/doi/pdf/10.1086/523694

Here we present multiwavelength observations of low-level heating in an erupting prominence observed in the UV and EUVover a wide range of temperatures and wavelengths by the Solar and Heliospheric Observatory (SOHO) Solar Ultraviolet Measurements of Emitted Radiation (SUMER) instrument and the Transition Region and Coronal Explorer (TRACE), and also inH_ by the Yunnan Astronomical Observatory. The eruption occurred on **2004 April 30**. The heating is relatively mild, leading only to the ionization of hydrogen and helium. It is also localized, occurring along the bottom edge of the erupting prominence and in a kinklike feature in the prominence. The heating is revealed as a decrease in the Lyman absorption relative to other parts of the prominence. This decrease results in an apparent increase in emission in all the lines observed by SUMER, especially those formed at temperatures of _10^5 K. However, this is due to the disappearance of cooler absorbing material in the prominence rather than to an increase in these higher temperature species. These observations suggest that there may be low-level heating occurring in other erupting prominences that do not show heating to coronal temperatures. They also indicate that the prominence-corona transition region is best modeled with two or more structures along the line of sight.We discuss the results in terms of models of heating in erupting prominences and observations of Lyman absorption in prominences.

A giant quiescent solar filament observed with high-resolution spectroscopy

C. **Kuckein**, M. Verma, C. Denker

Astronomy & Astrophysics 589, A84 **2016**

http://arxiv.org/pdf/1603.02505v1.pdf

A giant, quiet-Sun filament was observed with the high-resolution Echelle spectrograph at the Vacuum Tower Telescope at Observatorio del Teide on **2011 November 15**. A mosaic of spectra (10 maps of 100" X 182") was recorded simultaneously in the chromospheric absorption lines H-alpha and Na I D2. Physical parameters of the filament plasma were derived using Cloud Model (CM) inversions and line core fits. The spectra were complemented with full-disk filtergrams (He I 10830 A, H-alpha, and Ca II K) of the Chromspheric Telescope (ChroTel) and full-disk magnetograms of HMI. The filament had extremely large linear dimensions (817"), which corresponds to about 658 Mm along a great circle on the solar surface. A total amount of 175119 H-alpha contrast profiles were inverted using the CM approach. The inferred mean line-of-sight (LOS) velocity, Doppler width, and source function were similar to previous works of smaller quiescent filaments. However, the derived optical thickness was larger. LOS velocity trends inferred from the H-alpha line core fits were in accord, but smaller, than the ones obtained with CM inversions. Signatures of counter-streaming flows were detected in the filament.The largest conglomerates of brightenings in the line core of Na I D2 coincided well with small-scale magnetic fields as seen by HMI. Mixed magnetic polarities were detected close to the ends of barbs. The computation of photospheric horizontal flows based on HMI magnetograms revealed flow kernels with a size of 5-8 Mm and velocities of 0.30-0.45 km/s at the ends of the filament. The physical properties of extremely large filaments are similar to their smaller counterparts, except for the optical thickness which in our sample was found to be larger. We found that a part of the filament, which erupted the day before, is in the process of reestablishing its initial configuration.

An active region filament studied simultaneously in the chromosphere and photosphere I. Magnetic structure

C. **Kuckein**[1,2], V. Martínez Pillet[1] and R. Centeno

A&A 539, A131 (**2012**)

Aims. A thorough multiwavelength, multiheight study of the vector magnetic field in a compact active region filament (NOAA 10781) on 2005 July 3 and 5 is presented. We suggest an evolutionary scenario for this filament. Methods. Two different inversion codes were used to analyze the full Stokes vectors acquired with the Tenerife Infrared Polarimeter (TIP-II) in a spectral range that comprises the chromospheric He i 10 830 Å multiplet and the photospheric Si i 10 827 Å line. In addition, we used SOHO/MDI magnetograms, as well as BBSO and TRACE images, to study the evolution of the filament and its active region (AR). High-resolution images of the Dutch Open Telescope were also used.

Results. An active region filament (formed before our observing run) was detected in the chromospheric helium absorption images on July 3. The chromospheric vector magnetic field in this portion of the filament was strongly sheared (parallel to the filament axis), whereas the photospheric field lines underneath had an inverse polarity configuration. From July 3 to July 5, an opening and closing of the polarities on either side of the polarity inversion line (PIL) was recorded, resembling the recently discovered process of the sliding door effect seen by Hinode. This is confirmed with both TIP-II and SOHO/MDI data. During this time, a newly created region that contained pores and orphan penumbrae at the PIL was observed. On July 5, a normal polarity configuration was inferred from the chromospheric spectra, while strongly sheared field lines aligned with the PIL were found in the photosphere. In this same data set, the spine of the filament is also observed in a different portion of the field of view and is clearly mapped by the silicon line core.

Conclusions. The inferred vector magnetic fields of the filament suggest a flux rope topology. Furthermore, the observations indicate that the filament is divided in two parts, one which lies in the chromosphere and another one that stays trapped in the photosphere. Therefore, only the top of the helical structure is seen by the helium lines. The pores and orphan penumbrae at the PIL appear to be the photospheric counterpart of the extremely low-lying filament. We suggest that orphan penumbrae are formed in very narrow PILs of compact ARs and are the photospheric manifestation of flux ropes in the photosphere.

Magnetic field strength of active region filaments:

C. **Kuckein**, R. Centeno, V. MartMnez Pillet, R. Casini, R. Manso Sainz and T. Shimizu

A&A 501 (**2009**) 1113-1121

http://www.aanda.org/10.1051/0004-6361/200911800

Aims. We study the vector magnetic field of a filament observed over a compact active region neutral line.

Methods. Spectropolarimetric data acquired with TIP-II (VTT, Tenerife, Spain) of the 10 830 Å spectral region provide full Stokes vectors that were analyzed using three different methods: magnetograph analysis, Milne-Eddington inversions, and PCA-based atomic polarization inversions.

Results. The inferred magnetic field strengths in the filament are around 600–700 G by all these three methods. Longitudinal fields are found in the range of 100–200 G whereas the transverse components become dominant, with fields as high as 500–600 G. We find strong transverse fields near the neutral line also at photospheric levels.

Conclusions. Our analysis indicates that strong (higher than 500 G, but below kG) transverse magnetic fields are present in active region filaments. This corresponds to the highest field strengths reliably measured in these structures. The profiles of the helium 10 830 Å lines observed in this active region filament are dominated by the Zeeman effect.

Excitation of coronal loop oscillations by coronal rain

Petra **Kohutova** and Erwin Verwichte

UKSP Nugget: 88, June **2018**

http://www.uksolphys.org/uksp-nugget/88-excitation-of-coronal-loop-oscillations-by-coronal-rain/

Coronal rain is a common phenomenon occurring in active region coronal loops. As the name suggests, it shares many parallels with its terrestrial counterpart; it consists of cool plasma condensations falling from coronal heights towards the solar surface guided by magnetic field lines. Coronal rain is formed as a direct consequence of thermal instability. A coronal loop is likely to become thermally unstable if it is heated predominantly at the footpoints. If the thermal conduction along the loop is not efficient enough, the radiative losses from the plasma at the loop top can overcome the heating input from the footpoints, resulting in onset of a thermally unstable regime and in the runway cooling of the plasma at the loop top. This leads to the formation of cool and dense plasma condensations, which then fall towards the solar surface in the form of coronal rain showers. Recent high resolution observations have shown that coronal rain is much more common than previously thought [1], suggesting it has an important role in the chromosphere-corona mass cycle. Due to its origin, coronal rain also provides us with physical insight into the atmospheric thermal cycle. **2014/08/27**

Effect of a Radiation Cooling and Heating Function on Standing Longitudinal Oscillations in Coronal Loops

Sanjay **Kumar**, V. M. Nakariakov, Y.-J. Moon

ApJ **824** 8 **2016**

http://arxiv.org/pdf/1603.08335v1.pdf

Standing long-period (with the periods longer than several minutes) oscillations in large hot (with the temperature higher than 3 MK) coronal loops have been observed as the quasi-periodic modulation of the EUV and microwave intensity emission and the Doppler shift of coronal emission lines, and have been interpreted as standing slow magnetoacoustic (longitudinal) oscillations. Quasi-periodic pulsations of shorter periods, detected in thermal and non-thermal emissions in solar flares could be produced by a similar mechanism. We present theoretical modelling of the standing slow magnetoacoustic mode, showing that this mode of oscillation is highly sensitive to peculiarities of the radiative cooling and heating function. We generalised the theoretical model of standing slow magnetoacoustic oscillations in a hot plasma, including the effects of the radiative losses, and accounting for plasma heating. The heating mechanism is not specified and taken empirically to compensate the cooling by radiation and thermal-conduction. It is shown that the evolution of the oscillations is described by a generalised Burgers equation. Numerical solution of an initial value problem for the evolutionary equation demonstrates that different dependences of the radiative cooling and plasma heating on the temperature lead to different regimes of the oscillations, including growing, quasi-stationary and rapidly decaying. Our findings provide a theoretical foundation for probing the coronal heating function, and may explain the observations of decayless long-period quasi-periodic pulsations in flares. The hydrodynamic approach employed in this study should be considered with caution in the modelling of non-thermal emission associated with flares, as it misses potentially important non-hydrodynamic effects.

Partial Reflection and Trapping of a Fast-mode Wave in Solar Coronal Arcade Loops

Pankaj **Kumar**1,2 and D. E. Innes

2015 ApJ 803 L23

We report on the first direct observation of a fast-mode wave propagating along and perpendicular to cool (171 Å) arcade loops observed by the Solar Dynamics Observatory/Atmospheric Imaging Assembly (AIA). The wave was associated with an impulsive/compact flare near the edge of a sunspot. The EUV wavefront expanded radially outward from the flare center and decelerated in the corona from 1060 to 760 km s−1 within ~3–4 minutes. Part of the EUV wave propagated along a large-scale arcade of cool loops and was partially reflected back to the flare site. The phase speed of the wave was about 1450 km s−1, which is interpreted as a fast-mode wave. A second overlying loop arcade, orientated perpendicular to the cool arcade, is heated and becomes visible in the AIA hot channels. These hot loops sway in time with the EUV wave, as it propagated to and fro along the lower loop arcade. We suggest that an impulsive energy release at one of the footpoints of the arcade loops causes the onset of an EUV shock wave that propagates along and perpendicular to the magnetic field.

SDO/AIA Observations of a Reflecting Longitudinal Wave in a Coronal Loop

Pankaj **Kumar**, D.E. Innes, B. Inhester

2014

http://arxiv.org/pdf/1409.3896v1.pdf

We report high resolution observations from the SDO/AIA of intensity oscillations in a hot, T~8-10 MK, loop. The AIA images show a large coronal loop that was rapidly heated following plasma ejection from one of the loop's footpoints. A wave-like intensity enhancement, seen very clearly in the 131 and 94 \AA\ channel images, propagated ahead of the ejecta along the loop, and was reflected at the opposite footpoint. The wave reflected four times before fading. It was only seen in the hot, 131 and 94 \AA\ channels. The characteristic period and the decay time of the oscillation was ~630 and ~440 s, respectively. The phase speed was about 460-510 km/s which roughly matches the sound speed of the loop (430-480 km/s). The observed properties of the oscillation are consistent with the observations of Doppler shift oscillations discovered by the SOHO/SUMER and with their interpretation as slow magnetoacoustic waves. We suggest that the impulsive injection of plasma, following reconnection at one of the loop footpoints, led to rapid heating and the propagation of a longitudinal compressive wave along the loop. The wave bounces back and forth a couple of times before fading. **7 May 2012**

Solar Dynamics Observatory/Atmospheric Imaging Assembly Observations of a Reflecting Longitudinal Wave in a Coronal Loop

Pankaj **Kumar**1,2, D. E. Innes2, and B. Inheste

2013 ApJ 779 L7

We report high resolution observations from the Solar Dynamics Observatory/Atmospheric Imaging Assembly (SDO/AIA) of intensity oscillations in a hot, T ~ 8-10 MK, loop. The AIA images show a large coronal loop that was rapidly heated following plasma ejection from one of the loop's footpoints. A wave-like intensity enhancement, seen very clearly in the 131 and 94 Å channel images, propagated ahead of the ejecta along the loop, and was reflected at the opposite footpoint. The wave reflected four times before fading. It was only seen in the hot, 131 and

94 Å channels. The characteristic period and the decay time of the oscillation were ~630 and ~440 s, respectively. The phase speed was about 460-510 km s–1 which roughly matches the sound speed of the loop (430-480 km s–1). The observed properties of the oscillation are consistent with the observations of Dopper-shift oscillations discovered by the Solar and Heliospheric Observatory/Solar Ultraviolet Measurement of Emitted Radiation and with their interpretation as slow magnetoacoustic waves. We suggest that the impulsive injection of plasma, following reconnection at one of the loop footpoints, led to rapid heating and the propagation of a longitudinal compressive wave along the loop. The wave bounces back and forth a couple of times before fading.

Multi-Wavelength Observations of a Flux Rope Failed in the Eruption and Associated M-Class Flare from NOAA AR 11045

Pankaj **Kumar**1;2 _ A.K. Srivastava1;4 _B. Filippov3 _ R. Erdelyi4 _ Wahab Uddin1

E-print, July 2011**,** Volume 272, Number 2, 301-317, **2011, File**

We present the multiwavelength observations of a flux rope that was trying to erupt from NOAA AR 11045 and the associated M-class solar flare on **12 February 2010** using space-based and ground-based observations from TRACE, STEREO, SOHO/MDI, Hinode/XRT, and BBSO. While the flux rope was rising from the active region, an M1.1/2F class flare was triggered near one of its footpoints. We suggest that the flare triggering was due to the reconnection of a rising flux rope with the surrounding low-lying magnetic loops. The flux rope reached a projected height of ≈0.15R ☉ with a speed of ≈90 km s−1 while the soft X-ray flux enhanced gradually during its rise. The flux rope was suppressed by an overlying field, and the filled plasma moved towards the negative polarity field to the west of its activation site. We found the first observational evidence of the initial suppression of a flux rope due to a remnant filament visible both at chromospheric and coronal temperatures that evolved a couple of days earlier at the same location in the active region. SOHO/MDI magnetograms show the emergence of a bipole ≈12 h prior to the flare initiation. The emerged negative polarity moved towards the flux rope activation site, and flare triggering near the photospheric polarity inversion line (PIL) took place. The motion of the negative polarity region towards the PIL helped in the build-up of magnetic energy at the flare and flux rope activation site. This study provides unique observational evidence of a rising flux rope that failed to erupt due to a remnant filament and overlying magnetic field, as well as associated triggering of an M-class flare.

Mapping the Magnetic Field of Flare Coronal Loops

D. **Kuridze**1,2,3, M. Mathioudakis2, H. Morgan1, R. Oliver4,5, L. Kleint6,7, T. V. Zaqarashvili3,8,9, A. Reid2, J. Koza10, M. G. Löfdahl11, T. Hillberg

2019 ApJ 874 126

https://iopscience.iop.org/article/10.3847/1538-4357/ab08e9/pdf

https://arxiv.org/pdf/1902.07514.pdf

Here, we report on the unique observation of flaring coronal loops at the solar limb using high-resolution imaging spectropolarimetry from the Swedish 1 m Solar Telescope. The vantage position, orientation, and nature of the chromospheric material that filled the flare loops allowed us to determine their magnetic field with unprecedented accuracy using the weak-field approximation method. Our analysis reveals coronal magnetic field strengths as high as 350 G at heights up to 25 Mm above the solar limb. These measurements are substantially higher than a number of previous estimates and may have considerable implications for our current understanding of the extended solar atmosphere. **2017 September 10**

UKSP Nugget: #101 June **2019**

http://www.uksolphys.org/uksp-nugget/101-mapping-the-magnetic-field-of-solar-coronal-loops/

Failed filament eruption inside a coronal mass ejection in active region 11121⋆

D. **Kuridze**1,4, M. Mathioudakis1, A. F Kowalski2, P. H. Keys1, D. B. Jess1,5, K. S. Balasubramaniam3 and F. P. Keenan

A&A 552, A55 (**2013**)

Aims. We study the formation and evolution of a failed filament eruption observed in NOAA active region 11121 near the southeast limb on **November 6, 2010**.

Methods. We used a time series of SDO/AIA 304, 171, 131, 193, 335, and 94 Å images, SDO/HMI magnetograms, as well as ROSA and ISOON Hα images to study the erupting active region.

Results. We identify coronal loop arcades associated with a quadrupolar magnetic configuration, and show that the expansion and cancellation of the central loop arcade system over the filament is followed by the eruption of the filament. The erupting filament reveals a clear helical twist and develops the same sign of writhe in the form of inverse γ-shape.

Conclusions. The observations support the “magnetic breakout” process in which the eruption is triggered by quadrupolar reconnection in the corona. We propose that the formation mechanism of the inverse γ-shape flux rope is the magnetohydrodynamic helical kink instability. The eruption has failed because of the large-scale, closed, overlying magnetic loop arcade that encloses the active region.

Notes about collapse in magnetohydrodynamics

E.A.**Kuznetsov**, E.A.Mikhailov

2022

https://arxiv.org/pdf/2202.08121.pdf

We discuss a problem about magnetic collapse as a possible process for singularity formation of the magnetic field in a finite time within ideal magneto-hydrodynamics for incompressible fluids. This process is very important from the point of view of various astrophysical applications, in particular, as *a mechanism of magnetic filaments formation in the convective zone of the Sun.* The collapse possibility is connected with compressibility of continuously distributed magnetic field lines. A well-known example of the formation of magnetic filaments in the kinematic dynamo approximation with a given velocity field, first considered by Parker in 1963, rather indicates that the increase in the magnetic field is exponential in time. In the case of the kinematic approximation for the induction equation, the magnetic filaments formation is shown to occur in areas with a hyperbolic velocity profile.

First High Resolution Interferometric Observation of a Solar Prominence With ALMA

Nicolas **Labrosse**, Andrew S. Rodger, Krzysztof Radziszewski, Paweł Rudawy, Patrick Antolin, Lyndsay Fletcher, Peter J. Levens, Aaron W. Peat, Brigitte Schmieder, Paulo J. A. Simões

MNRAS **2022**

https://arxiv.org/pdf/2202.12434.pdf

We present the first observation of a solar prominence at 84−116 GHz using the high resolution interferometric imaging of ALMA. Simultaneous observations in Hα from Białkaw Observatory and with SDO/AIA reveal similar prominence morphology to the ALMA observation. The contribution functions of 3 mm and Hα emission are shown to have significant overlap across a range of gas pressures. We estimate the maximum millimetre-continuum optical thickness to be $\tau_{3mm} \approx 2$, and the brightness temperature from the observed Hα intensity. The brightness temperature measured by ALMA is ∼6000−7000 K in the prominence spine, which correlates well with the estimated brightness temperature for a gas temperature of 8000 K. **19th April 2018**

Plasma diagnostic in eruptive prominences from SDO/AIA observations at 304 Å

N. **Labrosse** and K. McGlinchey

A&A 537, A100 (**2012**)

Context. Theoretical calculations have shown that when solar prominences move away from the surface of the Sun, their radiative output is affected via the Doppler dimming or brightening effects.

Aims. In this paper we ask whether observational signatures of the changes in the radiative output of eruptive prominences can be found in EUV (extreme ultraviolet) observations of the first resonance line of ionised helium at 304 Å. We also investigate whether these observations can be used to perform a diagnostic of the plasma of the eruptive prominence.

Methods. We first look for suitable events in the SDO/AIA database. The variation of intensity of arbitrarily selected features in the 304 channel is studied as a function of velocity in the plane of the sky. These results are then compared with new non-LTE radiative transfer calculations of the intensity of the He ii 304 resonance line.

Results. We find that observations of intensities in various parts of the four eruptive prominences studied here are sometimes consistent with the Doppler dimming effect on the He ii 304 Å line. However, in some cases, one observes an increase in intensity in the 304 channel with velocity, in contradiction to what is expected from the Doppler dimming effect alone. The use of the non-LTE models allows us to explain the different behaviour of the intensity by changes in the plasma parameters inside the prominence, in particular the column mass of the plasma and its temperature.

Conclusions. The non-LTE models used here are more realistic than what was used in previous calculations. They are able to reproduce qualitatively the range of observations from SDO/AIA analysed in this study. With the help of non-LTE modelling, we can infer the plasma parameters in eruptive prominences from SDO/AIA observations at 304 Å.

Physics of Solar Prominences: I: Spectral Diagnostics and Non-LTE Modelling –

N. **Labrosse**, P. Heinzel, J.-C. Vial, T. Kucera, S. Parenti, S. Gunár, B. Schmieder, and G. Kilper.

Space Science Reviews, **2010**

http://arxiv.org/abs/1001.1620

This **review** paper outlines background information and covers recent advances made via the analysis of spectra and images of prominence plasma and the increased sophistication of non-LTE (ie when there is a departure from Local Thermodynamic Equilibrium) radiative transfer models. We first describe the spectral inversion techniques that have been used to infer the plasma parameters important for the general properties of the prominence plasma in both its cool core and the hotter prominence-corona transition region. We also review studies devoted to the observation of bulk motions of the prominence plasma and to the determination of prominence mass. However, a simple inversion of spectroscopic data usually fails when the lines become optically thick at certain wavelengths.

Therefore, complex non-LTE models become necessary. We thus present the basics of non-LTE radiative transfer theory and the associated multi-level radiative transfer problems. The main results of one- and two-dimensional models of the prominences and their fine-structures are presented. We then discuss the energy balance in various prominence models. Finally, we outline the outstanding observational and theoretical questions, and the directions for future progress in our understanding of solar prominences.

(See **Physics of Solar Prominences: II: Magnetic Structure and Dynamics –** D.H. **Mackay et al., 2010)**

Diagnostics of active and eruptive prominences through hydrogen and helium lines modelling

N. **Labrosse**1,*, J.-C. Vial2, and P. Gouttebroze2

E-print, April **2008**; Ann. Geophys.

In this study we show how hydrogen and helium lines modelling can be used to make a diagnostic of active and eruptive prominences. One motivation for this work is to identify the physical conditions during prominence activation and eruption. Hydrogen and helium lines are key in probing different parts of the prominence structure and inferring the plasma parameters. However, the interpretation of observations, being either spectroscopic or obtained with imaging, is not straightforward. Their resonance lines are optically thick, and the prominence plasma is out of local thermodynamic equilibrium due to the strong incident radiation coming from the solar disk. In view of the shift of the incident radiation occurring when the prominence plasma flows radially, it is essential to take into account velocity fields in the prominence diagnostic. Therefore we need to investigate the effects of the radial motion of the prominence plasma on hydrogen and helium lines. The method that we use is the resolution of the radiative transfer problem in the hydrogen and helium lines out of local thermodynamic equilibrium. We study the variation of the computed integrated intensities in H and He lines with the radial velocity of the prominence plasma. We can confirm that there exist suitable lines which can be used to make a diagnostic of the plasma in active and eruptive prominences in the presence of velocity fields.

Effect of motions in prominences on the helium resonance lines in the extreme ultraviolet:

N. **Labrosse**, P. Gouttebroze and J.-C. Vial

A&A 463 (2007) 1171-1179 (Section 'The Sun')

http://www.aanda.org/10.1051/0004-6361:20065775

The motion of the prominence plasma induces a Doppler dimming effect on the resonance lines of He I and He II. The velocity effects are particularly important for the He II λ 304 Å line as it is mostly formed by resonant diffusion of incident radiation under prominence conditions.

The Temperature of Quiescent Streamers during Solar Cycles 23 and 24

E. **Landi**1 and P. Testa

2014 ApJ 787 33

Recent in-situ determinations of the temporal evolution of the charge state distribution in the fast and slow solar wind have shown a general decrease in the degree of ionization of all the elements in the solar wind along solar cycles 23 and 24. Such a decrease has been interpreted as a cooling of the solar corona which occurred during the decline and minimum phase of solar cycle 23 from 2000 to 2010. In the present work, we investigate whether spectroscopic determinations of the temperature of the quiescent streamers show signatures of coronal plasma cooling during cycles 23 and 24. We measure the coronal electron density and thermal structure at the base of 60 quiescent streamers observed from 1996 to 2013 by SOHO/SUMER and Hinode/EIS and find that both quantities do now show any significant dependence on the solar cycle. We argue that if the slow solar wind is accelerated from the solar photosphere or chromosphere, the measured decrease in the in-situ wind charge state distribution might be due to an increased efficiency in the wind acceleration mechanism at low altitudes. If the slow wind originates from the corona, a combination of density and wind acceleration changes may be responsible for the in-situ results.

PROMINENCE PLASMA DIAGNOSTICS THROUGH EXTREME-ULTRAVIOLET ABSORPTION

E. **Landi**1 and F. Reale

2013 ApJ 772 71

In this paper, we introduce a new diagnostic technique that uses EUV and UV absorption to determine the electron temperature and column emission measure, as well as the He/H relative abundance of the absorbing plasma. If a realistic assumption on the geometry of the latter can be made and a spectral code such as CHIANTI is used, then this technique can also yield the absorbing plasma hydrogen and electron density. This technique capitalizes on the absorption properties of hydrogen and helium at different wavelength ranges and temperature regimes. Several cases where this technique can be successfully applied are described. This technique works best when the absorbing plasma is hotter than 15,000 K. We demonstrate this technique on AIA observations of plasma absorption during a coronal mass ejection eruption. This technique can be easily applied to existing observations of prominences and cold plasmas in the Sun from almost all space missions devoted to the study of the solar atmosphere, which we list.

On the Effect of the Interplanetary Medium on Nanodust Observations by the Solar Terrestrial Relations Observatory

G. **Le Chat**, K. Issautier, A. Zaslavsky, F. Pantellini, N. Meyer-Vernet, S. Belheouane, M. Maksimovic
2015
http://arxiv.org/pdf/1501.02632v1.pdf
New measurements using radio and plasma-wave instruments in interplanetary space have shown that nanometer-scale dust, or nanodust, is a significant contributor to the total mass in interplanetary space. Better measurements of nanodust will allow us to determine where it comes from and the extent to which it interacts with the solar wind. When one of these nanodust grains impacts a spacecraft, it creates an expanding plasma cloud, which perturbs the photoelectron currents. This leads to a voltage pulse between the spacecraft body and the antenna. Nanodust has a high charge/mass ratio, and therefore can be accelerated by the interplanetary magnetic field to speeds up to the speed of the solar wind: significantly faster than the Keplerian orbital speeds of heavier dust. The amplitude of the signal induced by a dust grain grows much more strongly with speed than with mass of the dust particle. As a result, nanodust can produce a strong signal, despite their low mass. The WAVES instruments on the twin Solar TErrestrial RElations Observatory spacecraft have observed interplanetary nanodust particles since shortly after their launch in 2006. After describing a new and improved analysis of the last five years of STEREO/WAVES Low Frequency Receiver data, a statistical survey of the nanodust characteristics, namely the rise time of the pulse voltage and the flux of nanodust, is presented. Agreement with previous measurements and interplanetary dust models is shown. The temporal variations of the nanodust flux are also discussed.

Observational Kinematic Characteristics of Blobs in Solar Coronal Helmet and Pseudo Streamers

Jae-Ok **Lee**1, Kyung-Suk Cho1,2, Junmo An3, Hwanhee Lee1, Jungjoon Seough1, Yeon-Han Kim1, and Pankaj Kumar4,5
2021 ApJL 920 L6
https://doi.org/10.3847/2041-8213/ac2422
We examine two helmet and two pseudo streamers (HSs and PSs) observed on 2018 and 2019. The HSs (PSs) have dark coronal cavities and stretched loop structures (twin coronal cavities and narrow plasma sheet) at their bases, which are well observed in K-Coronagraph (K-Cor). Their outer-corona structures (top of core, cusp, and stalk) are also clearly identified in LASCO-C2. By investigating LASCO-C2 images, we find the following characteristics. (1) Blobs persistently move outward along the centers of HSs and PSs as well as their legs until the base of a stalk. We also detect outward-moving blobs along their outsides. (2) Blobs along the HS centers formed below tops of cores (~2.6 R⊙), while the other HS and PS blobs might be generated below 2.0 R⊙. (3) HS blob speeds are generally similar to or smaller than the solar wind speed based on Parker's model, while PS ones are larger. (4) HS (PS) blob speeds along the streamer centers are slightly smaller (larger) than those along the streamer legs, might be explained by the expansion-factor model. The blob speeds inside streamer structures (centers and legs) are larger than outside ones closer to solar equator, similar to typical solar wind speed distributions at solar minimum. (5) Several blobs along the HS centers only show sudden speed jumps at streamer cusps. These might be caused by sunward tension forces of overlying stretched closed fields and/or bidirectional outflows by magnetic reconnections in the cusps.

The Role of Magnetic Topology in the Heating of Active Region Coronal Loops

J.-Y. **Lee**, Graham Barnes, K. D. Leka, Katharine K. Reeves, K. E. Korreck, L. Golub and E. E. DeLuca
2010 ApJ 723 1493-1506
We investigate the evolution of coronal loop emission in the context of the coronal magnetic field topology. New modeling techniques allow us to investigate the magnetic field structure and energy release in active regions (ARs). Using these models and high-resolution multi-wavelength coronal observations from the Transition Region and Coronal Explorer and the X-ray Telescope on Hinode, we are able to establish a relationship between the light curves of coronal loops and their associated magnetic topologies for NOAA AR 10963. We examine loops that show both transient and steady emission, and we find that loops that show many transient brightenings are located in

domains associated with a high number of separators. This topology provides an environment for continual impulsive heating events through magnetic reconnection at the separators. A loop with relatively constant X-ray and EUV emission, on the other hand, is located in domains that are not associated with separators. This result implies that larger-scale magnetic field reconnections are not involved in heating plasma in these regions, and the heating in these loops must come from another mechanism, such as small-scale reconnections (i.e., nanoflares) or wave heating. Additionally, we find that loops that undergo repeated transient brightenings are associated with separators that have enhanced free energy. In contrast, we find one case of an isolated transient brightening that seems to be associated with separators with a smaller free energy.

TURBULENT CHARACTERISTICS IN THE INTENSITY FLUCTUATIONS OF A SOLAR QUIESCENT PROMINENCE OBSERVED BY THE HINODE SOLAR OPTICAL TELESCOPE

E. **Leonardis**, S. C. Chapman and C. Foullon

2012 ApJ 745 185

We focus on Hinode Solar Optical Telescope (SOT) calcium II H-line observations of a solar quiescent prominence (QP) that exhibits highly variable dynamics suggestive of turbulence. These images capture a sufficient range of scales spatially (~0.1-100 arcsec) and temporally (~16.8 s-4.5 hr) to allow the application of statistical methods used to quantify finite range fluid turbulence. We present the first such application of these techniques to the spatial intensity field of a long-lived solar prominence. Fully evolved inertial range turbulence in an infinite medium exhibits multifractal scale invariance in the statistics of its fluctuations, seen as power-law power spectra and as scaling of the higher order moments (structure functions) of fluctuations which have non-Gaussian statistics; fluctuations δI(r, L) = I(r + L) – I(r) on length scale L along a given direction in observed spatial field I have moments that scale as δI(r, L) p ~ L ζ(p). For turbulence in a system that is of finite size, or that is not fully developed, one anticipates a generalized scale invariance or extended self-similarity (ESS) δI(r, L) p ~ G(L)ζ(p). For these QP intensity measurements we find scaling in the power spectra and ESS. We find that the fluctuation statistics are non-Gaussian and we use ESS to obtain ratios of the scaling exponents ζ(p): these are consistent with a multifractal field and show distinct values for directions longitudinal and transverse to the bulk (driving) flow. Thus, the intensity fluctuations of the QP exhibit statistical properties consistent with an underlying turbulent flow.

Modelling of Mg II lines in solar prominences

Peter James **Levens**, Nicolas Labrosse

A&A 625, A30 **2019**

https://arxiv.org/pdf/1902.00086.pdf

sci-hub.se/10.1051/0004-6361/201833132

Observations of the Mg II h and k lines in solar prominences with IRIS reveal a wide range of line shapes from simple non-reversed profiles to typical double-peaked reversed profiles with many other complex line shapes possible. The physical conditions responsible for this variety are not well understood. Our aim is to understand how physical conditions inside a prominence slab influence shapes and properties of emergent Mg II line profiles. We compute the spectrum of Mg II lines using a one-dimensional non-LTE radiative transfer code for two large grids of model atmospheres (isothermal isobaric, and with a transition region). The influence of the plasma parameters on the emergent spectrum is discussed in detail. Our results agree with previous studies. We present several dependencies between observables and prominence parameters which will help with interpretation of observations. A comparison with known limits of observed line parameters suggests that most observed prominences emitting in Mg II h and k lines are cold, low pressure, and optically thick structures. Our results indicate that there are good correlations between the Mg II k line intensities and the intensities of hydrogen lines, as well as the emission measure. One-dimensional non-LTE radiative transfer codes are well-suited to understand the main characteristics of the Mg II h and k line profiles in solar prominences, but more advanced codes will be necessary for detailed comparisons. **29 September 2013**

Comparing UV/EUV line parameters and magnetic field in a quiescent prominence with tornadoes

P. J. **Levens**, N. Labrosse, B. Schmieder, A. López Ariste, L. Fletcher

A&A 607, A16 **2017**

https://arxiv.org/pdf/1708.04606.pdf

https://www.aanda.org/articles/aa/pdf/2017/11/aa30808-17.pdf

Context. Understanding the close relationship between the plasma and the magnetic field is important to describe and explain the observed complex dynamics of solar prominences. Aims. We determine if a close relationship between plasma and magnetic field parameters measured in a well-observed solar prominence with high spatial resolution can be found. Methods. We select a prominence observed on **15 July 2014** from space (IRIS, Hinode, SDO) and from the ground (THEMIS). We perform a robust co-alignment of the data sets using a 2D cross-correlation technique. We derive the magnetic field parameters from spectropolarimetric measurements of the He I D3 line taken by THEMIS. Line ratios and line-of-sight velocities from the Mg II h and k lines observed by IRIS are compared with magnetic field strength, inclination and azimuth. Electron densities are calculated using Hinode/EIS Fe XII line ratios and also compared with THEMIS and IRIS data. Results. We find Mg II k/h ratios of around 1.4 everywhere, similar to values found previously in prominences. We also find that the magnetic field is strongest (around 30 G) and predominantly horizontal in the tornado-like legs of the prominence. The k3 Doppler shift is found to be between +/- 10 km/s everywhere. Electron densities at a temperature of 1.5e6 K are found to be around 1e9 /cm3. No significant correlations are found between the magnetic field parameters, and any of the other plasma parameters inferred from EUV spectroscopy, which may be explained by the large differences in the temperatures of the lines used in this study. Conclusions. This is the first time that a detailed statistical study of plasma and magnetic field parameters has been carried out at high spatial resolution in a prominence. Our results provide important constraints on future models of the plasma and magnetic field in these structures.

Magnetic field in atypical prominence structures: Bubble, tornado and eruption

P. J. **Levens**, B. Schmieder, A. López Ariste, N. Labrosse, K. Dalmasse, B. Gelly

2016 *ApJ* **826** 164

http://arxiv.org/pdf/1605.05964v1.pdf

https://iopscience.iop.org/article/10.3847/0004-637X/826/2/164/pdf

Spectropolarimetric observations of prominences have been obtained with the THEMIS telescope during four years of coordinated campaigns. Our aim is now to understand the conditions of the cool plasma and magnetism in `atypical' prominences, namely when the measured inclination of the magnetic field departs, to some extent, from the predominantly horizontal field found in `typical' prominences. What is the role of the magnetic field in these prominence types? Are plasma dynamics more important in these cases than the magnetic support? We focus our study on three types of `atypical' prominences (tornadoes, bubbles and jet-like prominence eruptions) that have all been observed by THEMIS in the He I D_3 line, from which the Stokes parameters can be derived. The magnetic field strength, inclination and azimuth in each pixel are obtained by using the Principal Component Analysis inversion method on a model of single scattering in the presence of the Hanle effect. The magnetic field in tornadoes is found to be more or less horizontal, whereas for the eruptive prominence it is mostly vertical. We estimate a tendency towards higher values of magnetic field strength inside the bubbles than outside in the surrounding prominence. In all of the models in our database, only one magnetic field orientation is considered for each pixel. While sufficient for most of the main prominence body, this assumption appears to be oversimplified in atypical prominence structures. We should consider these observations as the result of superposition of multiple magnetic fields, possibly even with a turbulent field component. **12 October, 2012, 15 October, 2012., May 7, 2014, May 23-24, 2014, 15 July 2014.**

Structure of prominence legs: Plasma and magnetic field

P. J. **Levens**, B. Schmieder, N. Labrosse, A. López Ariste

2016 818, Issue 1, article id. 31

http://arxiv.org/pdf/1512.04727v1.pdf

https://iopscience.iop.org/article/10.3847/0004-637X/818/1/31/pdf

We investigate the properties of a `solar tornado' observed on **15 July 2014**, and aim to link the behaviour of the plasma to the internal magnetic field structure of the associated prominence. We made multi-wavelength observations with high spatial resolution and high cadence using SDO/AIA, the IRIS spectrograph and the Hinode/SOT instrument. Along with spectropolarimetry provided by the THEMIS telescope we have coverage of both optically thick emission lines and magnetic field information. AIA reveals that the two legs of the prominence are strongly absorbing structures which look like they are rotating, or oscillating in the plane of the sky. The two prominence legs, which are both very bright in Ca II (SOT), are not visible in the IRIS Mg II slit-jaw images. This is explained by the large optical thickness of the structures in Mg II which leads to reversed profiles, and hence to lower integrated intensities at these locations than in the surroundings. Using lines formed at temperatures lower than 1 MK, we measure relatively low Doppler shifts on the order of +/- 10 km/s in the tornado-like structure. Between the two legs we see loops in Mg II, with material flowing from one leg to the other, as well as counterstreaming. It is difficult to interpret our data as showing two rotating, vertical structures which are unrelated to the loops. This kind of `tornado' scenario does not fit with our observations. The magnetic field in the two legs of the prominence is found to be preferentially horizontal.

On the plasma and magnetic field structure of prominence legs

Peter **Levens**, Nicolas Labrosse, Brigitte Schmieder & Arturo López Ariste

UKSP Nugget #55, March **2015**

http://www.uksolphys.org/?p=9654

Can we unweave the magnetic field from the twisted plasma in prominences?

On **15 July 2014**, a quiescent prominence was observed by several instruments, both ground and space-based, as part of an international campaign.

Formation of a Long Filament Through the Connection of Two Filament Segments Observed by CHASE

H. T. **Li**1,2, X. Cheng1,2, Y. W. Ni1,2, C. Li1,2, S. H. Rao1,2, J. H. Guo1,2,3, M. D. Ding1,2, and P. F. Chen1,2

2023 ApJL 958 L42

https://iopscience.iop.org/article/10.3847/2041-8213/ad0e10/pdf

https://arxiv.org/pdf/2311.14531.pdf

We present imaging and spectroscopic diagnostics of a long filament during its formation with the observations from the Chinese Hα Solar Explorer and Solar Dynamics Observatory. The seed filament first appeared at about 05:00 UT on **2022 September 13**. Afterward, it grew gradually and connected to another filament segment nearby, building up a long filament at about 20:00 UT on the same day. The CHASE Hα spectra show an obvious centroid absorption with mild broadening at the main spine of the long filament, which is interpreted as evidence of filament material accumulation. More interestingly, near the footpoints of the filament, persistent redshifts have been detected in the Hα spectra during the filament formation, indicating continuous drainage of filament materials. Furthermore, through inspecting the extreme-ultraviolet (EUV) images and magnetograms, it was found that EUV jets and brightenings appeared repeatedly at the junction of the two filament segments, where opposite magnetic polarities converged and canceled each other continuously. These results suggest the occurrence of intermittent magnetic reconnection that not only connects magnetic structures of the two filament segments but also supplies cold materials for the filament channel likely by the condensation of injected hot plasma, even though a part of the cold materials falls down to the filament footpoints at the same time.

A Statistical Study of Short-period Decayless Oscillations of Coronal Loops in an Active Region

Dong **Li**, David M. Long

ApJ **2022**

https://arxiv.org/pdf/2212.08804.pdf

Coronal loop oscillations are common phenomena in the solar corona, which are often classified as decaying and decayless oscillations. Using the high-resolution observation measured by the Extreme Ultraviolet Imager (EUI) onboard the Solar Orbiter, we statistical investigate small-scale transverse oscillations with short periods (<200 s) of coronal loops in an active region, i.e., NOAA 12965. A total of 111 coronal loops are identified in EUI 174 A images, and they all reveal transverse oscillations without any significant decaying, regarding as decayless oscillations. Oscillatory periods are measured from about 11 s to 185 s, with a median period of 40 s. Thus, they are also termed as short-period oscillations. The corresponding loop lengths are measured from about 10.5 Mm to 30.2 Mm, and a strong dependence of oscillatory periods on loop lengths is established, indicating that the short-period oscillations are standing kink-mode waves in nature. Based on the coronal seismology, kink speeds are measured to about 330-1910 km/s, and magnetic field strengths in coronal loops are estimated to about 4.1-25.2 G, while the energy flux carried by decayless kink oscillations lies in the range from roughly 7 W m^(-2) to 9220 W m^(-2). Our estimations suggest that the wave energy carried by short-period decayless kink oscillations can not support the coronal heating in the active region. **17 March 2022**

Direct Measurement of AIA 171 Coronal Loop Transparency

Hongbo **Li**1,2, Hengqiang Feng1, Zhanjun Tian1, Xuefei Zhang3, Jihong Liu4, Guoqing Zhao1, Yan Zhao1, Hao Cai1, Yuanxi Liang1, and Runze Guo1

2022 ApJ 934 135

https://iopscience.iop.org/article/10.3847/1538-4357/ac7da5/pdf

Observations suggest that coronal loops should not be completely transparent. The transparency of coronal loops is rarely investigated in spite of its key role in coronal diagnostics. Here, we present an original investigation of Atmospheric Imaging Assembly 171 coronal loop transparency directly from the radiation of visually intersecting coronal loops, which strongly indicates that the coronal loops may have significant opaqueness on the 171 Å radiation, and therefore should not be optical thin structures at least for some coronal lines. We suggest that this result may not only be helpful for explaining some basic observational features of coronal loops, but also in bringing new clues to the radiation-based diagnostics. **2016-02-02, 2016-03-13, 2016-05-04**

Grow-up of a Filament Channel by Intermittent Small-scale Magnetic Reconnection

H. T. **Li**, X. Cheng, J. H. Guo, X. L. Yan, L. F. Wang, Z. Zhong, C. Li, M. D. Ding

A&A 663, A127 **2022**

https://arxiv.org/pdf/2203.09110.pdf

https://www.aanda.org/articles/aa/pdf/2022/07/aa43115-22.pdf

Filament channel (FC), a plasma volume where the magnetic field is primarily aligned with the polarity inversion line, is believed to be the pre-eruptive configuration of coronal mass ejections. Nevertheless, evidence for how the

FC is formed is still elusive. In this paper, we present a detailed study on the build-up of a FC to understand its formation mechanism. The New Vacuum Solar Telescope of Yunnan Observatories and Optical and Near-Infrared Solar Eruption Tracer of Nanjing University, as well as the AIA and HMI on board Solar Dynamics Observatory are used to study the grow-up process of the FC. Furthermore, we reconstruct the non-linear force-free field (NLFFF) of the active region using the regularized Biot-Savart laws (RBSL) and magnetofrictional method to reveal three-dimension (3D) magnetic field properties of the FC. We find that partial filament materials are quickly transferred to longer magnetic field lines formed by small-scale magnetic reconnection, as evidenced by dot-like H{\alpha}/EUV brightenings and subsequent bidirectional outflow jets, as well as untwisting motions. The H{\alpha}/EUV bursts appear repeatedly at the same location and are closely associated with flux cancellation, which occurs between two small-scale opposite polarities and is driven by shearing and converging motions. The 3D NLFFF model reveals that the reconnection takes place in a hyperbolic flux tube that is located above the flux cancellation site and below the FC. The FC is gradually built up toward a twisted flux rope via series of small-scale reconnection events that occur intermittently prior to the eruption. **2020 Dec. 7-8**

Standing Sausage Perturbations in solar coronal loops with diffuse boundaries: An initial-value-problem perspective

Bo **Li**, Shao-Xia Chen, Ao-Long Li
ApJ **2022**
https://arxiv.org/pdf/2202.04435.pdf

Working in pressureless magnetohydrodynamics, we examine the consequences of some peculiar dispersive properties of linear fast sausage modes (FSMs) in one-dimensional cylindrical equilibria with a continuous radial density profile (ρ0(r)). As recognized recently on solid mathematical grounds, cutoff axial wavenumbers may be absent for FSMs when ρ0(r) varies sufficiently slowly outside the nominal cylinder. Trapped modes may therefore exist for arbitrary axial wavenumbers and density contrasts, their axial phase speeds in the long-wavelength regime differing little from the external Alfve´n speed. If these trapped modes indeed show up in the solutions to the associated initial value problem (IVP), then FSMs have a much better chance to be observed than expected with classical theory, and can be invoked to account for a considerably broader range of periodicities than practiced. However, with axial fundamentals in active region loops as an example, we show that this long-wavelength expectation is not seen in our finite-difference solutions to the IVP, the reason for which is then explored by superposing the necessary eigenmodes to re-solve the IVP. At least for the parameters we examine, the eigenfunctions of trapped modes are characterized by a spatial extent well exceeding the observationally reasonable range of the spatial extent of initial perturbations, meaning a negligible fraction of energy that a trapped mode can receive. We conclude that the absence of cutoff wavenumbers for FSMs in the examined equilibrium does not guarantee a distinct temporal behavior.

Persistent fast kink magnetohydrodynamic waves detected in a quiescent prominence

Dong **Li**, Jianchao Xue, Ding Yuan, Zongjun Ning
SCIENCE CHINA Physics, Mechanics & Astronomy **2022** Vol. 65 No. 3: 239611
https://arxiv.org/pdf/2201.07535.pdf

Small-scale, cyclic, transverse motions of plasma threads are usually seen in solar prominences, which are often interpreted as magnetohydrodynamic (MHD) waves. Here, we observed small-scale decayless transverse oscillations in a quiescent prominence, and they appear to be omnipresent. The oscillatory periods of the emission intensity and a proxy for the line-of-sight Doppler shift are about half period of the displacement oscillations. This feature agrees well with the fast kink-mode waves in a flux tube. All the moving threads oscillate transversally spatially in phase and exhibit no significant damping throughout the visible segments, indicating that the fast kink MHD waves are persistently powered and ongoing dissipating energy is transferred to the ambient plasma in the quiet corona. However, our calculations suggest that the energy taken by the fast kink MHD waves alone can not support the coronal heating on the quiet Sun. **8 December 2016**

Formation of a solar filament by magnetic reconnection and coronal condensation

Leping **Li**, Hardi Peter, Lakshmi Pradeep Chitta, Hongqiang Song
ApJL **919** L21 **2021**
https://arxiv.org/pdf/2109.05669.pdf
https://doi.org/10.3847/2041-8213/ac257f

In solar filament formation mechanisms, magnetic reconnection between two sets of sheared arcades forms helical structures of the filament with numerous magnetic dips, and cooling and condensation of plasma trapped inside the helical structures supply mass to the filament. Although each of these processes, namely, magnetic reconnection and coronal condensation have been separately reported, observations that show the whole process of filament formation are rare. In this Letter, we present the formation of a sigmoid via reconnection between two sets of coronal loops, and the subsequent formation of a filament through cooling and condensation of plasma inside the newly formed sigmoid. On **2014 August 27**, a set of loops in the active region 12151 reconnected with another set of loops that are located to the east. A longer twisted sigmoidal structure and a set of shorter lower-lying loops then formed. The observations coincide well with the tether-cutting model. The newly formed sigmoid remains stable and does not erupt as a coronal mass ejection. From the eastern endpoint, signatures of injection of material into the sigmoid (as brightenings) are detected, which closely outline the features of increasing emission measure at these locations. This may indicate the chromospheric evaporation caused by reconnection, supplying heated plasma into the sigmoid. In the sigmoid, thermal instability occurs, and rapid cooling and condensation of plasma take place, forming a filament. The condensations then flow bi-directionally to the filament endpoints. Our results provide a clear observational evidence of the filament formation via magnetic reconnection and coronal condensation.

An ultra-long and quite thin coronal loop without significant expansion

Dong **Li**, Ding Yuan, Marcel Goossens, Tom Van Doorsselaere, Wei Su, Ya Wang, Yang Su, Zongjun Ning

A&A 639, A114 **2020**

https://arxiv.org/pdf/2006.02629.pdf

https://www.aanda.org/articles/aa/pdf/2020/07/aa37974-20.pdf

Context. Coronal loops are the basic building blocks of the solar corona, which are related to the mass supply and heating of solar plasmas in the corona. However, their fundamental magnetic structures are still not well understood. Most coronal loops do not expand significantly, whereas the diverging magnetic field would have an expansion factor of about 5-10 over one pressure scale height. Aims. In this study, we investigate a unique coronal loop with a roughly constant cross section, it is ultra long and quite thin. A coronal loop model with magnetic helicity is presented to explain the small expansion of the loop width. Methods. This coronal loop was predominantly detectable in the 171 A channel of the Atmospheric Imaging Assembly (AIA). Then, the local magnetic field line was extrapolated by a Potential-Field-Source-Surface model. Finally, the differential emission measure analysis made from six AIA bandpasses was applied to obtain the thermal properties of this loop. Results. This coronal loop has a projected length of roughly 130 Mm, a width of about 1.5 +(-) 0.5 Mm and a lifetime of around 90 minutes. It follows an open magnetic field line. The cross section expanded very little (i.e., 1.5-2.0) along the loop length during its whole lifetime. This loop has a nearly constant temperature at about 0.7 +(-) 0.2 MK, whereas its density exhibits the typical structure of a stratified atmosphere. Conclusions. We use a thin twisted flux tube theory to construct a model for this non-expanding loop, and find that indeed with sufficient twist a coronal loop can attain equilibrium. However, we can not rule out other possibilities such as footpoint heating by small-scale reconnection, elevated scale height by a steady flow along the loop etc. **2016 March 23**

Plasma injection into a solar coronal loop

Leping **Li**, Hardi Peter

A&A **2019**

https://arxiv.org/pdf/1905.07800.pdf

Context. The details of the spectral profiles of extreme UV emission lines from solar active regions contain key information to investigate the structure, dynamics, and energetics of the solar upper atmosphere.

Aims. We characterize the line profiles not only through the Doppler shift and intensity of the bulk part of the profile. More importantly, we investigate the excess emission and asymmetries in the line wings to study twisting motions and helicity.

Methods. Weusearaste rscan of the Interface RegionImaging Spectrograph (IRIS) in an active region. We concentrate on the Si iv line at 1394 {\AA} that forms just below 0.1 MK and follow the plasma in a cool loop moving from one footpoint to the other. We apply single-Gaussian fits to the line core, determine the excess emission in the red and blue wings, and derive the red-blue line asymmetry.

Results. The blue wing excess at one footpoint shows injection of plasma into the loop that is then flowing to the other side. At the same footpoint, redshifts of the line core indicate that energy is deposited at around 0.1 MK. The enhanced pressure would then push down the cool plasma and inject some plasma into the loop. In the middle part of the loop, the spectral tilts of the line profiles indicate the presence of a helical structure of the magnetic field, and the line wings are symmetrically enhanced. This is an indication that the loop is driven through the injection of helicity at the loop feet.

Conclusions. If the loop is driven to be helical, then one can expect that the magnetic field will be in a turbulent state, as it has been shown by existing MHD models. The turbulent motions could provide an explanation of the (symmetric) line wing enhancements which have been seen also in loops at coronal temperatures, but have not been understood so far. **September 24, 2013**

Quasi-periodic fast propagating magnetoacoustic waves during the magnetic reconnection between solar coronal loops

Leping **Li**, Jun Zhang, Hardi Peter, Lakshmi Pradeep Chitta, Jiangtao Su, Hongqiang Song, Chun Xia, Yijun Hou

ApJL 868 L33 **2018**
https://arxiv.org/pdf/1811.08553.pdf
Employing Solar Dynamics Observatory/Atmospheric Imaging Assembly (AIA) multi-wavelength images, we have presented coronal condensations caused by magnetic reconnection between a system of open and closed solar coronal loops. In this Letter, we report the quasi-periodic fast magnetoacoustic waves propagating away from the reconnection region upward across the higher-lying open loops during the reconnection process. On **2012 January 19**, reconnection between the higher-lying open loops and lower-lying closed loops took place, and two sets of newly reconnected loops formed. Thereafter, cooling and condensations of coronal plasma occurred in the magnetic dip region of higher-lying open loops. During the reconnection process, disturbances originating from the reconnection region propagate upward across the magnetic dip region of higher-lying loops with the mean speed and mean speed amplitude of 200 and 30 km s−1, respectively. The mean speed of the propagating disturbances decreases from ∼230 km s−1 to ∼150 km s−1 during the coronal condensation process, and then increases to ∼220 km s−1. This temporal evolution of the mean speed anti-correlates with the light curves of the AIA 131 and 304 Å~channels that show the cooling and condensation process of coronal plasma. Furthermore, the propagating disturbances appear quasi-periodically with a peak period of 4 minutes. Our results suggest that the disturbances represent the quasi-periodic fast propagating magnetoacoustic (QFPM) waves originating from the magnetic reconnection between coronal loops.

Coronal Condensations Caused by Magnetic Reconnection between Solar Coronal Loops

Leping **Li**1,2,3, Jun Zhang1,3, Hardi Peter4, Lakshmi Pradeep Chitta4, Jiangtao Su1,3, Chun Xia5,6, Hongqiang Song2, and Yijun Hou1,
2018 ApJL 864 L4
https://arxiv.org/pdf/1808.09626.pdf
http://sci-hub.tw/http://iopscience.iop.org/article/10.3847/2041-8213/aad90a/meta
Employing Solar Dynamics Observatory/Atmospheric Imaging Assembly (AIA) multi-wavelength images, we report the coronal condensation during the magnetic reconnection (MR) between a system of open and closed coronal loops. Higher-lying magnetically open structures, observed in AIA 171 Å images above the solar limb, move downward and interact with the lower-lying closed loops, resulting in the formation of dips in the former. An X-type structure forms at the interface. The interacting loops reconnect and disappear. Two sets of newly reconnected loops then form and recede from the MR region. During the MR process, bright emission appears sequentially in the AIA 131 and 304 Å channels repeatedly in the dips of higher-lying open structures. This indicates the cooling and condensation process of hotter plasma from ~0.9 MK down to ~0.6 MK, and then to ~0.05 MK, also supported by the light curves of the AIA 171, 131, and 304 Å channels. The part of higher-lying open structures supporting the condensation participate in the successive MR. Without support from underlying loops, the condensation then rains back to the solar surface along the newly reconnected loops. Our results suggest that the MR between coronal loops leads to the condensation of hotter coronal plasma and its downflows. MR thus plays an active role in the mass cycle of coronal plasma because it can initiate the catastrophic cooling and condensation. This underlines that the magnetic and thermal evolution has to be treated together and cannot be separated, even in the case of catastrophic cooling. **2012 January 19**

Two Kinds of Dynamic Behavior in a Quiescent Prominence Observed by the NVST

Dong **Li**1, Yuandeng Shen, Zongjun Ning, Qingmin Zhang, Tuanhui Zhou
ApJ **863** 192 **2018**
https://arxiv.org/pdf/1807.03942.pdf
http://sci-hub.tw/http://iopscience.iop.org/article/10.3847/1538-4357/aad33f/meta
We present high-resolution observations of two kinds of dynamic behavior in a quiescent prominence using the New Vacuum Solar Telescope, i.e., Kelvin-Helmholtz instabilities (KHIs) and small-scale oscillations. The KHIs were identified as rapidly developed vortex-like structures with counter-clockwise/clockwise rotations in the Ha red-wing images at +0.3 A, which were produced by the strong shear-flows motions on the surface/interface of prominence plumes. The KHI growth rates are estimated to be about 0.0135 +(-)0.0004 and 0.0138 +(-) 0.0004. Our observational results further suggest that the shear velocities (i.e, supersonic) of the mass flows are fast enough to produce the strong deformation of the boundary and overcome the restraining surface tension force. This flow-driven instability might play a significant role in the process of plasma transfer in solar prominences. The small-scale oscillations perpendicular to the prominence threads are observed in the Ha line-center images. The oscillatory periods changed non-monotonically and showed two changing patterns, in which one firstly decreased slowly and then it changed to increase, while the other grew fast at the beginning and then it changed to decrease. Both of these two thread oscillations with changing periods were observed to be unstable for an entire cycle, and they were local in nature. All our findings indicate that the small-scale thread oscillations could be magnetohydrodynamic waves in the solar corona. **2017 September 18**

Heating and cooling of coronal loops observed by SDO

Li, L. P., Peter, H., Chen, F., and Zhang, J.
A&A, 583, A109 **2015**
E-print, Sept 2015
http://ddl.escience.cn/f/sHZh
Context: One of the most prominent processes suggested to heat the corona to well above 106 K builds on nanoflares, short bursts of energy dissipation. Aims: We compare observations to model predictions to test the validity of the nanoflare process. Methods: Using extreme UV data from AIA/SDO and HMI/SDO line-of-sight magnetograms we study the spatial and temporal evolution of a set of loops in active region **AR 11850**. Results: We find a transient brightening of loops in emission from Fe xviii forming at about 7.2 MK while at the same time these loops dim in emission from lower temperatures. This points to a fast heating of the loop that goes along with evaporation of material that we observe as apparent upward motions in the image sequence. After this initial phases lasting for some 10 min, the loops brighten in a sequence of AIA channels showing cooler and cooler plasma, indicating the cooling of the loops over a time scale of about one hour. A comparison to the predictions from a 1D loop model shows that this observation supports the nanoflare process in (almost) all aspects. In addition, our observations show that the loops get broader while getting brighter, which cannot be understood in a 1D model.
September 24, 2013

Conversion from mutual helicity to self-helicity observed with IRIS

L. **Li**, H. Peter, F. Chen, J. Zhang
A&A, **2014**
http://www2.mps.mpg.de/data/outgoing/lileping/aa.pdf
Context. In the upper atmosphere of the Sun observations show convincing evidence for crossing and twisted structures, which are interpreted as mutual helicity and self-helicity.
Aims. We use observations with the new Interface Region Imaging Spectrograph (IRIS) to show the conversion of mutual helicity into self-helicity in coronal structures on the Sun.
Methods. Using far UV spectra and slit-jaw images from IRIS and coronal images and magnetograms from SDO, we investigated the evolution of two crossing loops in an active region, in particular, the properties of the Si IV line profile in cool loops.
Results. In the early stage two cool loops cross each other and accordingly have mutual helicity. The Doppler shifts in the loops indicate that they wind around each other. As a consequence, near the crossing point of the loops (interchange) reconnection sets in, which heats the plasma. This is consistent with the observed increase of the line width and of the appearance of the loops at higher temperatures. After this interaction, the two new loops run in parallel, and in one of them shows a clear spectral tilt of the Si IV line profile. This is indicative of a helical (twisting) motion, which is the same as to say that the loop has self-helicity.
Conclusions. The high spatial and spectral resolution of IRIS allowed us to see the conversion of mutual helicity to self-helicity in the (interchange) reconnection of two loops. This is observational evidence for earlier theoretical speculations. **2013-09-27**

Magnetic reconnection between a solar filament and nearby coronal loops

Leping **Li**, Jun Zhang, Hardi Peter, Eric Priest, Huadong Chen, Lijia Guo, Feng Chen, Duncan Mackay
Nature Physics **2016**
http://arxiv.org/pdf/1605.03320v1.pdf
Magnetic reconnection, the rearrangement of magnetic field topology, is a fundamental physical process in magnetized plasma systems all over the universe1,2. Its process is difficult to be directly observed. Coronal structures, such as coronal loops and filament spines, often sketch the magnetic field geometry and its changes in the solar corona3. Here we show a highly suggestive observation of magnetic reconnection between an erupting solar filament and its nearby coronal loops, resulting in changes in connection of the filament. X-type structures form when the erupting filament encounters the loops. The filament becomes straight, and bright current sheets form at the interfaces with the loops. Many plasmoids appear in these current sheets and propagate bi-directionally. The filament disconnects from the current sheets, which gradually disperse and disappear, reconnects to the loops, and becomes redirected to the loop footpoints. This evolution of the filament and the loops suggests successive magnetic reconnection predicted by theories1 but rarely detected with such clarity in observations. Our results on the formation, evolution, and disappearance of current sheets, confirm three-dimensional magnetic reconnection theory and have implications for the evolution of dissipation regions and the release of magnetic energy for reconnection in many magnetized plasma systems. **January 1, 2012**

Subarcsecond Bright Points and Quasi-periodic Upflows Below a Quiescent Filament Observed by the IRIS

Ting **Li**, Jun Zhang
A&A 589, A114 **2016**
http://arxiv.org/pdf/1603.02809v1.pdf

Using UV spectra and SJIs from the IRIS, and coronal images and magnetograms from the Solar Dynamics Observatory (SDO), we present the new features in a quiescent filament channel: subarcsecond bright points (BPs) and quasi-periodic upflows. The BPs in the TR have a spatial scale of about 350−580 km and lifetime of more than several tens of minutes. They are located at stronger magnetic structures in the filament channel, with magnetic flux of about 1017−1018 Mx. Quasi-periodic brightenings and upflows are observed in the BPs and the period is about 4−5 min. The BP and the associated jet-like upflow comprise a "tadpole-shaped" structure. The upflows move along bright filament threads and their directions are almost parallel to the spine of the filament. The upflows initiated from the BPs with opposite polarity magnetic fields have opposite directions. The velocity of the upflows in plane of sky is about 5−50 km s−1. The emission line of Si IV 1402.77 {\AA} at the locations of upflows exhibits obvious blueshifts of about 5−30 km s−1, and the line profile is broadened with the width of more than 20 km s−1. The BPs seem to be the bases of filament threads and the upflows are able to convey mass for the dynamic balance of the filament. The "counter-streaming" flows in previous observations may be caused by the propagation of bi-directional upflows initiated from opposite polarity magnetic fields. We suggest that quasi-periodic brightenings of BPs and quasi-periodic upflows result from small-scale oscillatory magnetic reconnections, which are modulated by solar p-mode waves. **2015 February 13**

Conversion from mutual helicity to self-helicity observed with IRIS

Leping **Li**, Hardi Peter, Feng Chen, Jun Zhang

A&A, **2014**

http://arxiv.org/pdf/1410.5597v1.pdf

Context. In the upper atmosphere of the Sun observations show convincing evidence for crossing and twisted structures, which are interpreted as mutual helicity and self-helicity.
Aims. We use observations with the new Interface Region Imaging Spectrograph (IRIS) to show the conversion of mutual helicity into self-helicity in coronal structures on the Sun.
Methods. Using far UV spectra and slit-jaw images from IRIS and coronal images and magnetograms from SDO, we investigated the evolution of two crossing loops in an active region, in particular, the properties of the Si IV line profile in cool loops.
Results. In the early stage two cool loops cross each other and accordingly have mutual helicity. The Doppler shifts in the loops indicate that they wind around each other. As a consequence, near the crossing point of the loops (interchange) reconnection sets in, which heats the plasma. This is consistent with the observed increase of the line width and of the appearance of the loops at higher temperatures. After this interaction, the two new loops run in parallel, and in one of them shows a clear spectral tilt of the Si IV line profile. This is indicative of a helical (twisting) motion, which is the same as to say that the loop has self-helicity.
Conclusions. The high spatial and spectral resolution of IRIS allowed us to see the conversion of mutual helicity to self-helicity in the (interchange) reconnection of two loops. This is observational evidence for earlier theoretical speculations. **2013-09-27**

Standing sausage modes in coronal loops with plasma flow

Bo **Li**, Shao-Xia Chen, Li-Dong Xia, Hui Yu

A&A, 568, A31, **2014**

http://arxiv.org/pdf/1406.4688v1.pdf

Magnetohydrodynamic waves are important for diagnosing the physical parameters of coronal plasmas. Field-aligned flows appear frequently in coronal loops.We examine the effects of transverse density and plasma flow structuring on standing sausage modes trapped in coronal loops, and examine their observational implications. We model coronal loops as straight cold cylinders with plasma flow embedded in a static corona. An eigen-value problem governing propagating sausage waves is formulated, its solutions used to construct standing modes. Two transverse profiles are distinguished, one being the generalized Epstein distribution (profile E) and the other (N) proposed recently in Nakariakov et al.(2012). A parameter study is performed on the dependence of the maximum period Pmax and cutoff length-to-radius ratio (L/a) cutoff in the trapped regime on the density parameters (ρ0/ρ∞ and profile steepness p) and flow parameters (magnitude U0 and profile steepness u). For either profile, introducing a flow reduces Pmax relative to the static case. Pmax depends sensitively on p for profile N but is insensitive to p for profile E. By far the most important effect a flow introduces is to reduce the capability for loops to trap standing sausage modes: (L/a) cutoff may be substantially reduced in the case with flow relative to the static one. If the density distribution can be described by profile N, then measuring the sausage mode period can help deduce the density profile steepness. However, this practice is not feasible if profile E better describes the density distribution. Furthermore, even field-aligned flows with magnitudes substantially smaller than the ambient Alfv\'en speed can make coronal loops considerably less likely to support trapped standing sausage modes.

Parallel-cascade-based mechanisms for heating solar coronal loops: test against observations

Bo **Li**, Haixia Xie, Xing Li, Li-Dong Xia

2014

http://arxiv.org/pdf/1406.0404v2.pdf

The heating of solar coronal loops is at the center of the problem of coronal heating. Given that the origin of the fast solar wind has been tracked down to atmospheric layers with transition region or even chromospheric temperatures, it is worthy attempting to address whether the mechanisms proposed to provide the basal heating of the solar wind apply to coronal loops as well. We extend the loop studies based on a classical parallel-cascade scenario originally proposed in the solar wind context by considering the effects of loop expansion, and perform a parametric study to directly contrast the computed loop densities and electron temperatures with those measured by TRACE and YOHKOH/SXT. This comparison yields that with the wave amplitudes observationally constrained by SUMER measurements, while the computed loops may account for a significant fraction of SXT loops, they seem too hot when compared with TRACE loops. Lowering the wave amplitudes does not solve this discrepancy, introducing magnetic twist will make the comparison even less desirable. We conclude that the nanoflare heating scenario better explains ultraviolet loops, while turbulence-based steady heating mechanisms may be at work in heating a fraction of soft X-ray loops.

FINE-SCALE STRUCTURES OF FLUX ROPES TRACKED BY ERUPTING MATERIAL

Ting **Li** and Jun Zhang

2013 ApJ 770 L25

We present Solar Dynamics Observatory observations of two flux ropes tracked out by material from a surge and a failed filament eruption on **2012 July 29 and August 4**, respectively. For the first event, the interaction between the erupting surge and a loop-shaped filament in the east seems to "peel off" the filament and add bright mass into the flux rope body. The second event is associated with a C-class flare that occurs several minutes before the filament activation. The two flux ropes are, respectively, composed of 85 ± 12 and 102 ± 15 fine-scale structures, with an average width of about 1."6. Our observations show that two extreme ends of the flux rope are rooted in opposite polarity fields and each end is composed of multiple footpoints (FPs) of fine-scale structures. The FPs of the fine-scale structures are located at network magnetic fields, with magnetic fluxes from 5.6 × 1018 Mx to 8.6 × 1019 Mx. Moreover, almost half of the FPs show converging motion of smaller magnetic structures over 10 hr before the appearance of the flux rope. By calculating the magnetic fields of the FPs, we deduce that the two flux ropes occupy at least 4.3 × 1020 Mx and 7.6 × 1020 Mx magnetic fluxes, respectively.

The Evolution of Barbs of a Polar Crown Filament Observed by SDO

Leping **Li**, Jun Zhang

Solar Physics, January **2013**, Volume 282, Issue 1, pp 147-174

From **16 to 21 August 2010**, a northern (~ N60) polar crown filament was observed by Solar Dynamics Observatory (SDO). Employing the six-day SDO/AIA data, we identify 69 barbs, and select 58 of them, which appeared away from the western solar limb (≤ W60), as our sample. We systematically investigate the evolution of filament barbs. Three different types of apparent formation of barbs are detected, including i) the convergence of surrounding moving plasma condensations, comprised 55.2 % of our sample, ii) the flows of plasma condensations from the filament, comprised 37.9 %, and iii) the plasma injections from the neighboring brightening regions, comprised 6.9 %. We also find three different ways that barb disappear, involving: i) bi-lateral movements (44.8 %), and ii) outflowing of barb plasma (27.6 %) results in the disappearance of a barb, as well as iii) disappearance of a barb is associated with a neighboring brightening (27.6 %). The evolution of the magnetic fields, e.g. emergence and cancellation of magnetic flux, may cause the formation or disappearance of the barb magnetic structures. Barbs exchange plasma condensations with the surrounding atmosphere, filament, and nearby brightenings, leading to the increase or drainage of barb material. Furthermore, we find that all the barbs undergo oscillations. The average oscillation period, amplitude, and velocity are 30 min, 2.4 Mm, and 5.7 km s−1, respectively. Besides the oscillations, 21 (36 %) barbs manifested sideward motions having an average speed of 0.45 km s−1. Small-scale wave-like propagating disturbances caused by small-scale brightenings are detected, and the barb oscillations associated with these disturbances are also found. We propose that the kinematics of barbs are influenced or even caused by the evolution of the neighboring photospheric magnetic fields.

SDO/AIA OBSERVATIONS OF LARGE-AMPLITUDE LONGITUDINAL OSCILLATIONS IN A SOLAR FILAMENT

Ting **Li** and Jun Zhang

2012 ApJ 760 L10

We present the first Solar Dynamics Observatory/Atmospheric Imaging Assembly observations of the large-amplitude longitudinal (LAL) oscillations in the south and north parts (SP and NP) of a solar filament on **2012 April 7**. Both oscillations are triggered by flare activities close to the filament. The period varies with filamentary threads, ranging from 44 to 67 minutes. The oscillations of different threads are out of phase, and their velocity amplitudes vary from 30 to 60 km s–1, with a maximum displacement of about 25 Mm. The oscillations of the SP repeat for about four cycles without any significant damping and then a nearby C2.4 flare causes the transition from the LAL oscillations of the filament to its later eruption. The filament eruption is also associated with a coronal mass ejection and a B6.8 flare. However, the oscillations of the NP damp with time and die out at last. Our observations show that the activated part of the SP repeatedly shows a helical motion. This indicates that the magnetic structure of the filament is possibly modified during this process. We suggest that the restoring force is the coupling of the magnetic tension and gravity.

A SOLAR TORNADO OBSERVED BY AIA/SDO: ROTATIONAL FLOW AND EVOLUTION OF MAGNETIC HELICITY IN A PROMINENCE AND CAVITY

Xing **Li**1, Huw Morgan1,2, Drew Leonard1, and Lauren Jeska

2012 ApJL 752 L22

https://iopscience.iop.org/article/10.1088/2041-8205/752/2/L22/pdf

During **2011 September 24**, as observed by the Atmospheric Imaging Assembly instrument of the Solar Dynamic Observatory and ground-based Hα telescopes, a prominence and associated cavity appeared above the southwest limb. On **2011 September 25** 8:00 UT, material flows upward from the prominence core along a narrow loop-like structure, accompanied by a rise (≥50,000 km) of the prominence core and the loop. As the loop fades by 10:00, small blobs and streaks of varying brightness rotate around the top part of the prominence and cavity, mimicking a cyclone. The most intense and coherent rotation lasts for over three hours, with emission in both hot (~1 MK) and cold (hydrogen and helium) lines. We suggest that the cyclonic appearance and overall evolution of the structure can be interpreted in terms of the expansion of helical structures into the cavity, and the movement of plasma along helical structures which appears as a rotation when viewed along the helix axis. The coordinated movement of material between prominence and cavity suggests that they are structurally linked. Complexity is great due to the combined effect of these actions and the line-of-sight integration through the structure which contains tangled fields.

A huge solar tornado observed by Solar Dynamic Observatory

Xing **Li**, Huw Morgan, Drew Leonard and Lauren Jeska

UKSP nugget – 22, April **2012**

http://www.uksolphys.org/?p=4457

Reports of rotational or tornado-like behaviour of solar prominences and/or their associated cavities have been made for almost a century. These include ground-based observations of rotational eddies within prominences [5,3], spectroscopic evidence of filament rotation [4], tornado-like jets within prominences, and rotation of prominence cavities [8]. The Solar Dynamics Observatory (SDO) provides the necessary temporal and spatial resolution, and long-term systematic full-disk observations to view and interpret such events in detail.

25 September 2011

Interaction and Eruption of Two Filaments Observed by Hinode, SOHO, and STEREO

Y. **Li** and M. D. Ding

E-print, 18 Nov **2011, File**; Research in Astron. Astrophys.

We investigate the interaction between two filaments and the subsequent filament eruption event observed from different view angles by Hinode, the Solar and Heliospheric Observatory (SOHO), and the Solar Terrestrial Relations Observatory (STEREO). In the event, the two filaments rose high, interacted with each other, and finally were ejected along two different paths. We measure the bulk-flow velocity using spectroscopic data. We find significant outflows at the speed of a few hundreds of km/s during the filament eruption, and also some downflows at a few tens of km/s at the edge of the eruption region in the late stage of the eruption. The erupting material was composed of plasmas with a wide temperature range of 10^4?10^6 K. These results shed light on the filament nature and the coronal dynamics.

8 Feb 2010

THREE-DIMENSIONAL RECONSTRUCTION OF AN ERUPTING FILAMENT WITH SOLAR DYNAMICS OBSERVATORY AND STEREO OBSERVATIONS

Ting **Li**, Jun Zhang, Yuzong Zhang and Shuhong Yang

2011 ApJ 739 43, **File**

On **2010 August 1**, a global solar event was launched involving almost the entire Earth-facing side of the Sun. This event mainly consisted of a C3.2 flare, a polar crown filament eruption, and two Earth-directed coronal mass ejections. The observations from the Solar Dynamics Observatory (SDO) and STEREO showed that all the activities were coupled together, suggesting a global character of the magnetic eruption. We reconstruct the three-dimensional geometry of the polar crown filament using observations from three different viewpoints (STEREO A, STEREO B, and SDO) for the first time. The filament undergoes two eruption processes. First, the main body of the filament rises up, while it also moves toward the low-latitude region with a change in inclination by ~48° and expands only in the altitudinal and latitudinal direction in the field of view of the Atmospheric Imaging Assembly. We investigate the true velocities and accelerations of different locations along the filament and find that the highest location always has the largest acceleration during this eruption process. During the late phase of the first eruption, part of the filament material separates from the eastern leg. This material displays a projectile motion and moves toward the west at a constant velocity of 141.8 km s–1. This may imply that the polar crown filament consists of at least two groups of magnetic systems.

Three-Dimensional Reconstruction of an Erupting Filament with SDO and STEREO Observations

Ting **Li**, Jun Zhang, Yuzong Zhang, Shuhong Yang

E-print, July **2011, File**;

On **2010 August 1**, a global solar event was launched involving almost the entire Earth_facing side of the Sun. This event mainly consisted of a C3.2 flare, a polar crown filament eruption and two Earth-directed coronal mass ejections (CMEs). The observations from the Solar Dynamics Observatory (SDO) and the Solar Terrestrial Relations Observatory (STEREO) showed that all the activities were coupled together, suggesting a global character of the magnetic eruption. We reconstruct the three-dimensional geometry of the polar crown filament using observations from three different viewpoints (STEREO A, B and SDO) for the first time. The filament undergoes two eruption processes. Firstly, the main body of the filament rises up, while it also moves towards the low-latitude region with a change in inclination by _ 48◦ and expands only in the altitudinal and latitudinal direction in the field of view of Atmospheric Imaging Assembly. We investigate the true velocities and accelerations of different locations along the filament, and find that the highest location always has the largest acceleration during this eruption process. During the late phase of the first eruption, part of the filament material separates from the eastern leg. This material displays a projectile motion and moves towards the west at a constant velocity of 141.8 km s−1. This may imply that the polar crown filament consists of at least two groups of magnetic systems.

3D Shape and Evolution of Two Eruptive Filaments

Ting **Li**, Jun Zhang, Hui Zhao, Shuhong Yang

E-print, July, 2010, ApJ 720:144–149, **2010**

On **2009 Sep 26**, a dramatic and large filament (LF) and a small filament (SF) eruptions were observed in the He II 304 ??A line by the two EUVI telescopes aboard the STEREO A and B spacecrafts. The LF heads out into space and becomes the bright core of a gradual CME, while the eruption of the SF is characterized by motions of filament materials. Using stereoscopic analysis of EUVI data, we reconstruct the 3D shape and evolution of two eruptive filaments. For the first time, we investigate the true velocities and accelerations of 12 points along the axis of the LF, and find that the velocity and acceleration vary with the measured location. The highest points among the 12 points are the fastest in the first half hour, and then the points at the low-latitude leg of the LF become the fastest. For the SF, it is an asymmetric whip-like filament eruption, and the downward material motions lead to the disappearance of the former highlatitude endpoint and the formation of a new low-latitude endpoint. Based on the temporal evolution of the two filaments, we infer that the two filaments lie in the same filament channel. By combining EUVI, COR1 and COR2 data of STEREO A together, we find that there is no impulsive or fast acceleration in this event. It displays a weak and persistent acceleration for more than 17 hours. The average velocity and acceleration of the LF are 101.8 km s−1 and 2.9 m s−2, respectively. The filament eruptions are associated with a slow CME with the average velocity of 177.4 km s−1. The velocity of the CME is nearly 1.6 times as large as that of the filament material. This event is one example of a gradual filament eruption associated with a gradual CME. In addition, the moving direction of the LF changes from a non-radial to a nearly radial direction with a variation of inclination angle of nearly 38.2◦.

Observational Study of a Peculiar Solar Limb Event Occurred on 11 January 2002

Hui **Li** ¢ Jianqi You

E-print, Apr. **2009**

On 11 January 2002, using the Multi-channel Infrared Solar Spectrograph (MISS) at the Purple Mountain Observatory (PMO), we obtained H®, Ca ii 8542 ºA and He i 10830 ºA spectra and slit-jaw H® images of a peculiar solar limb event. A close resemblance of its intensity to that of a small °are and the GOES X-ray °ux indicates that it was an active prominence. However, its morphological evolution and velocity variation were di®erent from general typical active prominences, such as limb °ares, post-°are loops, surges and sprays. It started with the ejection of material from the °are site. In the early phase, the ejecta was as bright as a limb °are and kept rising until reaching the height of (8 { 10)£104 km at an almost constant velocity of 91.7 km s¡1 with its lower part always connected to the solar surface. EUV images in 195 ºA show similar structure as in the H® line, indicating the coexistence of plasmas with temperatures di®ering more than two orders of magnitude. Later some material started to fall back to another bright area on the solar surface. The falling material did not show the collimated structure of surges or the arc structure of °aring arches. A red-shift velocity of more than 200 km s¡1 was detected in a bright point close to the outer edge of the closed loop system formed later, which dispersed in a few minutes and became a part of the newly formed large loop. The ejected material did not leave the sun, indicating that the magnetic reconnection was not su±cient to remove the overlying ¯eld lines during the process. The spectral line pro¯les showed large widths and variable velocities, and therefore the line-pair method is not applicable to this event for the estimation of physical parameters.

Numerical simulations of prominence oscillations triggered by external perturbations

Valeriia **Liakh**, Manuel Luna, Elena Khomenko

A&A 673, A154 **2023**

https://arxiv.org/pdf/2303.15348.pdf

https://www.aanda.org/articles/aa/pdf/2023/05/aa45765-22.pdf

Several energetic disturbances have been identified as triggers of the large-amplitude oscillations (LAOs) in prominences. However, the mechanisms for LAOs excitation are not well understood. We aim to study these mechanisms, performing time-dependent numerical simulations in 2.5D and 2D setups using magnetohydrodynamic (MHD) code MANCHA3D. Two types of disturbances are applied to excite prominence oscillations, such as a perturbation associated with an eruption and the waves caused by an artificial energy release. In the simulation with the eruption, we obtain that it does not produce LAOs in the prominence located in its vicinity. While the erupting flux rope rises, an elongated current sheet forms behind it, which becomes unstable and breaks into plasmoids. The downward-moving plasmoids cause perturbations in the velocity field by merging with the post-reconnection loops. This velocity perturbation propagates in the surroundings and perturbs the nearby prominence. The analysis of the oscillatory motions of the prominence plasma reveals the excitation of small-amplitude oscillations (SAOs), which are a mixture of longitudinal and vertical oscillations. In the simulation with a distant artificial perturbation, a fast-mode shock wave is produced, and it gradually reaches two flux rope prominences at different distances. This shock wave excites vertical LAOs and longitudinal SAOs with similar amplitudes, periods, and damping times in both prominences. Finally, in the experiment with the external triggering of LAOs in a dipped arcade prominence model, we find that, although the vector normal to the front of a fast-mode shock wave is parallel to the spine of the dipped arcade well before the contact, this wave does not excite longitudinal LAOs. When the wave front approaches the prominence, it pushes the dense plasma down, establishing vertical LAOs.

Large-amplitude longitudinal oscillations in solar prominences simulated with different resolutions

Valeriia **Liakh**, Manuel Luna, Elena Khomenko

A&A 654, A145 **2021**

https://arxiv.org/pdf/2108.01143.pdf

https://doi.org/10.1051/0004-6361/202141524

Large-amplitude longitudinal oscillations (LALOs) in solar prominences have been widely studied in the last decades. However, their damping and amplification mechanisms are not well understood. In this study, we investigate the attenuation and amplification of LALOs using high-resolution numerical simulations with progressively increasing spatial resolutions. We performed time-dependent numerical simulations of LALOs using the 2D magnetic configuration that contains a dipped region. After the prominence mass loading in the magnetic dips, we triggered LALOs by perturbing the prominence mass along the magnetic field. We performed the experiments with four values of spatial resolution. In the simulations with the highest resolution, the period shows a good agreement with the pendulum model. The convergence experiment revealed that the damping time saturates at the bottom prominence region with improving the resolution, indicating the existence of a physical reason for the damping of oscillations. At the prominence top, the oscillations are amplified during the first minutes and then are slowly attenuated. The characteristic time suggests more significant amplification in the experiments with the highest spatial resolution. The analysis revealed that the energy exchange between the bottom and top prominence regions is responsible for the attenuation and amplification of LALOs. The high-resolution experiments are crucial for the study of the periods and the damping mechanism of LALOs. The period agrees with the pendulum model only when using high enough spatial resolution. The results suggest that numerical diffusion in simulations with insufficient spatial resolution can hide important physical mechanisms, such as amplification of oscillations.

Numerical simulations of large-amplitude oscillations in flux-rope solar prominences

Valeriia **Liakh**, Manuel Luna, Elena Khomenko

A&A 637, A75 **2020**

https://arxiv.org/pdf/2003.04343.pdf

https://www.aanda.org/articles/aa/pdf/2020/05/aa37083-19.pdf

Context. Large-amplitude oscillations (LAOs) of the solar prominences are very spectacular but poorly understood phenomena. These motions have amplitudes larger than 10kms−1 and can be triggered by the external perturbations, e.g., Moreton or EIT waves.
Aims. Our aim is to analyze the properties of large-amplitude oscillations using realistic prominence models and the triggering mechanism by external disturbances.
Methods. We perform time-dependent numerical simulations of LAOs using a magnetic flux rope model with two values of the shear angle and the density contrast. We study the internal modes of the prominence using the horizontal and vertical triggering. In addition, we use the perturbation that arrives from outside in order to understand how such external disturbance can produce LAOs.
Results. The period of longitudinal oscillations and its behavior with height show good agreement with the pendulum model. The period of transverse oscillations remains constant with height, suggesting a global normal mode. The transverse oscillations typically have shorter periods than the longitudinal oscillations.
Conclusions. The periods of the longitudinal and transverse oscillations show only weak dependence on the shear angle of the magnetic structure and the prominence density contrast. The external disturbance perturbs the flux rope exciting oscillations of both polarizations. Their properties are a mixture of those excited by purely horizontal and vertical driving.

Extracting the Heliographic Coordinates of Coronal Rays using Images from WISPR/Parker Solar Probe

P. C. **Liewer**, J. Qiu, F. Ark, P. Penteado, G. Stenborg, A. Vourlidas, J. R. Hall, P. Riley

Solar Phys. **297**, Article number: 128 **2022**

https://arxiv.org/pdf/2209.02779.pdf

https://doi.org/10.1007/s11207-022-02058-6

The Wide-field Imager for Solar Probe (WISPR) onboard Parker Solar Probe (PSP), observing in white light, has a fixed angular field of view, extending from 13.5 degree to 108 degree from the Sun and approximately 50 degree in the transverse direction. In **January 2021**, on its seventh orbit, PSP crossed the heliospheric current sheet (HCS) near perihelion at a distance of 20 solar radii. At this time, WISPR observed a broad band of highly variable solar wind and multiple coronal rays. For six days around perihelion, PSP was moving with an angular velocity exceeding that of the Sun. During this period, WISPR was able to image coronal rays as PSP approached and then passed under or over them. We have developed a technique for using the multiple viewpoints of the coronal rays to determine their location (longitude and latitude) in a heliocentric coordinate system and used the technique to determine the coordinates of three coronal rays. The technique was validated by comparing the results to observations of the coronal rays from Solar and Heliophysics Observatory (SOHO) / Large Angle and Spectrometric COronagraph (LASCO)/C3 and Solar Terrestrial Relations Observatory (STEREO)-A/COR2. Comparison of the rays' locations were also made with the HCS predicted by a 3D MHD model. In the future, results from this technique can be used to validate dynamic models of the corona. **17-18 Jan 2021**

Stereoscopic Analysis of the 31 August 2007 Prominence Eruption and Coronal Mass Ejection

P. C. **Liewer**, O. Panasenco, J. R. Hall

Solar Physics, January **2013**, Volume 282, Issue 1, pp 201-220

The spectacular prominence eruption and CME of 31 August 2007 are analyzed stereoscopically using data from NASA's twin Solar Terrestrial Relations Observatory (STEREO) spacecraft. The technique of tie pointing and triangulation (T&T) is used to reconstruct the prominence (or filament when seen on the disk) before and during the eruption. For the first time, a filament barb is reconstructed in three-dimensions, confirming that the barb connects the filament spine to the solar surface. The chirality of the filament system is determined from the barb and magnetogram and confirmed by the skew of the loops of the post-eruptive arcade relative to the polarity reversal boundary below. The T&T analysis shows that the filament rotates as it erupts in the direction expected for a filament system of the given chirality. While the prominence begins to rotate in the slow-rise phase, most of the rotation occurs during the fast-rise phase, after formation of the CME begins. The stereoscopic analysis also allows us to analyze the spatial relationships among various features of the eruption including the pre-eruptive filament, the flare ribbons, the erupting prominence, and the cavity of the coronal mass ejection (CME). We find that erupting prominence strands and the CME have different (non-radial) trajectories; we relate the trajectories to the structure of the coronal magnetic fields. The possible cause of the eruption is also discussed.

Stereoscopic Analysis of the 19 May 2007 Erupting Filament

P.C. **Liewer** · E.M. De Jong · J.R. Hall · R.A. Howard · W.T. Thompson · J.L. Culhane · L. Bone · L. van Driel-Gesztelyi

Solar Phys (**2009**) 256: 57–72, DOI 10.1007/s11207-009-9363-4, **File**

STEREO SCIENCE RESULTS AT SOLAR MINIMUM

A filament eruption, accompanied by a B9.5 flare, coronal dimming, and an EUV wave, was observed by the *Solar TERrestrial Relations Observatory* (STEREO) on 19 May 2007, beginning at about 13:00 UT. Here, we use observations from the SECCHI/EUVI telescopes and other solar observations to analyze the behavior and geometry of the filament before and during the eruption. At this time, STEREO A and B were separated by about 8.5°, sufficient to determine the three-dimensional structure of the filament using stereoscopy. The filament could be followed in SECCHI/EUVI 304 Å stereoscopic data from about 12 hours before to about 2 hours after the eruption, allowing us to determine the 3D trajectory of the erupting filament. From the 3D reconstructions of the filament and the chromospheric ribbons in the early stage of the eruption, simultaneous heating of both the rising filamentary material and the chromosphere directly below is observed, consistent with an eruption resulting from magnetic reconnection below the filament. Comparisons of the filament during eruption in 304 Å and H〈 show that when it becomes emissive in He II, it tends to disappear in H〈, indicating that the disappearance probably results from heating or motion, not loss, of filamentary material.

Undersampling effects on observed periods of coronal oscillations

Daye **Lim**1,2,⋆, Tom Van Doorsselaere1, Valery M. Nakariakov3,4, Dmitrii Y. Kolotkov3,4, Yuhang Gao5,1 and David Berghmans2

A&A, 690, L8 (**2024**)

https://www.aanda.org/articles/aa/pdf/2024/10/aa51684-24.pdf

Context. Recent observations of decayless transverse oscillations have revealed two branches in the relationship between period and loop length. One is a linear relationship, interpreted as a standing mode, while the other shows almost no correlation and has not yet been interpreted conclusively.

Aims. We investigated the undersampling effect on observed periods of decayless oscillations.

Methods. We considered oscillating coronal loops that closely follow the observed loop length distribution. Assuming that all oscillations are standing waves, we modelled a signal that represents decayless oscillations where the period is proportional to the loop length and the amplitude and phase are randomly drawn. We generated a downsampled signal from the original signal by considering different sample rates that mimic temporal cadences of telescopes, and analysed the periods for sampled signals using the fast Fourier transform.

Results. When the sampling cadence approaches the actual oscillation period, there is a greater tendency to overestimate the periods in short loops. We find the same two branches in the relationship between loop length and period of the sampled signals as those seen in the observations.

Conclusions. We find that long periods of decayless oscillations occurring in short loops could be the result of undersampling.

Higher Radial Harmonics of Sausage Oscillations in Coronal Loops

Daye **Lim**1,2, Valery M. Nakariakov1,3, Dae Jung Yu1,2, Il-Hyun Cho2, and Yong-Jae Moon1,2

2020 ApJ 893 62

https://doi.org/10.3847/1538-4357/ab7d3d

Impulsively excited sausage oscillations of a plasma cylinder with a smooth radial profile of Alfvén speed are analyzed with a numerical solution of the initial-value problem for a partial differential equation of the Klein–Gordon type, describing linear magnetoacoustic oscillations with a fixed axial wavelength and an azimuthal mode number. The range of analyzed ratios of Alfvén speeds outside and inside the cylinder is from 2 to 10. Both trapped and leaky regimes of the oscillations are considered. It is shown that even in the long-wavelength limit, i.e., for axial wavenumbers much smaller than the cutoff values, damping times of higher radial sausage harmonics could be significantly greater than the oscillation periods, i.e., several oscillation cycles could be present in the signal. The quality factors decrease with decfreasing ratios of Alfvén speeds outside and inside the cylinder. Oscillation periods of the second and third radial harmonics remain practically independent of the axial wavelength even when the wavelength is shorter than the radius of the cylinder. The ratios of oscillation periods of fundamental and higher radial and axial harmonics are found to be significantly different, up to a factor of two in the long-wavelength limit. It is concluded that higher radial harmonics could be responsible for the departure of observed sausage oscillation signals from a harmonic shape, especially during the first several cycles of the oscillation. Even in the absence of spatially resolved data, higher axial and radial harmonics can be distinguished from each other by the period ratios.

A New Comprehensive Data Set of Solar Filaments of 100 yr Interval. I

GangHua **Lin**, GaoFei Zhu, Xiao Yang, YongLiang Song, Mei Zhang, Suo Liu, XiaoFan Wang, JiangTao Su, Sheng Zheng, JiaFeng Zhang, DongYi Tao, ShuGuang Zeng, HaiMin Wang, Chang Liu, Yan Xu

ApJS **249** 11 **2020**

https://arxiv.org/pdf/2006.09082.pdf

https://doi.org/10.3847/1538-4365/ab92a5

Filaments are very common physical phenomena on the Sun and are often taken as important proxies of solar magnetic activities. The study of filaments has become a hot topic in the space weather research. For a more comprehensive understanding of filaments, especially for an understanding of solar activities of multiple solar cycles, it is necessary to perform a combined multifeature analysis by constructing a data set of multiple solar cycle data. To achieve this goal, we constructed a centennial data set that covers the Hα data from five observatories around the world. During the data set construction, we encountered varieties of problems, such as data fusion, accurate determination of the solar edge, classifying data by quality, dynamic threshold, and so on, which arose mainly due to multiple sources and a large time span of data. But fortunately, these problems were well solved. The data set includes seven types of data products and eight types of feature parameters with which we can implement the functions of data searching and statistical analyses. It has the characteristics of better continuity and highly complementary to space observation data, especially in the wavelengths not covered by space observations, and covers many solar cycles (including more than 60 yr of high-cadence data). We expect that this new comprehensive data set as well as the tools will help researchers to significantly speed up their search for features or events of interest, for either statistical or case study purposes, and possibly help them get a better and more comprehensive understanding of solar filament mechanisms.

Hα archive is at http://sun.bao.ac.cn/solarfilament/

Disappearance of a coronal hole induced by a filament activation

Ma **Lin**, Qu Zhong-Quan, Yan Xiao-Li, Xue Zhi-Ke

Research in Astron. & Astrophys., **2014**

http://arxiv.org/pdf/1404.7223v1.pdf

We present a rare observation of direct magnetic interaction between an activating filament and a coronal hole (CH). The filament was a quiescent one located at the northwest of the CH. It underwent a nonradial activation, during which filament material constantly fell and intruded into the CH. As a result, the CH was clearly destroyed by the intrusion. Brightenings appeared at the boundaries and in the interior of the CH, meanwhile, its west boundaries began to retreat and the area gradually shrank. It is noted that the CH went on shrinking after the end of the intrusion and finally disappeared entirely. Following the filament activation, three coronal dimmings (D1-D3) were formed, among which D1 and D2 persisted throughout the complete disappearance of the CH. The derived coronal magnetic configuration shows that the filament was located below an extended loop system which obviously linked D1 to D2. By comparison with this result of extrapolation, our observations imply that the interaction between the filament and the CH involved direct intrusion of the filament material to the CH and the disappearance of the CH might be due to interchange reconnection between the expanding loop system and the CH's open field. **2010 November 13**

SMALL-SCALE, DYNAMIC BRIGHT BLOBS IN SOLAR FILAMENTS AND ACTIVE REGIONS

Y. **Lin**, O. Engvold and L. H. M. Rouppe van der Voort

2012 ApJ 747 129

High-cadence high spatial resolution observations in Hα with the Swedish 1 m Solar Telescope on La Palma have revealed the existence of small-scale highly dynamic bright blobs. A fast wavelength tuning spectropolarimeter provides spectral information of these structures. The blobs slide along thin magnetic threads at speeds in the range from 45 km s–1 to 111 km s–1. The blobs have a slightly elongated shape and their lengths increase by a factor of three from close to half an arcsecond when they first appear until they disappear one to two minutes later. The brightest blobs show the highest speed. The widths of the Hα line emission of the blobs correspond to non-thermal velocities in the plasma less than 10 km s–1, which implies that they are not the result of shock-driven heating. The dynamic character of the bright blobs is similar to what can be expected from an MHD fast-mode pulse.

Filament Thread-like Structures and Their Small-amplitude Oscillations

Yong **Lin**

Space Science Reviews, Volume 158, Numbers 2-4, 237-266, **2011**

Thanks to gradually improving observational capabilities, both from space and ground-based observatories, it is now generally accepted that thin threads (width □200 km) constitute the building blocks of solar filaments and prominences. At ultra-small scales, high quality image sequences show a non-static picture of filaments and reveal that their oscillatory behavior is an important dynamic feature of these structures. Filament seismology sheds light on the internal magnetic structures of filaments and their interactions with surrounding solar regions. Understanding the overall magnetic topology of solar filaments and prominences including their small-scale thread-like structures is essential in interpretation and understanding of their oscillations. For this reason we aim here to present an update of the dynamic and spatial structures of prominences and filaments as inferred from high resolution observations in the past decennia. Some constraints in high resolution observations are addressed. Our **review** focuses mainly on the observational aspects and aims to summarize recent oscillation studies of individual filament threads and groups of threads. Finally, some theoretical interpretations of oscillations of filament threads and the inferred physical conditions of filament plasma are also discussed.

SWAYING THREADS OF A SOLAR FILAMENT

Y. **Lin**1, R. Soler2, O. Engvold1, J. L. Ballester2, Ø. Langangen1, R. Oliver2, and L. H. M. Rouppe van der Voort1

Astrophysical Journal, 704:870–876, **2009** October

From recent high-resolution observations obtained with the Swedish 1m Solar Telescope in La Palma, we detect swaying motions of individual filament threads in the plane of the sky. The oscillatory characters of these motions are comparable with oscillatory Doppler signals obtained from corresponding filament threads. Simultaneous recordings of motions in the line of sight and in the plane of the sky give information about the orientation of the oscillatory plane. These oscillations are interpreted in the context of the magnetohydrodynamic (MHD) theory. Kink MHD waves supported by the thread body are proposed as an explanation of the observed thread oscillations. On the basis of this interpretation and by means of seismological arguments, we give an estimation of the thread Alfv´en speed and magnetic field strength by means of seismological arguments.

Filament Substructures and their Interrelation

Y. **Lin**, S.F. Martin, and O. Engvold

ASP Conference Series, 2008, Vol. 383, 235-242

E-print, April 2008; **File**

http://folk.uio.no/yongl/Research/Filament_substructures_2007NSO24.pdf

The main structural components of solar filaments, their spines, barbs, and legs at the extreme ends of the spine, are illustrated from recent high-resolution observations. The thread-like structures appear to be present in filaments everywhere and at all times. They are the fundamental elements of solar filaments. The interrelation of the spines, barbs and legs are discussed. From observations, we present a conceptual model of the magnetic field of a filament. We suggest that only a single physical model is needed to explain filaments in a continuous spectrum represented by active region filaments at one end and quiescent filaments at the other end.

Evidence of Traveling Waves in Filament Threads

Y. **Lin** · O. Engvold · L.H.M. Rouppe van der Voort · M. van Noort

Solar Phys (**2007**) 246: 65–72

http://www.springerlink.com/content/y7nk808h60343k14/fulltext.pdf

High-resolution H〈 filtergrams (0.2_) obtained with the Swedish 1-m Solar Telescope resolve numerous very thin, thread-like structures in solar filaments. The threads are believed to represent thin magnetic flux tubes that must be longer than the observable threads. We report on evidence for small-amplitude (1 – 2 kms-1) waves propagating along a number of threads with an average phase velocity of 12 kms-1 and a wavelength of 4_. The oscillatory period of individual threads vary from 3 to 9 minutes. Temporal variation of the Doppler velocities averaged over a small area containing a number of individual threads shows a short-period (3.6 minutes) wave pattern. These short-period oscillations could possibly represent fast modes in accordance with numerical fibril models proposed by Díaz *et al.* (*Astron. Astrophys.* **379**, 1083, 2001). In some cases, it is clear that the propagating waves are moving in the same direction as the mass flows.

CAN LARGE TIME DELAYS OBSERVED IN LIGHT CURVES OF CORONAL LOOPS BE EXPLAINED IN IMPULSIVE HEATING?

Roberto **Lionello**1, Caroline E. Alexander2, Amy R. Winebarger2, Jon A. Linker1, and Zoran Mikić

2016 ApJ 818 129

The light curves of solar coronal loops often peak first in channels associated with higher temperatures and then in those associated with lower temperatures. The delay times between the different narrowband EUV channels have been measured for many individual loops and recently for every pixel of an active region observation. The time delays between channels for an active region exhibit a wide range of values. The maximum time delay in each channel pair can be quite large, i.e., >5000 s. These large time delays make-up 3%–26% (depending on the channel pair) of the pixels where a trustworthy, positive time delay is measured. It has been suggested that these time delays can be explained by simple impulsive heating, i.e., a short burst of energy that heats the plasma to a high temperature, after which the plasma is allowed to cool through radiation and conduction back to its original state. In this paper, we investigate whether the largest observed time delays can be explained by this hypothesis by simulating a series of coronal loops with different heating rates, loop lengths, abundances, and geometries to determine the range of expected time delays between a set of four EUV channels. We find that impulsive heating cannot address the largest time delays observed in two of the channel pairs and that the majority of the large time delays can only be explained by long, expanding loops with photospheric abundances. Additional observations may rule out these simulations as an explanation for the long time delays. We suggest that either the time delays found in this manner may not be representative of real loop evolution, or that the impulsive heating and cooling scenario may be too simple to explain the observations, and other potential heating scenarios must be explored.

THERMAL NON-EQUILIBRIUM REVISITED: A HEATING MODEL FOR CORONAL LOOPS

Roberto **Lionello**1, Amy R. Winebarger2, Yung Mok3, Jon A. Linker1, and Zoran Mikić

2013 ApJ 773 134

The location and frequency of events that heat the million-degree corona are still a matter of debate. One potential heating scenario is that the energy release is effectively steady and highly localized at the footpoints of coronal structures. Such an energy deposition drives thermal non-equilibrium solutions in the hydrodynamic equations in longer loops. This heating scenario was considered and discarded by Klimchuk et al. on the basis of their one-dimensional simulations as incapable of reproducing observational characteristics of loops. In this paper, we use three-dimensional simulations to generate synthetic emission images, from which we select and analyze six loops. The main differences between our model and that of Klimchuk et al. concern (1) dimensionality, (2) resolution, (3) geometrical properties of the loops, (4) heating function, and (5) radiative function. We find evidence, in this small set of simulated loops, that the evolution of the light curves, the variation of temperature along the loops, the density profile, and the absence of small-scale structures are compatible with the characteristics of observed loops. We conclude that quasi-steady footpoint heating that drives thermal non-equilibrium solutions cannot yet be ruled out as a viable heating scenario for EUV loops.

EMERGENCE OF HELICAL FLUX AND THE FORMATION OF AN ACTIVE REGION FILAMENT CHANNEL

B. W. **Lites**1,5, M. Kubo1,5, T. Berger2, Z. Frank2, R. Shine2, T. Tarbell2, A. Title2, T. J. Okamoto3, and K. Otsuji4,6

Astrophysical Journal, 718:474–487, **2010** July

We present comprehensive observations of the formation and evolution of a filament channel within NOAA Active Region (AR) 10978 from *Hinode/*Solar Optical Telescope and *TRACE*. We employ sequences of *Hinode* spectro-polarimeter maps of the AR, accompanying *Hinode* Narrowband Filter Instrument magnetograms in the Na i D1 line, *Hinode* Broadband Filter Instrument filtergrams in the Ca ii H line and *G*-band, *Hinode* X-ray telescope X-ray images, and *TRACE* Fe ix 171 Å image sequences. The development of the channel resembles qualitatively that presented by Okamoto et al. in that many indicators point to the emergence of a pre-existing sub-surface magnetic flux rope. The consolidation of the filament channel into a coherent structure takes place rapidly during the course of a few hours, and the filament form then gradually shrinks in width over the following two days. Particular to this filament channel is the observation of a segment along its length of horizontal, weak (500 G) flux that, unlike the rest of the filament channel, is not immediately flanked by strong vertical plage fields of opposite polarity on each side of the filament. Because this isolated horizontal field is observed in photospheric lines, we infer that it is unlikely that the channel formed as a result of reconnection in the corona, but the low values of inferred magnetic fill fraction along the entire length of the filament channel suggest that the bulk of the field resides somewhat above the low photosphere. Correlation tracking of granulation in the *G* band presents no evidence for either systematic flows toward the channel or systematic shear flows along it. The absence of these flows, along with other indications of these data from multiple sources, reinforces (but does not conclusively demonstrate) the picture of an emerging flux rope as the origin of this AR filament channel.

Field-aligned and Magnetic Reconnection Flows in a Magnetohydrodynamic Simulation of Prominence-cavity System

Tie **Liu**1,2, Yingna Su3,4, Yang Guo1,2, Jie Zhao3,4, and Haisheng Ji3,4

2023 ApJ 949 36

https://iopscience.iop.org/article/10.3847/1538-4357/acca82/pdf

Nested ring-shaped line-of-sight (LOS) oriented flows in coronal cavities have been observed in recent years but rarely explained. Using a magnetohydrodynamic simulation of a prominence-cavity system, we investigate the relationship between the simulated field-aligned flows, magnetic reconnection flows, and the LOS-oriented flows observed by the Coronal Multi-Channel Polarimeter. The field-aligned flows are along magnetic field lines toward the dips and driven by the hydrodynamic forces exerted by the prominence condensation. The reconnection flows are driven by the overlying reconnection and tether-cutting reconnection. The velocity of the reconnection flows increases from the quasi-static phase to the fast-rise phase, reaching several kilometers per second, which is similar to the speed of the field-aligned flows. We calculate the synthetic Doppler images by forward modeling and compare them with the observed LOS-oriented flows. The synthetic images show that the LOS-oriented flows of one ring with opposite internal flow driven by the field-aligned flows are identified in the simulation. And the synthetic images integrated along three different LOSs can resemble the observed direction reversal of the LOS-oriented flow in about 20 hr, when the included angle of two adjacent LOSs is about 10°. These results suggest that the observed LOS-oriented flows of one ring with an opposite internal flow may be explained by the LOS integration effect of field-aligned flows along different loops.

Formation of Quiescent Prominence Magnetic Field by Supergranulations

Qingjun **Liu**, Chun Xia

ApJL **934** L9 **2022**

https://arxiv.org/pdf/2207.06598.pdf

https://iopscience.iop.org/article/10.3847/2041-8213/ac80c6/pdf

To understand the formation of quiescent solar prominences, the origin of their magnetic field structures, i.e., magnetic flux ropes (MFRs), must be revealed. We use three-dimensional magnetofriction simulations in a spherical subdomain to investigate the role of typical supergranular motions in the long-term formation of a prominence magnetic field. Time-dependant horizontal supergranular motions with and without the effect of Coriolis force are simulated on the solar surface via Voronoi tessellation. The vortical motions by the Coriolis effect at boundaries of supergranules inject magnetic helicity into the corona. The helicity is transferred and accumulated along the polarity inversion line (PIL) as strongly sheared magnetic field via helicity condensation. The diverging motions of supergranules converge opposite magnetic polarities at the PIL and drive the magnetic reconnection between footpoints of the sheared magnetic arcades to form an MFR. The magnetic network, negative-helicity MFR in the northern hemisphere, and fragmented-to-continuous formation process of magnetic dip regions are in agreement with observations. Although diverging supergranulations, differential rotation, and meridional flows are included, the simulation without the Coriolis effect can not produce an MFR or sheared arcades to host a prominence. Therefore Coriolis force is a key factor for helicity injection and the formation of magnetic structures of quiescent solar prominences.

Numerical Simulation of Longitudinal Oscillation of Filament Based on Smoothed Particle Hydrodynamics (SPH) Method

Yu Xiang **Liu**, Hong Fu Qiang, Xue Ren Wang, Du Dou Wang, Yan Chao Wang & Lin Tao Zhang

Solar Physics volume 297, Article number: 66 (**2022**)

https://doi.org/10.1007/s11207-022-01999-2

The oscillations of solar coronal filaments have received significant interest, and the restoring force and damping mechanism are the focus of discussion. We study the basic physical principles of the multi-factor, coupled, longitudinal oscillations of a filament, including its dominant restoring force and the damping mechanism. Using the Smoothed Particle Hydrodynamics (SPH) method we have performed for the first time a one-dimensional (1D) hydrodynamic numerical simulation of the longitudinal oscillation of the prominence. We modeled the process of mass uplift, that is the chromosphere mass enters the corona directly with the uplifted magnetic-flux tube. We studied multiple parameters, including the mass density, the initial perturbation velocity, and the geometry of the magnetic depression. We found that a sudden velocity disturbance can result in the oscillation of the prominence mass along the magnetic dip. Our numerical simulation analysis and theoretical study show that the oscillation period can be expressed as D−0.616w0.978v00.261D−0.616w0.978v00.261 (where DD is the dip depth of the magnetic tube, ww is half the length of the prominence magnetic dip, and v0v0 is the initial velocity disturbance), which is slightly different from the previous linear pendulum theory. The particle-collision viscosity also affects the longitudinal-oscillation period. In a non-adiabatic process, the oscillation decays with time. Radiant cooling is the primary factor that causes damping. Plasma particles' collisional viscosity is also a cause of damping, which primarily occurs once the prominence moves to the farthest point from the equilibrium state. The proportional law of the attenuation time scale is deduced, that is τ∼l1.194ρ0.615D0.732ω−1.099v0−0.412τ∼l1.194ρ0.615D0.732ω−1.099v0−0.412 (where ll is the prominence length, and ρρ is the prominence density). Compared to previous simulations, v0v0 plays a more important role. The greater the amplitude, the greater the oscillation damping. The advantage of the SPH method used in this article is that it can avoid the accuracy loss caused by mesh distortion in extremely large deformations, and it can avoid the interface problem of the Euler mesh in the Euler method. Therefore, it is especially suitable for solving dynamic large deformation problems such as prominence oscillation and explosion.

Solar Filament Segmentation Based on Improved U-Nets

Dan **Liu**, Wei Song, Ganghua Lin & Haimin Wang

Solar Physics volume 296, Article number: 176 (**2021**)

https://link.springer.com/content/pdf/10.1007/s11207-021-01920-3.pdf

https://doi.org/10.1007/s11207-021-01920-3

To detect, track and characterize solar filaments more accurately, novel filament segmentation methods based on improved U-Nets are proposed. The full-disk Hαα images from the Huairou Solar Observing Station of the National Astronomical Observatory and the Big Bear Solar Observatory were used for training and verifying the effectiveness of different improved networks' filament segmentation performance. Comparative experiments with different solar dataset sizes and input image quality were performed. The impact of each improvement method on the segmentation effect was analyzed and compared based on experimental results. In order to further explore the influence of network depth on filament-segmentation accuracy, the segmentation results produced by Conditional Generative Adversarial Networks (CGAN) were obtained and compared with improved U-nets. Experiments verified that U-Net with an Atrous Spatial Pyramid Pooling Module performs better for high-quality input solar images regardless of dataset sizes. CGAN performs better for low-quality input solar images with large dataset size. The algorithm may provide guidance for filament segmentation and more accurate segmentation results with less noise were acquired.

Statistical Evidence for the Existence of Alfvénic Turbulence in Solar Coronal Loops

Jiajia **Liu**, Scott W. McIntosh, Ineke De Moortel, James Threlfall, Christian Bethge

2014 ApJ 797 7

http://arxiv.org/pdf/1411.5094v1.pdf

Recent observations have demonstrated that waves which are capable of carrying large amounts of energy are ubiquitous throughout the solar corona. However, the question of how this wave energy is dissipated (on which time and length scales) and released into the plasma remains largely unanswered. Both analytic and numerical models have previously shown that Alfv\'enic turbulence may play a key role not only in the generation of the fast solar wind, but in the heating of coronal loops. In an effort to bridge the gap between theory and observations, we expand on a recent study [De Moortel et al., ApJL, 782:L34, 2014] by analyzing thirty-seven clearly isolated coronal loops using data from the Coronal Multi-channel Polarimeter (CoMP) instrument. We observe Alfv\'enic perturbations with phase speeds which range from 250-750 km/s and periods from 140-270 s for the chosen loops. While excesses of high frequency wave-power are observed near the apex of some loops (tentatively supporting the onset of Alfv\'enic turbulence), we show that this excess depends on loop length and the wavelength of the observed oscillations. In deriving a proportional relationship between the loop length/wavelength ratio and the enhanced wave power at the loop apex, and from the analysis of the line-widths associated with these loops, our findings are supportive of the existence of Alfv\'enic turbulence in coronal loops.

Table 1 : *Statistical results of thirty-seven coronal loops in 2013*

Coronal Condensation in Funnel Prominences as Return Flows of the Chromosphere-Corona Mass Cycle

Liu, Wei; Berger, Thomas E.; and Low, B. C.

2014/01, Nature of Prominences and their role in Space Weather, Proceedings of the International Astronomical Union, IAU Symposium, Volume 300, pp. 441-442

http://sun.stanford.edu/~weiliu/research/publications/2013/2014IAUS_Liu_Berger_Low_funnel-prom.pdf

We present *SDO*/AIA observations of a potentially novel type of prominence, called "funnel prominence", that forms out of coronal condensation at magnetic dips.

They can drain a large amount of mass (up to ∼1015 g day−1) and may play an important role as return flows of the chromosphere-corona mass cycle.

SLOW RISE AND PARTIAL ERUPTION OF A DOUBLE-DECKER FILAMENT. I. OBSERVATIONS AND INTERPRETATION

Rui **Liu**1,2, Bernhard Kliem3,4, Tibor Török5, Chang Liu2, Viacheslav S. Titov5, Roberto Lionello5, Jon A. Linker5, and Haimin Wang

2012 ApJ 756 59

We study an active-region dextral filament that was composed of two branches separated in height by about 13 Mm, as inferred from three-dimensional reconstruction by combining SDO and STEREO-B observations. This "double-decker" configuration sustained for days before the upper branch erupted with a GOES-class M1.0 flare on **2010 August 7**. Analyzing this evolution, we obtain the following main results. (1) During the hours before the eruption, filament threads within the lower branch were observed to intermittently brighten up, lift upward, and then merge with the upper branch. The merging process contributed magnetic flux and current to the upper branch, resulting in its quasi-static ascent. (2) This transfer might serve as the key mechanism for the upper branch to lose equilibrium by reaching the limiting flux that can be stably held down by the overlying field or by reaching the threshold of the torus instability. (3) The erupting branch first straightened from a reverse S shape that followed the polarity inversion line and then writhed into a forward S shape. This shows a transfer of left-handed helicity in a sequence of writhe-twist-writhe. The fact that the initial writhe is converted into the twist of the flux rope excludes the helical kink instability as the trigger process of the eruption, but supports the occurrence of the instability in the main phase, which is indeed indicated by the very strong writhing motion. (4) A hard X-ray sigmoid, likely of coronal origin, formed in the gap between the two original filament branches in the impulsive phase of the associated flare. This supports a model of transient sigmoids forming in the vertical flare current sheet. (5) Left-handed magnetic helicity is inferred for both branches of the dextral filament. (6) Two types of force-free magnetic configurations are compatible with the data, a double flux rope equilibrium and a single flux rope situated above a loop arcade.

FIRST SDO/AIA OBSERVATION OF SOLAR PROMINENCE FORMATION FOLLOWING AN ERUPTION: MAGNETIC DIPS AND SUSTAINED CONDENSATION AND DRAINAGE

Wei **Liu**1,2, Thomas E. Berger1 and B. C. Low

2012 ApJ 745 L21

Imaging solar coronal condensation forming prominences was difficult in the past, a situation recently changed by Hinode and the Solar Dynamics Observatory (SDO). We present the first example observed with the SDO/Atmospheric Imaging Assembly, in which material gradually cools through multiple EUV channels in a transequatorial loop system that confines an earlier eruption. Nine hours later, this leads to eventual condensation at the dips of these loops, forming a moderate-size prominence of ~1014 g, to be compared to the characteristic 1015 g mass of a coronal mass ejection (CME). The prominence mass is not static but maintained by condensation at a high estimated rate of 1010 g s–1 against a comparable, sustained drainage through numerous vertical downflow threads, such that 96% of the total condensation (~1015 g) is drained in approximately one day. The mass condensation and drainage rates temporally correlate with the total prominence mass. The downflow velocity has a narrow Gaussian distribution with a mean of 30 km s–1, while the downward acceleration distribution has an exponential drop with a mean of ~1/6 g ⊙, indicating a significant canceling of gravity, possibly by the Lorentz force. Our observations show that a macroscopically quiescent prominence is microscopically dynamic, involving the passage of a significant mass through it, maintained by a continual mass supply against a comparable mass drainage, which bears important implications for CME initiation mechanisms in which mass unloading is important.

CRITICAL HEIGHT FOR THE DESTABILIZATION OF SOLAR PROMINENCES: STATISTICAL RESULTS FROM STEREO OBSERVATIONS

Kai **Liu**, Yuming Wang, Chenglong Shen1 and Shui Wang

2012 ApJ 744 168

At which height is a prominence inclined to be unstable, or where is the most probable critical height for the prominence destabilization? This question was statistically studied based on 362 solar limb prominences well recognized by Solar Limb Prominence Catcher and Tracker from 2007 April to the end of 2009. We found that there are about 71% disrupted prominences (DPs), among which about 42% of them did not erupt successfully and about 89% of them experienced a sudden destabilization process. After a comprehensive analysis of the DPs, we discovered the following: (1) Most DPs become unstable at a height of 0.06-0.14 R ⊙ from the s
there are two most probable critical heights at which a prominence is very likely to become unstable, the first one is 0.13 R ⊙ and the second one is 0.19 prominences (EPs)
exists, which decreases following a power law with increasing height and mass; accordingly, the kinetic energy of EPs has an upper limit too, which decreases as the critical height increases. (3) Stable prominences are generally longer and heavier than DPs, and not higher than 0.4 R ⊙. (4) A bou
mass ejections (CMEs); but there is no difference in apparent properties between EPs associated with CMEs and those that are not.

Evolution of filament barbs

R. **Liu**, Y. Xu, and H. Wang

Preprint BBSO#1460, **2010, File**; Mem. S.A.It. Vol. 81, 796

We present a selected few cases in which the sense of chirality of filament barbs changed within periods as short as hours. We investigate in detail a quiescent filament on **2003 September 10 and 11**. Of its four barbs displaying such changes, only one overlays a small polarity inversion line inside the EUV filament channel (EFC). No magnetic elements with magnitude above the noise level were detected at the endpoints of all barbs. In particular, a pair of barbs first approached toward, and then departed from, each other in Hα, with the barb endpoints migrating as far as ~ 10". We conclude that the evolution of the barbs was driven by flux emergence and cancellation of small bipolar units at the EFC border.

Observation of interactions between two erupting filaments

Yu **Liu**[1], Jiangtao Su[2],Yuandeng Shen[1] and Liheng Yang[1]

Solar and Stellar Variability: Impact on Earth and Planets, Proceedings IAU Symposium No. 264, **2009**, p. 99-101, A.G. Kosovichev, A.H. Andrei & J.-P. Rozelot, eds.

Y:\obridko\otchet09

Following the first observational study of the interaction between two distinct filaments (Su et al. 2007; hereafter, event 1), we present another interesting case observed by SMART telescope on 2005 June 25 with higher spatial resolution (hereafter, event 2). The two events are compared with each other. In event 1 the two filaments erupted subsequently and obvious mass flow was observed to be transferred from one erupting filament to one stable filament which triggered its eruption. On the contrary, in event 2, the two filaments erupted simultaneously and there was no transfer of material noticed between them during the initial stage. The two filaments merged together along the ejection path, indicating the bodily coalesce between the two interacting flux ropes. Moreover, event 1 was associated with a coronal mass ejection (CME), while event 2 was a failed filament eruption, thus without CME association.

AN INTRIGUING CHROMOSPHERIC JET OBSERVED BY *HINODE*: FINE STRUCTURE KINEMATICS AND EVIDENCE OF UNWINDING TWISTS

Wei **Liu**[1,2], Thomas E. Berger[1], Alan M. Title[1], and Theodore D. Tarbell[1]

Astrophysical Journal, 707:L37–L41, **2009** December, **File**

We report a chromospheric jet lasting for more than 1 hr observed by the *Hinode* Solar Optical Telescope in unprecedented detail. The ejection occurred in three episodes separated by 12–14 minutes, with the amount and velocity of material decreasing with time. The upward velocities range from 438 to 33 km s^{-1}, while the downward velocities of the material falling back have smaller values (mean:−56 km s^{-1}) and a narrower distribution (standard deviation: 14 km s^{-1}). The average acceleration inferred from parabolic spacetime tracks is 141 m s^{-2}, a fraction of the solar gravitational acceleration. The jet consists of fine threads (0._5–2_ wide), which exhibit coherent, oscillatory transverse motions perpendicular to the jet axis and about a common equilibrium position. These motions propagate upward along the jet, with the maximum phase speed of 744 ± 11 km s^{-1}at the leading front of the jet. The transverse oscillation velocities range from 151 to 26 km s^{-1}, amplitudes from 6.0 to 1.9 Mm, and periods from 250 to 536 s. The oscillations slow down with time and cease when the material starts to fall back. The falling material travels along almost straight lines in the original direction of ascent, showing no transverse motions. These observations are consistent with the scenario that the jet involves untwisting helical threads, which rotate about the axis of a single large cylinder and shed magnetic helicity into the upper atmosphere.
2007 February 9

Coronal Implosion and Particle Acceleration in the Wake of a Filament Eruption

Rui **Liu**, & Haimin Wang

E-print, Aug **2009**; ApJL, **703** L23-L28 doi: 10.1088/0004-637X/703/1/L23

We study the evolution of a group of TRACE 195 A coronal loops overlying a reverse S-shaped filament on **2001 June 15**. These loops were initially pushed upward with the filament ascending and kinking slowly, but as soon as the filament rose explosively, they began to contract at a speed of ~100 km/s, and sustained for at least 12 min, presumably due to the reduced magnetic pressure underneath with the filament escaping. Despite the contraction following the expansion, the loops of interest remained largely intact during the filament eruption, rather than formed via reconnection. These contracting loops naturally formed a shrinking trap, in which hot electrons of several keV, in an order of magnitude estimation, can be accelerated to nonthermal energies. A single hard X-ray burst, with no corresponding rise in GOES soft X-ray flux, was recorded by the Hard X-ray Telescope (HXT) on board Yohkoh, when the contracting loops expectedly approached the post-flare arcade originating from the filament eruption. HXT images reveal a coronal source distinctly above the top of the soft X-ray arcade by ~15". The injecting electron population for the coronal source (thin target) is hardening by ~1.5 powers relative to the footpoint emission (thick target), which is consistent with electron trapping in the weak diffusion limit. Although we can not rule out additional reconnection, observational evidences suggest that the shrinking coronal trap may play a significant role in the observed nonthermal hard X-ray emission during the flare decay phase.

NEW OBSERVATION OF FAILED FILAMENT ERUPTIONS: THE INFLUENCE OF ASYMMETRIC CORONAL BACKGROUND FIELDS ON SOLAR ERUPTIONS

Y. **Liu**[1,2], J. Su[3], Z. Xu[1], H. Lin[2], K. Shibata[4], and H. Kurokawa[4]

Astrophysical Journal, 696:L70–L73, **2009** May

http://www.iop.org/EJ/toc/-alert=43192/1538-4357/696/1

Failed filament eruptions not associated with a coronal mass ejection (CME) have been observed and reported as evidence for solar coronal field confinement on erupting flux ropes. In those events, each filament eventually returns to its origin on the solar surface. In this Letter, a new observation of two failed filament eruptions is reported which indicates that the mass of a confined filament can be ejected to places far from the original filament channel. The jetlike mass motions in the two failed filament eruptions are thought to be due to the asymmetry of the background coronal magnetic fields with respect to the locations of the filament channels. The asymmetry of the coronal fields is confirmed by an extrapolation based on a potential field model. The obvious imbalance between the positive and negative magnetic flux (with a ratio of 1:3) in the bipolar active region is thought to be the direct cause of the formation of the asymmetric coronal fields. We think that the asymmetry of the background fields can not only influence the trajectories of ejecta, but also provide a relatively stronger confinement for flux rope eruptions than the symmetric background fields do.

2005 June 25

Asymmetric Eruptive Filaments

Rui **Liu**, David Alexander, and Holly R. Gilbert

E-print, Oct **2008**, **File**; ApJ

Filaments are often observed to erupt asymmetrically, during which one leg is fixed to the photosphere (referred to as the anchored leg) while the other undertakes most of the dynamic motions (referred to as the active leg) during the eruptive process. In this paper, we present observations of a group of asymmetric eruptive filaments, in which two types of eruptions are identified: whipping-like, where the active leg whips upward, and hard X-ray sources shift toward the end of the anchored leg; and zipping-like, where the visible end of the active leg moves along the neutral line like the unfastening of a zipper as the filament arch rises and expands. During a zipping-like eruption, hard X-ray sources shift away from where the eruption initiates toward where the visible end of the active leg eventually stops moving. Both types of asymmetric eruptions can be understood in terms of how the highly sheared filament channel field, traced by filament material, responds to an external asymmetric magnetic confinement, where force imbalance occurs in the neighborhood of the visible end of the active leg. The dynamic motions of the active leg have a distinct impact on how hard X-ray sources shift, as observed by RHESSI.

THE EFFECT OF MAGNETIC RECONNECTION AND WRITHING IN A PARTIAL FILAMENT ERUPTION

Rui **Liu**,1 Holly R. Gilbert,1 David Alexander,1 and Yingna Su

The Astrophysical Journal, 680:1508-1515, **2008, File**

http://www.journals.uchicago.edu/doi/pdf/10.1086/587482

We present observations from **2007 March 2** of a partial filament eruption characterized by two distinct phases of writhing motions: a quasi-static, slowly evolving phase followed by a rapid kinking phase showing a bifurcation of the filament. The quasi-static kinking motions are observed before there is any heating or flaring evident in EUVor soft X-ray (SXR) observations. As the writhe of the filament develops, a sigmoid becomes sharply defined in the SXR. Prior to eruption onset, the sigmoid in the EUV appears to be composed of two separate looplike structures, which are discontinuous at the projected location where the sigmoid crosses the filament. Coincident with the onset of the eruption and the production of a GOES class B2 flare, the original ''two-loop'' EUV sigmoid is now observed as a single continuous structure lying above the filament, signifying the presence of magnetic reconnection and the associated dissipative heating of field lines above the filament. During the eruption, the escaping portion of the filament rotates quickly and erupts together with the expanding arched sigmoid. The portion of the filament that is left behind develops into an inverse SYshaped configuration. The separation of the filament, the EUV brightening at the separation location, and the surviving sigmoidal structure are all signatures of magnetic reconnection occurring within the body of the original filament. Other features of the same event reported by Sterling and coworkers, e.g., the flux cancellation at the polarity inversion line prior to the eruption and the SXR compact loop formed underneath the erupting sigmoid during the eruption, indicate that magnetic reconnection also occurred in the sheared core field beneath the filament. These results suggest that a combination of the kinking motions and internal tether-cutting are responsible for the initiation of the eruption. (See Sterling, et al., 2007).

A Study of Surges: II. On the Relationship between Chromospheric Surges and Coronal Mass Ejections
Yu **Liu**
Solar Phys (**2008**) 249: 75–84
http://www.springerlink.com/content/ur823033873g4m50/fulltext.pdf
Liu *et al.* (*Astrophys. J.* **628**, 1056, 2005a) described one surge **–** coronal mass ejection (CME) event showing a close relationship between solar chromospheric surge ejection and CME that had not been noted before. In this work, large Hα surges (> 72 Mm, or 100 arcsec) are studied. Eight of these were associated with CMEs. According to their distinct morphological features, Hα surges can be classified into three types: jetlike, diffuse, and closed loop. It was found that all of the jetlike surges were associated with jetlike CMEs (with angular widths ≤ 30 degrees); the diffuse surges were all associated with wide-angle CMEs (*e.g.*, halo); the closed-loop surges were not associated with CMEs. The exclusive relation between Hα surges and CMEs indicates difference in magnetic field configurations.The jetlike surges and related narrow CMEs propagate along coronal fields that are originally open. The unusual transverse mass motions in the diffuse surges are suggested to be due to magnetic reconnections in the corona that produce wide-angle CMEs. For the closed loop surges, their paths are just outlining stable closed loops close to the solar surface. Thus no CMEs are associated with them.

Magnetic Field Overlying Solar Eruption Regions and Kink and Torus Instabilities
Y. **Liu**
E-print, April **2008**; ApJL
http://soi.stanford.edu/~yliu/papers/kinktorus2008.pdf
Using a Potential Field Source Surface model (PFSS), we study magnetic field overlying erupted filaments in solar active regions. The filaments studied here were reported to experience a kink instability or a torus instability. The torus instability leads to a full eruption, while the kink instability leads to a full eruption or a failed eruption. It is found that for full eruption the field decreases with height more quickly than that for failed eruption. A dividing line between full eruption and failed eruption is also found to be likely connected with the decay index n of the horizontal potential field due to sources external of the filament ($n = -d\, log(Bex)/d\, log(h)$, where h is height): the decay index of failed eruption tends to be smaller than that of full eruption. The difference of the decay indexes between full eruption and failed eruption is statistically significant. These are supportive of previous theoretical and numerical simulation results. Another significant difference is the field strength at low altitude: for failed eruption, the field strength is about a factor of 3 stronger than that for the full eruption. It suggests that the field strength at low altitude may be another factor in deciding whether or not a full eruption can take place. On the other hand, the decay index for the torus-instability full eruption events exhibits no trend to exceed the decay index for the kink-instability full eruption events on average, different from a suggestion derived from some MHD simulations. We discuss possible reasons that may cause this discrepancy.

Quiescent and Eruptive Prominences at Solar Minimum: A Statistical Study via an Automated Tracking System
I. P. **Loboda**, S. A. Bogachev
Solar Phys. Volume 290, Issue 7, pp 1963-1980 **2015**
http://arxiv.org/pdf/1506.09102v2.pdf
We employ an automated detection algorithm to perform a global study of solar prominence characteristics. We process four months of TESIS observations in the He II 304 A line taken close to the solar minimum of 2008-2009 and focus mainly on quiescent and quiescent-eruptive prominences. We detect a total of 389 individual features ranging from 25x25 to 150x500 Mm in size and obtain distributions of many their spatial characteristics, such as latitudinal position, height, size and shape. To study their dynamics, we classify prominences as either stable or eruptive and calculate their average centroid velocities, which are found to be rarely exceeding 3 km/s. Besides, we give rough estimates of mass and gravitational energy for every detected prominence and use these values to evaluate the total mass and gravitational energy of all simultaneously existing prominences (10e12-10e14 kg and 10e29-10e31 erg, respectively). Finally, we investigate the form of the gravitational energy spectrum of prominences and derive it to be a power-law of index -1.1 +- 0.2. **26 September 2009**

Compositing Eclipse Images from the Ground and from Space
Christian A**. Lockwood**1, Jay M. Pasachoff1, Daniel B. Seaton2, David H. Sliski3, and Nicolas Lefaudeux4
2020 Res. Notes AAS 4 133
https://doi.org/10.3847/2515-5172/abacb5
https://iopscience.iop.org/article/10.3847/2515-5172/abacb5
We present composite white-light images of the **2019 July 2**, total solar eclipse, from the minimum of the solar-activity cycle. We exhibit high-resolution high dynamic range composites from three observation sites in Chile, including one made of 646 individual ground-based images and with such a wide field it exceeds the field of view of

the Naval Research Laboratory's C2 and C3 coronagraphs aboard ESA's Solar and Heliospheric Observatory. We compare the resolution of the coronal streamers and other magnetic phenomena of the corona. We also show continuity of features on the solar surface as observed from NOAA's GOES-16 and GOES-17 Solar Ultraviolet Imager.

Fast magnetohydrodynamic oscillation of longitudinally inhomogeneous prominence threads: an analogue with quantum harmonic oscillator

S. N. **Lomineishvili**, T. V. Zaqarashvili, I. Zhelyazkov, A. G. Tevzadze

A&A 565, A35, **2014**

http://arxiv.org/pdf/1403.6027v1.pdf

Context. Previous works indicate that the frequency ratio of second and first harmonics of kink oscillations tends towards 3 in the case of prominence threads. This is not a straightforward result, so it requires adequate explanation.
Aims. We aim to study the magnetohydrodynamic oscillations of longitudinally inhomogeneous prominence threads and to shed light on the problem of the frequency ratio.
Methods. The classical Sturm-Liouville problem is used for the threads with longitudinally inhomogeneous plasma density. We show that the spatial variation of total pressure perturbations along the thread is governed by the stationary Schrödinger equation, where the longitudinal inhomogeneity of plasma density stands for the potential energy. The Schrödinger equation appears as the equation of quantum harmonic oscillator for a parabolic profile of plasma density. Consequently, the equation has bounded solutions in terms of Hermite polynomials.
Results. Boundary conditions at the thread surface lead to a transcendental dispersion equation with Bessel functions. The thin flux tube approximation of the dispersion equation shows that the frequency of kink waves is proportional to the expression $\alpha(2n + 1)$, where α is the density inhomogeneity parameter, and n the longitudinal mode number. Consequently, the ratio of the frequencies of second and first harmonics tends to 3 in prominence threads. The numerical solution of the dispersion equation shows that the ratio decreases only slightly for thicker tubes in the case of less longitudinal inhomogeneity of the external density, therefore the thin flux tube limit is a good approximation for prominence oscillations. However, stronger longitudinal inhomogeneity of external density may lead to the significant shift in the frequency ratio for wider tubes, and therefore the thin tube approximation may fail.
Conclusions. The tendency of frequency ratio of second and first harmonics towards 3 in prominence threads is explained by the analogy of the oscillations with quantum harmonic oscillator, where the density inhomogeneity of the threads plays a role as the potential energy.

Localized Reconnection Heating Inferred from the Three-dimensional Locations of Bright Active Region Coronal Loops

Dana **Longcope**1, Marika McCarthy1, and Anna Malanushenko

2020 ApJ 901 147

https://doi.org/10.3847/1538-4357/abb2a9

Coronal loops observed in soft X-rays and extreme ultraviolet imaging data offer direct evidence that coronal plasma is heated by some mechanism. That mechanism appears to energize a particular bundle of field lines somehow selected from the magnetized coronal volume. Magnetic reconnection localized to a patch within a coronal current sheet is one mechanism that would select a flux bundle at the same time it energized it. Since magnetic reconnection occurs preferentially at topological boundaries, we would expect to find coronal loops concentrated there if it were at work. We explore this hypothesis using a data set, previously compiled by McCarthy et al., consisting of 301 coronal loops interconnecting a pair of active regions over a 48 hr period. That work computed the three-dimensional geometries and magnetic field strengths for most of the loops. This revealed many bright loops lying at the periphery of the interconnecting flux domain, possibly created and energized by the reconnection that created the interconnecting flux. There were, however, many loops well inside the domain which would be difficult to attribute to that mode of reconnection. Here we use detailed magnetic models of the interconnecting domain to show that these internal loops tend to occur along internal boundaries: separatrices. This offers a novel form of evidence that coronal loops are the products of patchy reconnection even under quiescent conditions.

Fast magnetohydrodynamic oscillations of a coronal loop embedded in a potential coronal arcade

I. P**. Lopin**⋆

A&A, 691, A353 (**2024**)

https://www.aanda.org/articles/aa/pdf/2024/11/aa52220-24.pdf

Context. Observations indicate variable widths exhibited by fan coronal loops and flare loops that tend to widen towards the apex. Short-period, quasi-periodic pulsations in solar flares are often interpreted in terms of the fast-sausage oscillations of flare loops and the collective vertical vibrations of arcade loops are attributed with the vertical kink mode. Both phenomena are used as a seismological tool to estimate the physical parameters in the corona.

Aims. We performed an analytical study of fast sausage and kink oscillations in coronal loops, given the effects of loop curvature, expansion, and Alfvén speed variation.
Methods. We modelled a coronal loop as a dense expanding curved magnetic slab embedded within a potential coronal arcade, using a zero-β plasma limit. We obtained the dispersion relation that governs fast waves in the model and studied it both numerically and analytically.
Results. The effects of loop expansion and variable Alfvén speed reduce the cut-off frequency and increase the cut-off wavenumbers for fast sausage and kink waves. Moreover, the principal vertical kink mode has a cut-off and strongly attenuates in the leaky regime. The frequency increase is found to be minor for the global sausage mode both in the trapped and leaky regimes, with a frequency shift within a few percent. We found that in our model, where the Alfvén speed increases from the footpoints to the loop top, the spatial profile of the longitudinal fundamental is broadened and the antinodes of the first overtone are shifted towards the footpoints.
Conclusions. Using the classical expression for the cut-off wavenumber of the global sausage mode in a straight waveguide results in an underestimation of the density contrast constraint in flare loops. Instead, the suggested formula accounting for variations in loop widths provides more accurate results. The frequency of the global sausage mode can be correctly determined with the straight slab model.

Transverse Oscillations and Kelvin–Helmholtz Instability in Curved Arcade Loops with Siphon Flows

Igor **Lopin**

2024 ApJ 972 38

https://iopscience.iop.org/article/10.3847/1538-4357/ad6318/pdf

The effect of plasma flow in curved arcade loops on transverse waves and oscillations is examined analytically. The model under study is a semicircular magnetic slab with finite transverse extensions and a mass flow inside, in the zero-β plasma approximation. It is found that in the quasi-perpendicular propagation limit, the model supports two fast surface modes: one with higher (FSW+) and another with lower (FSW−) frequency. For a weak flow, the frequency of the FSW+ (FSW−) increases (decreases) as the flow speed grows in both propagating and quasi-standing wave regimes. We show that the FSW+ and FSW− are subjected to the Kelvin–Helmholtz (KH) instability, and the threshold flow is greater (less than) the internal Alfvén speed for the FSW+ (FSW−). The presence of plasma flow results in modifying the period ratio P1/2P2 of the fundamental harmonic to the first overtone with P1/2P2 less (more) than 1 for the FSW+ (FSW−), and this effect degenerates in the straight waveguide limit. The sub-Alfvénic flow can prohibit resonant absorption of kink modes when the frequencies of the FSW+ and FSW− become out of the Alfvén continuum. It is also shown that in the static case and for a weak flow case, the FSW+ (FSW−) is interpreted as a vertically (horizontally) polarized kink mode, while for moderate flow, both modes have oblique polarization. We apply the developed theory to interpret the observational cases of kink oscillations in coronal loops with signatures of a siphon flow and the onset of KH instability induced by the blowout jet along a loop-shaped magnetic structure.

Seismology of Curved Coronal Loops Using Multiperiodic Kink Oscillations.

Lopin, I.

Sol Phys 299, 68 (**2024**).

https://doi.org/10.1007/s11207-024-02305-y

It was shown recently that the model of a semicircular magnetic slab with oblique wave propagation and finite plasma-� supports two fast surface modes, one of which produces vertical and the other horizontal kink-like motions. Their phase speeds (frequencies) depend upon the internal plasma-� and slab aspect ratio. Thus the theory predicts the coexistence of two kink modes with different polarizations and periods in a single oscillating loop. In the present work, we aim to perform some analytical extensions of the developed theory and propose methods for seismological estimation of internal plasma-� and internal Alfvén speed on the bases of multiperiodic kink oscillations of coronal loops. We show that when two fundamental modes of vertically and horizontally polarized kink oscillations with different periods are observed in a single coronal loop, this provides the seismological estimation of the internal plasma-� and Alfvén speed. We also show that the combined effect of a finite plasma-� and a slab curvature modifies the ratio of periods �1/2�2 of the fundamental mode and first overtone of a certain kink oscillation and the internal plasma-� can be estimated using detected �1/2�2. We also suggest that the strands with different temperatures that constitute the multithermal loops should oscillate with different periods and this may provide an estimate to the internal Alfvén speed in such loops. These findings are applied to a number of observations of multiperiodic coronal loop kink oscillations. Furthermore, a number of unusual observational results and the results of numerical simulations of kink oscillations in curved magnetic loops were interpreted on the bases of the developed theory.

Decayless low-amplitude transverse oscillations in short coronal loops as manifestations of driven slow modes

I **Lopin**, I Nagorny

MNRAS, Volume 527, Issue 3, January **2024**, Pages 5741–5750,

https://doi.org/10.1093/mnras/stad3527

https://academic.oup.com/mnras/article-pdf/527/3/5741/53980109/stad3527.pdf

A recent theoretical study of slow magnetoacoustic oscillations in a curved magnetic slab shows that the principal slow mode causes both dominant longitudinal motions and radial (transverse) kink-like motions of a slab. This modification of wave properties occurs due to the violation of the symmetry of wave motions with respect to the waveguide axis and the slow to fast wave interaction in curved magnetic configurations. In this work, we carry out a comprehensive investigation of the principal slow mode depending on the model parameters. It is shown that the dominance of longitudinal motions in the principal slow mode decreases as both the internal plasma-β and slab aspect ratio increase. The results are used to explain the observed small amplitude decayless transverse oscillations in short coronal loops. In particular, these phenomena are interpreted as direct manifestation of slow mode oscillations in curved coronal loops excited at the footpoints by compressible oscillations of the underlying atmospheric layers. Numerical calculations have shown that the observed velocity range of $V = 0.6$–$5\ \mathrm{km\ s^{-1}}$ corresponds to radial velocity amplitudes in the principal slow mode, provided that the plasma-β inside the short loops is in the range of $\beta_i = 0.3$–0.5 and the loop aspect ratio $0.15 \leq a/R \leq 0.25$. These parameters appear to be typical for low-lying small coronal loops extending from the transition region to the lower corona.

The Effect of Mass Flow on Slow MHD Oscillations of Curved Solar Coronal Loops

Igor **Lopin**

Solar Physics volume 298, Article number: 101 (**2023**)

https://doi.org/10.1007/s11207-023-02197-4

Slow-mode standing waves are examined in the model of a bent magnetic slab with a plasma flow directed along curved magnetic field lines. The dispersion relation is obtained and studied both numerically and analytically regarding the principal slow mode. It is found that flow decreases the longitudinal oscillating motions and increases the radial kink-like motions, both produced by the principal slow mode. This feature may result in the development of Kelvin-Helmholtz instability when the flow speed exceeds the critical value, and this threshold depends on the azimuthal number m. When flow exists, a quasi-stationary wave structure that satisfies the footpoint boundary conditions has the form of a propagating wave modulated by a sinusoidal envelope. The corresponding eigenfrequencies of oscillations are found to decrease with increasing flow speed until $u<c_{Ti}$. The results obtained are used for seismological estimation of a plasma flow speed in coronal fan loops experiencing slow mode oscillations.

Slow mode oscillations in curved arcade loops

I **Lopin**, I Nagorny

MNRAS, Volume 519, Issue 4, March **2023**, Pages 5579–5589,

https://doi.org/10.1093/mnras/stad062

In this work we theoretically investigate the effect of curvature on the slow-mode oscillations in coronal loop arcade. A simple model of an arc circle magnetic slab is used to simulate curved coronal magnetic structures. Solving the set of magnetohydrodynamic (MHD) equations for a compressible plasma, we obtain the dispersion relation that governs the compressible MHD modes in the model. A band of slow body modes with phase speeds close to the internal tube speed and a single hybrid slow mode with phase speed close to the external tube speed are found to exist under typical coronal circumstances. The principal slow body and hybrid modes both produce radial kink-like displacements of the slab axis and distort its cross-section. These motions are accompanied with the dominating longitudinal oscillations. Such mode properties may result in Doppler shift and intensity oscillations as well as oscillating spatial displacements, observed in coronal loops. A number of observations of long-period oscillations in arcade loops are interpreted on the basis of the developed theory.

Fast-sausage oscillations in coronal loops with smooth boundary

I. **Lopin**1 and I. Nagorny

A&A 572, A60 (2014)

Aims. The effect of the transition layer (shell) in nonuniform coronal loops with a continuous radial density profile on the properties of fast-sausage modes are studied analytically and numerically.

Methods. We modeled the coronal waveguide as a structured tube consisting of a cord and a transition region (shell) embedded within a magnetic uniform environment. The derived general dispersion relation was investigated

analytically and numerically in the context of frequency, cut-off wave number, and the damping rate of fast-sausage oscillations for various values of loop parameters.
Results. The frequency of the global fast-sausage mode in the loops with a diffuse (or smooth) boundary is determined mainly by the external Alfvén speed and longitudinal wave number. The damping rate of such a mode can be relatively low. The model of coronal loop with diffuse boundary can support a comparatively low-frequency, global fast-sausage mode of detectable quality without involving extremely low values of the density contrast. The effect of thin transition layer (corresponds to the loops with steep boundary) is negligible and produces small reductions of oscillation frequency and relative damping rate in comparison with the case of step-function density profile. Seismological application of obtained results gives the estimated Alfvén speed outside the flaring loop about 3.25 Mm/s.

Kink Wave Propagation in Thin Isothermal Magnetic Flux Tubes

I. P. **Lopin**, I. G. Nagorny, E. Nippolainen

Solar Physics, Volume 289, Issue 8, pp 3033-3041 **2014**

We investigated the propagation of kink waves in thin and isothermal expanding flux tubes in cylindrical geometry. By using the method of radial expansion for fluctuating variables we obtained a new kink wave equation. We show that including the radial component of the tube magnetic field leads to cutoff-free propagation of kink waves along thin flux tubes.

Testing the Accuracy of Coimbra Astronomical Observatory Solar Filament Historical Series (1929–1941)

Ana **Lourenço**, Ricardo Gafeira, Vitor Bonifácio, Teresa Barata, João Fernandes & Eva Silva

Solar Physics volume 296, Article number: 155 (**2021**)

https://link.springer.com/content/pdf/10.1007/s11207-021-01892-4.pdf

https://doi.org/10.1007/s11207-021-01892-4

The present work aims to validate the positions of solar filaments published in the Annals of Coimbra University Astronomical Observatory, currently the Geophysical and Astronomical Observatory of the University of Coimbra, corresponding to years 1929 to 1941. The published Stonyhurst positions were obtained by an original method devised in the early 20th century that used a spherical calculator instrument, a wood-made model of the Sun. We used the digital images of the original spectroheliograms to measure the positions of the filaments, and heliographic coordinates were determined with the routines implemented in the Python package Sunpy. The correlation coefficients between both sets of coordinates are positive and highly significant. The results validate the method used at the Coimbra observatory and the published data. We conclude that the Coimbra solar filament catalogues are reliable and can therefore be considered for future solar activity studies.

THE HYDROMAGNETIC INTERIOR OF A SOLAR QUIESCENT PROMINENCE. II. MAGNETIC DISCONTINUITIES AND CROSS-FIELD MASS TRANSPORT

B. C. **Low**1, W. Liu2,3, T. Berger2,4, and R. Casini

2012 ApJ 757 21

This second paper of the series investigates the transverse response of a magnetic field to the independent relaxation of its flux tubes of fluid seeking hydrostatic and energy balance, under the frozen-in condition and suppression of cross-field thermal conduction. The temperature, density, and pressure naturally develop discontinuities across the magnetic flux surfaces separating the tubes, requiring the finite pressure jumps to be compensated by magnetic-pressure jumps in cross-field force balance. The tangentially discontinuous fields are due to discrete currents in these surfaces, δ-function singularities in the current density that are fully admissible under the rigorous frozen-in condition but must dissipate resistively if the electrical conductivity is high but finite. The magnetic field and fluid must thus endlessly evolve by this spontaneous formation and resistive dissipation of discrete currents taking place intermittently in spacetime, even in a low-β environment. This is a multi-dimensional effect in which the field plays a central role suppressed in the one-dimensional (1D) slab model of the first paper. The study begins with an order-of-magnitude demonstration that of the weak resistive and cross-field thermal diffusivities in the corona, the latter is significantly weaker for small β. This case for spontaneous discrete currents, as an important example of the general theory of Parker, is illustrated with an analysis of singularity formation in three families of two-dimensional generalizations of the 1D slab model. The physical picture emerging completes the hypothesis formulated in Paper I that this intermittent process is the origin of the dynamic interiors of a class of quiescent prominences revealed by recent Hinode/SOT and SDO/AIA high-resolution observations.

THE HYDROMAGNETIC INTERIOR OF A SOLAR QUIESCENT PROMINENCE. I. COUPLING BETWEEN FORCE BALANCE AND STEADY ENERGY TRANSPORT

B. C. **Low**1, T. Berger2, R. Casini1, and W. Liu

2012 ApJ 755 34

This series of papers investigates the dynamic interiors of quiescent prominences revealed by recent Hinode and SDO/AIA high-resolution observations. This first paper is a study of the static equilibrium of the Kippenhahn-Schlüter diffuse plasma slab, suspended vertically in a bowed magnetic field, under the frozen-in condition and subject to a theoretical thermal balance among an optically thin radiation, heating, and field-aligned thermal conduction. The everywhere-analytical solutions to this nonlinear problem are an extremely restricted subset of the physically admissible states of the system. For most values of the total mass frozen into a given bowed field, force balance and steady energy transport cannot both be met without a finite fraction of the total mass having collapsed into a cold sheet of zero thickness, within which the frozen-in condition must break down. An exact, resistive hydromagnetic extension of the Kippenhahn-Schlüter slab is also presented, resolving the mass-sheet singularity into a finite-thickness layer of steadily falling dense fluid. Our hydromagnetic result suggests that the narrow, vertical prominence Hα threads may be falling across magnetic fields, with optically thick cores much denser and ionized to much lower degrees than conventionally considered. This implication is discussed in relation to (1) the recent SDO/AIA observations of quiescent prominences that are massive and yet draining mass everywhere in their interiors, (2) the canonical range of 5-60 G determined from spectral polarimetric observations of prominence magnetic fields over the years, and (3) the need for a more realistic multi-fluid treatment.

Study of the excitation of large-amplitude oscillations in a prominence by nearby flares

Manuel **Luna**1,2⋆, Reetika Joshi3,4, Brigitte Schmieder5,6,7, Fernando Moreno-Insertis8,9, Valeriia Liakh6 and Jaume Terradas1,2

A&A, 691, A354 (**2024**)

https://arxiv.org/pdf/2410.10223

https://www.aanda.org/articles/aa/pdf/2024/11/aa50869-24.pdf

Context. Large-amplitude oscillations are a common occurrence in solar prominences. These oscillations are triggered by energetic phenomena such as jets and flares. On **March 14–15, 2015**, a filament partially erupted in two stages, leading to oscillations in different parts of it.

Aims. In this study, we aim to explore the longitudinal oscillations resulting from the eruption, with special focus on unravelling the underlying mechanisms responsible for their initiation. We pay special attention to the huge oscillation on March 15.

Methods. The oscillations and jets were analysed using the time-distance technique. For the study of flares and their interaction with the filament, we analysed the different AIA channels in detail and used the differential-emission-measure (DEM) technique.

Results. In the initial phase of the event, a jet induces the fragmentation of the filament, which causes it to split into two segments. One of the segments remains in the same position, while the other is detached and moves to a different location. This causes oscillations in both segments: (a) the change of position apparently causes the detached segment to oscillate longitudinally with a period of 69 ± 3 minutes; (b) the jet flows reach the remaining filament also producing longitudinal oscillations with a period of 62 ± 2 minutes. In the second phase, on March 15, another jet seemingly activates the detached filament eruption. After the eruption, there is an associated flare. A large longitudinal oscillation is produced in the remnant segment with a period of 72 ± 2 minutes and a velocity amplitude of 73 ± 16. During the triggering of the oscillation, bright field lines connect the flare with the filament. These only appear in the AIA 131 Å and 94 Å channels, indicating that they contain very hot plasma. The DEM analysis also confirms this result. Both indicate that a plasma of around 10 MK pushes the prominence from its south-eastern side, displacing it along the field lines and initiating the oscillation. From this evidence, the flare and not the preceding jet initiates the oscillation. The hot plasma from the flare escapes and flows into the filament channel structure.

Conclusions. In this paper, we shed light on how flares can initiate the huge oscillations in filaments. We propose an explanation in which part of the post-flare loops reconnect with the filament channel's magnetic-field lines that host the prominence.

Automatic detection technique for solar filament oscillations in GONG data

Manuel **Luna**, Joan-René Merou Mestre, Frédéric Auchère

A&A **2022**

https://arxiv.org/pdf/2209.05087.pdf

Solar filament oscillations have been known for decades. Now thanks to the new capabilities of the new telescopes, these periodic motions are routinely observed. Oscillations in filaments show key aspects of their structure. A systematic study of filament oscillations over the solar cycle can shed light on the evolution of the prominences. This work is a proof of concept that aims to automatically detect and parameterise such oscillations using Hα data from the GONG network of telescopes. The proposed technique studies the periodic fluctuations of every pixel of the Hα data cubes. Using the FFT we compute the power spectral density (PSD). We define a criterion to consider whether it is a real oscillation or whether it is a spurious fluctuation. This consists in considering that the peak in the PSD must be greater than several times the background noise with a confidence level of 95\%. The background noise is well fitted to a combination of red and white noise. We applied the method to several observations already

reported in the literature to determine its reliability. We also applied the method to a test case, which is a data set in which the oscillations of the filaments were not known a priori. The method shows that there are areas in the filaments with PSD above the threshold value. The periodicities obtained are in general agreement with the values obtained by other methods. In the test case, the method detects oscillations in several filaments. We conclude that the proposed spectral technique is a powerful tool to automatically detect oscillations in prominences using Hα data.
1 Jan 2014, 9 Feb 2014, 13 Feb 2014, 16 Jun 2014, 15 Mar 2015, 9 Feb 2022

Extension and validation of the pendulum model for longitudinal solar prominence oscillations

M. **Luna**, J. Terradas, J. Karpen, J. L. Ballester
A&A 660, A54 **2022**
https://arxiv.org/pdf/2202.07957.pdf
https://www.aanda.org/articles/aa/pdf/2022/04/aa42907-21.pdf
Longitudinal oscillations in prominences are common phenomena on the Sun. 660, A54Previous theoretical studies of longitudinal oscillations made two simplifying assumptions: uniform gravity and semi-circular dips on the supporting flux tubes. However, the gravity is not uniform and realistic dips are not semi-circular. To understand the effects of including the nonuniform solar gravity on longitudinal oscillations, and explore the validity of the pendulum model with different flux-tube geometries. We first derive the equation describing the motion of the plasma along the flux tube including the effects of nonuniform gravity, yielding corrections to the original pendulum model. We also compute the full numerical solutions for the normal modes, and compare them with the new pendulum approximation. We have found that the nonuniform gravity introduces a significant modification in the pendulum model. We have also found a cut-off period, i.e. the longitudinal oscillations cannot have a period longer than 167 minutes. In addition, considering different tube geometries, the period depends almost exclusively on the radius of curvature at the bottom of the dip. We conclude that nonuniform gravity significantly modifies the pendulum model. These corrections are important for prominence seismology, because the inferred values of the radius of curvature and minimum magnetic-field strength differ substantially from those of the old model. However, we find that the corrected pendulum model is quite robust and is still valid for non-circular dips.

Large-amplitude prominence oscillations following the impact by a coronal jet

Manuel **Luna**, Fernando Moreno-Insertis
ApJ **912** 75 **2021**
https://arxiv.org/pdf/2103.02661.pdf
https://doi.org/10.3847/1538-4357/abec46
Observational evidence shows that coronal jets can hit prominences and set them in motion. The impact leads to large-amplitude oscillations (LAOs) of the prominence. In this paper we attempt to understand this process via 2.5D MHD numerical experiments. In our model, the jets are generated in a sheared magnetic arcade above a parasitic bipolar region located in one of the footpoints of the filament channel (FC) supporting the prominence. The shear is imposed with velocities not far above observed photospheric values; it leads to a multiple reconnection process, as in previous jet models. Both a fast Alfvénic perturbation and a slower supersonic front preceding a plasma jet are issued from the reconnection site; in the later phase, a more violent (eruptive) jet is produced. The perturbation and jets run along the FC; they are partially reflected at the prominence and partially transmitted through it. There results a pattern of counter-streaming flows along the FC and oscillations of the prominence. The oscillations are LAOs (with amplitude above 10 kms^{-1}) in parts of the prominence both in the longitudinal and transverse directions. In some field lines, the impact is so strong that the prominence mass is brought out of the dip and down to the chromosphere along the FC. Two cases are studied with different heights of the arcade above the parasitic bipolar region, leading to different heights for the region of the prominence perturbed by the jets. The obtained oscillation amplitudes and periods are in general agreement with the observations.

GONG Catalog of Solar Filament Oscillations Near Solar Maximum

Manuel **Luna**, Judith Karpen, José Luís Ballester, Karin Muglach, Jaume Terradas, Therese Kucera, Holly Gilbert
Astrophysical Journal Supplement Series **236** 35 **2018**
https://arxiv.org/pdf/1804.03743.pdf
We have catalogued 196 filament oscillations from the GONG Hα network data during several months near the maximum of solar cycle 24 (January - June 2014). Selected examples from the catalog are described in detail, along with our statistical analyses of all events. Oscillations were classified according to their velocity amplitude: 106 small-amplitude oscillations (SAOs), with velocities < 10 km s^{-1} , and 90 large-amplitude oscillations (LAOs), with velocities > 10 km s^{-1} . Both SAOs and LAOs are common, with one event of each class every two days on the visible side of the Sun. For nearly half of the events we identified their apparent trigger. The period distribution has a mean value of 58±15 min for both types of oscillations. The distribution of the damping time per period peaks at τ/P = 1.75 and 1.25 for SAOs and LAOs respectively. We confirmed that LAO damping rates depend nonlinearly on

the oscillation velocity. The angle between the direction of motion and the filament spine has a distribution centered at 27◦ for all filament types. This angle agrees with the observed direction of filament-channel magnetic fields, indicating that most of the catalogued events are longitudinal (i.e., undergo field-aligned motions). We applied seismology to determine the average radius of curvature in the magnetic dips, R ≈ 89 Mm, and the average minimum magnetic-field strength, B ≈ 16 G. The catalog is available to the community online, and is intended to be expanded to cover at least 1 solar cycle**. 1 Jan 2014, 9 Feb 2014, 13 Feb 2014, 29 March 2014, 26 May 2014, 30 May 2014, 21 Apr 2014**
Table

Large-Amplitude Longitudinal Oscillations Triggered by the Merging of Two Solar Filaments: Observations and Magnetic Field Analysis

M. **Luna**, Y. Su, B. Schmieder, R. Chandra, T. A. Kucera

ApJ **850** 143 **2017**

https://arxiv.org/pdf/1711.01038.pdf

We follow the eruption of two related intermediate filaments observed in Hα (from GONG) and in EUV (from SDO/AIA) and the resulting large-amplitude longitudinal oscillations of the plasma in the filament channels. The events occurred in and around the decayed active region AR12486 on **2016 January 26**. Our detailed study of the oscillation reveals that the periods of the oscillations are about one hour. In Hα the period decreases with time and exhibits strong damping. The analysis of 171~\AA\ images shows that the oscillation has two phases, an initial long period phase and a subsequent oscillation with a shorter period. In this wavelength the damping appears weaker than in Hα. The velocity is the largest ever detected in a prominence oscillation, approximately 100 kms−1. Using SDO/HMI magnetograms we reconstruct the magnetic field of the filaments modeled as flux ropes by using a flux-rope insertion method. Applying seismological techniques we determine that the radii of curvature of the field lines in which cool plasma is condensed are in the range 75-120~Mm, in agreement with the reconstructed field. In addition, we infer a field strength of ≥7 to 30 gauss, depending on the electron density assumed; that is also in agreement with the values from the reconstruction (8-20 gauss). The poloidal flux is zero and the axis flux is of the order of 1020 to 1021 Mx, confirming the high shear existing even in a non-active filament.

The effects of magnetic-field geometry on longitudinal oscillations of solar prominences: Cross-sectional area variation for thin tubes

M. **Luna**, A. J. Diaz, R. Oliver, J. Terradas, J. Karpen

A&A 593, A64 **2016**

http://arxiv.org/pdf/1607.02996v1.pdf

Solar prominences are subject to both field-aligned (longitudinal) and transverse oscillatory motions, as evidenced by an increasing number of observations. Large-amplitude longitudinal motions provide valuable information on the geometry of the filament-channel magnetic structure that supports the cool prominence plasma against gravity. Our pendulum model, in which the restoring force is the gravity projected along the dipped field lines of the magnetic structure, best explains these oscillations. However, several factors can influence the longitudinal oscillations, potentially invalidating the pendulum model. The aim of this work is to study the influence of large-scale variations in the magnetic field strength along the field lines, i.e., variations of the cross-sectional area along the flux tubes supporting prominence threads. We studied the normal modes of several flux tube configurations, using linear perturbation analysis, to assess the influence of different geometrical parameters on the oscillation properties. We found that the influence of the symmetric and asymmetric expansion factors on longitudinal oscillations is small. We conclude that the longitudinal oscillations are not significantly influenced by variations of the cross-section of the flux tubes, validating the pendulum model in this context.

On the robustness of the pendulum model for large-amplitude longitudinal oscillations in prominences

M. **Luna**, J. Terradas, E. Khomenko, M. Collados, A. de Vicente

ApJ 817 157 **2016**

http://arxiv.org/pdf/1512.05125v1.pdf

Large-amplitude longitudinal oscillations (LALOs) in prominences are spectacular manifestations of the solar activity. In such events nearby energetic disturbances induce periodic motions on filaments with displacements comparable to the size of the filaments themselves and with velocities larger than 20 km/s. The pendulum model, in which the gravity projected along a rigid magnetic field is the restoring force, was proposed to explain these events. However, it can be objected that in a realistic situation where the magnetic field reacts to the mass motion of the heavy prominence, the simplified pendulum model could be no longer valid. We have performed non-linear time-dependent numerical simulations of LALOs considering a dipped magnetic field line structure. In this work we demonstrate that for even relatively weak magnetic fields the pendulum model works very well. We therefore validate the pendulum model and show its robustness, with important implications for prominence seismology purposes. With this model it is possible to infer the geometry of the dipped field lines that support the prominence.

Are tornado-like magnetic structures able to support solar prominence plasma?

M. **Luna**, F. Moreno-Insertis & E. Priest

ApJL **808** L23 **2015**

http://www.iac.es/preprints/files/PP15069.pdf

http://arxiv.org/pdf/1507.01455v1.pdf

https://iopscience.iop.org/article/10.1088/2041-8205/808/1/L23/pdf

Recent high-resolution and high-cadence observations have surprisingly suggested that prominence barbs exhibit apparent rotating motions suggestive of a tornado-like structure. Additional evidence has been provided by Doppler measurements. The observations reveal opposite velocities for both hot and cool plasma on the two sides of a prominence barb. This motion is persistent for several hours and has been interpreted in terms of rotational motion of prominence feet. Several authors suggest that such barb motions are rotating helical structures around a vertical axis similar to tornadoes on Earth. One of the difficulties of such a proposal is how to support cool prominence plasma in almost-vertical structures against gravity. In this work we model analytically a tornado-like structure and try to determine possible mechanisms to support the prominence plasma. We have found that the Lorentz force can indeed support the barb plasma provided the magnetic structure is sufficiently twisted and/or significant poloidal flows are present.

Observations and Implications of Large-Amplitude Longitudinal Oscillations in a Solar Filament

M. **Luna**, K. Knizhnik, K. Muglach, J. Karpen, H. Gilbert, T.A. Kucera, V. Uritsky

E-print, March **2014**; ApJ, **2014** 785 79

http://arxiv.org/pdf/1403.0381v1.pdf

On 20 August 2010 an energetic disturbance triggered large-amplitude longitudinal oscillations in a nearby filament. The triggering mechanism appears to be episodic jets connecting the energetic event with the filament threads. In the present work we analyze this periodic motion in a large fraction of the filament to characterize the underlying physics of the oscillation as well as the filament properties. The results support our previous theoretical conclusions that the restoring force of large-amplitude longitudinal oscillations is solar gravity, and the damping mechanism is the ongoing accumulation of mass onto the oscillating threads. Based on our previous work, we used the fitted parameters to determine the magnitude and radius of curvature of the dipped magnetic field along the filament, as well as the mass accretion rate onto the filament threads. These derived properties are nearly uniform along the filament, indicating a remarkable degree of cohesiveness throughout the filament channel. Moreover, the estimated mass accretion rate implies that the footpoint heating responsible for the thread formation, according to the thermal nonequilibrium model, agrees with previous coronal heating estimates. We estimate the magnitude of the energy released in the nearby event by studying the dynamic response of the filament threads, and discuss the implications of our study for filament structure and heating.

THE EFFECTS OF MAGNETIC-FIELD GEOMETRY ON LONGITUDINAL OSCILLATIONS OF SOLAR PROMINENCES

M. **Luna**1, A. J. Díaz2,3, and J. Karpen

2012 ApJ 757 98

We investigate the influence of the geometry of the solar filament magnetic structure on the large-amplitude longitudinal oscillations. A representative filament flux tube is modeled as composed of a cool thread centered in a dipped part with hot coronal regions on either side. We have found the normal modes of the system and establish that the observed longitudinal oscillations are well described with the fundamental mode. For small and intermediate curvature radii and moderate to large density contrast between the prominence and the corona, the main restoring force is the solar gravity. In this full wave description of the oscillation a simple expression for the oscillation frequencies is derived in which the pressure-driven term introduces a small correction. We have also found that the normal modes are almost independent of the geometry of the hot regions of the tube. We conclude that observed large-amplitude longitudinal oscillations are driven by the projected gravity along the flux tubes and are strongly influenced by the curvature of the dips of the magnetic field in which the threads reside.

LARGE-AMPLITUDE LONGITUDINAL OSCILLATIONS IN A SOLAR FILAMENT

M. **Luna**1 and J. Karpen

2012 ApJ 750 L1

We have developed the first self-consistent model for the observed large-amplitude oscillations along filament axes that explains the restoring force and damping mechanism. We have investigated the oscillations of multiple threads formed in long, dipped flux tubes through the thermal nonequilibrium process, and found that the oscillation properties predicted by our simulations agree with the observed behavior. We then constructed a model for the large-amplitude longitudinal oscillations that demonstrates that the restoring force is the projected gravity in the tube where the threads oscillate. Although the period is independent of the tube length and the constantly growing mass, the motions are strongly damped by the steady accretion of mass onto the threads by thermal nonequilibrium. The observations and our model suggest that a nearby impulsive event drives the existing prominence threads along their supporting tubes, away from the heating deposition site, without destroying them. The subsequent oscillations occur because the displaced threads reside in magnetic concavities with large radii of curvature. Our model yields a powerful seismological method for constraining the coronal magnetic field and radius of curvature of dips. Furthermore, these results indicate that the magnetic structure is most consistent with the sheared-arcade model for filament channels.

FORMATION AND EVOLUTION OF A MULTI-THREADED SOLAR PROMINENCE

M. **Luna**, J. T. Karpen2 and C. R. DeVore

2012 ApJ 746 30

We investigate the process of formation and subsequent evolution of prominence plasma in a filament channel and its overlying arcade. We construct a three-dimensional time-dependent model of an intermediate quiescent prominence suitable to be compared with observations. We combine the magnetic field structure of a three-dimensional sheared double arcade with one-dimensional independent simulations of many selected flux tubes, in which the thermal nonequilibrium process governs the plasma evolution. We have found that the condensations in the corona can be divided into two populations: threads and blobs. Threads are massive condensations that linger in the flux tube dips. Blobs are ubiquitous small condensations that are produced throughout the filament and overlying arcade magnetic structure, and rapidly fall to the chromosphere. The threads are the principal contributors to the total mass, whereas the blob contribution is small. The total prominence mass is in agreement with observations, assuming reasonable filling factors of order 0.001 and a fixed number of threads. The motion of the threads is basically horizontal, while blobs move in all directions along the field. We have generated synthetic images of the whole structure in an Hα proxy and in two EUV channels of the Atmospheric Imaging Assembly instrument on board Solar Dynamics Observatory, thus showing the plasma at cool, warm, and hot temperatures. The predicted differential emission measure of our system agrees very well with observations in the temperature range log T = 4.6-5.7. We conclude that the sheared-arcade magnetic structure and plasma behavior driven by thermal nonequilibrium fit the abundant observational evidence well for typical intermediate prominences.

Modelling and observations: Comparison of the magnetic field properties in a prominence

D. H. **Mackay**1, B. Schmieder2, A. López Ariste3 and Y. Su4,5

A&A 637, A3 (**2020**)

https://www.aanda.org/articles/aa/pdf/2020/05/aa36656-19.pdf

Context. Direct magnetic field measurements in solar prominences occur infrequently and are difficult to make and interpret. As a consequence, alternative methods are needed to derive the main properties of the magnetic field that supports the prominence mass. This is important for our understanding of solar prominences, but also for understanding how eruptive prominences may affect space weather.

Aims. We present the first direct comparison of the magnetic field strength derived from spectro-polarimetric observations of a solar prominence, with corresponding results from a theoretical flux rope model constructed from on-disc normal component magnetograms.

Methods. We first used spectro-polarimetric observations of a prominence obtained with the magnetograph THEMIS operating in the Canary Islands to derive the magnetic field of the observed prominence by inverting the Stokes parameters measured in the He D3 line. Next, we constructed two data-constrained non-linear force-free field (NLFFF) models of the same prominence. In one model we assumed a strongly twisted flux rope solution, and in the other a weakly twisted flux rope solution.

Results. The physical extent of the prominence at the limb (height and length) is best reproduced with the strongly twisted flux rope solution. The line-of-sight average of the magnetic field for the strongly twisted solution results in a magnetic field that has a magnitude of within a factor of 1−2 of the observed magnetic field strength. For the peak field strength along the line of sight, an agreement to within 20% of the observations is obtained for the strongly twisted solution. The weakly twisted solution produces significantly lower magnetic field strengths and gives a poor agreement with the observations.

Conclusions. The results of this first comparison are promising. We found that the flux rope insertion method of producing a NLFFF is able to deduce the overall properties of the magnetic field in an observed prominence.

Physics of Solar Prominences: II: Magnetic Structure and Dynamics –

D.H. **Mackay**, J.T. Karpen, J.L. Ballester, B. Schmieder and G. Aulanier.

Space Science Reviews, **2010,** 151, 333.

http://arxiv.org/abs/1001.1635

Observations and models of solar prominences are **review**ed. We focus on non-eruptive prominences, and describe recent progress in four areas of prominence research: (1) magnetic structure deduced from observations and models, (2) the dynamics of prominence plasmas (formation and flows), (3) Magneto-hydrodynamic (MHD) waves in prominences and (4) the formation and large-scale patterns of the filament channels in which prominences are located. Finally, several outstanding issues in prominence research are discussed, along with observations and models required to resolve them.

(See **Physics of Solar Prominences: I: Spectral Diagnostics and Non-LTE Modelling –** N. **Labrosse et al. 2010)**

A Non-Linear Force-Free Field Model for the Evolving Magnetic Structure of Solar Filaments

Duncan H. **Mackay**[1] and A. A. van Ballegooijen

Solar Phys., 260(2), 321-346, **2009**

In this paper the effect of a small magnetic element approaching the main body of a solar filament is considered through non-linear force-free field modeling. The filament is represented by a series of magnetic dips. Once the dips are calculated, a simple hydrostatic atmosphere model is applied to determine which structures have sufficient column mass depth to be visible in Hα. Two orientations of the bipole are considered, either parallel or anti-parallel to the overlying arcade. The magnetic polarity that lies closest to the filament is then advected towards the filament. Initially for both the dominant and minority polarity advected elements, right/left bearing barbs are produced for dextral/sinsitral filaments. The production of barbs due to dominant polarity elements is a new feature. In later stages the filament breaks into two dipped sections and takes a highly irregular, non-symmetrical form with multiple pillars. The two sections are connected by field lines with double dips even though the twist of the field is less than one turn. Reconnection is not found to play a key role in the break up of the filament. The non-linear force-free fields produce very different results to extrapolated linear-force free fields. For the cases considered here the linear force-free field does not produce the break up of the filament nor the production of barbs as a result of dominant polarity elements.

Where Do Solar Filaments Form?: Consequences for Theoretical Models

Duncan H. **Mackay**, Victor Gaizauskas, Anthony R. Yeates

Solar Phys. 248(1), 51-65, **2008**

http://www.springerlink.com/content/9m74783742414738/fulltext.pdf

This paper examines the locations where large, stable solar filaments form relative to magnetic bipoles lying underneath them.

Finally, current observations and theoretical models for the formation of filaments are discussed in the context of the present results. We conclude that key elements in the formation of the majority of filaments considered within this study must be the convergence of magnetic flux resulting in either flux cancellation or coronal reconnection.

Dynamics and plasma properties of an X-ray jet from SUMER, EIS, XRT, and EUVI A & B simultaneous observations*

M. S. **Madjarska**

A&A 526, A19 (**2011**)

Context. Small-scale transient phenomena in the quiet Sun are believed to play an important role in coronal heating and solar wind generation. One of them, called “X-ray jet”, is the subject of our study.

Aims. We intend to investigate the dynamics, evolution, and physical properties of this phenomenon.

Methods. We combine multi-instrument observations obtained simultaneously with the SUMER spectrometer onboard SoHO, with EIS and XRT onboard Hinode, and with EUVI/SECCHI onboard the Ahead and Behind STEREO spacecrafts. We derive plasma parameters such as temperatures and densities as well as dynamics by using spectral lines formed in the temperature range from 10 000 K to 12 MK. We also use an image difference technique to investigate the evolution of the complex structure of the studied phenomenon.

Results. With the available unique combination of data we were able to establish that the formation of a jet-like event is triggered by not one, but several energy depositions, which are most probably originating from magnetic reconnection. Each energy deposition is followed by the expulsion of pre-existing or newly reconnected loops and/or collimated flow along open magnetic field lines. We derived in great detail the dynamic process of X-ray jet formation and evolution. For the first time we also found spectroscopically a temperature of 12 MK (Fe xxiii 263.76 Å) and density of 4 × 1010 cm-3 in the quiet Sun, obtained from a pair of Fe xii lines with a maximum formation temperature of 1.3 × 106 K, in an energy deposition region. We point out a problem concerning an uncertainty in using the SUMER Mg x 624.9 Å line for coronal diagnostics. We clearly identified two types of up-flow: one collimated up-flow along open magnetic field lines and a plasma cloud formed from the expelled BP loops. We also report a cooler down-flow along closed magnetic field lines. A comparison is made with a model developed by Moreno-Insertis et al. (2008).

Explosive events associated with a surge

M.S. **Madjarska**, J.G. Doyle & B. de Pontieu

E-print, June **2009**; ApJ, **701** 253-259, **2009** doi: 10.1088/0004-637X/701/1/253

The solar atmosphere contains a wide variety of small-scale transient features. Here, we explore the inter-relation between some of them such as surges, explosive events and blinkers via simultaneous spectral and imaging data taken with the TRACE imager, the SUMER, and CDS spectrometers on board SoHO, and SVST La Palma. The features were observed in spectral lines with formation temperatures from 10,000 K to 1 MK and with the TRACE Fe ix/x 171 A filter. The Halpha filtergrams were taken in the wings of the H 6365 A line at ?700 mA and ?350 mA. The alignment of all data both in time and solar XY shows that SUMER line profiles, which are attributed to explosive events, are due to a surge phenomenon. The surge?s up- and down-flows which often appear simultaneously correspond to the blue- and red-shifted emission of the transition region N V 1238.82 A and O V 629.77 A lines as well as radiance increases of the C I, S I and S II and Si II chromospheric lines. Some parts of the surge are also visible in the TRACE 171 A images which could suggest heating to coronal temperatures. The surge is triggered, most probably, by one or more Elerman bombs which are best visible in H ?350 A but were also registered by TRACE Fe IX/X 171 A and correspond to a strong radiance increase in the CDS Mg IX 368.07 A line. With the present study we demonstrate that the division of small-scale transient events into a number of different subgroups, for instance explosive events, blinkers, spicules, surges or just brightenings, is ambiguous, implying that the definition of a feature based only on either spectroscopic or imaging characteristics as well as insufficient spectral and spatial resolution can be incomplete.

Evolution and Dynamics of a Solar Active Prominence

Tetsuya **Magara**

2015

http://arxiv.org/pdf/1508.00672v1.pdf

The life of a solar active prominence, one of the most remarkable objects on the Sun, is full of dynamics; after first appearing on the Sun the prominence continuously evolves with various internal motions and eventually produces a global eruption toward the interplane- tary space. Here we report that the whole life of an active prominence is successfully re- produced by performing as long-term a magnetohydrodynamic simulation of a magnetized prominence plasma as was ever done. The simulation reveals underlying dynamic processes that give rise to observed properties of an active prominence: invisible subsurface flows self- consistently produce the cancellation of magnetic flux observed at the photosphere, while observed and somewhat counterintuitive strong upflows are driven against gravity by en- hanced gas pressure gradient force along a magnetic field line locally standing vertical. The most highlighted dynamic event, transition into an eruptive phase, occurs as a natural con- sequence of the self-consistent evolution of a prominence plasma interacting with a magnetic field, which is obtained by seamlessly reproducing dynamic processes involved in the forma- tion and eruption of an active prominence.

The dynamics and observability of circularly polarized kink waves

N. **Magyar**, T. Duckenfield, T. Van Doorsselaere, V. M. Nakariakov

A&A 659, A73 **2022**

https://arxiv.org/pdf/2112.14951.pdf

https://doi.org/10.1051/0004-6361/202141945

https://www.aanda.org/articles/aa/pdf/2022/03/aa41945-21.pdf

Context. Kink waves are routinely observed in coronal loops. Resonant absorption is a well-accepted mechanism that extracts energy from kink waves. Nonlinear kink waves are know to be affected by the Kelvin-Helmholtz instability. However, all previous numerical studies consider linearly polarized kink waves. Aims. We study the properties of circularly polarized kink waves on straight plasma cylinders, for both standing and propagating waves, and compare them to the properties of linearly polarized kink waves. Methods. We use the code MPI-AMRVAC to solve the full 3D Magnetohydrodynamic (MHD) equations for a straight magnetic cylinder, excited by both standing and propagating circularly polarized kink (m = 1) modes. Results. The damping due to resonant absorption is independent of the polarization state. The morphology or appearance of the induced resonant flow is different for the two polarizations, however, there are essentially no differences in the forward-modeled Doppler signals. For nonlinear oscillations, the growth rate of small scales is determined by the total energy of the oscillation rather than the perturbation amplitude. We discuss possible implications and seismological relevance.

Standing kink waves in sigmoid solar coronal loops: implications for coronal seismology

N. **Magyar**, V. M. Nakariakov

2020 ApJL 894 L23

https://arxiv.org/pdf/2004.14083.pdf

Using full three-dimensional magnetohydrodynamic numerical simulations, we study the effects of magnetic field sigmoidity or helicity on the properties of the fundamental kink oscillation of solar coronal loops. Our model consists of a single denser coronal loop, embedded in a plasma with dipolar force-free magnetic field with a constant alpha-parameter. For the loop with no sigmoidity, we find that the numerically determined oscillation period of the fundamental kink mode matches the theoretical period calculated using WKB theory. In contrast, with increasing sigmoidity of the loop, the actual period is increasingly smaller than the one estimated by WKB theory. Translated through coronal seismology, increasing sigmoidity results in magnetic field estimates which are increasingly shifting towards higher values, and even surpassing the average value for the highest alpha value considered. Nevertheless, the estimated range of the coronal magnetic field value lies within the mimimal/maximal limits, proving the robustness coronal seismology. We propose that the discrepancy in the estimations of the absolute value of the force-free magnetic field could be exploited seismologically to determine the free energy of coronal loops, if averages of the internal magnetic field and density can be reliably estimated by other methods.

uksp_nug #109 2020 http://www.uksolphys.org/uksp-nugget/109-kink-oscillations-of-sigmoid-coronal-loops/

The instability and non-existence of multi-stranded loops, when driven by transverse waves

N. **Magyar**, T. Van Doorsselaere

ApJ **823** 82 **2016**

http://arxiv.org/pdf/1604.04078v1.pdf

In recent years, omni-present transverse waves have been observed in all layers of the solar atmosphere. Coronal loops are often modeled as a collection of individual strands, in order to explain their thermal behaviour and appearance. We perform 3D ideal MHD simulations to study the effect of a continuous small amplitude transverse footpoint driving on the internal structure of a coronal loop composed of strands. The output is also converted to synthetic images, corresponding to the AIA 171 A and 193 A passbands, using FoMo. We show that the multi-stranded loop ceases to exist in the traditional sense of the word, because the plasma is efficiently mixed perpendicularly to the magnetic field, with the Kelvin-Helmholtz instability acting as the main mechanism. The final product of our simulation is mixed loop with density structures on a large range of scales, resembling a power-law. Thus, multi-stranded loops are unstable to driving by transverse waves, and this raises a strong doubt on the usability and applicability of coronal loop models consisting of independent strands.

Numerical simulations of transverse oscillations in radiatively cooling coronal loops

N. **Magyar**1⋆, T. Van Doorsselaere1 and A. Marcu

A&A 582, A117 (**2015**)

http://arxiv.org/pdf/1510.08760v1.pdf

Aims. We aim to study the influence of radiative cooling on the standing kink oscillations of a coronal loop.
Methods. Using the FLASH code, we solved the 3D ideal magnetohydrodynamic equations. Our model consists of a straight, density enhanced and gravitationally stratified magnetic flux tube. We perturbed the system initially, leading to a transverse oscillation of the structure, and followed its evolution for a number of periods. A realistic radiative cooling is implemented. Results are compared to available analytical theory.
Results. We find that in the linear regime (i.e. low amplitude perturbation and slow cooling) the obtained period and damping time are in good agreement with theory. The cooling leads to an amplification of the oscillation amplitude. However, the difference between the cooling and non-cooling cases is small (around 6% after 6 oscillations). In high amplitude runs with realistic cooling, instabilities deform the loop, leading to increased damping. In this case, the difference between cooling and non-cooling is still negligible at around 12%. A set of simulations with higher density loops are also performed, to explore what happens when the cooling takes place in a very short time ($t_{cool} \approx$ 100 s). In this case, the difference in amplitude after nearly 3 oscillation periods for the low amplitude case is 21% between cooling and non-cooling cases. We strengthen the results of previous analytical studies that state that the amplification due to cooling is ineffective, and its influence on the oscillation characteristics is small, at least for the cases shown here. Furthermore, the presence of a relatively strong damping in the high amplitude runs even in the fast cooling case indicates that it is unlikely that cooling could alone account for the observed, flare-related

undamped oscillations of coronal loops. These results may be significant in the field of coronal seismology, allowing its application to coronal loop oscillations with observed fading-out or cooling behaviour.

The Coronal Veil

A. **Malanushenko**, M.C.M. Cheung, C.E. DeForest, J.A. Klimchuk, M. Rempel

ApJ **927** 1 **2021**

https://arxiv.org/pdf/2106.14877.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/ac3df9/pdf

Coronal loops, seen in solar coronal images, are believed to represent emission from magnetic flux tubes with compact cross-sections. We examine the 3D structure of plasma above an active region in a radiative magnetohydrodynamic simulation to locate volume counterparts for coronal loops. In many cases, a loop cannot be linked to an individual thin strand in the volume. While many thin loops are present in the synthetic images, the bright structures in the volume are fewer, and of complex shape. We demonstrate that this complexity can form impressions of thin bright loops, even in the absence of thin bright plasma strands. We demonstrate the difficulty of discerning from observations whether a particular loop corresponds to a strand in the volume, or a projection artifact. We demonstrate how apparently isolated loops could deceive observers, even when observations from multiple viewing angles are available.

While we base our analysis on a simulation, the main findings are independent from a particular simulation setup and illustrate the intrinsic complexity involved in interpreting observations resulting from line-of-sight integration in an optically thin plasma.

We propose alternative interpretation for strands seen in EUV images of the corona. The "coronal veil" hypothesis is mathematically more generic, and naturally explains properties of loops that are difficult to address otherwise -- such as their constant cross section and anomalously high density scale height. We challenge the paradigm of coronal loops as thin magnetic flux tubes, offering new understanding of solar corona and, by extension, of other magnetically confined bright, hot plasmas.

Three-dimensional reconstruction of type U radio bursts: a novel remote sensing approach for coronal loops

S. **Mancuso**, D. Barghini, A. Bemporad, D. Telloni, D. Gardiol, F. Frassati, I. Bizzarri, C. Taricco

A&A **2022**

https://arxiv.org/pdf/2212.02147.pdf

Type U radio bursts are impulsive coherent radio emissions produced by the Sun that indicate the presence of subrelativistic electron beams propagating along magnetic loops in the solar corona. In this work, we present the analysis of a type U radio burst that was exceptionally imaged on **2011 March 22** by the Nançay Radioheliograph (NRH) at three different frequencies (298.7, 327.0, and 360.8 MHz). Using a novel modelling approach, we show for the first time that the use of high-resolution radio heliograph images of type U radio bursts can be sufficient to both accurately reconstruct the 3D morphology of coronal loops (without recurring to triangulation techniques) and to fully constrain their physical parameters. At the same time, we can obtain unique information on the dynamics of the accelerated electron beams, which provides important clues as to the plasma mechanisms involved in their acceleration and as to why type U radio bursts are not observed as frequently as type III radio bursts. We finally present plausible explanations for a problematic aspect related to the apparent lack of association between the modeled loop as inferred from radio images and the extreme-ultraviolet (EUV) structures observed from space in the same coronal region

Investigating coronal loop morphology and dynamics from two vantage points

Sudip **Mandal**, Hardi Peter, James A. Klimchuk, Sami K. Solanki, Lakshmi Pradeep Chitta, Regina Aznar Cuadrado, Udo Schühle, Luca Teriaca, David Berghmans, Cis Verbeeck, Frédéric Auchère, Koen Stegen

A&A Letter **2024**

https://arxiv.org/pdf/2401.07349.pdf

Coronal loops serve as the fundamental building blocks of the solar corona. Therefore, comprehending their properties is essential in unraveling the dynamics of the Sun's upper atmosphere. In this study, we conduct a comparative analysis of the morphology and dynamics of a coronal loop observed from two different spacecraft: the High Resolution Imager (HRIEUV) of the Extreme Ultraviolet Imager aboard the Solar Orbiter and the Atmospheric Imaging Assembly (AIA) aboard the Solar Dynamics Observatory. These spacecraft were separated by 43∘ during this observation. The main findings of this study are: (1) The observed loop exhibits similar widths in both the HRIEUV and AIA data, suggesting that the cross-sectional shape of the loop is circular; (2) The loop maintains a uniform width along its entire length, supporting the notion that coronal loops do not exhibit expansion; (3) Notably, the loop undergoes unconventional dynamics, including thread separation and abrupt downward movement. Intriguingly, these dynamic features also appear similar in data from both spacecraft. Although based on observation of a single loop, these results raise questions about the validity of the coronal veil hypothesis and underscore the intricate and diverse nature of complexity within coronal loops**. 7 Apr 2023**

What drives decayless kink oscillations in active region coronal loops on the Sun?

Sudip **Mandal**, Lakshmi P. Chitta, Patrick Antolin, Hardi Peter, Sami K. Solanki, Frédéric Auchère, +++
A&AL 666, L2 **2022**
https://arxiv.org/pdf/2209.04251.pdf
https://www.aanda.org/articles/aa/pdf/2022/10/aa44403-22.pdf
We study here the phenomena of decayless kink oscillations in a system of active region (AR) coronal loops. Using high resolution observations from two different instruments, namely the Extreme Ultraviolet Imager (EUI) on board Solar Orbiter and the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory, we follow these AR loops for an hour each on three consecutive days. Our results show significantly more resolved decayless waves in the higher-resolution EUI data compared with the AIA data. Furthermore, the same system of loops exhibits many of these decayless oscillations on Day-2, while on Day-3, we detect very few oscillations and on Day-1, we find none at all. Analysis of photospheric magnetic field data reveals that at most times, these loops were rooted in sunspots, where supergranular flows are generally absent. This suggests that supergranular flows, which are often invoked as drivers of decayless waves, are not necessarily driving such oscillations in our observations. Similarly, our findings also cast doubt on other possible drivers of these waves, such as a transient driver or mode conversion of longitudinal waves near the loop footpoints. In conclusion, through our analysis we find that none of the commonly suspected sources proposed to drive decayless oscillations in active region loops seems to be operating in this event and hence, the search for that elusive wave driver needs to continue. **3-5 Mar 2022**

Reflection Of Propagating Slow Magneto-acoustic Waves In Hot Coronal Loops : Multi-instrument Observations and Numerical Modelling

Sudip **Mandal**, Ding Yuan, Xia Fang, Dipankar Banerjee, Vaibhav Pant, Tom Van Doorsselaere
ApJ **828** 72 **2016**
http://arxiv.org/pdf/1604.08133v1.pdf
Slow MHD waves are important tools for understanding the coronal structures and dynamics. In this paper, we report a number of observations, from X-Ray Telescope (XRT) on board HINODE and SDO/AIA of reflecting longitudinal waves in hot coronal loops. To our knowledge, this is the first report of this kind as seen from the XRT and simultaneously with the AIA. The wave appears after a micro-flare occurs at one of the footpoints. We estimate the density and the temperature of the loop plasma by performing DEM analysis on the AIA image sequence. The estimated speed of propagation is comparable or lower than the local sound speed suggesting it to be a propagating slow wave. The intensity perturbation amplitudes, in every case, falls very rapidly as the perturbation moves along the loop and eventually vanishes after one or more reflections. To check the consistency of such reflection signatures with the obtained loop parameters, we perform a 2.5D MHD simulation, which uses the parameters obtained from our observation as inputs and performed forward modelling to synthesize AIA 94~\r{A} images. Analyzing the synthesized images, we obtain the same properties of the observables as for the real observation. From the analysis we conclude that a footpoint heating can generate slow wave which then reflects back and forth in the coronal loop before fading out. Our analysis on the simulated data shows that the main agent for this damping is the anisotropic thermal conduction. **22nd January, 2013, 27th January 2013, 10th December 2015,**

Forward Modelling of Propagating Slow Waves in Coronal Loops and Their Frequency-Dependent Damping

Sudip **Mandal**, Norbert Magyar, Ding Yuan, Tom Van Doorsselaere, Dipankar Banerjee
ApJ 820 13 **2016**
http://arxiv.org/pdf/1602.00787v1.pdf
Propagating slow waves in coronal loops exhibit a damping which depends upon the frequency of the waves. In this study we aim to investigate the relationship of the damping length (Ld) with the frequency of the propagating wave. We present a 3-D coronal loop model with uniform density and temperature and investigate the frequency dependent damping mechanism for the four chosen wave periods. We include the thermal conduction to damp the waves as they propagate through the loop. The numerical model output has been forward modelled to generate synthetic images of SDO/AIA 171 \r{A} and 193 \r{A} channels. The use of forward modelling, which incorporates the atomic emission properties into the intensity images, allows us to directly compare our results with the real observations. The results show that the damping lengths vary linearly with the periods. We also measure the contributions of the emission properties on the damping lengths by using density values from the simulation. In addition to that} we have also calculated the theoretical dependence of Ld with wave periods and showed that it is consistent with the results we obtained from the numerical

modelling and earlier observations.

Propagating Disturbances along fan-like coronal loops in an active region

S. **Mandal**, T. Samanta, D. Banerjee, S. Krishna Prasad, L. Teriaca

Research in Astronomy and Astrophysics (RAA) **2015**

Propagating disturbances are often observed in active region fan-like coronal loops. They were thought to be due to slow mode MHD waves based on some of the observed properties. But the recent studies involving spectroscopy indicate that they could be due to high speed quasi-periodic upflows which are difficult to distinguish from upward propagating slow waves. In this context, we have studied a fan loop structure in the active region AR 11465 using simultaneous spectroscopic and imaging observations from Extreme-ultraviolet Imaging Spectrometer (EIS) on board Hinode and Atmospheric Imaging Assembly (AIA) on board SDO. Analysis of the data shows significant oscillations at different locations. We explore the variations in different line parameters to determine whether the waves or flows could cause these oscillations to improve the current understanding on the nature of these disturbances. **2012 April 26**

How Can Active Region Plasma Escape into the Solar Wind from Below a Closed Helmet Streamer?

C. H. **Mandrini**, F. A. Nuevo, A. M. Vásquez, P. Démoulin, L. van Driel-Gesztelyi, D. Baker, J. L. Culhane, G. D. Cristiani, M. Pick

E-print, Sept **2014**; Solar Phys., Volume 289, Issue 11, pp 4151-4171 **2014**

http://arxiv.org/pdf/1409.7369v1.pdf

Recent studies show that active-region (AR) upflowing plasma, observed by the EUV-Imaging Spectrometer (EIS) onboard Hinode, can gain access to open-field lines and be released into the solar wind (SW) via magnetic-interchange reconnection at magnetic null-points in pseudo-streamer configurations. When only one bipolar AR is present on the Sun and is fully covered by the separatrix of a streamer, such as AR 10978 in **December 2007**, it seems unlikely that the upflowing AR plasma can find its way into the slow SW. However, signatures of plasma with AR composition have been found at 1 AU by Culhane et al. (Solar Phys. 289, 3799, 2014) that apparently originated west of AR 10978. We present a detailed topology analysis of AR 10978 and the surrounding large-scale corona based on a potential-field source-surface (PFSS) model. Our study shows that it is possible for the AR plasma to move around the streamer separatrix and be released into the SW via magnetic reconnection, which occurs in at least two main steps. We analyse data from the Nançay Radioheliograph (NRH) in a search for evidence of the chain of magnetic reconnections that we propose. We find a noise storm above the AR and several varying sources at 150.9 MHz. Their locations suggest that they might be associated with particles accelerated during the first-step reconnection process at a null point well outside of the AR. We find no evidence of the second reconnection step in the radio data, however. Our results demonstrate that even when it appears highly improbable for the AR plasma to reach the SW, indirect channels involving a sequence of reconnections can make it possible.

Two fluid dynamics in solar prominences

S. J. González **Manrique** (1 and 2 and 3 and 4), E. Khomenko (2 and 3), M. Collados (2 and 3), C. Kuckein (2 and 3), T. Felipe (2 and 3), P. Gömöry (4)

A&A **2023**

https://arxiv.org/pdf/2311.03183.pdf

Solar prominences contain a significant amount of neutral species. The dynamics of the ionised and neutral fluids composing the prominence plasma can be slightly different if the collisional coupling is not strong enough. Large-scale velocities can be quantified by Doppler effect. Small-scale velocities leave their imprint on the width of spectral lines. Here we use one spectral line of ionised and two spectral lines of neutral elements to measure the resolved and unresolved velocities in a prominence with the aim to investigate the possible decoupling of the observed charged and neutral species. A prominence was observed with the German Vacuum Tower Telescope on **June 17, 2017**. Time series consisting of repeated 10-position scans were performed while recording simultaneously the intensity spectra of the Ca II 854.2 nm, H{\alpha} 656.28 nm, and HeD3 587.56 nm lines. The line-of-sight velocities and the Doppler width of the three spectral lines were determined at every spatial position and temporal moment. To make sure all spectral lines were sampling the same plasma volume, we applied selection criteria to identify locations with optically thin plasma. The velocities of the three spectral lines turned out to be very similar over this region, with the ionised Ca II showing velocity excursions systematically larger compared to those of the neutral lines of H{\alpha} and He I at some moments. The latter were found to be much closer to each other. The analysis of the Doppler widths indicated that the C aII line shows an excess of unresolved motions. The dynamics of the ionised and neutral plasma components in the observed prominence was very close one to the other. The differences found may indicate that a localised decoupling between ions and neutrals may appear at particular spatial locations or instants of time.

Tracking downflows from the chromosphere to the photosphere in a solar arch filament system

S. J. González **Manrique** (1), C. Kuckein (2), A. Pastor Yabar (3), A. Diercke (2,4), M. Collados (5), P. Gömöry (1), S. Zhong (6,7), Y. Hou (6,7), C. Denker

ApJ **890** 82 **2020**

https://arxiv.org/pdf/2001.07078.pdf

https://doi.org/10.3847/1538-4357/ab6cee

We study the dynamics of plasma along the legs of an arch filament system (AFS) from the chromosphere to the photosphere, observed with high-cadence spectroscopic data from two ground-based solar telescopes: the GREGOR telescope (Tenerife) using the GREGOR Infrared Spectrograph (GRIS) in the He I 10830 Å range and the Swedish Solar Telescope (La Palma) using the CRisp Imaging Spectro-Polarimeter to observe the Ca II 8542 Å and Fe I 6173 Å spectral lines. The temporal evolution of the draining of the plasma was followed along the legs of a single arch filament from the chromosphere to the photosphere. The average Doppler velocities inferred at the upper chromosphere from the He I 10830 Å triplet reach velocities up to 20-24~km~s−1, in the lower chromosphere and upper photosphere the Doppler velocities reach up to 11~km~s−1 and 1.5~km~s−1 in the case of the Ca II 8542 Å and Si I 10827 Å spectral lines, respectively. The evolution of the Doppler velocities at different layers of the solar atmosphere (chromosphere and upper photosphere) shows that they follow the same LOS velocity pattern, which confirm the observational evidence that the plasma drains towards the photosphere as proposed in models of AFSs. The Doppler velocity maps inferred from the lower photospheric Ca I 10839 Å or Fe I 6173 Å spectral lines do not show the same LOS velocity pattern. Thus, there is no evidence that the plasma reaches the lower photosphere. The observations and the nonlinear force-free field extrapolations demonstrate that the magnetic field loops of the AFS rise with time. We found flow asymmetries at different footpoints of the AFS. The NLFFF values of the magnetic field strength give us a clue to explain these flow asymmetries. **2015 April 17**

Temporal evolution of arch filaments as seen in He I 10830 Å

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A&A **2018**

https://arxiv.org/pdf/1807.00728.pdf

We study the evolution of an arch filament system (AFS) and of its individual arch filaments to learn about the processes occurring in them. We observed the AFS at the GREGOR solar telescope on Tenerife at high cadence with the very fast spectroscopic mode of the GREGOR Infrared Spectrograph (GRIS) in the He I 10830 \AA\ spectral range. The He I triplet profiles were fitted with analytic functions to infer line-of-sight (LOS) velocities to follow plasma motions within the AFS. We tracked the temporal evolution of an individual arch filament over its entire lifetime, as seen in the He I 10830 \AA\ triplet. The arch filament expanded in height and extended in length from 13" to 21". The lifetime of this arch filament is about 30 min. About 11 min after the arch filament is seen in He I, the loop top starts to rise with an average Doppler velocity of 6 km/s. Only two minutes later, plasma drains down with supersonic velocities towards the footpoints reaching a peak velocity of up to 40 km/s in the chromosphere. The temporal evolution of He I 10830 \AA\ profiles near the leading pore showed almost ubiquitous dual red components of the He I triplet, indicating strong downflows, along with material nearly at rest within the same resolution element during the whole observing time. We followed the arch filament as it carried plasma during its rise from the photosphere to the corona. The material then drained toward the photosphere, reaching supersonic velocities, along the legs of the arch filament. Our observational results support theoretical AFS models and aids in improving future models. **2015 April 17**

Relative Kinematics of the Leading Edge and the Prominence in Coronal Mass Ejections

Darije **Mariˇci´c** · Bojan Vršnak · Dragan Roša

Solar Phys (**2009**) 260: 177–189, **File**

We present a statistical analysis of the relationship between the kinematics of the leading edge and the eruptive prominence in coronal mass ejections (CMEs). We study the acceleration phase of **18 CMEs** in which kinematics was measured from the pre-eruption stage up to the post-acceleration phase. In all CMEs, the three part structure (the leading edge, the cavity, and the prominence) was clearly recognizable from early stages of the eruption. The data show a distinct correlation between the duration of the leading edge (LE) acceleration and eruptive prominence (EP) acceleration. In the majority of events (78%) the acceleration phase onset of the LE is very closely synchronized (within ±20 min) with the acceleration of EP. However, in two events the LE acceleration started significantly earlier than the EP acceleration (>50 min), and in two events the EP acceleration started earlier than the LE acceleration (>40 min). The average peak acceleration of LEs (281 ms−2) is about two times larger than the average peak acceleration of EPs (136 ms−2). For the first time, our results quantitatively demonstrate the level of synchronization of the acceleration phase of LE and EP in a rather large sample of events, *i.e.*, we quantify how often the eruption develops in a "self-similar" manner.

Multi wavelength investigation of the eruption of a sigmoidal quiescent filament?

Ch. **Marque**, P. Lantos1, and J. P. Delaboudini_ere

A&A 387, 317{325 (**2002**), **File**

We report the _rst observation of a filament eruption in the metric and decimetric range, where the behavior of the filament can be followed during the event via thermal radio emission diagnostics. The event, occurring on **February 28th 2001**, involved a quiescent filament in a sigmoid magnetic configuration, whose eruption is triggered by the birth of a small parasitic polarity. Faint radio bursts mark the beginning of the event, which shows the appearance of a brightness temperature depression associated with the filament seen in eit, and its propagation on the disk up to the limb. The event is associated with a halo CME observed with the coronagraphs lasco C2 and C3, which shows a significant spatial and temporal continuity with the radio observations. Finally, static dimmings, similar to what is currently observed in EUV or SXR domains, are also detected in the radio band, around the site of the eruption. Movies of the event are attached to this article.

The Build-up to Eruptive Solar Events Viewed as the Development of Chiral Systems

Sara F. **Martin**, Olga Panasenco, Mitchell A. Berger, Oddbjorn Engvold, Yong Lin, Alexei A. Pevtsov, Nandita Srivastava

2nd ATST - EAST Workshop in Solar Physics: Magnetic Fields from the Photosphere to the Corona, ASP Conference Series, Vol. 463, p.157, **2012, File**

When we examine the chirality or observed handedness of the chromospheric and coronal structures involved in the long-term build-up to eruptive events, we find that they evolve in very specific ways to form two and only two sets of large-scale chiral systems. Each system contains spatially separated components with both signs of chirality, the upper portion having negative (positive) chirality and the lower part possessing positive (negative) chirality. The components within a system are a filament channel (represented partially by sets of chromospheric fibrils), a filament (if present), a filament cavity, sometimes a sigmoid, and always an overlying arcade of coronal loops. When we view these components as parts of large-scale chiral systems, we more clearly see that it is not the individual components of chiral systems that erupt but rather it is the approximate upper parts of an entire evolving chiral system that erupts. We illustrate the typical pattern of build-up to eruptive solar events first without and then including the chirality in each stage of the build-up. We argue that a complete chiral system has one sign of handedness above the filament spine and the opposite handedness in the barbs and filament channel below the filament spine. If the spine has handedness, the observations favor its having the handedness of the filament cavity and coronal loops above. As the separate components of a chiral system form, we show that the system appears to maintain a balance of right-handed and left-handed features, thus preserving an initial near-zero net helicity. Each individual chiral system may produce many successive eruptive events above a single filament channel.

6 Jun, 2010, 17 Sept, 2010, 20 Sept 2010, 2010 Sep 28,30 Sept 2010

Transverse kink oscillations of inhomogeneous prominence threads: numerical analysis and Hα forward modelling

David **Martínez-Gómez**, Roberto Soler, Jaume Terradas, Elena Khomenko

A&A 658, A106 **2021**

https://arxiv.org/pdf/2111.09036.pdf

https://doi.org/10.1051/0004-6361/202141968

https://www.aanda.org/articles/aa/pdf/2022/02/aa41968-21.pdf

Prominence threads are very long and thin flux tubes which are partially filled with cold plasma. Observations have shown that transverse oscillations are frequent in these solar structures. The observations are usually interpreted as the fundamental kink mode, while the detection of the first harmonic remains elusive. Here, we aim to study how the density inhomogeneity in the longitudinal and radial directions modify the periods and damping times of kink oscillations, and how this effect would be reflected in observations. We solve the ideal magnetohydrodynamics equations through two different methods: a) performing 3D numerical simulations, and b) solving a 2D generalised eigenvalue problem. We study the dependence of the periods, damping times and amplitudes of transverse kink oscillations on the ratio between the densities at the centre and at the ends of the tube, and on the average density. We apply forward modelling on our 3D simulations to compute synthetic Hα profiles. We confirm that the ratio of the period of the fundamental oscillation mode to the period of the first harmonic increases as the ratio of the central density to the footpoint density is increased or as the averaged density of the tube is decreased. We find that the damping times due to resonant absorption decrease as the central to footpoint density ratio increases. Contrary to the case of longitudinally homogeneous tubes, we find that the damping time to period ratio also increases as the density ratio is increased or the average density is reduced. We present snapshots and time-distance diagrams of the emission in the Hα line. The results presented here have implications for the field of prominence seismology. While the Hα emission can be used to detect the fundamental mode, the first harmonic is barely detectable in Hα. This may explain the lack of detections of the first harmonic.

Multi-fluid approach to high-frequency waves in plasmas. III. Nonlinear regime and plasma heating

David **Martínez-Gómez**

ApJ **2018**

https://arxiv.org/pdf/1802.08134.pdf

The multi-fluid modelling of high-frequency waves in partially ionized plasmas has shown that the behavior of magnetohydrodynamics waves in the linear regime is heavily influenced by the collisional interaction between the different species that form the plasma. Here, we go beyond linear theory and study large-amplitude waves in partially ionized plasmas using a nonlinear multi-fluid code. It is known that in fully ionized plasmas, nonlinear Alfvén waves generate density and pressure perturbations. Those nonlinear effects are more pronounced for standing oscillations than for propagating waves. By means of numerical simulations and analytical approximations, we examine how the collisional interaction between ions and neutrals affects the nonlinear evolution. The friction due to collisions dissipates a fraction of the wave energy, which is transformed into heat and consequently rises the temperature of the plasma. As an application, we investigate frictional heating in a plasma with physical conditions akin to those in a solar quiescent prominence.

Onset of the Kelvin-Helmholtz instability in partially ionized magnetic flux tubes

David **Martinez-Gomez**, Roberto Soler and Jaume Terradas

A&A 578, A104 **2015**

Context: Recent observations of solar prominences show the presence of turbulent flows that may be caused by Kelvin-Helmholtz instabilites (KHI). However, the observed flow velocities are below the classical threshold for the onset of KHI in fully ionized plasmas. Aims: We investigate the effect of partial ionization on the onset of KHI in dense and cool cylindrical magnetic flux tubes surrounded by a hotter and lighter environment. Methods: The linearized governing equations of a partially ionized two-fluid plasma are used to describe the behavior of small-amplitude perturbations superimposed on a magnetic tube with longitudinal mass flow. A normal mode analysis is performed to obtain the dispersion relation for linear incompressible waves. We focus on the appearance of unstable solutions and study the dependence of their growth rates on various physical parameters. An analytical approximation of the KHI linear growth rate for slow flows and strong ion-neutral coupling is obtained. An application to solar prominence threads is given. Results: The presence of a neutral component in a plasma may contribute to the onset of the KHI even for sub-Alfvénic longitudinal shear flows. Collisions between ions and neutrals reduce the growth rates of the unstable perturbations but cannot completely suppress the instability. Conclusions: Turbulent flows in solar prominences with sub-Alfvénic flow velocities may be interpreted as consequences of KHI in partially ionized plasmas.

Small-amplitude oscillations in solar filaments

G. P. **Mashnich**, V. S. Bashkirtsev and A. I. Khlystova

Astronomy Reports, Volume 56, Number 3 (**2012**), 241-249

The temporal and spatial properties of small-amplitude oscillations have been studied using spectral observations of motions in solar filaments carried out at the Sayan Solar Observatory (Institute of Solar-Terrestrial Physics, Russian Academy of Sciences). Oscillations with different periods and spatial scales exist simultaneously in filaments. Swaying motions of filaments in the plane of the sky have been detected. The character of these oscillatory motions is compared with oscillations in the Doppler velocity at the same filament sites.

Dissipative instabilities in a partially ionised prominence plasma slab: II. The effect of compressibility

J. F. **Mather**, I. Ballai, R. Erdelyi

A&A 610, A56 (**2018**)

https://arxiv.org/pdf/1711.09855.pdf

http://sci-hub.tw/https://www.aanda.org/articles/aa/abs/2018/02/aa31080-17/aa31080-17.html
This present study deals with the dissipative instability that appears in a compressible partially ionised plasma slab embedded in a uniform magnetic field, modelling the state of the plasma in solar prominences. In the partially ionised plasma, the dominant dissipative effect is the Cowling resistivity. The regions outside the slab (modelling the solar corona) are fully ionised, and the dominant mechanism of dissipation is viscosity. Analytical solutions to the extended magnetohydrodynamic (MHD) equations are found inside and outside of the slab and solutions are matched at the boundaries of the slab. The dispersion relation is derived and solutions are found analytically in the slender slab limit, while the conditions necessary for the appearance of the instability is investigated numerically for the entire parameter space. Our study is focussed on the effect of the compressibility on the generation and evolution of instabilities. We find that compressibility reduces the threshold of the equilibrium flow, where waves can be unstable, to a level that is comparable to the internal cusp speed, which is of the same order of flow speeds that are currently observed in solar prominences. Our study addresses only the slow waves, as these are the most likely perturbations to become unstable, however the time-scales of the instability are found to be rather large ranging from 105-107 seconds. It is determined that the instability threshold is further influenced by the concentration of neutrals and the strength of the viscosity of the corona. Interestingly, these two latter aspects have opposite effects. Our numerical analysis shows that the interplay between the equilibrium flow, neutrals and dispersion can change considerably the nature of waves.

Solar Cycle Evolution of Filaments over a Century: Investigations with the Meudon and McIntosh Hand-drawn Archives

Rakesh **Mazumder**, Subhamoy Chatterjee, Dibyendu Nandy, Dipankar Banerjee

ApJ **919** 125 **2021**

https://arxiv.org/pdf/2106.04320.pdf

https://doi.org/10.3847/1538-4357/ac09f6

Hand-drawn synoptic maps from the Meudon Observatory (1919 onwards) and the McIntosh archive (1967 onwards) are two important sources of long-term, manually recorded filament observations. In this study, we calibrate the Meudon maps and subsequently identify filaments through an automated method. We extract physical parameters from this filament database and perform a comparative study of their long-term evolution focusing on the cotemporal period of McIntosh and Meudon observations. The spatio-temporal evolution of filaments manifests in the form of a filament butterfly diagram, indicating further that they are intimately related to the large-scale solar cycle. Physical descriptors such as the number and length of filaments, which are tracers of solar surface magnetic field, have cycles which are phase-locked with the 11 year sunspot cycle. The tilt angle distribution of filaments - both near or distant from active region locations - indicates that their origin is due to either large-scale surface magnetic field or inter-active region field evolution. This study paves the way for constructing a composite series of hand-drawn filament data with minimal gaps stretching the time span of solar filament observations to a century. On the one hand, this would serve as useful constraints for models of magnetic field emergence and evolution on the Sun's surface over multiple solar cycles, and on the other hand, this filament database may be used to guide the reconstruction of filament-prominence associated eruptive events before the space age

Simultaneous longitudinal and transverse oscillations in filament threads after a failed eruption⋆

Rakesh **Mazumder**1,2, Vaibhav Pant3, Manuel Luna4,5 and Dipankar Banerjee

A&A 633, A12 (**2020**)

https://doi.org/10.1051/0004-6361/201936453

https://arxiv.org/pdf/1910.11260.pdf

Context. Longitudinal and transverse oscillations are frequently observed in the solar prominences and/or filaments. These oscillations are excited by a large-scale shock wave, impulsive flares at one leg of the filament threads, or due to any low coronal eruptions. We report simultaneous longitudinal and transverse oscillations in the filament threads of a quiescent region filament. We observe a large filament in the northwest of the solar disk on July 6, 2017. On July 7, 2017, it starts rising around 13:00 UT. We then observe a failed eruption and subsequently the filament threads start to oscillate around 16:00 UT.
Aims. We analyse oscillations in the threads of a filament and utilize seismology techniques to estimate magnetic field strength and length of filament threads.
Methods. We placed horizontal and vertical artificial slits on the filament threads to capture the longitudinal and transverse oscillations of the threads. Data from Atmospheric Imaging Assembly onboard Solar Dynamics Observatory were used to detect the oscillations.
Results. We find signatures of large-amplitude longitudinal oscillations (LALOs). We also detect damping in LALOs. In one thread of the filament, we observe large-amplitude transverse oscillations (LATOs). Using the pendulum model, we estimate the lower limit of magnetic field strength and radius of curvature from the observed parameter of LALOs.

Conclusions. We show the co-existence of two different wave modes in the same filament threads. We estimate magnetic field from LALOs and suggest a possible range of the length of the filament threads using LATOs. **July 6-7 2017**

Properties of filament in Solar cycle 20-23 from McIntosh database

Rakesh **Mazumder**

Research in Astron. Astrophys. **Vol 19, No 6**, 80 **2019**

https://arxiv.org/pdf/1812.02489.pdf

Filament is a cool, dense structure suspended in the solar corona. The eruption of a filament is often associated with coronal mass ejection (CME), which has an adverse effect on space weather. Hence, the study of filament has attracted much attention in the recent past. The tilt angle of active region (AR) magnetic bipoles is a crucial parameter in the context of the solar dynamo. It governs the conversion efficiency of the toroidal magnetic field to poloidal magnetic field. The filament always forms over the Polarity Inversion Lines (PILs). So the study of tilt angles of the filament can provide valuable information about generation of magnetic field in the Sun. We study the tilt angle of filaments and other properties of it using McIntosh archive data. We fit a straight line to each filament to estimate its tilt angle. We study the variation of mean tilt angle with time. The latitude distribution of positive tilt angle filaments and negative tilt angle filaments reveal that there is a dominance of positive tilt angle filaments in the southern hemisphere and negative tilt angle filaments dominate in the northern hemisphere. We study the variation of the mean tilt angle for low and high latitude separately. Study of temporal variation of filament number reveals that total filament number and low latitude filament number varies cyclically, in phase with the solar cycle. The number of filaments in high latitude is less, and they also show a cyclic pattern in temporal variation. We also study the north-south asymmetry of filament for different latitude criteria.

The Association of Filaments, Polarity Inversion Lines, and Coronal Hole Properties with the Sunspot Cycle: An Analysis of the McIntosh Database

Rakesh **Mazumder**, Prantika Bhowmik, Dibyendu Nandy

ApJ **868** 52 **2018**

https://arxiv.org/pdf/1810.02133.pdf

sci-hub.tw/10.3847/1538-4357/aae68a

Filaments and coronal holes, two principal features observed in the solar corona are sources of space weather variations. Filament formation is closely associated with polarity inversion lines (PIL) on the solar photosphere which separate positive and negative polarities of the surface magnetic field. The origin of coronal holes is governed by large-scale unipolar magnetic patches on the photosphere from where open magnetic field lines extend to the heliosphere. We study properties of filaments, PILs and coronal holes in solar cycles 20, 21, 22 and 23 utilizing the McIntosh archive. We detect a prominent cyclic behavior of filament length, PIL length, and coronal hole area with significant correspondence with the solar magnetic cycle. The spatio-temporal evolution of the geometric centers of filaments shows a butterfly-like structure and distinguishable pole-ward migration of long filaments during cycle maxima. We identify this rush to the poles of filaments to be co-temporal with the initiation of polar field reversal as gleaned from Mount Wilson and Wilcox Solar Observatory polar field observations and quantitatively establish their temporal correspondence. We analyze the filament tilt angle distribution to constrain their possible origins. Majority of the filaments exhibit negative and positive tilt angles in the northern and the southern hemispheres, respectively -- strongly suggesting that their formation is governed by the overall large-scale magnetic field distribution on the solar photosphere and not by the small-scale intra-active region magnetic field configurations. We also investigate the hemispheric asymmetry in filaments, PILs, and coronal holes. We find that the hemispheric asymmetry in filaments and PILs are positively correlated -- whereas coronal hole asymmetry is uncorrelated -- with sunspot area asymmetry.

Multi-spacecraft observations of coronal loops to verify a force-free field reconstruction and infer loop cross sections

Marika I. **McCarthy**, Dana W. Longcope, Anna Malanushenko

ApJ 913 56 **2021**

https://arxiv.org/pdf/2104.02722.pdf

https://doi.org/10.3847/1538-4357/abf4d5

Active region EUV loops are believed to trace a subset of magnetic field lines through the corona. Malanushenko et al. (2009) proposed a method, using loop images and line-of-sight photospheric magnetograms, to infer the three-dimensional shape and field strength along each loop. McCarthy et al. (2019) used this novel method to compute the total magnetic flux interconnecting a pair of active regions observed by SDO/AIA. They adopted the common assumption that each loop had a circular cross section. The accuracy of inferred shape and circularity of cross sections can both be tested using observations of the same loops from additional vantage points as provided by STEREO/EUVI. Here, we use multiple viewing angles to confirm the three-dimensional structure of loops. Of 151 viable cases, 105 (69.5%) matched some form of visible coronal structure when viewed approximately in quadrature. A loop with a circular cross-section should appear of a similar width in different perspectives. In contradiction to this, we find a puzzling lack of correlation between loop diameters seen from different perspectives, even an anti-correlation in some cases. Features identified as monolithic loops in AIA may, in fact, be more complex density enhancements. The 30.5% of reconstructions from AIA which did not match any feature in EUVI might be such enhancements. Others may be genuine loop structures, but with elliptical cross sections. We observe an anti-correlation between diameter and brightness, lending support to the latter hypothesis. Of 13 suitable for width analysis, four loops are consistent with non-circular cross sections, where we find anti-correlation in both comparisons.

OPTICAL SPECTROSCOPY OF Hα FILAMENTS IN COOL CORE CLUSTERS: KINEMATICS, REDDENING, AND SOURCES OF IONIZATION

Michael **McDonald**1, Sylvain Veilleux2 and David S. N. Rupke

2012 ApJ 746 153

We have obtained deep, high spatial and spectral resolution, long-slit spectra of the Hα nebulae in the cool cores of nine galaxy clusters. This sample provides a wealth of information on the ionization state, kinematics, and reddening of the warm gas in the cool cores of galaxy clusters. We find evidence for only small amounts of reddening in the extended, line-emitting filaments, with the majority of filaments having $E(B - V) < 0.2$. We find, in agreement with previous works, that the optical emission in cool core clusters has elevated low-ionization line ratios. The combination of [O III]/Hβ, [N II]/Hα, [S II]/Hα, and [O I]/Hα allow us to rule out collisional ionization by cosmic rays, thermal conduction, and photoionization by intracluster medium (ICM) X-rays and active galactic nuclei as strong contributors to the ionization in the bulk of the optical line-emitting gas in both the nuclei and filaments. The data are adequately described by a composite model of slow shocks and star formation. This model is further supported by an observed correlation between the line widths and low-ionization line ratios which becomes stronger in systems with more modest star formation activity based on far-ultraviolet observations. We find that the more extended, narrow filaments tend to have shallower velocity gradients and narrower line widths than the compact filamentary complexes. We confirm that the widths of the emission lines decrease with radius, from FWHM ~600 km s^{-1} in the nuclei to FWHM ~100 km s^{-1} in the most extended filaments. The variation of line width with radius is vastly different than what is measured from stellar absorption lines in a typical giant elliptical galaxy, suggesting that the velocity width of the warm gas may in fact be linked to ICM turbulence and, thus, may provide a glimpse into the amount of turbulence in cool cores. In the central regions ($r < 10$ kpc) of several systems the warm gas shows kinematic signatures consistent with rotation, consistent with earlier work. We find that the kinematics of the most extended filaments in this sample are broadly consistent with both infall and outflow, and recommend further studies linking the warm gas kinematics to both radio and X-ray maps in order to further understand the observed kinematics.

ON THE ORIGIN OF THE EXTENDED H*α* FILAMENTS IN COOLING FLOW CLUSTERS

Michael **McDonald**1, Sylvain Veilleux1, David S. N. Rupke2, and Richard Mushotzky1

Astrophysical Journal, 721:1262–1283, **2010**

We present a high spatial resolution H*α* survey of 23 cooling flow clusters using the Maryland Magellan Tunable Filter, covering 1–2 orders of magnitude in cooling rate, *dM/dt* , temperature, and entropy. We find that 8/23 (35%) of our clusters have complex, filamentary morphologies at H*α*, while an additional 7/23 (30%) have marginally extended or nuclear H*α* emission, in general agreement with previous studies of line emission in cooling flow cluster brightest cluster galaxies. A weak correlation between the integrated near-UV luminosity and the H*α* luminosity is also found for our complete sample with a large amount of scatter about the expected relation for photoionization by young stars. We detect H*α* emission out to the X-ray cooling radius, but no further, in several clusters and find a strong correlation between the H*α* luminosity contained in filaments and the X-ray cooling flow rate of the cluster, suggesting that the warm ionized gas is linked to the cooling flow. Furthermore, we detect a strong enhancement in the cooling properties of the intracluster medium (ICM) coincident with the H*α* emission, compared to the surrounding ICM at the same radius. While the filaments in a few clusters may be entrained by buoyant radio bubbles, in general, the radially infalling cooling flow model provides a better explanation for the observed trends. The correlation of the H*α* and X-ray properties suggests that conduction may be important in keeping the filaments ionized. The thinness of the filaments suggests that magnetic fields are an important part of channeling the gas and shielding it from the surrounding hot ICM.

Plasma parameters in eruptive prominences from SDO/AIA observations

Kristopher **McGlinchey** and Nicolas Labrosse

UKSP Nuggets, 21, March **2012**

http://www.uksolphys.org/?p=4247

Theory predicts that when a solar prominence erupts into the corona, the intensity of the He II line at 304 Å will decrease as a function of the radial velocity of the plasma [1,2]. This predicted change in the radiation output is due to the so-called Doppler dimming effect. Doppler dimming is the decrease in intensity of an atomic resonance line that is pumped by external radiation, when the plasma in which it forms moves so that the pump line is Doppler shifted out of resonance (in the moving frame). Doppler dimming is widely used to diagnose the solar wind speed, and in this nugget we look for the Doppler dimming signature during prominence eruptions. If found, this could provide a diagnostic tool to probe the thermodynamic conditions of the plasma in eruptive prominences. We use He II images from the AIA on board the Solar Dynamics Observatory.

The Great Solar Active Region NOAA 12192: Helicity Transport, Filament Formation, and Impact on the Polar Field

Tyler C. **McMaken**1,2 and Gordon J. D. Petrie

2017 ApJ 840 100

http://sci-hub.cc/10.3847/1538-4357/aa6d0b

The solar active region (AR), NOAA 12192, appeared in **2014 October** as the largest AR in 24 years. Here we examine the counterintuitive nature of two diffusion-driven processes in the region: the role of helicity buildup in the formation of a major filament, and the relationship between the effects of supergranular diffusion and meridional flow on the AR and on the polar field. Quantitatively, calculations of current helicity and magnetic twist from Helioseismic and Magnetic Imager (HMI) vector magnetograms indicate that, though AR 12192 emerged with negative helicity, positive helicity from subsequent flux emergence, consistent with the hemispheric sign-preference of helicity, increased over time within large-scale, weak-field regions such as those near the polarity inversion line (PIL). Morphologically, Atmospheric Imaging Assembly observations of filament barbs, sigmoidal patterns, and bases of Fe xii stalks initially exhibited signatures of negative helicity, and the long filament that subsequently formed had a strong positive helicity consistent with the helicity buildup along the PIL. We find from full-disk HMI magnetograms that AR 12192's leading positive flux was initially closer to the equator but, owing either to the region's magnetic surroundings or to its asymmetric flux density distribution, was transported poleward more quickly on average than its trailing negative flux, contrary to the canonical pattern of bipole flux transport. This behavior caused the AR to have a smaller effect on the polar fields than expected and enabled the formation of the very long neutral line where the filament formed.

Self-consistent equilibrium models of prominence thin threads heated by Alfvén waves propagating from the photosphere

Llorenç **Melis**, Roberto Soler, Jaume Terradas

A&A 676, A25 **2023**

https://arxiv.org/pdf/2306.13434.pdf

https://www.aanda.org/articles/aa/pdf/2023/08/aa46459-23.pdf

The fine structure of solar prominences is made by thin threads that outline the magnetic field lines. Observations show that transverse waves of Alfvénic nature are ubiquitous in prominence threads. These waves are driven at the photosphere and propagate to prominences suspended in the corona. Heating due to Alfvén wave dissipation could be a relevant mechanism in the cool and partially ionized prominence plasma. We explore the construction of 1D equilibrium models of prominence thin threads that satisfy energy balance between radiative losses, thermal conduction, and Alfvén wave heating. We assume the presence of a broadband driver at the photosphere that launches Alfvén waves towards the prominence. An iterative method is implemented, in which the energy balance equation and the Alfvén wave equation are consecutively solved. From the energy balance equation and considering no wave heating initially, we compute the equilibrium profiles along the thread of the temperature, density, ionisation fraction. We use the Alfvén wave equation to compute the wave heating rate, which is then put back in the energy balance equation to obtain new equilibrium profiles. The process is repeated until convergence to a self-consistent thread model heated by Alfvén waves is achieved. We have obtained equilibrium models composed of a cold and dense thread, a extremely thin PCTR, and an extended coronal region. The length of the cold thread decreases with the temperature at the prominence core and increases with the Alfvén wave energy flux. Equilibrium models are not possible for sufficiently large wave energy fluxes when the wave heating rate inside the cold thread becomes larger than radiative losses. The maximum value of the wave energy flux that allows an equilibrium depends on the prominence core temperature. This constrains the existence of equilibria in realistic conditions.

Alfven wave heating in partially ionized thin threads of solar prominences

Llorenc **Melis**, Roberto Soler, Jose Luis Ballester

A&A 650, A45 **2021**

https://arxiv.org/pdf/2103.16599.pdf

https://www.aanda.org/articles/aa/pdf/2021/06/aa40523-21.pdf

https://doi.org/10.1051/0004-6361/202140523

There is observational evidence of the presence of small-amplitude transverse magnetohydrodynamic (MHD) waves with a wide range of frequencies in the threads of solar prominences. It is believed that the waves are driven at the photosphere and propagate along the magnetic field lines up to prominences suspended in the corona. The dissipation of MHD wave energy in the partially ionized prominence plasma is a heating mechanism whose relevance needs to be explored. Here we consider a simple 1D model for a non-uniform thin thread and investigate the heating associated with dissipation of Alfven waves. The model assumes an ad hoc density profile and a uniform pressure, while the temperature and ionization degree are self-consistently computed considering either LTE or non-LTE approximations for the hydrogen ionization. A broadband driver for Alfven waves is placed at one end of the magnetic field line, representing photospheric excitation. The Alfvenic perturbations along the thread are obtained by solving the linearized MHD equations for a partially ionized plasma in the single-fluid approximation.We find that wave heating in the partially ionized part of the thread is significant enough to compensate for energy losses due to radiative cooling. A greater amount of heating is found in the LTE case because the ionization degree for core prominence temperatures is lower than that in the non-LTE approximation. This results in a greater level of dissipation due to ambipolar diffusion in the LTE case. Conversely, in the hot coronal part of the model, the plasma is fully ionized and wave heating is negligible. The results of this simple model suggest that MHD wave heating can be relevant for the energy balance in prominences. Further studies based on more elaborate models are required.

The height of chromospheric loops in an emerging flux region

L. **Merenda**1, A. Lagg1 and S. K. Solanki.

A&A 532, A63 (**2011**)

Context. The chromospheric layer observable with the He i 10 830 Å triplet is strongly warped. The analysis of the magnetic morphology of this layer therefore requires a reliable technique to determine the height at which the He i absorption takes place.

Aims. The He i absorption signature connecting two pores of opposite polarity in an emerging flux region is investigated. This signature is suggestive of a loop system connecting the two pores. We aim to show that limits can be set on the height of this chromospheric loop system.

Methods. The increasing anisotropy in the illumination of a thin, magnetic structure intensifies the linear polarization signal observed in the He i triplet with height. This signal is altered by the Hanle effect. We apply an inversion technique incorporating the joint action of the Hanle and Zeeman effects, with the absorption layer height being one of the free parameters.

Results. The observed linear polarization signal can be explained only if the loop apex is higher than ≈ 5 Mm. Best agreement with the observations is achieved for a height of 6.3 Mm.

Conclusions. The strength of the linear polarization signal in the loop apex is inconsistent with the assumption of a He i absorption layer at a constant height level. The determined height supports the earlier conclusion that dark He 10 830 Å filaments in emerging flux regions trace emerging loops.

Joint action of phase mixing and nonlinear effects in MHD waves propagating in coronal loops

Claudio **Meringolo**, Francesco Pucci, Giuseppe Nisticò, Oreste Pezzi, Sergio Servidio, Francesco Malara

A&A **2024**

https://arxiv.org/pdf/2312.15355.pdf

We investigate the interplay of phase mixing and the nonlinear turbulent cascade in the evolution and dissipation of Alfvén waves using compressible magnetohydrodynamics numerical simulations. We consider perturbations in the form of torsional waves, both propagating and standing, or turbulent fluctuations, or a combination of the two. The main purpose is to study how phase mixing and nonlinear couplings jointly work to produce small scales in different regimes.

We conduct a numerical campaign to explore the typical parameters as the loop length, the amplitude and spatial profile of the perturbations, and the dissipative coefficients. A pseudo-spectral code is employed to solve the three-dimensional compressible magnetohydrodynamic equations, modeling the evolution of perturbations propagating in a flux tube corresponding to an equilibrium configuration with cylindrical symmetry.

We find that phase mixing takes place for moderate amplitudes of the turbulent component even in a distorted, non-axisymmetric configuration, building small scales that are locally transverse to the density gradient. The dissipative time decreases with increasing the percentage of the turbulent component. This behavior is verified both for propagating and standing waves. Even in the fully turbulent case, a mechanism qualitatively similar to phase mixing occurs: it actively generates small scales together with the nonlinear cascade, thus providing the shortest dissipative time. General considerations are given to identify this regime in the parameter space. The turbulent perturbation also distorts the background density, locally increasing the Alfvén velocity gradient and further contributing to accelerating the formation of small scales.

Filaments and the magnetic configuration - I. Observation of the solar case

N. **Meunier** and X. Delfosse

A&A 532, A18 (**2011**)

Context. The emission of Ca and Hα is correlated for the Sun, but this does not seem to be true for other stars. We previously demonstrated that this lack of correlation could be due to the presence of filaments.

Aims. We aim to establish a link between the activity level, the magnetic configuration, and the number of filaments, and therefore with observables of other stars that the Sun.
Methods. We studied the relationship between the filaments and the magnetic configuration using a large scale approach on MDI/SOHO magnetograms and a large sample of filaments. We validated the reconstruction of synthetic time series of filament surface coverage representative of the magnetic configuration, and then apply it to observations over a full solar cycle.
Results. We derived quantitative criteria that relates the presence of filaments to the properties at polarity inversion lines, hereafter PIL, magnetic field gradient, and unipolar areas on the solar surface (size and distance to these areas). We also observed that the number of PIL pixels is anti-correlated with the activity level, and the increase in filament surface coverage is due to the modification of the PIL pixel properties. We reconstructed synthetic time series of filaments that are in good agreement with observations.
Conclusions. This work validates our method, which will later be applied to solar and stellar simulations.

Dynamics of a solar prominence tornado observed by SDO/AIA on 2012 November 7-8

I. **Mghebrishvili**, T. V. Zaqarashvili, V. Kukhianidze, G. Ramishvili, B. Shergelashvili, A. Veronig, S. Poedts

ApJ 810: 89 **2015**
http://arxiv.org/pdf/1508.06788v1.pdf
https://iopscience.iop.org/article/10.1088/0004-637X/810/2/89/pdf

We study the detailed dynamics of a solar prominence tornado using time series of 171, 304, 193 and 211 {\AA} spectral lines obtained by Solar Dynamics Observatory/ Atmospheric Imaging Assembly during **2012 November 7-8**. The tornado first appeared at 08:00 UT, November 07, near the surface, gradually rose upwards with the mean speed of ~ 1.5 km s−1 and persisted over 30 hr. Time-distance plots show two patterns of quasi-periodic transverse displacements of the tornado axis with periods of 40 and 50 minute at different phases of the tornado evolution. The first pattern occurred during the rising phase and can be explained by the upward motion of the twisted tornado. The second pattern occurred during the later stage of evolution when the tornado already stopped rising and could be caused either by MHD kink waves in the tornado or by the rotation of two tornado threads around a common axis. The later hypothesis is supported by the fact that the tornado sometimes showed a double structure during the quasi-periodic phase. 211 and 193 {\AA} spectral lines show a coronal cavity above the prominence/tornado, which started expansion at ~ 13:00 UT and continuously rose above the solar limb. The tornado finally became unstable and erupted together with the corresponding prominence as coronal mass ejection (CME) at 15:00 UT, November 08. The final stage of the evolution of the cavity and the tornado-related prominence resembles the magnetic breakout model. On the other hand, the kink instability may destabilize the twisted tornado, and consequently prominence tornadoes can be used as precursors for CMEs.

Study of a Prominence Eruption using PROBA2/SWAP and STEREO/EUVI Data

M. **Mierla**, D. B. Seaton, D. Berghmans, I. Chifu, A. De Groof, B. Inhester, L. Rodriguez, G. Stenborg, A. N. Zhukov

Solar Physics, August **2013**, Volume 286, Issue 1, pp 241-253

Observations of the early rise and propagation phases of solar eruptive prominences can provide clues about the forces acting on them through the behavior of their acceleration with height. We have analyzed such an event, observed on **13 April 2010** by SWAP on PROBA2 and EUVI on STEREO. A feature at the top of the erupting prominence was identified and tracked in images from the three spacecraft. The triangulation technique was used to derive the true direction of propagation of this feature. The reconstructed points were fitted with two mathematical models: i) a power-law polynomial function and ii) a cubic smoothing spline, in order to derive the accelerations. The first model is characterized by five degrees of freedom while the second one is characterized by ten degrees of freedom. The results show that the acceleration increases smoothly, and it is continuously increasing with height. We conclude that the prominence is not accelerated immediately by local reconnection, but rather is swept away as part of a large-scale relaxation of the coronal magnetic field.

Nonlinear Resonant Excitation of Fast Sausage Waves in Current-Carrying Coronal Loops

B. B. **Mikhalyaev**, D. B. Bembitov

Solar Physics, November **2014**, Volume 289, Issue 11, pp 4069-4083

We consider a model of a coronal loop that is a cylindrical magnetic tube with two surface electric currents. Its principal sausage mode has no cut-off in the long-wavelength limit. For typical coronal conditions, the period of the mode is between one and a few minutes. The sausage mode of flaring loops could cause long-period pulsations observed in microwave and hard X-ray ranges. There are other examples of coronal oscillations: long-period pulsations of active-region quiet loops in the soft X-ray emission are observed. We assume that these can also be caused by sausage waves. The question arises of how the sausage waves are generated in quiet loops. We assume that they can be generated by torsional oscillations. This process can be described in the framework of the nonlinear three-wave interaction formalism. The periods of interacting torsional waves are similar to the periods of torsional oscillations observed in the solar atmosphere. The timescale of the sausage-wave excitation is not much longer than the periods of interacting waves, so that the sausage wave is excited before torsional waves are damped.

THE IMPORTANCE OF GEOMETRIC EFFECTS IN CORONAL LOOP MODELS

Zoran **Mikić**1, Roberto Lionello1, Yung Mok2, Jon A. Linker1, and Amy R. Winebarger

2013 ApJ 773 94

We systematically investigate the effects of geometrical assumptions in one-dimensional (1D) models of coronal loops. Many investigations of coronal loops have been based on restrictive assumptions, including symmetry in the loop shape and heating profile, and a uniform cross-sectional area. Starting with a solution for a symmetric uniform-area loop with uniform heating, we gradually relax these restrictive assumptions to consider the effects of nonuniform area, nonuniform heating, a nonsymmetric loop shape, and nonsymmetric heating, to show that the character of the solutions can change in important ways. We find that loops with nonuniform cross-sectional area are more likely to experience thermal nonequilibrium, and that they produce significantly enhanced coronal emission, compared with their uniform-area counterparts. We identify a process of incomplete condensation in loops experiencing thermal nonequilibrium during which the coronal parts of loops never fully cool to chromospheric temperatures. These solutions are characterized by persistent siphon flows. Their properties agree with observations (Lionello et al.) and may not suffer from the drawbacks that led Klimchuk et al. to conclude that thermal nonequilibrium is not consistent with observations. We show that our 1D results are qualitatively similar to those seen in a three-dimensional model of an active region. Our results suggest that thermal nonequilibrium may play an important role in the behavior of coronal loops, and that its dismissal by Klimchuk et al., whose model suffered from some of the restrictive assumptions we described, may have been premature.

Inference of magnetic fields in inhomogeneous prominences

Ivan **Milic**, Marianne Faurobert, Olga Atanackovic

A&A 597, A31 (**2017**)

http://arxiv.org/pdf/1609.04954v1.pdf

Most of the quantitative information about the magnetic field vector in solar prominences comes from the analysis of the Hanle effect acting on lines formed by scattering. As these lines can be of non-negligible optical thickness, it is of interest to study the line formation process further. We investigate the multidimensional effects on the interpretation of spectropolarimetric observations, particularly on the inference of the magnetic field vector. We do this by analyzing the differences between multidimensional models, which involve fully self-consistent radiative transfer computations in the presence of spatial inhomogeneities and velocity fields, and those which rely on simple one-dimensional geometry. We study the formation of a prototype line in ad hoc inhomogeneous, isothermal 2D prominence models. We solve the NLTE polarized line formation problem in the presence of a large-scale oriented magnetic field. The resulting polarized line profiles are then interpreted (i.e. inverted) assuming a simple 1D slab model. We find that differences between input and the inferred magnetic field vector are non-negligible. Namely, we almost universally find that the inferred field is weaker and more horizontal than the input field. Spatial inhomogeneities and radiative transfer have a strong effect on scattering line polarization in the optically thick lines. In real-life situations, ignoring these effects could lead to a serious misinterpretation of spectropolarimetric observations of chromospheric objects such as prominences.

PLASMA DYNAMICS AT THE PROMINENCE-CORONA INTERFACE

W. J. **Miloch**1,3,4, S. R. Habbal2, and R. Esse

2012 ApJ 752 85

The interface between the cool and dense plasma typical of a prominence and its tenuous and hot surrounding coronal plasma is poorly understood. We study the plasma dynamics at this interface using a three-dimensional particle-in-cell code, which enables us to carry out simulations on spatial and temporal scales of the order of the Debye length and plasma period, respectively. The results show that anomalous Bohm diffusion across magnetic field lines occurs at the interface, leading to mixing of the two plasmas. It is also shown that collisions with neutral hydrogen within the prominence plasma are of little importance for the plasma dynamics in the prominence-corona transition region. In particular, the temperature of the prominence plasma crossing the interface into the corona can become anisotropic due to preferential heating by instabilities originating from unstable velocity distributions. Our results pertain to spatial scales significantly smaller than scales commonly used in magnetohydrodynamic simulations, and they shed light on processes that are very likely to be present at the interface.

A THREE-DIMENSIONAL MODEL OF ACTIVE REGION 7986: COMPARISON OF SIMULATIONS WITH OBSERVATIONS

Yung **Mok**1, Zoran Mikić2, Roberto Lionello2, Cooper Downs2, and Jon A. Linker

2016 ApJ 817 15

In the present study, we use a forward modeling method to construct a 3D thermal structure encompassing active region 7986 of 1996 August. The extreme ultraviolet (EUV) emissions are then computed and compared with observations. The heating mechanism is inspired by a theory on Alfvén wave turbulence dissipation. The magnetic structure is built from a Solar and Heliospheric Observatory (SOHO)/MDI magnetogram and an estimated torsion parameter deduced from observations. We found that the solution to the equations in some locations is in a thermal nonequilibrium state. The time variation of the density and temperature profiles leads to time dependent emissions, which appear as thin, loop-like structures with uniform cross-section. Their timescale is consistent with the lifetime of observed coronal loops. The dynamic nature of the solution also leads to plasma flows that resemble observed coronal rain. The computed EUV emissions from the coronal part of the fan loops and the high loops compare favorably with SOHO/EIT observations in a quantitative comparison. However, the computed emission from the lower atmosphere is excessive compared to observations, a symptom common to many models. Some factors for this discrepancy are suggested, including the use of coronal abundances to compute the emissions and the neglect of atmospheric opacity effects.

Inferring physical parameters in solar prominence threads

M. **Montes-Solís**, I. Arregui

A&A 622, A88 **2019**

https://arxiv.org/pdf/1812.07262.pdf

High resolution observations have permitted to resolve the solar prominences/filaments as sets of threads/fibrils. However, the values of the physical parameters of these threads and their structuring remain poorly constrained. We use prominence seismology techniques to analyse transverse oscillations in threads through the comparison between magnetohydrodynamic (MHD) models and observations. We apply Bayesian methods to obtain two different types of information. We first infer the marginal posterior distribution of physical parameters, such as the magnetic field strength or the length of the thread, when a totally filled tube, a partially filled tube, and three damping models (resonant absorption in the Alfvén continuum, resonant absorption in the slow continuum, and Cowling's diffusion) are considered as certain. Then, we compare the relative plausibility between alternative MHD models by computing the Bayes factors. Well constrained probability density distributions can be obtained for the magnetic field strength, the length of the thread, the density contrast, and parameters associated to damping models. When comparing the damping models of resonant absorption in the Alfvén continuum, resonant absorption in the slow continuum and Cowling's diffusion due to partial ionisation of prominence plasma, the resonant absorption in the Alfvén continuum is the most plausible mechanism in explaining the existing observations. Relations between periods of fundamental and first overtone kink modes with values around 1 are better explained by expressions of the period ratio in the long thread approximation, while the rest of the values are more probable in the short thread limit for the period ratio. Our results show that Bayesian analysis offers valuable methods for performing parameter inference and model comparison in the context of prominence seismology.

Comparison of Damping Mechanisms for Transverse Waves in Solar Coronal Loops

María **Montes-Solís**1,2 and Iñigo Arregui1,2

2017 ApJ 846 89

https://arxiv.org/pdf/1709.03347.pdf

We present a method to assess the plausibility of alternative mechanisms to explain the damping of magnetohydrodynamic transverse waves in solar coronal loops. The considered mechanisms are resonant absorption of kink waves in the Alfvén continuum, phase mixing of Alfvén waves, and wave leakage. Our methods make use of Bayesian inference and model comparison techniques. We first infer the values for the physical parameters that control the wave damping, under the assumption of a particular mechanism, for typically observed damping timescales. Then, the computation of marginal likelihoods and Bayes factors enable us to quantify the relative plausibility between the alternative mechanisms. We find that, in general, the evidence is not large enough to support a single particular damping mechanism as the most plausible one. Resonant absorption and wave leakage offer the most probable explanations in strong damping regimes, while phase mixing is the best candidate for weak/moderate damping. When applied to a selection of 89 observed transverse loop oscillations, with their corresponding measurements of damping timescales and taking into account data uncertainties, we find that positive evidence for a given damping mechanism is only available in a few cases.

Initiation of Coronal Mass Ejections (обзор)

Ronald L. **Moore** and Alphonse C. Sterling
AGU Geophysical Monograph 165, Solar Eruptions and Energetic Particles,
ed. N. Gopalswamy, R. Mewaldt, & J. Torsti, p. 43, **2006; File**
We describe three different mechanisms that singly or in combination can trigger the explosion: (1) runaway internal tether-cutting reconnection, (2) runaway external tether-cutting reconnection, and (3) ideal MHD instability or loss or equilibrium.

Energy Dissipation in Coronal Loops: Statistical Analysis of Intermittent Structures in Magnetohydrodynamic Turbulence

Laura F. **Morales**1,2, Pablo Dmitruk1,3, and Daniel O. Gómez1,4
2020 ApJ 894 90
https://doi.org/10.3847/1538-4357/ab8462
The power-law energy distribution observed in dissipation events ranging from flares down to nanoflares has been associated either to intermittent turbulence or to self-organized criticality. Despite the many studies conducted in recent years, it is unclear whether these two paradigms are mutually exclusive or they are complementary manifestations of the complexity of the system. We numerically integrate the magnetohydrodynamic equations to simulate the dynamics of coronal loops driven at their bases by footpoint motions. After a few photospheric turnover times, a stationary turbulent regime is reached, displaying a broadband power spectrum and a dissipation rate consistent with the cooling rates of the plasma confined in these loops. Our main goal is to determine whether the intermittent features observed in this turbulent flow can also be regarded as manifestations of self-organized criticality. A statistical analysis of the energy, area, and lifetime of the dissipative structures observed in these simulations displays robust scaling laws. We calculated the critical exponents characterizing the avalanche dynamics, and the spreading exponents that quantify the growth of these structures over time. In this work we also calculate the remaining critical exponents for several activity thresholds and verify that they satisfy the conservation relations predicted for self-organized critical systems. These results can therefore be regarded as a bona fide test supporting that the stationary turbulent regimes characterizing coronal loops also correspond to states of self-organized criticality.

The width, density and outflow of solar coronal streamers

Huw **Morgan**, Anthony C. Cook
2020 *ApJ* **893** 57
https://arxiv.org/pdf/2003.04809.pdf
https://iopscience.iop.org/article/10.3847/1538-4357/ab7e32/pdf
Characterising the large-scale structure and plasma properties of the inner corona is crucial to understand the source and subsequent expansion of the solar wind and related space weather effects. Here we apply a new coronal rotational tomography method, along with a method to narrow streamers and refine the density estimate, to COR2A/STEREO observations from a period near solar minimum and maximum, gaining density maps for heights between 4 and 8\Rs. The coronal structure is highly radial at these heights, and the streamers are very narrow, in some regions only a few degrees in width. The mean densities of streamers is almost identical between solar minimum and maximum. However, streamers at solar maximum contain around 50\%\ more total mass due to their larger area. By assuming a constant mass flux, and constraints on proton flux measured by Parker Solar Probe (PSP), we estimate an outflow speed within solar minimum streamers of 50-120\kms\ at 4\Rs, increasing to 90-250\kms\ at 8\Rs. Accelerations of around 6\mss\ are found for streamers at a height of 4\Rs, decreasing with height. The solar maximum slow wind shows a higher acceleration to extended distances compared to solar minimum. To satisfy the solar wind speeds measured by PSP, there must be a mean residual acceleration of around 1-2\mss\ between 8 and 40\Rs. Several aspects of this study strongly suggest that the coronal streamer belt density is highly variable on small scales, and that the tomography can only reveal a local spatial and temporal average.

LONGITUDINAL DRIFTS OF STREAMERS ACROSS THE HELIOSPHERIC CURRENT SHEET

Huw **Morgan**
2011 ApJ 738 190
Potential field source surface (PFSS) extrapolations of the photospheric magnetic field provide a qualitatively correct model of the coronal magnetic structure. We show that the magnetic structure provided by PFSS describes a framework within which high-density coronal streamers are distributed. However, the density structures have considerable freedom to drift longitudinally along the magnetic structure. Some caution must therefore be taken when using PFSS models as proxies for the coronal density structure. In particular, while measurements of coronal rotation using PFSS models provide an estimate of the large-scale magnetic structure rotation, they are not valid measurements of the density rotation. Furthermore, attempts to assign a consistent rate of rotation to the electron corona over long time periods are not always valid since the movement is dominated by structural reconfiguration. These conclusions are reached by the application of solar rotational tomography to LASCO C2/Solar and

Heliospheric Observatory observations during solar minimum (1996-1997), revealing the changing density structure of the equatorial streamer belt at a height of 4 R .

Observational Aspects of the Three-dimensional Coronal Structure Over a Solar Activity Cycle

Huw **Morgan** and Shadia Rifai Habbal

2010 ApJ 710 1-15

Solar rotational tomography is applied to almost eleven years of Large Angle Spectrometric Coronagraph C2/*Solar and Heliospheric Observatory* data, revealing for the first time the behavior of the large-scale coronal density structures, also known as streamers, over almost a full solar activity cycle. This study gives an overview of the main results of this project. (1) Streamers are most often shaped as extended, narrow plasma sheets. The sheets can be extremely narrow at times ($\leq 0.14 \times 10^6$ km at 4 $R_\odot$). This is over twice their heliocentric angular thickness at 1 AU. (2) At most times outside the height of solar maximum, there are two separate stable large helmet streamer belts extending from mid-latitudes (in both north and south). At solar minimum, the streamers converge and join near the equator, giving the impression of a single large helmet streamer. Outside of solar minimum, the two streamers do not join, forming separate high-density sheets in the extended corona (one in the north, another in the south). At solar maximum, streamers rise radially from their source regions, while during the ascending and descending activity phases, streamers are skewed toward the equator. (3) For most of the activity cycle, streamers share the same latitudinal extent as filaments on the disk, showing that large-scale stable streamers are closely linked to the same large-scale photospheric magnetic configuration, which give rise to large filaments. (4) The poleward footpoints of the streamers are often above crown polar filaments and the equatorial footpoints are above filaments or active regions (or above the photospheric neutral lines which underlie these structures). The high-density structures arising from the equatorial active regions either rise and form the equatorial footpoints of mid-latitude quiescent streamers, or form unstable streamers at the equator, not connected to the quiescent streamer structure at higher latitude (so there are often three streamer sheets sharing the same extended longitudinal region). (5) Comparison between the tomography results and a potential field source surface model shows that streamers are not necessarily associated with a magnetic polarity reversal, but rather are regions containing field lines arising from widely separated sources at the Sun. We call these convergence sheets. (6) There is considerable differential rotation of streamers at high latitudes, which makes comparison between disk and coronal structure complicated. The presence of differential rotation has implications for many areas of coronal and heliospheric research.

MAPPING THE STRUCTURE OF THE CORONA USING FOURIER BACKPROJECTION TOMOGRAPHY

Huw **Morgan**, Habbal, Lugaz

ApJ 690 1119-1129, **2009** doi: 10.1088/0004-637X/690/2/1119

Estimating the structure, or density distribution, of the solar corona from a set of two-dimensional white-light images made by coronagraphs is a critical challenge in coronal physics. This work describes new data-analysis procedures which are used to create global maps of the coronal structure at heights where the corona becomes approximately radial ($\geq 3\ R$). The technique, which is named Qualitative Solar Rotational Tomography (QSRT), uses total brightness white light observations, processed with a suitable background subtraction and a Normalizing Radial Graded Filter (NRGF). These observations are made with high frequency by the Large Angle and Spectrometric Coronagraph Experiment (LASCO) C2 coronagraph, which allows a standard Fourier-transform-based tomographical reconstruction. In this paper, we first test the technique using a model corona. QSRT is then applied to a set of observations made during Carrington Rotation (CR) 2000-2001 (2003 March 16 to 2003 March 31). Since the maps are constructed from data which are normalized using the NRGF process, QSRT cannot give electron density directly. Nevertheless, the tests using the model corona demonstrate the technique's ability to give a good qualitative reconstruction of the coronal structure at high latitude, with decreasing but acceptable accuracy at the equator. These tests also demonstrate QSRT's insensitivity to noise. For the LASCO C2 observations, good agreement is found between synthetic images calculated from the reconstructed corona and the original observations, and good agreement is found between the distribution of density in a QSRT reconstruction and that found using a global MHD model. Despite their lack of quantitative information on absolute electron density, the resulting maps (which are constructed directly from high-resolution coronal data observed at the appropriate height), contain useful information on the distribution of density in the corona.

Eruptive and quasi-eruptive disappearing solar filaments and their relationship with coronal activities.

Morimoto T., Kurorawa H.

Publ.Astron.Soc.Japan. **2003**. V.55. No.6. P.1141–1151; **File**.

By measuring the 3-D velocity fields of 35 disappearing filaments (Disparition Brusques: DBs) on the solar disk, we studied the causal relationship between the motions of Hα DBs and the associated coronal phenomena. Using the derived 3-D velocity fields of the DBs, we developed a method to judge whether a DB is ejected into interplanetary space or whether it remains in the solar atmosphere. We compared the DB type thus obtained with the presence of coronal mass ejections (CMEs) and other associated coronal activities. It is inferred that eruptive filaments are always followed by the formation of arcades, while most quasi-eruptive events are followed by localized changes in soft X-rays and the EUV. A close causal relation between eruptive filaments and CMEs was also found: of 15 DBs for which Solar and Heliospheric Observatory Large Angle and Spectrometric Coronagraph data were available, all eight of the eruptive ones were associated with CMEs, while no CMEs were found following any of the 7 quasieruptive ones. These observational results indicate that the motions of Hα disappearing filaments are causally related to the associated coronal activities and also to the appearance of CMEs, and that an accurate analysis of their 3-D velocities is important not only for a better understanding of their acceleration and heating mechanisms, but also for predicting the occurrence of CMEs and geomagnetic storms.

Daily Variations of Plasma Density in the Solar Streamer Belt

Huw **Morgan**1

2021 ApJ 922 165

https://iopscience.iop.org/article/10.3847/1538-4357/ac1799/pdf

https://doi.org/10.3847/1538-4357/ac1799

Improved space weather diagnostics depend critically on improving our understanding of the evolution of the slow solar wind in the streamer belts near the Sun. Recent innovations in tomography techniques are opening a new window on this complex environment. In this work, a new time-dependent technique is applied to COR2A/Solar Terrestrial Relations Observatory observations from a period near solar minimum (2018 November 11) for heliocentric distances of 4–8 $R_\odot$. For the first time, we find density variations of large amplitude throughout the quiescent streamer belt, ranging between 50% and 150% of the mean density, on timescales of tens of hours to days. Good agreement is found with Parker Solar Probe measurements at perihelion; thus, the variations revealed by tomography must form a major component of the slow solar wind variability, distinct from coronal mass ejections or smaller transients. A comparison of time series at different heights reveals a consistent time lag, so that changes at 4 $R_\odot$ occur later at increasing height, corresponding to an outward propagation speed of around 100 km s^{-1}. This speed may correspond to either the plasma sound speed or the bulk outflow speed depending on an important question: are the density variations caused by the spatial movement of a narrow streamer belt (moving magnetic field, constant plasma density), or changes in plasma density within a nonmoving streamer belt (rigid magnetic field, variable density), or a combination of both? **2018 November 04-07**

Model fitting of kink waves in the solar atmosphere: Gaussian damping and time-dependence

R. J. **Morton**, K. Mooroogen

A&A **2016**

http://arxiv.org/pdf/1607.05905v1.pdf

{Observations of the solar atmosphere have shown that magnetohydrodynamic waves are ubiquitous throughout. Improvements in instrumentation and the techniques used for measurement of the waves now enables subtleties of competing theoretical models to be compared with the observed waves behaviour. Some studies have already begun to undertake this process. However, the techniques employed for model comparison have generally been unsuitable and can lead to erroneous conclusions about the best model. The aim here is to introduce some robust statistical techniques for model comparison to the solar waves community, drawing on the experiences from other areas of astrophysics. In the process, we also aim to investigate the physics of coronal loop oscillations. } {The methodology exploits least-squares fitting to compare models to observational data. We demonstrate that the residuals between the model and observations contain significant information about the ability for the model to describe the observations, and show how they can be assessed using various statistical tests. In particular we discuss the Kolmogorov-Smirnoff one and two sample tests, as well as the runs test. We also highlight the importance of including any observational trend line in the model-fitting process.} {To demonstrate the methodology, an observation of an oscillating coronal loop undergoing standing kink motion is used. The model comparison techniques provide evidence that a Gaussian damping profile provides a better description of the observed wave attenuation than the often used exponential profile. This supports previous analysis from Pascoe et al. (2016). Further, we use the model comparison to provide evidence of time-dependent wave properties of a kink oscillation, attributing the behaviour to the thermodynamic evolution of the local plasma.}

Magneto-seismological insights into the penumbral chromosphere and evidence for wave damping in spicules

R J **Morton**

A&A, **2014**
http://arxiv.org/pdf/1405.3203v1.pdf
The observation of propagating magneto-hydrodynamic kink waves in magnetic structures and measurement of their properties (amplitude, phase speed) can be used to diagnose the plasma conditions in the neighbourhood of the magnetic structure via magneto-seismology (MS). We aim to reveal properties of the chromosphere/Transition Region above the sunspot penumbra using this technique. Hinode observed a sunspot as it was crossing the limb, providing a unique side on view of the sunspot atmosphere. The presence of large spicule-like jets is evident in \ion{Ca}{II} H images. The jets are found to support transverse wave motions that displace the central axis, which can be interpreted as a kink wave. The properties of a wave event are measured and used to determine the magnetic and density stratification along the structure. We also measure the width of the spicule and the intensity profile along the structure. The measured wave properties reveal an initial rapid increase in amplitude with height above the solar surface, followed by a decrease in amplitude. The MS inversion suggests this initial increase corresponds to large changes in density and magnetic field strength. In addition, we provide the first measurements of spicule width with height, which confirm that the spicule under goes rapid expansion. The measured expansion shows good agreement with the results from the MS. The observed variations in plasma parameters are suggested to be partly due to the presence of a gravitational stratified, ambient atmosphere. Combining width measurements with phase speed measurements implies the observed decrease in wave amplitude at greater heights can be explained by wave damping. Hence, we provide the first direct evidence of wave damping in chromospheric spicules and the quality factor of the damping is found to be significantly smaller than estimated coronal values.

Observations of quasi-periodic phenomena associated with a large blowout solar jet

R. J. **Morton**, A. K. Srivastava, R. Erd'elyi
E-print, April **2012**, A&A
A variety of periodic phenomena have been observed in conjunction with large solar jets. We aim to find further evidence for {(quasi-)}periodic behaviour in solar jets and determine what the periodic behaviour can tell us about the excitation mechanism and formation process of the large solar jet. Using the 304 {AA} (He-II), 171 {AA} (Fe IX), 193 {AA} (Fe XII/XXIV) and 131 {AA} (Fe VIII/XXI) filters on-board the Solar Dynamic Observatory (SDO) Atmospheric Imaging Assembly (AIA), we investigate the intensity oscillations associated with a solar jet. Evidence is provided for multiple magnetic reconnection events occurring between a pre-twisted, closed field and open field lines. Components of the jet are seen in multiple SDO/AIA filters covering a wide range of temperatures, suggesting the jet can be classified as a blowout jet. Two bright, elongated features are observed to be co-spatial with the large jet, appearing at the jet's footpoints. Investigation of these features reveal they are defined by multiple plasma ejections. The ejecta display (quasi-)periodic behaviour on timescales of 50 s and have rise velocities of 40-150 km,s-1 along the open field lines. Due to the suggestion that the large jet is reconnection-driven and the observed properties of the ejecta, we further propose that these ejecta events are similar to type-II spicules. The bright features also display (quasi-)periodic intensity perturbations on the timescale of 300 s. Possible explanations for the existence of the (quasi-)periodic perturbations in terms of jet dynamics and the response of the transition region are discussed.
20 January 2011

The influence of coronal loop cooling on transverse oscillations."

by Richard **Morton** and Robert Erdélyi, University of Sheffield
UKSP nugget, March **2011**
http://www.uksolphys.org/?p=2335
The mystery of rapid damping of loop oscillations is solved by plasma cooling.

TRANSVERSE OSCILLATIONS OF A COOLING CORONAL LOOP

R. J. Morton and R. Erdélyi
ApJ 707 750-760, **2009**
Here we present an investigation into how cooling of the plasma influences the oscillation properties (e.g., eigenfunctions and eigenfrequencies) of transverse (i.e., kink) magnetohydrodynamic (MHD) waves in a compressible magnetic flux tube embedded in a gravitationally stratified and uniformly magnetized atmosphere. The cooling is introduced via a temperature-dependent density profile. A time-dependent governing equation is derived and an approximate zeroth-order solution is then obtained. From this the influence of cooling on the behavior of the eigenfrequencies and eigenfunctions of the transverse MHD waves is determined for representative cooling timescales. It is shown analytically, as the loop cools, how the amplitude of the perturbations is found to decrease as time increases. For cooling timescales of 900-2000 s (as observed in typical EUV loops), it is shown that the cooling has important and relevant influence on the damping times of loop oscillations. Next, the theory is put to the test. The damping due to cooling is fitted to a representative observation of standing kink oscillation of EUV loops. It is

also shown with an explicit approximate analytical form, how the period of the fundamental and first harmonic of the kink mode changes with time as the loop cools. A consequence of this is that the value of the period ratio P_1/P_2, a tool that is popular in magneto-seismological studies in coronal diagnostics, decreases from the value of a uniform loop, 2, as the temperature decreases. The rate of change in P_1/P_2 is dependent upon the cooling timescale and is well within the observable range for typical EUV loops. Further to this, the magnitude of the anti-node shift of the eigenfunctions of the first harmonic is shown to continually increase as the loop cools, giving additional impetus to the use of spatial magneto-seismology of the solar atmosphere. Finally, we suggest that measurements of the rate of change in the eigenfunctions and eigenfrequencies of MHD oscillations can provide values for the cooling timescale and a further insight into the physics of coronal loops.

Failed Eruption of a Filament as a Driver for Vertical Oscillations of Coronal Loops

T. **Mrozek**

Solar Physics, Volume 270, Number 1, 191-203, **2011, File**

We present observations of a failed eruption of a magnetic flux rope recorded during the M6.2 flare of **14 July 2004**. The observations were mainly made with TRACE 171 Å and 1600 Å filters. The flare was accompanied by a destabilization of a magnetic structure observed as a filament eruption. After an initial acceleration, the eruption slowed down and finally was stopped by the overlying coronal loops. The observations suggest that the whole event is well described by the quadrupole model of a solar flare. The failed eruption stretched the overlying loops, and they were then observed to be oscillating. We were able to observe clear vertical polarization of the oscillatory motion in the TRACE images. The derived parameters of the oscillatory motion are an initial amplitude of 9520 km, a period of 377 s, and an exponential damping time of 500 s. Differences between the existing models and the observations have been found. The analyzed event is the second sample for global vertical kink waves found besides the first by Wang and Solanki (Astrophys. J. Lett. 421, 33, 2004).

EVIDENCE FOR MIXED HELICITY IN ERUPTING FILAMENTS

K. **Muglach**1, Y.-M. Wang, and B. Kliem

Astrophysical Journal, 703:976–981, **2009** September 20

Erupting filaments are sometimes observed to undergo a rotation about the vertical direction as they rise. This rotation of the filament axis is generally interpreted as a conversion of twist into writhe in a kink-unstable magnetic flux rope. Consistent with this interpretation, the rotation is usually found to be clockwise (as viewed from above) if the post-eruption arcade has right-handed helicity, but counterclockwise if it has left-handed helicity. Here, we describe two non-active-region filament events recorded with the Extreme-Ultraviolet Imaging Telescope on the *Solar and Heliospheric Observatory* in which the sense of rotation appears to be opposite to that expected from the helicity of the post-event arcade. Based on these observations, we suggest that the rotation of the filament axis is, in general, determined by the net helicity of the erupting system, and that the axially aligned core of the filament can have the opposite helicity sign to the surrounding field. In most cases, the surrounding field provides the main contribution to the net helicity. In the events reported here, however, the helicity associated with the filament "barbs" is opposite in sign to and dominates that of the overlying arcade.

Topologically Driven Coronal Dynamics - A Mechanism for Coronal Hole Jets

D.A.N. **Müller** and S.K. Antiochos

E-print, April 2008

Bald patches are magnetic topologies in which the magnetic field is concave up over part of a photospheric polarity inversion line. A bald patch topology is believed to be the essential ingredient for filament channels and is often found in extrapolations of the observed photospheric field. Using an analytic source-surface model to calculate the magnetic topology of a small bipolar region embedded in a global magnetic dipole field, we demonstrate that although common in closed-field regions close to the solar equator, bald patches are unlikely to occur in the open-field topology of a coronal hole. Our results give rise to the following question: What happens to a bald patch topology when the surrounding field lines open up? This would be the case when a bald patch moves into a coronal hole, or when a coronal hole forms in an area that encompasses a bald patch. Our magnetostatic models show that, in this case, the bald patch topology almost invariably transforms into a null point topology with a spine and a fan. We argue that the time-dependent evolution of this scenario will be very dynamic since the change from a bald patch to null point topology cannot occur via a simple ideal evolution in the corona. We discuss the implications of these findings for recent Hinode XRT observations of coronal hole jets and give an outline of planned time-dependent 3D MHD simulations to fully assess this scenario.

DETERMINING THE STRUCTURE OF SOLAR CORONAL LOOPS USING THEIR EVOLUTION

Fana M. **Mulu-Moore**, Amy R. Winebarger1, Harry P. Warren2 and Markus J. Aschwanden

2011 ApJ 733 59

Despite significant progress in understanding the dynamics of the corona, there remain several unanswered questions about the basic physical properties of coronal loops. Recent observations from different instruments have yielded contradictory results about some characteristics of coronal loops, specifically as to whether the observed loops are spatially resolved. In this paper, we examine the evolution of coronal loops through two extreme-ultraviolet filters and determine if they evolve as a single cooling strand. We measure the temporal evolution of eight active region loops previously studied and found to be isothermal and resolved by Aschwanden & Nightingale. All eight loops appear in "hotter" TRACE filter images (Fe XII 195 Å) before appearing in the "cooler" (Fe IX/Fe X 171 Å) TRACE filter images. We use the measured delay between the two filters to calculate a cooling time and then determine if that cooling time is consistent with the observed lifetime of the loop. We do this twice: once when the loop appears (rise phase) and once when it disappears (decay phase). We find that only one loop appears consistent with a single cooling strand and hence could be considered to be resolved by TRACE. For the remaining seven loops, their observed lifetimes are longer than expected for a single cooling strand. We suggest that these loops could be formed of multiple cooling strands, each at a different temperature. These findings indicate that the majority of loops observed by TRACE are unresolved

Analysis of the Coronal Mass Ejections through Axial Field Direction of Solar Filaments and IMF Bz

Kashvi **Mundra**, V. Aparna, Petrus C. H. Martens

ApJ **2020**

https://arxiv.org/pdf/2011.02123.pdf

In the past, there have been many studies claiming that the effects of geomagnetic storms strongly depends on the orientation of the magnetic-cloud part of the Coronal Mass Ejections (CMEs). Aparna & Martens (2020), using Halo-CME data from 2007-2017, have shown that the magnetic field orientation of filaments at the location where CMEs originate can be effectively used for predicting the onset of geo-magnetic storms. The purpose of this study is to extend their survey by analyzing the halo-CME data for 1996-2006. The correlation of filament axial direction and their corresponding Bz signatures are used to form a more extensive reasoning for the claims presented by Aparna & Martens before. This study utilizes SOHO EIT 195 Å, MDI magnetogram images, KSO and BBSO Hα images for the time period, along with ACE data for inter-planetary magnetic field signatures. Correlating all these, we have found that the trend in Aparna & Martens' study of a high likelihood of the correlation between the axial field direction and Bz orientation, persists for the data between 1996-2006 as well. **September 16th, 2000, 02/09/2001, 2000-11-01**

An alternative measure of solar activity from detailed sunspot datasets

Judit **Muraközy**, Tünde Baranyi, András Ludmány

Solar Phys. **2016**

http://arxiv.org/pdf/1603.05870v1.pdf

The sunspot number is analyzed by using detailed sunspot data, including aspects of observability, sunspot sizes, and proper identification of sunspot groups as discrete entities of the solar activity. The tests show that besides the subjective factors there are also objective causes of the ambiguities in the series of sunspot numbers. To introduce an alternative activity measure the physical meaning of the sunspot number has to be reconsidered. It contains two components whose numbers are governed by different physical mechanisms, this is one source of the ambiguity. This article suggests an activity index, which is the amount of emerged magnetic flux. The only long-term proxy measure is the detailed sunspot area dataset with proper calibration to the magnetic flux amount. The Debrecen sunspot databases provide an appropriate source for the establishment of the suggested activity index.

Numerical simulations of multi-shell plasma twisters in the solar atmosphere

K. **Murawski**, A.K. Srivastava, Z.E. Musielak, B.N. Dwivedi

ApJ **2015**

http://arxiv.org/pdf/1505.03793v1.pdf

We perform numerical simulations of impulsively generated Alfv\'en waves in an isolated photospheric flux tube, and explore the propagation of these waves along such magnetic structure that extends from the photosphere, where these waves are triggered, to the solar corona, and analyze resulting magnetic shells. Our model of the solar atmosphere is constructed by adopting the temperature distribution based on the semi-empirical model and specifying the curved magnetic field lines that constitute the magnetic flux tube which is rooted in the solar photosphere. The evolution of the solar atmosphere is described by 3D, ideal magnetohydrodynamic equations that are numerically solved by the FLASH code. Our numerical simulations reveal, based on the physical properties of the multi-shell magnetic twisters and the amount of energy and momentum associated with them, that these multi-shell magnetic twisters may be responsible for the observed heating of the lower solar corona and for the formation of solar wind. Moreover, it is likely that the existence of these twisters can be verified by high-resolution observations.

Torsional Alfvén waves in solar magnetic flux tubes of axial symmetry

K. **Murawski**1, A. Solov'ev2, Z. E. Musielak3,4, A. K. Srivastava5 and J. Kraśkiewicz

A&A 577, A126 (**2015**)

Aims. Propagation and energy transfer of torsional Alfvén waves in solar magnetic flux tubes of axial symmetry is studied.
Methods. An analytical model of a solar magnetic flux tube of axial symmetry is developed by specifying a magnetic flux and deriving general analytical formulas for the equilibrium mass density and gas pressure. The main advantage of this model is that it can be easily adopted to any axisymmetric magnetic structure. The model is used to numerically simulate the propagation of nonlinear Alfvén waves in such 2D flux tubes of axial symmetry embedded in the solar atmosphere. The waves are excited by a localized pulse in the azimuthal component of velocity and launched at the top of the solar photosphere, and they propagate through the solar chromosphere, the transition region, and into the solar corona.
Results. The results of our numerical simulations reveal a complex scenario of twisted magnetic field lines and flows associated with torsional Alfvén waves, as well as energy transfer to the magnetoacoustic waves that are triggered by the Alfvén waves and are akin to the vertical jet flows. Alfvén waves experience about 5% amplitude reflection at the transition region. Magnetic (velocity) field perturbations that experience attenuation (growth) with height agree with analytical findings. The kinetic energy of magnetoacoustic waves consists of 25% of the total energy of Alfvén waves. The energy transfer may lead to localized mass transport in the form of vertical jets, as well as to localized heating because slow magnetoacoustic waves are prone to dissipation in the inner corona.

New analytical and numerical models of solar coronal loop: I. Application to forced vertical kink oscillations

K. **Murawski**, A. Solov'ev, J. Kraskiewicz, A.K. Srivastava

A&A, 576, A22 **201**4

http://arxiv.org/pdf/1411.7465v1.pdf

Aims. We construct a new analytical model of a solar coronal loop that is embedded in a gravitationally stratified and magnetically confined atmosphere. On the basis of this analytical model, we devise a numerical model of solar coronal loops. We adopt it to perform the numerical simulations of its vertical kink oscillations excited by an external driver. Methods. Our model of the solar atmosphere is constructed by adopting a realistic temperature distribution and specifying the curved magnetic field lines that constitute a coronal loop. This loop is described by 2D, ideal magnetohydro- dynamic equations that are numerically solved by the FLASH code. Results. The vertical kink oscillations are excited by a periodic driver in the vertical component of velocity, acting at the top of the photosphere. For this forced driver with its amplitude 3 km/s, the excited oscillations exhibit about 1.2 km/s amplitude in their velocity and the loop apex oscillates with its amplitude in displacement of about 100 km. Conclusions. The newly devised analytical model of the coronal loops is utilized for the numerical simulations of the vertical kink oscillations, which match well with the recent observations of decay-less kink oscillations excited in solar loops. The model will have further implications on the study of waves and plasma dynamics in coronal loops, revealing physics of energy and mass transport mechanisms in the localized solar atmosphere.

Fast Magnetic Twister and Plasma Perturbations in a 3-D Coronal Arcade

K. **Murawski**, A.K. Srivastava, Z. E. Musielak

2014

http://arxiv.org/pdf/1404.4176v1.pdf

We present results of 3-D numerical simulations of a fast magnetic twister excited above a foot-point of the potential solar coronal arcade that is embedded in the solar atmosphere with the initial VAL-IIIC temperature profile, which is smoothly extended into the solar corona. With the use of the FLASH code, we solve 3-D ideal magnetohydrodynamic equations by specifying a twist in the azimuthal component of magnetic field in the solar chromosphere. The imposed perturbation generates torsional Alfv\'en waves as well as plasma swirls that reach the other foot-point of the arcade and partially reflect back from the transition region. The two vortex channels are evident in the generated twisted flux-tube with a fragmentation near its apex that results from the initial twist as well as from the morphology of the tube. The numerical results are compared to observational data of plasma motions in

a solar prominence. The comparison shows that the numerical results and the data qualitatively agree even though the observed plasma motions occur over comparatively large spatio-temporal scales in the prominence.
4-Aug-2012

Triggering Mechanism for the Filament Eruption on 2005 September 13 in Active Region NOAA 10808

Kaori **Nagashima**, Hiroaki Isobe, Takaaki Yokoyama, Takako T. Ishii, Takenori J. Okamoto, and Kazunari Shibata

The Astrophysical Journal, 668:533-545, 2007, File

We suggest the process toward the eruption as follows: First, a series of small flares played a role in changing the topology of the loops overlying the filament. Second, the small flares gradually changed the equilibrium state of the filament and caused the filament to ascend slowly over two days. Finally, a C2.9 flare that occurred when the filament was close to the critical point for loss of equilibrium directly led to the catastrophic filament eruption right after itself.

Transition from decaying to decayless kink oscillations of solar coronal loops

Valery M **Nakariakov**, Yu Zhong, Dmitrii Y Kolotkov

MNRAS Volume 531, Issue 4, July **2024**, Pages 4611–4618,

https://doi.org/10.1093/mnras/stae1483

https://watermark.silverchair.com/stae1483.pdf

The transition of an impulsively excited kink oscillation of a solar coronal loop to an oscillation with a stationary amplitude, i.e. the damping pattern, is determined using the low-dimensional self-oscillation model. In the model, the decayless kink oscillations are sustained by the interaction of the oscillating loop with an external quasi-steady flow. The analytical solution is based on the assumption that the combined effect of the effective dissipation, for example, by resonant absorption, and interaction with an external flow, is weak. The effect is characterized by a dimensionless coupling parameter. The damping pattern is found to depend upon the initial amplitude and the coupling parameter. The approximate expression shows a good agreement with a numerical solution of the self-oscillation equation. The plausibility of the established damping pattern is demonstrated by an observational example. Notably, the damping pattern is not exponential, and the characteristic decay time is different from the time determined by the traditionally used exponential damping fit. Implications of this finding for seismology of the solar coronal plasmas are discussed. In particular, it is suggested that a very rapid, in less than the oscillation period, decay of the oscillation to the stationary level, achieved for larger values of the coupling parameter, can explain the relative rareness of the kink oscillation events. **2012 May 30**

Do Periods of Decayless Kink Oscillations of Solar Coronal Loops Depend on Noise?

Valery M. **Nakariakov**, Dmitrii Y. Kolotkov, Sihui Zhong

MNRAS   Volume 516, Issue 4 Pages 5227–5231   **2022**

https://arxiv.org/pdf/2209.06343.pdf

https://warwick.ac.uk/fac/sci/physics/research/cfsa/people/valery/research/Decayless_theory.pdf

https://doi.org/10.1093/mnras/stac2628

Decayless kink oscillations of solar coronal loops are studied in terms of a low-dimensional model based on a randomly driven Rayleigh oscillator with coefficients experiencing random fluctuations. The model considers kink oscillations as natural modes of coronal loops, decaying by linear resonant absorption. The damping is counteracted by random motions of the loop footpoints and the interaction of the loop with external quasi-steady flows with random fluctuations. In other words, the model combines the self-oscillatory and randomly driven mechanisms for the decayless behaviour. The random signals are taken to be of the stationary red noise nature. In the noiseless case, the model has an asymptotically stationary oscillatory solution, i.e., a kink self-oscillation. It is established that the kink oscillation period is practically independent of noise. This finding justifies the seismological estimations of the kink and Alfvén speeds and the magnetic field in an oscillating loop by kink oscillations, based on the observed oscillation period. The oscillatory patterns are found to be almost harmonic. Noisy fluctuations of external flows modulate the amplitude of the almost monochromatic oscillatory pattern symmetrically, while random motions of the loop footpoints cause antisymmetric amplitude modulation. Such modulations are also consistent with the observed behaviour. **24th June 2021**

V. M. **Nakariakov** · S. A. Anfinogentov · P. Antolin · R. Jain · D. Y. Kolotkov · E. G. Kupriyanova · D. Li · N. Magyar · G. Nistic`o · D. J. Pascoe · A. K. Srivastava · J. Terradas · S. Vasheghani Farahani · G. Verth · D. Yuan · I. V. Zimovets

Space Science Reviews volume 217, Article number: 73   **2021**

https://warwick.ac.uk/fac/sci/physics/research/cfsa/people/valery/research/eprints/kink_nakariakov_rev1.pdf

https://arxiv.org/pdf/2109.11220

https://link.springer.com/content/pdf/10.1007/s11214-021-00847-2.pdf
https://doi.org/10.1007/s11214-021-00847-2
Kink oscillations of coronal loops, i.e., standing kink waves, is one of the most studied dynamic phenomena in the solar corona. The oscillations are excited by impulsive energy releases, such as low coronal eruptions. Typical periods of the oscillations are from a few to several minutes, and are found to increase linearly with the increase in the major radius of the oscillating loops. It clearly demonstrates that kink oscillations are natural modes of the loops, and can be described as standing fast magnetoacoustic waves with the wavelength determined by the length of the loop. Kink oscillations are observed in two different regimes. In the rapidly decaying regime, the apparent displacement amplitude reaches several minor radii of the loop. The damping time which is about several oscillation periods decreases with the increase in the oscillation amplitude, suggesting a nonlinear nature of the damping. In the decayless regime, the amplitudes are smaller than a minor radius, and the driver is still debated. The review summarises major findings obtained during the last decade, and covers both observational and theoretical results. Observational results include creation and analysis of comprehensive catalogues of the oscillation events, and detection of kink oscillations with imaging and spectral instruments in the EUV and microwave bands. Theoretical results include various approaches to modelling in terms of the magnetohydrodynamic wave theory. Properties of kink oscillations are found to depend on parameters of the oscillating loop, such as the magnetic twist, stratification, steady flows, temperature variations and so on, which make kink oscillations a natural probe of these parameters by the method of magnetohydrodynamic seismology. **27 Oct 2014**

Properties of slow magnetoacoustic oscillations of solar coronal loops by multi-instrumental observations

Nakariakov, V. M., Kosak, M. K., Kolotkov, D. Y., Anfinogentov, S. A., Kumar, P., Moon, Y.-J.
ApJL **874** L1 **2019**
https://warwick.ac.uk/fac/sci/physics/research/cfsa/people/valery/Nakariakov_rev5.pdf
https://doi.org/10.3847/2041-8213/ab0c9f
Rapidly decaying oscillations of the thermal emission detected in the decay phase of solar and stellar flares are usually interpreted as standing or sloshing (reflecting) slow magnetoacoustic oscillations. We determine the scalings of the oscillation periods, damping times and amplitudes with the temperature, considering both standing and sloshing oscillations detected with different instruments. In addition, the time evolution of different spatial harmonics of a sloshing oscillation is considered. Parameters of slow oscillations observed in the EUV, X-ray, and microwave bands, and published in the literature, are used. The damping time of slow oscillations is found to scale almost linearly with the oscillation period, as the period to 0.87± 0.1, giving the average Q-factor determined as the ratio of the damping time to the period, of about 1. The Q-factor is found to scale with the relative amplitude to the power of 0.33+0.10-0.11 with 95 % confidence. The amplitudes of different spatial harmonics forming a sloshing pulse show similar time evolution, suggesting that the period-dependent dissipation is counteracted by another mechanism. The results obtained indicate that the damping of slow oscillations depends on the oscillation amplitude, and that the competition of nonlinear and dissipative effects could allow for the existence of wave pulses of a sustained shape. **2012 May 7**

Effect of local thermal equilibrium misbalance on long-wavelength slow magnetoacoustic waves

Nakariakov, V.M., Afanasyev, A.N., Kumar, S., Moon, Y.-J.
ApJ 849:62, **2017**
https://www2.warwick.ac.uk/fac/sci/physics/research/cfsa/people/valery/research/eprints/Nakariakov_2017_ApJ_849_62.pdf
Evolution of slow magnetoacoustic waves guided by a cylindrical magnetic flux tube that represents a coronal loop or plume, is modelled accounting for the effects of finite gas pressure, weak nonlinearity, dissipation by thermal conduction and viscosity, and the misbalance between the cooling by optically thin radiation and unspecified heating of the plasma. An evolutionary equation of the Burgers-Malthus type is derived. It is shown that the cooling/heating misbalance, determined by the derivatives of the combined radiative cooling and heating function, with respect to the density, temperature and magnetic field at the thermal equilibrium affect the wave rather strongly. This effect may either cause additional damping, or counteract it, or lead to the gradual amplification of the wave. In the latter case the coronal plasma acts as an active medium for the slow magnetoacoustic waves. The effect of the cooling/heating misbalance could be important for coronal slow waves, and could be responsible for certain discrepancies between theoretical results and observations, in particular the increased or decreased damping lengths and times, detection of the waves at certain heights only, and excitation of compressive oscillations. The results obtained open up a possibility for the diagnostics of the coronal heating function by slow magnetoacoustic waves.

Undamped transverse oscillations of coronal loops as a self-oscillatory process

Nakariakov, V. M., Anfinogentov, S., Nistico, G., Lee, D.-H.
A&A, Letter **2016**
http://www2.warwick.ac.uk/fac/sci/physics/research/cfsa/people/valery/research/eprints/Nakariakov_rev_twocolumns.pdf
Context. Standing transverse oscillations of coronal loops are observed to operate in two regimes, the rapidly decaying large amplitude oscillations, and undamped small amplitude oscillations. In the latter regime the damping should be compensated by energy supply, which allows the loop to perform almost monochromatic oscillations with almost constant amplitude. Different loops oscillate with different periods. The oscillation amplitude does not show dependence on the loop length or the oscillation period. Aims. We aim to develop a low-dimensional model explaining the undamped kink oscillations as a self-oscillatory process caused by the effect of negative friction. The source of energy is an external quasi-steady flow, e.g. supergranulation motions near the loop footpoints or external flows in the corona. Methods. We demonstrate that the interaction of a quasi-steady flow with a loop can be described by a Rayleigh oscillator equation that is a nonlinear ordinary differential equation, with the damping and resonant terms determined empirically. Results. Low-amplitude self-oscillatory solutions to the Rayleigh oscillator equation are harmonic signals of constant amplitude, which is consistent with the observed properties of undamped kink oscillations. The period of self-oscillations is determined by the frequency of the kink mode. The damping by dissipation and mode conversion is compensated by the continuous energy deposition at the frequency of the natural oscillation. Conclusions. We propose that undamped kink oscillations of coronal loops may be caused by the interaction of the loops with quasi-steady flows, and hence are self-oscillations, in analogy with producing a tune by a stick moving across a violin string**. 8th of March, 2011**

SAUSAGE OSCILLATIONS OF CORONAL PLASMA STRUCTURES
V. M. **Nakariakov**1,2, C. Hornsey1, and V. F. Melniko
2012 ApJ 761 134
The dependence of the period of sausage oscillations of coronal loops on length together with the depth and steepness of the radial profile are determined. We performed a parametric study of linear axisymmetric fast magnetoacoustic (sausage) oscillations of coronal loops modeled as a field-aligned low-β plasma cylinder with a smooth inhomogeneity of the plasma density in the radial direction. The density decreases smoothly in the radial direction. Sausage oscillations are impulsively excited by a perturbation of the radial velocity, localized at the cylinder axis and with a harmonic dependence on the longitudinal coordinate. The initial perturbation results in either a leaky or a trapped sausage oscillation, depending upon whether the longitudinal wavenumber is smaller or greater than a cutoff value, respectively. The period of the sausage oscillations was found to always increase with increasing longitudinal wavelength, with the dependence saturating in the long-wavelength limit. Deeper and steeper radial profiles of the Alfvén speed correspond to more efficient trapping of sausage modes: the cutoff value of the wavelength increases with the steepness and the density (or Alfvén speed) contrast ratio. In the leaky regime, the period is always longer than the period of a trapped mode of a shorter wavelength in the same cylinder. For shallow density profiles and shorter wavelengths, the period increases with wavelength. In the long-wavelength limit, the period becomes independent of the wavelength and increases with the depth and steepness of the radial profile of the Alfvén speed.

Catalog of Decaying Kink Oscillations of Coronal Loops in the 24th Solar Cycle
Alena **Nechaeva**1,2, Ivan V. Zimovets1, V. M. Nakariakov3,4, and C. R. Goddard3
2019 ApJS 241 31
sci-hub.se/10.3847/1538-4365/ab0e86
https://iopscience.iop.org/article/10.3847/1538-4365/ab0e86/pdf
A catalog of kink oscillations of solar coronal loops, which spans during almost all of solar cycle 24, is presented. The catalog is based on the observations made in the extreme ultraviolet band at 171 Å with Solar Dynamics Observatory/Atmospheric Imaging Assembly and includes parameters of 223 oscillating loops in 96 oscillation events. The catalog provides the information about the oscillation locations, time, and dates of the events, associated flare, initial displacement, oscillation period, exponential damping time, and apparent amplitude. The vast majority of the oscillation detections, 84%, were made in the loops situated near or off the solar limb. The oscillation periods are found to range from 1 to 28 minutes, with 74% of the events that have the period in the range of 2–10 minutes. About 90% of the oscillations have the apparent amplitude in the range of 1–10 Mm. The oscillating loop lengths are 70–600 Mm. The typical apparent amplitude is about 1% of the loop length. The oscillation period scales linearly with the loop length, and the damping time scales linearly with the period, which confirm previous findings. The oscillation quality factor scales with the amplitude to the power of minus 0.7. No statistically significant evidence of correlation was found between both the oscillation period and the mean sunspot number, and the loop length and mean sunspot number. The catalog provides the research community with the foundation for the further statistical study of kink oscillations and their use for coronal seismology.
Table 1 Parameters of 223 Decaying Kink Oscillations of Coronal Loops Detected with SDO/AIA at 171 Å in 2010–2018

The Effect Of Cooling On Driven Kink Oscillations Of Coronal Loops

C. J. **Nelson**, A. A. Shukhobodskiy, R. Erdélyi, M. Mathioudakis

Frontiers in Astronomy and Space Science 6:45 **2019**

https://arxiv.org/pdf/1905.13137.pdf

https://www.frontiersin.org/articles/10.3389/fspas.2019.00045/full

https://doi.org/10.3389/fspas.2019.00045

Ever since their detection two decades ago, standing kink oscillations in coronal loops have been extensively studied both observationally and theoretically. Almost all driven coronal loop oscillations (e.g., by flares) are observed to damp through time often with Gaussian or exponential profiles. Intriguingly, however, it has been shown theoretically that the amplitudes of some oscillations could be modified from Gaussian or exponential profiles if cooling is present in the coronal loop systems. Indeed, in some cases the oscillation amplitude can even increase through time. In this article, we analyse a flare-driven coronal loop oscillation observed by the Solar Dynamics Observatory's Atmospheric Imaging Assembly (SDO/AIA) in order to investigate whether models of cooling can explain the amplitude profile of the oscillation and whether hints of cooling can be found in the intensity evolution of several SDO/AIA filters. During the oscillation of this loop system, the kink mode amplitude appears to differ from a typical Gaussian or exponential profile with some hints being present that the amplitude increases. The application of cooling coronal loop modelling allowed us to estimate the density ratio between the loop and the background plasma, with a ratio of between 2.05-2.35 being returned. Overall, our results indicate that consideration of the thermal evolution of coronal loop systems can allow us to better describe oscillations in these structures and return more accurate estimates of the physical properties of the loops (e.g., density, scale height, magnetic field strength). **20 October 2012**

Field-Aligned Current Mechanisms of Prominence Destabilization

Petko **Nenovski**

In: Exploring the Solar Wind, Ed. Marian Lazar, **2012**

http://www.intechopen.com/books/exploring-the-solar-wind

Extreme-ultraviolet and hard X-ray signatures of electron acceleration during the failed eruption of a filament

A. **Netzel**, T. Mrozek, S. Kołomański, and S. Gburek

E-print, Dec **2012**; A&A 548, A89, **2012**

Aims. We search for extreme-ultraviolet (EUV) brightenings in TRACE 171 ? images and hard X-ray (HXR) bursts observed during failed eruptions. We expect that if an eruption is confined by interaction with overlaying magnetic structures, we should observe effects caused by reconnection between magnetic structures and acceleration of particles.

Methods. We used TRACE observations of three well-observed failed eruptions. A semi-automated method was used to search for abrupt brightness changes in the TRACE field of view. The EUV images were compared to the HXR spatial distribution reconstructed from YOHKOH/HXT and RHESSI data. The EUV light curves of a selected area were compared to height profiles of eruption, HXR emission, and the HXR photon spectral index of a power-law fit to the HXR data.

Results. We have found that EUV brightenings are closely relatedto the eruption velocity decrease, to HXR bursts, and to episodes of hardening of the HXR spectra. The EUV-brightened areas are observed far from the flaring structure, in footpoints of large systems of loops observed 30?60 min after the maximum of a flare. These are not ?post-flare? loops, which are also observed, but at significantly lower heights. The high-lying systems of loops are observed at heights equal to the height at which the eruption was observed to stop. We observed only one HXR source that was spatially correlated with EUV brightening. For other EUV-brightened areas we estimated the expected brightness of HXR sources.

Conclusions. We find that EUV brightenings are produced by interaction between the erupting structure with overlaying loops. The interaction is strong enough to heat the system of high loops. These loops cool and are visible in the EUV range about 30?60 min later. The estimated brightness of HXR sources associated with EUV brightenings shows that they are too weak to be detected with present instruments. However, next-generation instruments will have sufficient dynamic range and sensitivity to enable such observations.

SOL1999-10-22T09:16, SOL2004-07-14T05:23, SOL2004-08-13T18:12

Decayless longitudinal oscillations of a solar filament maintained by quasi-periodic jets

Y. W. **Ni**, J. H. Guo, Q. M. Zhang, J. L. Chen, C. Fang, P. F. Chen

A&A 663, A31 **2022**

https://arxiv.org/pdf/2203.15660.pdf

Context: As a ubiquitous phenomenon, large-amplitude longitudinal filament oscillations usually decay in 1--4 periods. Recently, we observed a decayless case of such oscillations in the corona. Aims: We try to understand the physical process that maintains the decayless oscillation of the filament. Methods: Multi-wavelength imaging observations and magnetograms are collected to study the dynamics of the filament oscillation and its associated phenomena. To explain the decayless oscillations, we also perform one-dimensional hydrodynamic numerical simulations using the MPI-AMRVAC code. Results: In observations, the filament oscillates decaylessly with a period of 36.4±0.3 min for almost 4 hours before eruption. During oscillations, four quasi-periodic jets emanate from a magnetic cancellation site near the filament. The time interval between neighboring jets is ∼68.9±1.0 min. Numerical simulations constrained by the observations reproduced the decayless longitudinal oscillations. However, it is surprising to find that the period of the decayless oscillations is not consistent with the pendulum model. Conclusions: We propose that the decayless longitudinal oscillations of the filament are maintained by quasi-periodic jets, which is verified by the hydrodynamic simulations. More importantly, it is found that, when driven by quasi-periodic jets, the period of the filament longitudinal oscillations depends also on the driving period of the jets, not simply the pendulum period. With a parameter survey in simulations, we derived a formula, by which one can derive the pendulum oscillation period using the observed period of decayless filament oscillations and the driving periods of jets. **2014 July 5**

BEHAVIOR OF THE SPINES IN A QUIESCENT PROMINENCE OBSERVED BY *HINODE/*SOT

Z. **Ning**1, W. Cao, and P. R. Goode

Astrophysical Journal, 707:1124–1130, **2009** December

We report the behaviors of the spines in a quiescent prominence from the observations on **2008 January 15** made with *Hinode/*SOT in Hα +0.076 Å, Hα−0.34 Å, and Ca ii H line filters. Two spines (1 and 2) are visible in this event. In the spacetime plots of the Hα and Ca ii intensities, the two spines seem to gradually move closer together, and finally merge, then separate again. Their behaviors are separated into two kinds of typical motions. On the Doppler diagrams, the spine 1 has a dominant redshift, and spine 2 favors a blueshift, which reveals that the spines 1 and 2 firstly display the drifting motions in opposite directions. The former is drifting northward, while the latter drifts southward. Second, both spines display large-scale oscillating motions. Their oscillating velocities, amplitudes, and periods have average values of 3 km s−1, ±5 Mm, and 98 minutes, respectively, indicating a small-amplitude oscillation with a long period. After the sinusoidal fitting, both spines almost exhibit an antiphase oscillating motions. The spine 2 oscillates 135◦ ahead of the spine 1. Such antiphase oscillations would reflect the coupling of the transverse oscillations of the spines in this prominence.

Small-scale oscillations in a quiescent prominence observed by HINODE/SOT Prominence oscillations

Z. **Ning**[1], W. Cao[2], T. J. Okamoto[3], K. Ichimoto[3, 4], and Z. Q. Qu[5]

A&A 499, 595-600 (**2009**), DOI: 10.1051/0004-6361/200810853

http://www.aanda.org/10.1051/0004-6361/200810853

Context. Investigations of the behavior of small-scale threads can provide an alternative approach to studying prominence dynamics and understanding its origin and nature.

Aims. The behavior of threads are analyzed in a quiescent prominence, including drifting and both the horizontally and vertically oscillating motions. These indicate waves in the solar prominence.

Methods. We used the Hα images at a setting wavelength of +0.076 Å. A quiescent prominence was observed by HINODE/SOT on **2008 January 15** for about 3 h in total.

Results. Consistent with previous findings, prominences show numerous thread-like structures. Some threads clearly exhibit both vertically and horizontally oscillatory motions, while others are only drifting. Complicated cases show both drifting and oscillatory motions simultaneously. In the upper part of the prominence, the threads are oscillating independently of each other. We find that three threads oscillate with the same phase for at least two periods. The oscillations seem to be strongly damped since they disappear after a few periods. The maximum number of observed periods is 8 in our observations. In the lower part of the prominence, however, the different threads have a mixed character with the individual oscillatory motions unstable for one entire period. Most oscillatory motions will disappear after a half period or less, while the new oscillatory motions are excited nearby. A 5-min period is predominant, and the oscillating amplitudes show an average value of +-3.5 km s^{-1}. We find some upflows in the spicule layer, and they appear to transport the mass from photosphere (or spicules themselves) to the prominence. These upflows have an average velocity amplitude of 0.8 km s^{-1}.

Conclusions. The threads exhibit three distinct behaviors. The first is only drifting, the second is typically oscillating, and the third shows both characteristics. There are no substantial differences between the periods of horizontally and vertically oscillating threads in this prominence.

Three-Dimensional Reconstruction of Coronal Features: A Python Tool for Geometric Triangulation

Giuseppe **Nisticò**

Solar Physics volume 298, Article number: 36 (**2023**)

https://link.springer.com/content/pdf/10.1007/s11207-023-02122-9.pdf

The determination of the three-dimensional (3D) geometry of coronal features is important for understanding the magnetic structuring of the solar atmosphere. In this context, the length of a coronal loop, which is subject to standing transverse oscillations, is a crucial parameter in coronal seismology for the correct estimation of the phase speed of the wave and, consequently, of the Alfvén speed and coronal magnetic-field strength. Simultaneous space-based observations of the solar corona from different vantage points, e.g. one from the Solar Dynamics Observatory (SDO) and the second from the Solar TErrestrial RElations Observatory (STEREO), have permitted the reconstruction of the geometry of coronal loops. Nisticò, Verwichte, and Nakariakov (Entropy 15, 4520, 2013) proposed a method based on principal component analysis for fitting an ensemble of 3D points that sample a coronal loop. This method was shown to retrieve easily the main geometric parameters that define a loop, such as the loop axes and the loop plane. In this article, an extension of that work is presented that includes a Python tool for performing geometric triangulation of coronal features seen by two different observers.

Dynamics of a Multi-Thermal Loop in the Solar Corona

G. **Nistico**, S. Anfinogentov, and V. M. Nakariakov

E-print, July **2014**; A&A 570, A84 (**2014**)

http://www2.warwick.ac.uk/fac/sci/physics/research/cfsa/people/nistico/publications/paper_multi_thermal_loop.pdf

Context. We present an observation of a long-living multi-thermal coronal loop, visible in different EUV wavebands of SDO/AIA in a quiet-Sun region close to the Western solar limb.

Aims. Analysis of persistent kink displacements of the loop seen in different bandpasses that correspond to different temperatures of the plasma allows to reveal fine, sub-resolution structuring of the loop.

Methods. A vertically oriented slit is taken at the loop top and time-distance maps are made from it. Loop displacements in time-distance maps are automatically tracked with the Gaussian fitting technique and fitted with a ``guessed'' sinusoidal function. Wavelet transform are further used in order to quantify the periodicity variation in time of the kink oscillations.

Results. The loop strands are found to oscillate with the periods ranging between 3-15 minutes. The oscillations are observed in intermittent regime with changes of the period and phase in time. The oscillations are different at three analysed wavelengths.

Conclusions. This finding suggests that the loop-like threads seen at different wavelengths are not co-spatial, and hence that the loop consists of several multi-thermal strands. The detected irregularity of the oscillation can be associated with a stochastic driver acting at the footpoints of the loop. **21 January 2013**

3D Reconstruction of Coronal Loops by the Principal Component Analysis

Giuseppe **Nistico**, Erwin Verwichte, Valery M. Nakariakov

E-print, Oct **2013;** *Entropy*

Knowing the three dimensional structure of plasma filaments in the uppermost part of the solar atmosphere, known as coronal loops, and especially their length, is an important parameter in the wave-based diagnostics of this part of the Sun. The combination of observations of the Sun from different points of observations in space, thanks to the most recent missions including SDO and STEREO, allows us to infer information on the geometrical shape of coronal loops in the 3D space. Here, we propose a new method to reconstruct the loop shape starting from stereoscopically determined 3D points, which sample the loop length, by the Principal Component Analysis. This method is shown to retrieve in an easy way the main parameters that define loop, e.g. the minor and major axes, the loop plane, the azimuthal and inclination angles, for the special case of a coplanar loop. **27th June, 2007, 21-22 January, 2013**

Decayless coronal loop oscillations seen by SDO/AIA

Giuseppe **Nisticò**, V. M. Nakariakov, and E. Verwichte

UKSP Nugget: 35, May **2013**

http://www.uksolphys.org/?p=6162

Kink oscillations of coronal loops suggestive of two distinct drivers.

Decaying and decayless transverse oscillations of a coronal loop⋆
G. **Nisticò**1, V. M. Nakariakov1,2 and E. Verwichte
A&A 552, A57 (**2013**)
Aims. We investigate kink oscillations of loops observed in an active region with the Atmospheric Imaging Assembly (AIA) instrument on board the Solar Dynamics Observatory (SDO) spacecraft before and after a flare.
Methods. The oscillations were depicted and analysed with time-distance maps, extracted from the cuts taken parallel or perpendicular to the loop axis. Moving loops were followed in time with steadily moving slits. The period of oscillations and its time variation were determined by best-fitting harmonic functions.
Results. We show that before and well after the occurrence of the flare, the loops experience low-amplitude decayless oscillations. The flare and the coronal mass ejection associated to it trigger large-amplitude oscillations that decay exponentially in time. The periods of the kink oscillations in both regimes (about 240 s) are similar. An empirical model of the phenomenon in terms of a damped linear oscillator excited by a continuous low-amplitude harmonic driver and by an impulsive high-amplitude driver is found to be consistent with the observations.

Plasma Outflows in Coronal Streamers
Giancarlo **Noci** and Elena Gavryuseva
The Astrophysical Journal Letters, Volume 658, Number 1, Page L63, **2007** [http://www.journals.uchicago.edu/cgi-bin/resolve?ApJL21344]

Three-Dimensional Reconstruction and Thermal Modeling of Observed Loops
Federico A. **Nuevo**, Cecilia Mac Cormack, Marcelo C. López Fuentes, Alberto M. Vásquez & Cristina H. Mandrini
Solar Physics volume 295, Article number: 171 (**2020**)
https://link.springer.com/content/pdf/10.1007/s11207-020-01739-4.pdf
https://arxiv.org/pdf/2011.09575.pdf
Due to their characteristic temperature and density, loop structures in active regions (ARs) can be seen bright in extreme ultraviolet (EUV) and soft X-ray images. The semiempirical determination of the three-dimensional (3D) distribution of basic physical parameters (electronic density and temperature, and magnetic field) is a key constraint for coronal heating models. In this work we develop a technique for the study of EUV bright loops based on differential emission measure (DEM) analysis and we first apply it to AR structures observed by the {Atmospheric Imaging Assembly} (AIA) on board the {Solar Dynamics Observatory} (SDO). The 3D structure and intensity of the magnetic field of the observed EUV loops are modelled using force-free field extrapolations based on magnetograms taken by the {Helioseismic and Magnetic Imager} (HMI) on board SDO. In this work we report the results obtained for several bright loops identified in different ARs. Our analysis indicates that the mean and width of the temperature distributions are nearly invariant along the loop lengths. For a particular loop we study its temporal evolution and find that these characteristics remain approximately constant for most of its life time. The appearance and disappearance of this loop occurs at time-scales much shorter than its life time of ≈2.5 hours. The results of this analysis are compared with numerical simulations using the zero-dimensional (0D) hydrodynamic model, Enthalpy-Based Thermal Evolution of Loops (EBTEL). We study two alternative heating scenarios: first, we apply a constant heating rate assuming loops in quasi-static equilibrium, and second, we heat the loops using impulsive events or nanoflares. We find that all the observed loops are overdense with respect to a quasi-static equilibrium solution and that the nanoflare heating better reproduces the observed densities and temperatures. **11-29-2010**

Nonlinear Fast Magnetosonic Waves in Solar Prominence Pillars
Leon **Ofman**, Therese A. Kucera, C. Richard DeVore
ApJ **944** 210 **2023**
https://arxiv.org/pdf/2301.04503.pdf
https://iopscience.iop.org/article/10.3847/1538-4357/acb13b/pdf
We investigate the properties of nonlinear fast magnetosonic (NFM) waves in a solar prominence, motivated by recent high-resolution and high-cadence Hinode/SOT observations of small-scale oscillations in a prominence pillar. As an example, we analyze the details of the **2012 February 14** Hinode/SOT observations of quasi-periodic propagating features consistent with NFM waves, imaged in emission in Ca~II and in the far blue wing of H_alpha. We perform wavelet analysis and find oscillations in the 1-3 min period range. Guided by these observations, we model the NFM waves with a three-dimensional magnetohydrodynamics (3D MHD) model, extending previous 2.5D MHD studies. The new model includes the structure of the high-density, low-temperature material of the prominence pillar embedded in the hot corona, in both potential and non-force-free sheared magnetic field configurations. The nonlinear model demonstrates the effects of mode coupling and the propagating density compressions associated with linear and NFM waves. The guided fast magnetosonic waves, together with density compressions and currents, are reproduced in the 3D pillar structure. We demonstrate or the first time the dynamic

effects of the Lorentz force due to the magnetic shear in the non-force-free field on the pillar structure and on the propagation of the waves. The insights gained from the 3D MHD modeling are useful for improving coronal seismology of prominence structures that exhibit fast MHD wave activity.

Fast Magnetosonic Waves and Flows in a Solar Prominence Foot: Observations and Modeling

Leon **Ofman**, Therese A. Kucera

ApJ **899** 99 **2020**

https://arxiv.org/pdf/2006.05885.pdf

https://doi.org/10.3847/1538-4357/aba2eb

We study recent observations of propagating fluctuations in a prominence foot with Hinode Solar Optical Telescope (SOT) high-resolution observations in Ca~II and H alpha emission which we identify as nonlinear fast magnetosnic waves. Here we analyze further the observations of propagating waves and flows with Interface Region Imaging Spectrograph (IRIS) Mg~II slit jaw images, in addition to Hinode/SOT Ca~II images. We find that the waves have typical periods in the range of 5 - 11 minutes and wavelengths in the plane of the sky (POS) of about 2000 km, while the flows in narrow threads have typical speed in the POS of ~16-46 km/s. We also detect apparent kink oscillations in the threads with flowing material, and apply coronal seismology to estimate the magnetic field strength in the range 5-17 G. Using 2.5D MHD we model the combined effects of nonlinear waves and flows on the observed dynamics of the prominence material, and reproduce the propagating and refracting fast magnetosonic waves, as well as standing kink-mode waves in flowing material along the magnetic field. The modeling results are in good qualitative agreements with the observations of the various waves and flows in the prominence foot, further confirming coronal seismology analysis and improving the understanding of the fine scale dynamics of the prominence material**. 2016 January 7**

Nonlinear MHD waves in a Prominence Foot

Leon **Ofman**, Kalman Knizhnik, Therese Kucera, Brigitte Schmieder

2015 ApJ 813 124

http://arxiv.org/pdf/1509.07911v1.pdf

We study nonlinear waves in a prominence foot using 2.5D MHD model motivated by recent high-resolution observations with Hinode/SOT in Ca~II emission of a prominence on **October 10, 2012** showing highly dynamic small-scale motions in the prominence material. Observations of Hα intensities and of Doppler shifts show similar propagating fluctuations. However the optically thick nature of the emission lines inhibits unique quantitative interpretation in terms of density. Nevertheless, we find evidence of nonlinear wave activity in the prominence foot by examining the relative magnitude of the fluctuation intensity ($\delta I/I \sim \delta n/n$). The waves are evident as significant density fluctuations that vary with height, and apparently travel upward from the chromosphere into the prominence material with quasi-periodic fluctuations with typical period in the range of 5-11 minutes, and wavelengths ∼<2000 km. Recent Doppler shift observations show the transverse displacement of the propagating waves. The magnetic field was measured with THEMIS instrument and was found to be 5-14 G. For the typical prominence density the corresponding fast magnetosonic speed is ∼20 km s^{-1}, in qualitative agreement with the propagation speed of the detected waves. The 2.5D MHD numerical model is constrained with the typical parameters of the prominence waves seen in observations. Our numerical results reproduce the nonlinear fast magnetosonic waves and provide strong support for the presence of these waves in the prominence foot. We also explore gravitational MHD oscillations of the heavy prominence foot material supported by dipped magnetic field structure.

Three-dimensional multi-fluid model of a coronal streamer belt with a tilted magnetic dipole

L. **Ofman**, E. Provornikova, L. Abbo, and S. Giordano

Ann. Geophys., 33, 47-53, **2015**

http://www.ann-geophys.net/33/47/2015/angeo-33-47-2015.pdf

Observations of streamers in EUV emission with SOHO/UVCS show dramatic differences in line profiles and latitudinal variations of heavy ions emission compared to hydrogen Ly α emission. In order to use ion emission observations of streamers as the diagnostics of the slow solar wind properties, an adequate model of a streamer including heavy ions is required. We extended previous 2.5D multi-species MHD model of a coronal streamer to 3D spherical geometry, and as the first approach we consider a tilted dipole configuration of the solar magnetic field. The aim of the present study is to test the 3D results by comparing to previous 2.5D model result for a 3D case with moderate departure from azimuthal symmetry. The model includes O^5+ ions with preferential empirical heating and allows calculating their density, velocity and temperature in coronal streamers. We present the first results of our 3D multi-fluid model showing the parameters of protons, electrons and heavy ions (O^5+) at the steady-state solar corona with tilted steamer belt. We find that the 3D results are in qualitative agreement with our previous 2.5D model, and show longitudinal variation in the variables in accordance with the titled streamer belt structure. Properties of heavy coronal ions obtained from the 3D model together with EUV spectroscopic observations of streamers will help understanding the 3D structures of streamers reducing line-of-sight integration ambiguities, and the physics of the slow solar wind, identifying the locations of its sources in the corona.

OBSERVATIONS AND MODELS OF SLOW SOLAR WIND WITH Mg9 + IONS IN QUIESCENT STREAMERS

L. **Ofman**1,2,4, L. Abbo3, and S. Giordano

2013 ApJ 762 18

Quiescent streamers are characterized by a peculiar UV signature as pointed out by the results from the observations of the Ultraviolet and Coronograph Spectrometer (UVCS) on board SOHO: the intensity of heavy-ion emission lines (such as O VI) shows dimmer core relative to the edges. Previous models show that the structure of the heavy-ion streamer emission relates to the acceleration regions of the slow solar wind at streamer legs and to gravitational settling processes in the streamer core. Observations of Mg9 + ion EUV emission in coronal streamers at solar minimum were first reported by the UVCS instrument. The Mg X 625 Å emission is an order of magnitude smaller than the O VI 1032 Å emission, requiring longer exposures to obtain statistically significant results. Here, Mg X coronal observations are analyzed and compared, for the first time, with the solar minimum streamer structure in hydrogen and O VI emissions. We employ the 2.5D three-fluid model, developed previously to study the properties of O5 + ions in streamers, and calculate for the first time the density, temperature, and outflow structure of Mg9 + ions in the solar minimum streamer. The Mg9 + ions are heated by an empirical radial heating function constrained by observations of the kinetic ion temperature obtained from Mg X emission line profiles. The detailed structure of Mg9 + density, temperature, and outflow speed is determined by the Coulomb momentum and energy exchange as well as electromagnetic interactions with electrons and protons in the three-fluid model of the streamer. The results of the model are in good qualitative agreement with observations, and provide insights on the possible link between the magnetic structure of the streamer, slow solar wind sources, and relative abundances of heavy ions.

MULTI-FLUID MODEL OF A STREAMER AT SOLAR MINIMUM AND COMPARISON WITH OBSERVATIONS

Leon **Ofman**1,3, Lucia Abbo2 and Silvio Giordano

2011 ApJ 734 30

We present the results of a time-dependent 2.5-dimensional three-fluid magnetohydrodynamic model of the coronal streamer belt, which is compared with the slow solar wind plasma parameters obtained in the extended corona by the UV spectroscopic data from the Ultraviolet Coronagraph Spectrometer (UVCS) on board SOHO during the past minimum of solar activity (Carrington Rotation 1913). Our previous three-fluid streamer model has been improved by considering the solar magnetic field configuration relevant for solar minimum conditions, and preferential heating for O5 + ions. The model was run until a fully self-consistent streamer solution was obtained in the quasi-steady state. The plasma parameters from the multi-fluid model were used to compute the expected UV observables from H I Lyα 1216 Å and O VI 1032 Å spectral lines, and the results were compared in detail with the UVCS measurements. A good agreement between the model and the data was found. The results of the study provide insight into the acceleration and heating of the multi-ion slow solar wind.

Helical motions of fine-structure prominence threads observed by Hinode and IRIS

Takenori J. **Okamoto**, Wei Liu, Saku Tsuneta

ApJ 831 126 2016

http://arxiv.org/pdf/1608.00123v1.pdf

Fine-structure dynamics in solar prominences holds critical clues to understanding their physical nature of significant space-weather implications. We report evidence of rotational motions of horizontal helical threads in two active-region prominences observed by the \emph{Hinode} and/or \emph{IRIS} satellites at high resolution. In the first event, we found transverse motions of brightening threads at speeds up to 55~km~s−1 seen in the plane of the sky. Such motions appeared as sinusoidal space--time trajectories with a typical period of ∼390~s, which is consistent with plane-of-sky projections of rotational motions. Phase delays at different locations suggest propagation of twists along the threads at phase speeds of 90--270~km~s−1. At least 15 episodes of such motions occurred in two days, none associated with any eruption. For these episodes, the plane-of-sky speed is linearly correlated with the vertical travel distance, suggestive of a constant angular speed. In the second event, we found Doppler velocities of 30--40~km~s−1 in opposite directions in the top and bottom portions of the prominence, comparable to the plane-of-sky speed. The moving threads have about twice broader line widths than stationary threads. These observations, when taken together, provide strong evidence for rotations of helical prominence threads, which were likely driven by unwinding twists triggered by magnetic reconnection between twisted prominence magnetic fields and ambient coronal fields. **2007 February 8–10, 2013 October 19**

Resonant Absorption of Transverse Oscillations and Associated Heating in a Solar Prominence. I- Observational aspects

Takenori J. **Okamoto**, Patrick Antolin, Bart De Pontieu, Han Uitenbroek, Tom Van Doorsselaere, Takaaki Yokoyama

ApJ **809** 71 **2015**

http://arxiv.org/pdf/1506.08965v1.pdf

Transverse magnetohydrodynamic (MHD) waves have been shown to be ubiquitous in the solar atmosphere and can in principle carry sufficient energy to generate and maintain the Sun's million-degree outer atmosphere or corona. However, direct evidence of the dissipation process of these waves and subsequent heating has not yet been directly observed. Here we report on high spatial, temporal, and spectral resolution observations of a solar prominence that show a compelling signature of so-called resonant absorption, a long hypothesized mechanism to efficiently convert and dissipate transverse wave energy into heat. Aside from coherence in the transverse direction, our observations show telltale phase differences around 180 degrees between transverse motions in the plane-of-sky and line-of-sight velocities of the oscillating fine structures or threads, and also suggest significant heating from chromospheric to higher temperatures. Comparison with advanced numerical simulations support a scenario in which transverse oscillations trigger a Kelvin-Helmholtz instability (KHI) at the boundaries of oscillating threads via resonant absorption. This instability leads to numerous thin current sheets in which wave energy is dissipated and plasma is heated. Our results provide direct evidence for wave-related heating in action, one of the candidate coronal heating mechanisms. **19 October 2013**

A RISING COOL COLUMN AS A SIGNATURE OF HELICAL FLUX EMERGENCE AND FORMATION OF PROMINENCE AND CORONAL CAVITY

Takenori J. **Okamoto** 1,2,3, Saku Tsuneta 1 and Thomas E. Berger

2010 ApJ 719 583

Continuous observations were performed of a quiescent prominence with the Solar Optical Telescope on board the Hinode satellite on **2006 December 23 and 24**. A peculiar slowly rising column of ~104 K plasma develops from the lower atmosphere during the observations. The apparent ascent speed of the column is 2 km s–1, while the fine structures of the column exhibit much faster motion of up to 20 km s–1. The column eventually becomes a faint low-lying prominence. An overlying coronal cavity associated with the appearance of the column seen in the X-ray and EUV moves upward at ~5 km s–1. We discuss the relationship between these episodes and suggest that they are due to the emergence of a helical flux rope that undergoes reconnection with lower coronal fields, possibly carrying material into the coronal cavity. Under the assumption of the emerging flux scenario, the lower velocity of 2 km s–1 and the higher one of 20 km s–1 in the column are attributed to the rising motion of the emerging flux and to the outflow driven by magnetic reconnection between the emerging flux and the pre-existing coronal field, respectively. The present paper gives a coherent explanation of the enigmatic phenomenon of the rising column with the emergence of the helical rope and its effect on the corona. We discuss the implications that the emergence of such a helical rope has on the dynamo process in the convection zone.

PROMINENCE FORMATION ASSOCIATED WITH AN EMERGING HELICAL FLUX ROPE

Takenori J. **Okamoto**1, Saku Tsuneta1, Bruce W. Lites2, Masahito Kubo2, Takaaki Yokoyama3, Thomas E. Berger4, Kiyoshi Ichimoto5, Yukio Katsukawa1, Shin'ichi Nagata5, Kazunari Shibata5, Toshifumi Shimizu6, Richard A. Shine4, Yoshinori Suematsu1, Theodore D. Tarbell4, and Alan M. Title4

The Astrophysical Journal, 697:913–922, **2009** May 20 doi:10.1088/0004-637X/697/1/913

http://www.iop.org:80/EJ/toc/-alert=43190/0004-637X/697/1

The formation and evolution process and magnetic configuration of solar prominences remain unclear. In order to study the formation process of prominences, we examine continuous observations of a prominence in NOAA AR 10953 with the Solar Optical Telescope on the *Hinode* satellite. As reported in our previous Letter, we find a signature suggesting that a helical flux rope emerges from below the photosphere under a pre-existing prominence. Here we investigate more detailed properties and photospheric indications of the emerging helical flux rope, and discuss their relationship to the formation of the prominence. Our main conclusions are: (1) a dark region with absence of strong vertical magnetic fields broadens and then narrows in Ca ii H-line filtergrams. This phenomenon is consistent with the emergence of the helical flux rope as photospheric counterparts. The size of the flux rope is roughly 30,000 km long and 10,000 km wide. The width is larger than that of the prominence. (2)No shear motion or converging flows are detected, but we find diverging flows such as mesogranules along the polarity inversion line. The presence of mesogranules may be related to the emergence of the helical flux rope. (3) The emerging helical flux rope reconnects with magnetic fields of the pre-existing prominence to stabilize the prominence for the next several days. We thus conjecture that prominence coronal magnetic fields emerge in the form of helical flux ropes that contribute to the formation and maintenance of the prominence.

EMERGENCE OF A HELICAL FLUX ROPE UNDER AN ACTIVE REGION PROMINENCE

Takenori J. **Okamoto**,1,2,3 Saku Tsuneta,1 Bruce W. Lites,4 Masahito Kubo,4 Takaaki Yokoyama,5
Thomas E. Berger,6 Kiyoshi Ichimoto,1 Yukio Katsukawa,1 Shin'ichi Nagata,2
Kazunari Shibata,2 Toshifumi Shimizu,7 Richard A. Shine,6 Yoshinori Suematsu,1
Theodore D. Tarbell,6 and Alan M. Title6

The Astrophysical Journal, 673: L215–L218, **2008**

http://www.journals.uchicago.edu/doi/pdf/10.1086/528792

Continuous observations were obtained of NOAA AR 10953 with the Solar Optical Telescope (SOT) on board the ***Hinode*** satellite from **2007 April 28 to May 9**. A prominence was located over the polarity inversion line (PIL) to the southeast of the main sunspot. These observations provided us with a time series of vector magnetic fields on the photosphere under the prominence.We found four features: (1) The abutting opposite-polarity regions on the two sides along the PIL first grew laterally in size and then narrowed. (2) These abutting regions contained vertically weak but horizontally strong magnetic fields. (3) The orientations of the horizontal magnetic fields along the PIL on the photosphere gradually changed with time from a normal-polarity configuration to an inversepolarity one. (4) The horizontal magnetic field region was blueshifted. These indicate that helical flux rope was emerging from below the photosphere into the corona along the PIL under the preexisting prominence.We suggest that this supply of a helical magnetic flux to the corona is associated with evolution and maintenance of active region prominences.

Dynamics of coronal rain and descending plasma blobs in solar PROMINENCES: II. PARTIALLY IONIZED CASE

Oliver, R., Soler, R., Terradas, J., Zaqarashvili, T. V.

2016 *ApJ* **818** 128

http://solar.uib.es/media/RO/FallingBlobs-PIP/ms.pdf

http://arxiv.org/pdf/1510.08277v1.pdf

Coronal rain clumps and prominence knots are dense condensations with chromospheric to transition region temperatures that fall down in the much hotter corona. Their typical speeds are in the range 30--150~km~s-1 and of the order of 10--30~km~s-1, respectively, i.e., they are considerably smaller than free fall velocities. These cold blobs contain a mixture of ionized and neutral material that must be dynamically coupled in order to fall together, as observed. We investigate this coupling by means of hydrodynamic simulations in which the coupling arises from the friction between ions and neutrals. The numerical simulations presented here are an extension of those of oliver2014} to the partially ionized case. We find that, although the relative drift speed between the two species is smaller than 1~m~s^{-1 at the blob center, it is sufficient to produce the forces required to strongly couple charged particles and neutrals. The ionization degree has no discernible effect on the main results of our previous work for a fully ionized plasma: the condensation has an initial acceleration phase followed by a period with roughly constant velocity and, in addition, the maximum descending speed is clearly correlated with the ratio of initial blob to environment density.

Propagation and dispersion of transverse wave trains in magnetic flux tubes

R. **Oliver**, M. S. Ruderman, J. Terradas

E-print, Feb **2014; 2014** ApJ 789 48

The dispersion of small amplitude, impulsively excited wave trains propagating along a magnetic flux tube is investigated. The initial disturbance is a localized transverse displacement of the tube that excites a fast kink wave packet. The spatial and temporal evolution of the perturbed variables (density, plasma displacement, velocity, ...) is given by an analytical expression containing an integral that is computed numerically. We find that the dispersion of fast kink wave trains is more important for shorter initial disturbances (i.e. more concentrated in the longitudinal direction) and for larger density ratios (i.e. for larger contrasts of the tube density with respect to the environment density). This type of excitation generates a wave train whose signature at a fixed position along a coronal loop is a short event (duration ~ 20 s) in which the velocity and density oscillate very rapidly with typical periods of the order of a few seconds. The oscillatory period is not constant but gradually declines during the course of this event. Peak values of the velocity are of the order of 10 km/s and are accompanied by maximum density variations of the order of 10-15% the unperturbed loop density.

Dynamics of coronal rain and descending plasma blobs in solar prominences: I. Fully ionised case

R. **Oliver**, R. Soler, J. Terradas, T. V. Zaqarashvili, M. L. Khodachenko

E-print, Nov **2013**, **2014** ApJ 784 21

Observations of active regions and limb prominences often show cold, dense blobs descending with an acceleration smaller than that of free fall. The dynamics of these condensations falling in the solar corona is investigated in this paper using a simple fully ionised plasma model. We find that the presence of a heavy condensation gives rise to a dynamical rearrangement of the coronal pressure that results in the formation of a large pressure gradient that opposes gravity. Eventually this pressure gradient becomes so large that the blob acceleration vanishes or even points upwards. Then, the blob descent is characterised by an initial acceleration phase followed by an essentially constant velocity phase. These two stages can be identified in published time-distance diagrams of coronal rain events. Both the duration of the first stage and the velocity attained by the blob increase for larger values of the ratio of blob to coronal density, for larger blob mass, and for smaller coronal temperature. Dense blobs are characterised by a detectable density growth (up to 60% in our calculations) and by a steepening of the density in their lower part, that could lead to the formation of a shock. They also emit sound waves that could be detected as small intensity changes with periods of the order of 100 s and lasting between a few and about ten periods. Finally, the curvature of the falling path is only relevant when a very dense blob falls along inclined magnetic field lines.

Prominence seismology using small amplitude oscillations

R. **Oliver**

E-print, Feb **2009**

Quiescent prominences are thin slabs of cold, dense plasma embedded in the much hotter and rarer solar corona. Although their global shape is rather irregular, they are often characterised by an internal structure consisting of a large number of thin, parallel threads piled together. Prominences often display periodic disturbances mostly observed in the Doppler displacement of spectral lines and with an amplitude typically of the order of or smaller than 2--3 km s^{-1}, a value which seems to be much smaller than the characteristic speeds of the prominence plasma (namely the Alfv'en and sound velocities). Two particular features of these small amplitude prominence oscillations is that they seem to damp in a few periods and that they seem not to affect the whole prominence structure. In addition, in high spatial resolution observations, in which threads can be discerned, small amplitude oscillations appear to be clearly associated to these fine structure constituents. Prominence seismology tries to bring together the results from these observations (e.g. periods, wavelengths, damping times) and their theoretical modeling (by means of the magnetohydrodynamic theory) to gain insight into physical properties of prominences that cannot be derived from direct observation. In this paper we discuss works that have not been described in previous reviews, namely the first seismological application to solar prominences and theoretical advances on the attenuation of prominence oscillations.

Direct Observations of Plasma Upflows and Condensation in a Catastrophically Cooling Solar Transition Region Loop

N. B. **Orange**, D. L. Chesny, H. M. Oluseyi, K. Hesterly, M. Patel, and P. Champey

2013 ApJ 778 90

http://arxiv.org/pdf/1501.04999v1.pdf

Minimal observational evidence exists for fast transition region (TR) upflows in the presence of cool loops. Observations of such occurrences challenge notions of standard solar atmospheric heating models as well as their description of bright TR emission. Using the EUV Imaging Spectrometer on board Hinode, we observe fast upflows ($v_\lambda \leq -10$ km s–1) over multiple TR temperatures ($5.8 \leq \log T \leq 6.0$) at the footpoint sites of a cool loop ($\log T \leq 6.0$). Prior to cool loop energizing, asymmetric flows of +5 km s–1 and –60 km s–1 are observed at footpoint sites. These flows, speeds, and patterns occur simultaneously with both magnetic flux cancellation (at the site of upflows only) derived from the Solar Dynamics Observatory's Helioseismic Magnetic Imager's line-of-sight magnetogram images, and a 30% mass influx at coronal heights. The incurred non-equilibrium structure of the cool loop leads to a catastrophic cooling event, with subsequent plasma evaporation indicating that the TR is the heating site. From the magnetic flux evolution, we conclude that magnetic reconnection between the footpoint and background field is responsible for the observed fast TR plasma upflows.

The magnetic field configuration of a solar prominence inferred from spectropolarimetric observations in the He i 10 830 Å triplet⋆

D. **Orozco Suárez**1,2, A. Asensio Ramos1,2 and J. Trujillo Bueno

A&A 566, A46 (**2014**)

Context. Determining the magnetic field vector in quiescent solar prominences is possible by interpreting the Hanle and Zeeman effects in spectral lines. However, observational measurements are scarce and lack high spatial resolution.

Aims. We determine the magnetic field vector configuration along a quiescent solar prominence by interpreting spectropolarimetric measurements in the He i 1083.0 nm triplet obtained with the Tenerife Infrared Polarimeter installed at the German Vacuum Tower Telescope of the Observatorio del Teide.

Methods. The He i 1083.0 nm triplet Stokes profiles were analyzed with an inversion code that takes the physics responsible for the polarization signals in this triplet into account. The results are put into a solar context with the help of extreme ultraviolet observations taken with the Solar Dynamic Observatory and the Solar Terrestrial Relations Observatory satellites.

Results. For the most probable magnetic field vector configuration, the analysis depicts a mean field strength of 7 gauss. We do not find local variations in the field strength except that the field is, on average, lower in the prominence body than in the prominence feet, where the field strength reaches ~25 gauss. The averaged magnetic field inclination with respect to the local vertical is ~77°. The acute angle of the magnetic field vector with the prominence main axis is 24° for the sinistral chirality case and 58° for the dextral chirality. These inferences are in rough agreement with previous results obtained from the analysis of data acquired with lower spatial resolutions.

Time evolution of plasma parameters during the rise of a prominence instability

D. **Orozco Suárez**, J. A. Díaz, A. Asensio Ramos, J. Trujillo Bueno

ApJL, **2014** 785 L10

http://arxiv.org/pdf/1403.5640v1.pdf

We present high spatial resolution spectropolarimetric observations of a quiescent hedgerow prominence taken in the He I 1083.0 nm triplet. The observation consisted of a time series in sit-and-stare mode of 36 minutes of duration. The spectrograph's slit crossed the prominence body and we recorded the time evolution of individual vertical threads. Eventually, we observed the development of a dark Rayleigh-Taylor plume that propagated upward with a velocity, projected onto the plane of the sky, of 17 km/s. Interestingly, the plume apex collided with the prominence threads pushing them aside. We inferred Doppler shifts, Doppler widths, and magnetic field strength variations by interpreting the He I Stokes profiles with the HAZEL code. The Doppler shifts show that clusters of threads move coherently while individual threads have oscillatory patterns. Regarding the plume we found strong redshifts (9-12 km/s) and large Doppler widths (10 km/s) at the plume apex when it passed through the prominence body and before it disintegrated. We associate the redshifts with perspective effects while the Doppler widths are more likely due to an increase in the local temperature. No local variations of the magnetic field strength associated with the passage of the plume were found; this leads us to conclude that the plumes are no more magnetized than the surroundings. Finally, we found that some of the threads oscillations are locally damped, what allowed us to apply prominence seismology techniques to infer additional prominence physical parameters.

Does a solar filament barb always correspond to a prominence foot?

Y. **Ouyang**, P. F. Chen, S. Q. Fan, B. Li, A. A. Xu

ApJ **894** 64 **2020**

https://arxiv.org/pdf/2003.11976.pdf

https://doi.org/10.3847/1538-4357/ab83f9

Solar filaments are dark structures on the solar disk, with an elongated spine and several barbs extending out from the spine. When appearing above the solar limb, a filament is called a prominence, with with several feet extending down to the solar surface. It was generally thought that filament barbs are simply the prominence feet veering away from the spine and down to the solar surface. However, it was recently noticed that there might be another dynamic type of barbs, which were proposed to be due to filament thread longitudinal oscillation. If this is the case, the dynamic barbs would not extend down to the solar surface. With the quadrature observations of a filament barb on **2011 June 5** from the {\it Solar Dynamics Observatory} and the {\it STEREO} satellites, we confirm that the filament barb is due to filament thread longitudinal oscillations. Viewed from the side, the filament barb looks like an appendix along the spine of the prominence, and does not extend down to the solar surface as a foot.

CHIRALITY AND MAGNETIC CONFIGURATIONS OF SOLAR FILAMENTS

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2017 ApJ 835 94 DOI 10.3847/1538-4357/835/1/94

http://sci-hub.cc/10.3847/1538-4357/835/1/94

It has been revealed that the magnetic topology in the solar atmosphere displays hemispheric preference, i.e., helicity is mainly negative/positive in the northern/southern hemispheres, respectively. However, the strength of the hemispheric rule and its cyclic variation are controversial. In this paper, we apply a new method based on the filament drainage to 571 erupting filaments from 2010 May to 2015 December in order to determine the filament chirality and its hemispheric preference. It is found that 91.6% of our sample of erupting filaments follows the hemispheric rule of helicity sign. It is also found that the strength of the hemispheric preference of the quiescent filaments decreases slightly from ~97% in the rising phase to ~85% in the declining phase of solar cycle 24, whereas the strength of the intermediate filaments keeps a high value around 96 ± 4% at all times. Only the active-region filaments show significant variations. Their strength of the hemispheric rule rises from ~63% to ~95% in the rising phase, and keeps a high value of 82% ± 5% during the declining phase. Furthermore, during a half-year period around the solar maximum, their hemispheric preference totally vanishes. Additionally, we also diagnose the magnetic configurations of the filaments based on our indirect method and find that in our sample of erupting events, 89% are inverse-polarity filaments with a flux rope magnetic configuration, whereas 11% are normal-polarity filaments with a sheared arcade configuration. **2012-02-10**

Solar cycle evolution of dipolar and pseudostreamer belts and their relation to the slow solar wind†

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JGR, Volume 119, Issue 1, pages 36–46, January **2014**

Dipolar streamers are coronal structures formed by open solar flux converging from coronal holes of opposite polarity. Thus the dipolar streamer belt traces the coronal foot print of the heliospheric current sheet (HCS), and it is strongly associated with the origin of slow solar wind. Pseudostreamers, on the other hand, separate converging regions of open solar flux from coronal holes of the same polarity and do not contain current sheets. They have recently received a great deal of interest as a possible additional source of slow solar wind. Here we add to that growing body of work by using the potential-field source-surface model to determine the occurrence and location of dipolar and pseudostreamers over the last three solar cycles. In addition to providing new information about pseudostreamer morphology, the results help explain why the observations taken during the first Ulysses perihelion pass in 1995 showed noncoincidence between dipolar streamer belt and the locus of slowest flow. We find that Carrington rotation averages of the heliographic latitudes of dipolar and pseudostreamer belts are systematically shifted away from the equator, alternately in opposite directions, with a weak solar cycle periodicity, thus keeping slow wind from the web of combined streamer belts approximately symmetric about the equator. The largest separation of dipolar and pseudostreamer belts occurred close to the Ulysses pass, allowing a unique opportunity to see that slow wind from pseudostreamer belts north of the southward-displaced dipolar belt was responsible for the noncoincident pattern.

Modelling of asymmetric nanojets in coronal loops

Paolo **Pagano**, Patrick Antolin, Antonio Petralia

A&A 656, A141 **2021**

https://arxiv.org/pdf/2109.04854.pdf

https://www.aanda.org/articles/aa/pdf/2021/12/aa41030-21.pdf

https://doi.org/10.1051/0004-6361/202141030

Observations of reconnection jets in the solar corona are emerging as a possible diagnostic to study highly elusive coronal heating. Such nanojets can be observed in coronal loops and they have been linked to nanoflares. However, while models successfully describe the bilateral post-reconnection magnetic slingshot effect that leads to the jets, observations reveal that nanojets are unidirectional, or highly asymmetric, with only the jet travelling inward with respect to the coronal loop's curvature being clearly observed. The aim of this work is to address the role of the curvature of the coronal loop in asymmetric reconnection jets. In order to do so, we first use a simplified analytical model where we estimate the post-reconnection tension forces based on the local intersection angle between the pre-reconnection magnetic field lines and on their post-reconnection retracting length towards new equilibria. Second, we use a simplified numerical magnetohydrodynamic (MHD) model to study how two opposite propagating jets evolve in curved magnetic field lines. Our analytical model demonstrates that in the post-reconnection reorganised magnetic field, the inward directed magnetic tension is inherently stronger (up to 3 orders of magnitude) than the outward directed one and that, with a large enough retracting length, a regime exists where the outward directed tension disappears, leading to no outward jet at large, observable scales. Our MHD numerical model provides support for these results proving also that in the following time evolution the inward jets are consistently more energetic. The degree of asymmetry is also found to increase for small-angle reconnection and for more localised reconnection regions. This work shows that the curvature of the coronal loops plays a role in the asymmetry of the reconnection jets and inward directed jets are more likely to occur and more energetic.

Flux emergence event underneath a filament

J. **Palacios**, Y. Cerrato, C. Cid, A. Guerrero, E. Saiz

Proceedings of the International Astronomical Union, **2015**, Volume 305 'Polarimetry: From the Sun to Stars and Stellar Environments **2017**
https://arxiv.org/pdf/1704.00681.pdf
Flux emergence phenomena are relevant at different temporal and spatial scales. We have studied a flux emergence region underneath a filament. This filament elevated itself smoothly, and the associated CME reached Earth. In this study we investigate the size and amount of flux in the emergence event. The flux emergence site appeared just beneath a filament. The emergence acquired a size of 24 Mm in half a day. The unsigned magnetic flux density from LOS-magnetograms is around 1 kG at its maximum. The transverse field as well as the filament eruption were also analysed. **2013, 29 Sept**

Featuring dark coronal structures: physical signatures of filaments and coronal holes for automated recognition

Judith **Palacios**, Consuelo Cid, Elena Saiz, Yolanda Cerrato, Antonio Guerrero
IAUS 300 Proceedings, **2013**, 'Nature of Prominences and their Role in Space Weather' **2017**
https://arxiv.org/pdf/1704.00692.pdf
Filaments may be mistaken for coronal holes when observed in extreme ultraviolet (EUV) images; however, a closer and more careful look reveals that their photometric properties are different. The combination of EUV images with photospheric magnetograms shows some characteristic differences between filaments and coronal holes. We have performed analyses with 7 different SDO/AIA wavelengths (94, 131, 171, 211, 193, 304, 335~\AA) and SDO/HMI magnetograms obtained in September 2011 and March 2012 to study coronal holes and filaments from the photometric, magnetic, and also geometric point of view, since projection effects play an important role on the aforementioned traits.

Apparent Solar Tornado - Like Prominences

Olga **Panasenco**, Sara F. Martin, Marco Velli
Solar Physics, February **2014**, Volume 289, Issue 2, pp 603-622
https://link.springer.com/content/pdf/10.1007/s11207-013-0337-1.pdf
Recent high-resolution observations from the Solar Dynamics Observatory (SDO) have reawakened interest in the old and fascinating phenomenon of solar tornado-like prominences. This class of prominences was first introduced by Pettit (1932), who studied them over many years. Observations of tornado prominences similar to the ones seen by SDO had already been documented by Secchi (1877) in his famous "Le Soleil". High resolution and high cadence multiwavelength data obtained by SDO reveal that the tornado-like appearance of these prominences is mainly an illusion due to projection effects. We discuss two different cases where prominences on the limb might appear to have a tornado-like behavior. One case of apparent vortical motions in prominence spines and barbs arises from the (mostly) 2D counterstreaming plasma motion along the prominence spine and barbs together with oscillations along individual threads. The other case of apparent rotational motion is observed in prominence cavities and results from the 3D plasma motion along the writhed magnetic fields inside and along the prominence cavity as seen projected on the limb. Thus, the "tornado" impression results either from counterstreaming and oscillations or from the projection on the plane of the sky of plasma motion along magnetic field lines, rather than from a true vortical motion around an (apparent) vertical or horizontal axis. We discuss the link between tornado-like prominences, filament barbs, and photospheric vortices at their base. **27 November 1999; 2012/03/27-28; 2012/02/08; 16 June 2011; 2011/09/25; 23 July 2012; September 13, 2010; September 20, 2010**

Origins of Rolling, Twisting and Non-Radial Propagation of Eruptive Solar Events

Olga **Panasenco**, Sara F. Martin, Marco Velli, Angelos Vourlidas
E-print, Dec **2012**; Solar Phys., 2013
We demonstrate that major asymmetries in erupting filaments and CMEs, namely major twists and non-radial motions are typically related to the larger-scale ambient environment around eruptive events. Our analysis of prominence eruptions observed by the STEREO, SDO and SOHO spacecraft shows that prominence spines retain, during the initial phases, the thin ribbon-like topology they had prior to the eruption. This topology allows bending, rolling, and twisting during the early phase of the eruption, but not before. The combined ascent and initial bending of the filament ribbon is non-radial in the same general direction as for the enveloping CME. However, the non-radial motion of the filament is greater than that of the CME. In considering the global magnetic environment around CMEs, as approximated by the Potential Field Source Surface (PFSS) model, we find that the non-radial propagation of both erupting filaments and associated CMEs is correlated with the presence of nearby coronal holes, which deflect the erupting plasma and embedded fields. In addition, CME and filament motions respectively are guided towards weaker field regions, namely null points existing at different heights in the overlying configuration. Due to the presence of the coronal hole, the large-scale forces acting on the CME may be asymmetric. We find that the CME propagates usually non-radially in the direction of least resistance, which is always away from the coronal hole. We demonstrate these results using both low and high latitude examples.

Coronal Pseudostreamers: Source of Fast or Slow Solar Wind?

Olga **Panasenco**, Marco Velli

E-print, Dec **2012**; Solar Wind 13: Proceedings of the Thirteenth International Solar Wind Conference

We discuss observations of pseudostreamers and their 3D magnetic configuration as reconstructed with potential field source surface (PFSS) models to study their contribution to the solar wind. To understand the outflow from pseudostreamers the 3D expansion factor must be correctly estimated. Pseudostreamers may contain filament channels at their base in which case the open field lines diverge more strongly and the corresponding greater expansion factors lead to slower wind outflow, compared with pseudostreamers in which filament channels are absent. In the neighborhood of pseudostreamers the expansion factor does not increase monotonically with distance from the sun, and doesn't simply depend on the height of the pseudostreamer null point but on the entire magnetic field configuration.

Rolling motion in erupting prominences observed by STEREO

Olga **Panasenco**, , , Sara Martina, Anand D. Joshib and Nandita Srivastava

Journal of Atmospheric and Solar-Terrestrial Physics

Volume 73, Issue 10, 20 June **2011**, Pages 1129-1137, **File**

We analyze the large-scale dynamical forms of three erupting prominences (filaments) observed by at least one of the two STEREO spacecraft and which reveal evidence of sideways rolling motion beginning at the crest of the erupting filament. We find that all three events were also highly non-radial and occurred adjacent to large coronal holes. For each event, the rolling motion and the average non-radial outward motion of the erupting filament and associated CME were away from a neighboring coronal hole. The location of each coronal hole was adjacent to the outer boundary of the arcade of loops overlying the filaments. The erupting filaments were all more non-radial than the CMEs but in the same general direction. From these associations, we make the hypothesis that the degree of the roll effect depends on the level of force imbalances inside the filament arcade related to the coronal hole and the relative amount of magnetic flux on each side of the filament, while the non-radial motion of the CME is related to global magnetic configuration force imbalances. Our analyses of the prominence eruption best observed from both STEREO-A and STEREO-B shows that its spine retained the thin ribbon-like topology that it had prior to the eruption. This topology allows bending, rolling, and twisting during the early phase of the eruption.

Research Highlights

► The rolling motion of the erupting filament is away from a neighboring coronal hole. ► The non-radial motion of the associated CME is away from a neighboring coronal hole. ► The erupting filaments were all more non-radial than the CMEs but in the same general direction. ► The rolling motion depends on the level of force imbalances inside the filament arcade. ► The non-radial motion of the CME is related to global magnetic configuration force imbalances.

The non-ideal finite Larmor radius effect in the solar atmosphere

B P **Pandey**, Mark Wardle

Monthly Notices of the Royal Astronomical Society, Volume 513, Issue 2, June **2022**, Pages 1842–1857, https://doi.org/10.1093/mnras/stac1028

The dynamics of the partially ionized solar atmosphere is controlled by the frequent collisions and charge exchange between the predominant neutral hydrogen atoms and charged ions. At signal frequencies below or of the order of either of the collision or charge exchange frequencies, the magnetic stress is felt by both the charged and neutral particles simultaneously. The resulting neutral-mass loading of the ions leads to the rescaling of the effective ion-cyclotron frequency (it becomes the Hall frequency), and the resultant effective Larmor radius becomes of the order of few kms. Thus, the finite Larmor radius effect that manifests as the ion and neutral pressure stress tensors operates over macroscopic scales. Whereas parallel and perpendicular (with respect to the magnetic field) viscous momentum transport competes with the Ohm and Hall diffusion of the magnetic field in the photosphere–chromosphere, the gyroviscous effect becomes important only in the transition region between the chromosphere and corona, where it competes with the ambipolar diffusion. The wave propagation in the gyroviscous effect-dominated medium depends on the plasma β (a ratio of the thermal and magnetic energies). The abundance of free energy makes gyro waves unstable with the onset condition exactly opposite of the Hall instability. However, the maximum growth rate is identical to the Hall instability. For a flow gradient of $\sim 0.1 s^{-1} \sim 0.1 s^{-1}$, the instability growth time is 1 min. Thus, the transition region may become subject to this fast-growing gyroviscous instability.

Network Jets as the Driver of Counter-streaming Flows in a Solar Filament/Filament Channel

Navdeep K. **Panesar**1,2, Sanjiv K. Tiwari1,2, Ronald L. Moore3,4, and Alphonse C. Sterling4

2020 ApJL 897 L2

https://doi.org/10.3847/2041-8213/ab9ac1

https://arxiv.org/pdf/2006.04249.pdf

Counter-streaming flows in a small (100" long) solar filament/filament channel are directly observed in high-resolution Solar Dynamics Observatory (SDO)/Atmospheric Imaging Assembly (AIA) extreme-ultraviolet (EUV) images of a region of enhanced magnetic network. We combine images from SDO/AIA, SDO/Helioseismic and Magnetic Imager (HMI), and the Interface Region Imaging Spectrograph (IRIS) to investigate the driving mechanism of these flows. We find that: (i) counter-streaming flows are present along adjacent filament/filament channel threads for ~2 hr, (ii) both ends of the filament/filament channel are rooted at the edges of magnetic network flux lanes along which there are impinging fine-scale opposite-polarity flux patches, (iii) recurrent small-scale jets (known as network jets) occur at the edges of the magnetic network flux lanes at the ends of the filament/filament channel, (iv) the recurrent network jet eruptions clearly drive the counter-streaming flows along threads of the filament/filament channel, (v) some of the network jets appear to stem from sites of flux cancelation, between network flux and merging opposite-polarity flux, and (vi) some show brightening at their bases, analogous to the base brightening in coronal jets. The average speed of the counter-streaming flows along the filament/filament channel threads is 70 km s−1. The average widths of the AIA filament/filament channel and the Hα filament are 4" and 2."5, respectively, consistent with the earlier findings that filaments in EUV images are wider than in Hα images. Thus, our observations show that the continually repeated counter-streaming flows come from network jets, and these driving network jet eruptions are possibly prepared and triggered by magnetic flux cancelation. **8 Jan 2016**

On the Structure and Evolution of a Polar Crown Prominence/Filament System

N. K. **Panesar**, D. E. Innes, D. J. Schmit, S. K. Tiwari

Solar Physics, Volume 289, Issue 8, pp 2971-2991 **2014**

http://arxiv.org/pdf/1402.4989v1.pdf

Polar crown prominences, that partially circle the Sun's poles between 60° and 70° latitude, are made of chromospheric plasma. We aim to diagnose the 3D dynamics of a polar crown prominence using high-cadence EUV images from the Solar Dynamics Observatory (SDO)/AIA at 304, 171, and 193 Å and the Ahead spacecraft of the Solar Terrestrial Relations Observatory (STEREO-A)/EUVI at 195 Å. Using time series across specific structures, we compare flows across the disk in 195 Å with the prominence dynamics seen on the limb. The densest prominence material forms vertical columns that are separated by many tens of Mm and connected by dynamic bridges of plasma that are clearly visible in 304/171 Å two-colour images. We also observe intermittent but repetitious flows with velocity 15 km s−1 in the prominence that appear to be associated with EUV bright points on the solar disk. The boundary between the prominence and the overlying cavity appears as a sharp edge. We discuss the structure of the coronal cavity seen both above and around the prominence. SDO/HMI and GONG magnetograms are used to infer the underlying magnetic topology. The evolution and structure of the prominence with respect to the magnetic field seems to agree with the filament-linkage model. 13 February 2011

First Imaging Observation of Standing Slow Wave in Coronal Fan loops

V. **Pant**, A. Tiwari, D. Yuan, D. Banerjee

ApJL **847** L5 **2017**

https://arxiv.org/pdf/1708.06946.pdf

We observe intensity oscillations along coronal fan loops associated with the active region AR 11428. The intensity oscillations were triggered by blast waves which were generated due to X-class flares in the distant active region AR 11429. To characterise the nature of oscillations, we created time-distance maps along the fan loops and noted that the intensity oscillations at two ends of the loops were out of phase. As we move along the fan loop, the amplitude of the oscillations first decreased and then increased. The out-of-phase nature together with the amplitude variation along the loop implies that these oscillations are very likely to be standing waves. The period of the oscillations are estimated to be ∼27 min, damping time to be ∼45 min and phase velocity projected in the plane of sky ∼ 65-83 km s−1. The projected phase speeds were in the range of acoustic speed of coronal plasma at about 0.6 MK which further indicates that these are slow waves. To best of our knowledge, this is the first report on the existence of the standing slow waves in non-flaring fan loops. **2012 March 7**

Simultaneous longitudinal and transverse oscillation in an active filament

V. **Pant**, R. Mazumder, D. Yuan, D. Banerjee, A. K. Srivastava, Y. Shen

Solar Phys. Volume 291, Issue 11, pp 3303–3315 **2016**

https://arxiv.org/pdf/1611.03984v1.pdf

We report on the co-existence of longitudinal and transverse oscillations in an active filament. On **March 15th 2013**, a M1.1 class flare was observed in the active region AR 11692. A CME was found to be associated with the flare. {The CME generated a shock wave that triggered the oscillations in a nearby filament}, situated at the south-west of the active region as observed from National Solar Observatory (NSO)\textit{Global Oscillation Network Group}(GONG) Hα images. In this work we report the longitudinal oscillations in the two ends of the filament, co-existing with the transverse oscillations. We propose a scenario in which {an} incoming shock wave hits the filament obliquely and triggers both longitudinal and transverse oscillations. Using the observed parameters, we estimate the lower limit of the magnetic field strength. We use simple pendulum model with gravity as the restoring force to estimate the radius of curvature. We also calculate the mass accretion rate which causes the filament motions to damp quite fast.

MHD Seismology of a loop-like filament tube by observed kink waves

V. **Pant**, A.K. Srivastava, D. Banerjee, M. Goossens, P.F. Chen, N.C. Joshi, Y.H. Zhou

RAA, **2015**

http://arxiv.org/pdf/1503.02281v1.pdf

We report and analyze the observational evidence of global kink oscillations in a solar filament as observed in H alpha by National Solar Observatory (NSO)/Global Oscillation Network Group (GONG) instrument. An M1.1-class flare in active region 11692 on **2013 March 15** induced a global kink mode in the filament lying in the south-west of AR11692.We find periods of about 61 - 67 minutes and damping times of 92 - 117 minutes at three vertical slice positions chosen in and around the filament apex. We find that the waves are damped. From the observed global kink mode period and damping time scale using the theory of resonant absorption we perform prominence seismology. We estimate a lower cut-off value for the inhomogeneity length-scale to be around 0.34 - 0.44 times the radius of the filament cross-section.

Sausage Mode Propagation in a Thick Magnetic Flux Tube

A. **Pardi**, I. Ballai, A. Marcu, B. Orza

Solar Physics, April **2014**, Volume 289, Issue 4, pp 1203-1214

The aim of this paper is to model the propagation of slow magnetohydrodynamic (MHD) sausage waves in a thick expanding magnetic flux tube in the context of the quiescent (VAL-C) solar atmosphere. The propagation of these waves is found to be described by the Klein–Gordon equation. Using the governing MHD equations and the VAL-C atmosphere model we study the variation of the cut-off frequency along and across the magnetic tube guiding the waves. Due to the radial variation of the cut-off frequency the flux tubes act as low frequency filters for the waves.

Elemental composition in quiescent prominences

S. **Parenti**, G. Del Zanna, J.-C. Vial

A&A 625, A52 **2019**

https://arxiv.org/pdf/1905.00871.pdf

The first ionization potential (FIP) bias is currently used to trace the propagation of solar features ejected by the wind and solar eruptions (coronal mass ejections). The FIP bias also helps us to understand the formation of prominences, as it is a tracer for the solar origin of prominence plasma.
This work aims to provide elemental composition and FIP bias in quiescent solar prominences. This is key information to link these features to remnants of solar eruptions measured in-situ within the heliosphere and to constrain the coronal or photospheric origin of prominence plasma.
We used the differential emission measure technique to derive the FIP bias of two prominences. Quiet Sun chromospheric and transition region data were used to test the atomic data and lines formation processes. We used lines from low stage of ionization of \ion{Si}{}, \ion{S}{}, \ion{Fe}{}, \ion{C}{}, \ion{N}{}, \ion{O}{}, \ion{Ni}{}, \ion{Mg,}{} and \ion{Ne}{}, constraining the FIP bias in the range 4.2≤logT≤5.8. We adopted a density-dependent ionization equilibrium.
We showed that the two prominences have photospheric composition. We confirmed a photospheric composition in the quiet Sun. We also identified opacity and/or radiative excitation contributions to the line formation of a few lines regularly observed in prominences.
With our results we thus provide important elements for correctly interpreting the upcoming Solar Orbiter/SPICE spectroscopic data and to constrain prominence formation.

Solar Prominences: Observations **Review**

Parenti, Susanna

Living Reviews in Solar Physics, **2014**, , 11:1

https://link.springer.com/content/pdf/10.12942%2Flrsp-2014-1.pdf

Solar prominences are one of the most common features of the solar atmosphere. They are found in the corona but they are one hundred times cooler and denser than the coronal material, indicating that they are thermally and pressure isolated from the surrounding environment. Because of these properties they appear at the limb as bright features when observed in the optical or the EUV cool lines. On the disk they appear darker than their background, indicating the presence of a plasma absorption process (in this case they are called filaments). Prominence plasma is embedded in a magnetic environment that lies above magnetic inversion lines, denoted a filament channel.

This paper aims at providing the reader with the main elements that characterize these peculiar structures, the prominences and their environment, as deduced from observations. The aim is also to point out and discuss open questions on prominence existence, stability and disappearance.
The review starts with a general introduction of these features and the instruments used for their observation. Section 2 presents the large scale properties, including filament morphology, thermodynamical parameters, magnetic fields, and the properties of the surrounding coronal cavity, all in stable conditions. Section 3 is dedicated to small-scale observational properties, from both the morphological and dynamical points of view. Section 4 introduces observational aspects during prominence formation, while Section 5 reviews the sources of instability leading to prominence disappearance or eruption. Conclusions and perspectives are given in Section 6.

ON THE NATURE OF PROMINENCE EMISSION OBSERVED BY SDO/AIA
S. **Parenti**1, B. Schmieder2, P. Heinzel3, and L. Golub
2012 ApJ 754 66
The prominence-corona transition region (PCTR) plays a key role in the thermal and pressure equilibrium of solar prominences. Our knowledge of this interface is limited and several major issues remain open, including the thermal structure and, in particular, the maximum temperature of the detectable plasma. The high signal-to-noise ratio of images obtained by the Atmospheric Imaging Assembly (AIA) on NASA's Solar Dynamics Observatory clearly shows that prominences are often seen in emission in the 171 and 131 bands. We investigate the temperature sensitivity of these AIA bands for prominence observations, in order to infer the temperature content in an effort to explain the emission. Using the CHIANTI atomic database and previously determined prominence differential emission measure distributions, we build synthetic spectra to establish the main emission-line contributors in the AIA bands. We find that the Fe IX line always dominates the 171 band, even in the absence of plasma at >106 K temperatures, while the 131 band is dominated by Fe VIII. We conclude that the PCTR has sufficient plasma emitting at >4 × 105 K to be detected by AIA.

A MODEL FOR SOLAR POLAR JETS
E. **Pariat** et al **2009** ApJ 691 61-74
http://www.iop.org/EJ/abstract/0004-637X/691/1/61
We propose a model for the jetting activity that is commonly observed in the Sun's corona, especially in the open-field regions of polar coronal holes. Magnetic reconnection is the process driving the jets and a relevant magnetic configuration is the well known null-point and fan-separatrix topology. The primary challenge in explaining the observations is that reconnection must occur in a short-duration energetic burst, rather than quasi-continuously as is implied by the observations of long-lived structures in coronal holes, such as polar plumes. The key idea underlying our model for jets is that reconnection is forbidden for an axisymmetrical null-point topology. Consequently, by imposing a twisting motion that maintains the axisymmetry, magnetic stress can be built up to high levels until an ideal instability breaks the symmetry and leads to an explosive release of energy via reconnection. Using three-dimensional magnetohydrodynamic simulations, we demonstrate that this mechanism does produce massive, high-speed jets driven by nonlinear Alfvén waves. We discuss the implications of our results for observations of the solar corona.

Temperature of Solar Prominences Obtained with the Fast Imaging Solar Spectrograph on the 1.6 m New Solar Telescope at the Big Bear Solar Observatory
Hyungmin **Park**, Jongchul Chae, Donguk Song, …
Solar Physics, November **2013**, Volume 288, Issue 1, pp 105-116
We observed solar prominences with the Fast Imaging Solar Spectrograph (FISS) at the Big Bear Solar Observatory on **30 June 2010 and 15 August 2011**. To determine the temperature of the prominence material, we applied a nonlinear least-squares fitting of the radiative transfer model. From the Doppler broadening of the Hα and Ca ii lines, we determined the temperature and nonthermal velocity separately. The ranges of temperature and nonthermal velocity were 4000 – 20 000 K and 4 – 11 km s−1. We also found that the temperature varied much from point to point within one prominence.

Oscillation and Evolution of Coronal Loops in a Dynamical Solar Corona
David J. **Pascoe**1*, Christopher R. Goddard2 and Tom Van Doorsselaere1
Front. Astron. Space Sci., 7:61 **2020**

https://doi.org/10.3389/fspas.2020.00061
https://www.frontiersin.org/articles/10.3389/fspas.2020.00061/full
Observations have revealed two regimes of kink oscillations of coronal loops. Large amplitude oscillations excited by impulsive energy releases such as coronal mass ejections are characterized by their strong damping by resonant absorption. Lower amplitude oscillations may also be excited and sustained by the ubiquitous motions present in the corona and so are characterized as being decayless. We perform numerical simulations to study the oscillation and evolution of coronal loops in a dynamical environment. We investigate the observational signatures of kink oscillations and the Kelvin-Helmholtz instability in terms of high-resolution seismological and spatial data analysis techniques. We find that low amplitude kink oscillations are capable of generating significant changes in the loop profile which can affect estimates of the transverse loop inhomogeneity based on seismological and forward modeling methods. The disparity between methods may be indicative of non-linear evolution of coronal loops. The influence on forward modeling estimates could also account for previous observational evidence favoring loops having wider inhomogeneous layers.

Tracking and Seismological Analysis of Multiple Coronal Loops in an Active Region

D. J. **Pascoe**1, A. Smyrli2, and T. Van Doorsselaere
2020 ApJ 898 126
https://doi.org/10.3847/1538-4357/aba0a6
We present a new method to track the position and evolution of coronal loops designed for observations such as active regions in which multiple loops appear in close proximity or overlap with each other along the observational line of sight. The method is based on modeling a time–distance map containing one or more loops and fitting the modeled map to observational data, as opposed to the commonly used technique of analyzing each frame independently. This allows us to control the variability of the model, informed by our physical interpretation, and use the trends present to help constrain the model parameters. We apply our method to an observation of a bundle of coronal loops previously investigated using a spatiotemporal autocorrelation method and compare our results. A benefit of our method is that it provides the time series for the position of the loops that may be used for further analysis using established seismological techniques. We demonstrate this by modeling the oscillation of several loops in response to flaring energy releases that occur during the observation, and we find evidence of loop evolution consistent with the Kelvin–Helmholtz instability.

Coronal Loop Seismology Using Standing Kink Oscillations With a Lookup Table

David J. **Pascoe**, Alan W. Hood and Tom Van Doorsselaere
Front. Astron. Space Sci. 6:22 **2019**
sci-hub.ru/10.3389/fspas.2019.00022
https://doi.org/10.3389/fspas.2019.00022
https://www.frontiersin.org/articles/10.3389/fspas.2019.00022/full
The transverse structure of coronal loops plays a key role in the physics but the small transverse scales can be difficult to observe directly. For wider loops the density profile may be estimated by forward modeling of the transverse intensity profile. The transverse density profile may also be estimated seismologically using kink oscillations in coronal loops. The strong damping of kink oscillations is attributed to resonant absorption and the damping profile contains information about the transverse structure of the loop. However, the analytical descriptions for damping by resonant absorption presently only describe the behavior for thin inhomogeneous layers. Previous numerical studies have demonstrated that this thin boundary approximation produces poor estimates of the damping behavior in loops with wider inhomogeneous layers. Both the seismological and forward modeling approaches suggest loops have a range of layer widths and so there is a need for a description of the damping behavior that accurately describes such loops. We perform a parametric study of the damping of standing kink oscillations by resonant absorption for a wide range of inhomogeneous layer widths and density contrast ratios, with a focus on the values most relevant to observational cases. We describe the damping profile produced by our numerical simulations without prior assumption of its shape and compile our results into a lookup table which may be used to produce accurate seismological estimates for kink oscillation observations.

Spatiotemporal Analysis of Coronal Loops Using Seismology of Damped Kink Oscillations and Forward Modeling of EUV Intensity Profiles

D. J. **Pascoe**1,2, S. A. Anfinogentov1,3, C. R. Goddard1, and V. M. Nakariakov1,4
2018 ApJ 860 31
http://sci-hub.tw/http://iopscience.iop.org/0004-637X/860/1/31/
The shape of the damping profile of kink oscillations in coronal loops has recently allowed the transverse density profile of the loop to be estimated. This requires accurate measurement of the damping profile that can distinguish the Gaussian and exponential damping regimes, otherwise there are more unknowns than observables. Forward modeling of the transverse intensity profile may also be used to estimate the width of the inhomogeneous layer of a

loop, providing an independent estimate of one of these unknowns. We analyze an oscillating loop for which the seismological determination of the transverse structure is inconclusive except when supplemented by additional spatial information from the transverse intensity profile. Our temporal analysis describes the motion of a coronal loop as a kink oscillation damped by resonant absorption, and our spatial analysis is based on forward modeling the transverse EUV intensity profile of the loop under the isothermal and optically thin approximations. We use Bayesian analysis and Markov chain Monte Carlo sampling to apply our spatial and temporal models both individually and simultaneously to our data and compare the results with numerical simulations. Combining the two methods allows both the inhomogeneous layer width and density contrast to be calculated, which is not possible for the same data when each method is applied individually. We demonstrate that the assumption of an exponential damping profile leads to a significantly larger error in the inferred density contrast ratio compared with a Gaussian damping profile.

Seismology of contracting and expanding coronal loops using damping of kink oscillations by mode coupling

D.J. **Pascoe**, A.J.B. Russell, S.A. Anfinogentov, P.J.A. Simões, C.R. Goddard, V.M. Nakariakov, L. Fletcher

A&A 607, A8 **2017**

http://www2.warwick.ac.uk/fac/sci/physics/staff/research/davidpascoe/seis_contract.pdf
https://www.aanda.org/articles/aa/pdf/2017/11/aa30915-17.pdf

Aims. We extend recently developed seismological methods to analyse oscillating loops which feature a large initial shift in the equilibrium position and investigate additional observational signatures related to the loop environment and oscillation driver.
Methods. We model the motion of coronal loops as a kink oscillation damped by mode coupling, accounting for any change in loop length and the possible presence of parallel harmonics in addition to the fundamental mode. We apply our model to a loop which rapidly contracts due to a post-flare implosion (SOL**2012-03-09**) and a loop with a large lateral displacement (SOL**2012-10-20**).
Results. The seismological method is used to calculate plasma parameters of the oscillating loops including the transverse density profile, magnetic field strength, and phase mixing timescale. For SOL2012-03-09 the period of oscillation has a linear correlation with the contracting motion and suggests the kink speed remains constant during the oscillation. The implosion excitation mechanism is found to be associated with an absence of additional parallel harmonics.
Conclusions. The improved Bayesian analysis of the coronal loop motion allows for accurate seismology of plasma parameters, and the evolution of the period of oscillation compared with the background trend can be used to distinguish between loop motions in the plane of the loop and those perpendicular to it. The seismologically inferred kink speed and density contrast imply sub-Alfvénic (MA = 0.16 ± 0.03) propagation of the magnetic reconfiguration associated with the implosion, as opposed to triggering by a wave propagating at the Alfvén speed.

Coronal loop density profile estimated by forward modelling of EUV intensity

D. J. **Pascoe**, C. R. Goddard, S. Anfinogentov, and V. M. Nakariakov

A&A **2017**

http://www.aanda.org/articles/aa/pdf/forth/aa30458-17.pdf

Aims. The transverse density structuring of coronal loops was recently calculated for the first time using the general damping profile for kink oscillations. This seismological method assumes a density profile with a linear transition region.We consider to what extent this density profile accounts for the observed intensity profile of the loop, and how the transverse intensity profile may be used to complement the seismological technique.
Methods. We use isothermal and optically transparent approximations for which the intensity of extreme ultraviolet (EUV) emission is proportional to the square of the plasma density integrated along the line of sight.We consider four different models for the transverse density profile; the generalised Epstein profile, the step function, the linear transition region profile, and a Gaussian profile. The effect of the point spread function is included and Bayesian analysis is used for comparison of the models.
Results. The two profiles with finite transitions are found to be preferable to the step function profile, which supports the interpretation of kink mode damping as being due to mode coupling. The estimate of the transition layer width using forward modelling is consistent with the seismological estimate.
Conclusions. For wide loops, that is those observed with sufficiently high spatial resolution, this method can provide an independent estimate of density profile parameters for comparison with seismological estimates. In the ill-posed case of only one of the Gaussian or exponential damping regimes being observed, it may provide additional information to allow a seismological inversion to be performed. Alternatively, it may be used to obtain structuring information for loops that do not oscillate.

Coronal loop seismology using damping of standing kink oscillations by mode coupling II. additional physical effects and Bayesian analysis

D. J. **Pascoe**, S. Anfinogentov, G. Nistico, C. R. Goddard, and V. M. Nakariakov

A&A 600, A78 **2017**

http://www2.warwick.ac.uk/fac/sci/physics/staff/research/davidpascoe/mc2.pdf

The strong damping of kink oscillations of coronal loops can be explained by mode coupling. The damping envelope depends on the transverse density profile of the loop. Observational measurements of the damping envelope have been used to determine the transverse loop structure which is important for understanding other physical processes such as heating. The general damping envelope describing the mode coupling of kink waves consists of a Gaussian damping regime followed by an exponential damping regime. Recent observational detection of these damping regimes has been employed as a seismological tool. We extend the description of the damping behaviour to account for additional physical effects, namely a time-dependent period of oscillation, the presence of additional longitudinal harmonics, and the decayless regime of standing kink oscillations. We examine four examples of standing kink oscillations observed by the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO). We use forward modelling of the loop position and investigate the dependence on the model parameters using Bayesian inference and Markov Chain Monte Carlo (MCMC) sampling. Our improvements to the physical model combined with the use of Bayesian inference and MCMC produce improved estimates of model parameters and their uncertainties. Calculation of the Bayes factor also allows us to compare the suitability of different physical models. We also use a new method based on spline interpolation of the zeroes of the oscillation to accurately describe the background trend of the oscillating loop. This powerful and robust method allows for accurate seismology of coronal loops, in particular the transverse density profile, and potentially reveals additional physical effects.

Standing sausage modes in curved coronal slabs

D. J. **Pascoe** and V. M. Nakariakov

A&A 593, A52 **2016**

http://wrap.warwick.ac.uk/80290/14/WRAP_1273366-px-080716-ms_accepted%20%25281%2529.pdf

Magnetohydrodynamic waveguides such as dense coronal loops can support standing modes. The ratios of the periods of oscillations for different longitudinal harmonics depend on the dispersive nature of the waveguide and so may be used as a seismological tool to determine coronal parameters. We extend models of standing sausage modes in low β coronal loops to include the effects of loop curvature. The behaviour of standing sausage modes in this geometry is used to explain the properties of observed oscillations which cannot be accounted for using straight loop models. We perform 2D numerical simulations of an oscillating coronal loop, modelled as a dense slab embedded in a potential magnetic field. The loop is field-aligned and so experiences expansion with height in addition to being curved. Standing sausage modes are excited by compressive perturbations of the loop and their properties are studied. The spatial profiles of standing sausage modes are found to be modified by the expanding loop geometry typical for flaring loops and modelled by a potential magnetic field in our simulations. Longitudinal harmonics of order $n > 1$ have antinodes which are shifted towards the loop apex and the amplitude of antinodes near the loop apex is smaller than those near the loop footpoints. We find that the observation of standing sausage modes by Nakariakov et al. (2003) is consistent with interpretation in terms of the global mode ($n = 1$) and third harmonic ($n = 3$). This interpretation accounts for the period ratio and spatial structure of the observed oscillations.

Spatially resolved observation of the fundamental and second harmonic standing kink modes using SDO/AIA

D. J. **Pascoe**, C. R. Goddard, and V. M. Nakariakov

A&A 593, A53 **2016**

http://wrap.warwick.ac.uk/79792/1/WRAP_1273366-px-230616-ms_accepted.pdf

We consider a coronal loop kink oscillation observed by the Atmospheric Imaging Assembly (AIA) of the Solar Dynamics Observatory (SDO) which demonstrates two strong spectral components. The period of the lower frequency component being approximately twice that of the shorter frequency component suggests the presence of harmonics. We examine the presence of two longitudinal harmonics by investigating the spatial dependence of the loop oscillation. The time-dependent displacement of the loop is measured at 15 locations along the loop axis. For each position the detrended displacement is fitted as the sum of two damped sinusoids, having periods P1 and P2, and a damping time τ. The shorter period component exhibits anti-phase oscillations in the loop legs. We interpret the observation in terms of the first (global or fundamental) and second longitudinal harmonics of the standing kink mode. The strong excitation of the second harmonic appears connected to the preceding coronal mass ejection

(CME) which displaced one of the loop legs. The oscillation parameters found are P1 = 5.00 " 0.62 minutes, P2 = 2.20 " 0.23 minutes, P1/2P2 = 1.15 " 0.22, and τ/P = 3.35 " 1.45. **9 February 2011**

Coronal loop seismology using damping of standing kink oscillations by mode coupling

D. J. **Pascoe**, C. R. Goddard, G. Nisticò, S. Anfinogentov and V. M. Nakariakov

A&A 589, A136 (**2016**)

Context. Kink oscillations of solar coronal loops are frequently observed to be strongly damped. The damping can be explained by mode coupling on the condition that loops have a finite inhomogeneous layer between the higher density core and lower density background. The damping rate depends on the loop density contrast ratio and inhomogeneous layer width.

Aims. The theoretical description for mode coupling of kink waves has been extended to include the initial Gaussian damping regime in addition to the exponential asymptotic state. Observation of these damping regimes would provide information about the structuring of the coronal loop and so provide a seismological tool.

Methods. We consider three examples of standing kink oscillations observed by the Atmospheric Imaging Assembly (AIA) of the Solar Dynamics Observatory (SDO) for which the general damping profile (Gaussian and exponential regimes) can be fitted. Determining the Gaussian and exponential damping times allows us to perform seismological inversions for the loop density contrast ratio and the inhomogeneous layer width normalised to the loop radius. The layer width and loop minor radius are found separately by comparing the observed loop intensity profile with forward modelling based on our seismological results.

Results. The seismological method which allows the density contrast ratio and inhomogeneous layer width to be simultaneously determined from the kink mode damping profile has been applied to observational data for the first time. This allows the internal and external Alfvén speeds to be calculated, and estimates for the magnetic field strength can be dramatically improved using the given plasma density.

Conclusions. The kink mode damping rate can be used as a powerful diagnostic tool to determine the coronal loop density profile. This information can be used for further calculations such as the magnetic field strength or phase mixing rate.

Excitation and damping of broadband kink waves in the solar corona

D. J. **Pascoe**1, A. N. Wright2, I. De Moortel2 and A. W. Hood

A&A 578, A99 (**2015**)

Context. Observations such as those by the Coronal Multi-Channel Polarimeter (CoMP) have revealed that broadband kink oscillations are ubiquitous in the solar corona.

Aims. We consider footpoint-driven kink waves propagating in a low β coronal plasma with a cylindrical density structure. We investigate the excitation and damping of propagating kink waves by a broadband driver, including the effects of different spatial profiles for the driver.

Methods. We employ a general spatial damping profile in which the initial stage of the damping envelope is approximated by a Gaussian profile and the asymptotic state by an exponential one. We develop a method of accounting for the presence of these different damping regimes and test it using data from numerical simulations.

Results. Strongly damped oscillations in low density coronal loops are more accurately described by a Gaussian spatial damping profile than an exponential profile. The consequences for coronal seismology are investigated and applied to observational data for the ubiquitous broadband waves observed by CoMP. Current data cannot distinguish between the exponential and Gaussian profiles because of the levels of noise. We demonstrate the importance of the spatial profile of the driver on the resulting damping profile. Furthermore, we show that a small-scale turbulent driver is inefficient at exciting propagating kink waves.

Standing Kink Modes in Three-dimensional Coronal Loops

D. J. **Pascoe** and I. De Moortel

2014 ApJ 784 101

So far, the straight flux tube model proposed by Edwin & Roberts is the most commonly used tool in practical coronal seismology, in particular, to infer values of the (coronal) magnetic field from observed, standing kink mode oscillations. In this paper, we compare the period predicted by this basic model with three-dimensional (3D) numerical simulations of standing kink mode oscillations, as the period is a crucial parameter in the seismological inversion to determine the magnetic field. We perform numerical simulations of standing kink modes in both straight and curved 3D coronal loops and consider excitation by internal and external drivers. The period of oscillation for the displacement of dense coronal loops is determined by the loop length and the kink speed, in agreement with the estimate based on analytical theory for straight flux tubes. For curved coronal loops embedded in a magnetic arcade and excited by an external driver, a secondary mode with a period determined by the loop length and external Alfvén speed is also present. When a low number of oscillations is considered, these two periods can result in a single, non-resolved (broad) peak in the power spectrum, particularly for low values of the density contrast for which the two periods will be relatively similar. In that case (and for this particular geometry), the presence of this additional mode would lead to ambiguous seismological estimates of the magnetic field strength.

COUPLED ALFVÉN AND KINK OSCILLATIONS IN CORONAL LOOPS

D. J. **Pascoe** et al

2010 ApJ 711 990-996

Observations have revealed ubiquitous transverse velocity perturbation waves propagating in the solar corona. However, there is ongoing discussion regarding their interpretation as kink or Alfvén waves. To investigate the nature of transverse waves propagating in the solar corona and their potential for use as a coronal diagnostic in MHD seismology, we perform three-dimensional numerical simulations of footpoint-driven transverse waves propagating in a low β plasma. We consider the cases of both a uniform medium and one with loop-like density structure and perform a parametric study for our structuring parameters. When density structuring is present, resonant absorption in inhomogeneous layers leads to the coupling of the kink mode to the Alfvén mode. The decay of the propagating kink wave as energy is transferred to the local Alfvén mode is in good agreement with a modified interpretation of the analysis of Ruderman & Roberts for standing kink modes. Numerical simulations support the most general interpretation of the observed loop oscillations as a coupling of the kink and Alfvén modes. This coupling may account for the observed predominance of outward wave power in longer coronal loops since the observed damping length is comparable to our estimate based on an assumption of resonant absorption as the damping mechanism.

STEREO/SECCHI Stereoscopic Observations Constraining the Initiation of Polar Coronal Jets

S. **Patsourakos**, E. Pariat, A. Vourlidas, S. K. Antiochos, J. P. Wuelser

E-print, May 2008; ApJL, 680:L73–L76, **2008**

We report on the first stereoscopic observations of polar coronal jets made by the EUVI/SECCHI imagers on board the twin STEREO spacecraft. The significantly separated viewpoints (_ 11◦) allowed us to infer the 3D dynamics and morphology of a well-defined EUV coronal jet for the first time. Triangulations of the jet's location in simultaneous image pairs led to the true 3D position and thereby its kinematics. Initially the jet ascends slowly at _10-20 kms−1 and then, after an apparent 'jump' takes place, it accelerates impulsively to velocities exceeding 300 kms−1 with accelerations exceeding the solar gravity. Helical structure is the most important geometrical feature of the jet which shows evidence of untwisting. The jet structure appears strikingly different from each of the two STEREO viewpoints: face-on in the one viewpoint and edge-on in the other. This provides conclusive evidence that the observed helical structure is real and is not resulting from possible projection effects of single viewpoint observations. The clear demonstration of twisted structure in polar jets compares favorably with synthetic images from a recent MHD simulation of jets invoking magnetic untwisting as their driving mechanism. Therefore, the latter can be considered as a viable mechanism for the initiation of polar jets.

Mg II h&k fine structure prominence modelling and the consequences for observations

A. W. **Peat**1,2, N. Labrosse2 and P. Gouttebroze3,⋆

A&A 679, A156 (**2023**)

https://www.aanda.org/articles/aa/pdf/2023/11/aa47246-23.pdf

Aims. Using 2D Mg II h&k solar prominence modelling, our aim is to understand the formation of complex line profiles and how these are seen by the Interface Region Imaging Spectrograph (IRIS). Additionally, we see how the properties of these simulated observations are interpreted through the use of traditional 1D prominence modelling.
Methods. We used a cylindrical non-local thermodynamic equilibrium (NLTE) 2D complete redistribution (CRD) code to generate a set of cylindrical prominence strands, which we stacked behind each other to produce complex line profiles. Then, with the use of the point spread functions (PSFs) of IRIS, we were able to predict how IRIS would observe these line profiles. We then used the 1D NLTE code PROM in combination with the Cross Root Mean Square method (xRMS) to find the properties recovered by traditional 1D prominence modelling.
Results. Velocities of magnitude lower than 10 km s−1 are sufficient to produce asymmetries in the Mg II h&k lines. However, convolution of these with the PSFs of IRIS obscures this detail and returns standard looking single peaks. By increasing the velocities by a factor of three, we recover asymmetric profiles even after this convolution. The properties recovered by xRMS appear adequate at first, but the line profiles chosen to fit these profiles do not satisfactorily represent the line profiles. This is likely due to the large line width of the simulated profiles.
Conclusions. Asymmetries can be introduced by multithread models with independent Doppler velocities. The large line width created by these models makes it difficult for traditional 1D forward modelling to find good matches. This may also demonstrate degeneracies in the solution recovered by single-species 1D modelling.

Solar prominence diagnostics from non-LTE modelling of Mgii h&k line profiles

Aaron W. **Peat**, Nicolas Labrosse, Brigitte Schmieder, Krzysztof Barczynski

A&A 653, A5 **2021**
https://arxiv.org/pdf/2106.10351.pdf
https://www.aanda.org/articles/aa/pdf/2021/09/aa40907-21.pdf
https://doi.org/10.1051/0004-6361/202140907

Aims: We investigate a new method to for obtaining the plasma parameters of solar prominences observed in the Mgii h&k spectral lines by comparing line profiles from the IRIS satellite to a bank of profiles computed with a one-dimensional non-local thermodynamic equilibrium (non-LTE) radiative transfer code.
Methods: Using a grid of 1007 one-dimensional non-LTE radiative transfer models we carry out this new method to match computed spectra to observed line profiles while accounting for line core shifts not present in the models. The prominence observations were carried out by the IRIS satellite on 19 April 2018.
Results: The prominence is very dynamic with many flows. The models are able to recover satisfactory matches in areas of the prominence where single line profiles are observed. We recover: mean temperatures of 6000 to 50,000K; mean pressures of 0.01 to 0.5 dyne cm−2; column masses of 3.7×10−8 to 5×10−4 g cm−2; a mean electron density of 7.3×108 to 1.8×1011 cm−3; and an ionisation degree nHII/nHI=0.03−4500. The highest values for the ionisation degree are found in areas where the line of sight crosses mostly plasma from the PCTR, correlating with high mean temperatures and correspondingly no Hα emission.
Conclusions: This new method naturally returns information on how closely the observed and computed profiles match, allowing the user to identify areas where no satisfactory match between models and observations can be obtained. Regions where satisfactory fits were found were more likely to contain a model encompassing a PCTR. The line core shift can also be recovered from this new method, and it shows a good qualitative match with that of the line core shift found by the quantile method. This demonstrates the effectiveness of the approach to line core shifts in the new method. **17-19 Apr 2018**

Interchange reconnection dynamics in a solar coronal pseudo-streamer⋆

T. **Pellegrin-Frachon**1, S. Masson1,2, É. Pariat1, P. F. Wyper3 and C. R. DeVore4

A&A 675, A55 (**2023**)
https://www.aanda.org/articles/aa/pdf/2023/07/aa45611-22.pdf

Context. The generation of the slow solar wind remains an open problem in heliophysics. One of the current theories among those aimed at explaining the injection of coronal plasma in the interplanetary medium is based on interchange reconnection. It assumes that the exchange of magnetic connectivity between closed and open fields allows the injection of coronal plasma in the interplanetary medium to travel along the newly reconnected open field. However, the exact mechanism underlying this effect is still poorly understood.
Aims. Our objective is to study this scenario in a particular magnetic structure of the solar corona: a pseudo-streamer. This topological structure lies at the interface between open and closed magnetic field and is thought to be involved in the generation of the slow solar wind.
Methods. We performed innovative 3D magnetohydrodynamic (MHD) simulations of the solar corona with a pseudo-streamer, using the Adaptively Refined MHD Solver (ARMS). By perturbing the quasi-steady ambient state with a simple photospheric, large-scale velocity flow, we were able to generate a complex dynamics of the open-and-closed boundary of the pseudo-streamer. We studied the evolution of the connectivity of numerous field lines to understand its precise dynamics.
Results. We witnessed different scenarios of opening of the magnetic field initially closed under the pseudo-streamer: one-step interchange reconnection dynamics, along with more complex scenarios, including a coupling between pseudo-streamer and helmet streamer, as well as back-and-forth reconnections between open and closed connectivity domains. Finally, our analysis revealed large-scale motions of a newly opened magnetic field high in the corona that may be explained by slipping reconnection.
Conclusions. By introducing a new analysis method for the magnetic connectivity evolution based on distinct closed-field domains, this study provides an understanding of the precise dynamics underway during the opening of a closed field, which enables the injection of closed-field, coronal plasma in the interplanetary medium. Further studies shall provide synthetic observations for these diverse outgoing flows, which could be measured by Parker Solar Probe and Solar Orbiter.

The role of asymmetries in coronal rain formation during thermal non-equilibrium cycles⋆

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A&A 658, A71 (**2022**)
https://www.aanda.org/articles/aa/pdf/2022/02/aa40477-21.pdf
https://doi.org/10.1051/0004-6361/202140477

Context. Thermal non-equilibrium (TNE) produces several observables that can be used to constrain the spatial and temporal distribution of solar coronal heating. Its manifestations include prominence formation, coronal rain, and long-period intensity pulsations in coronal loops. The recent observation of abundant periodic coronal rain associated with intensity pulsations allowed for these two phenomena to be unified as the result of TNE condensation and evaporation cycles. On the other hand, many observed intensity pulsation events show little to no coronal rain formation.
Aims. Our goal is to understand why some TNE cycles produce such abundant coronal rain, while others produce little to no rain.
Methods. We reconstructed the geometry of the periodic coronal rain event, using images from the Extreme Ultraviolet Imager (EUVI) onboard the Solar Terrestrial Relations Observatory (STEREO), and magnetograms from the Helioseismic and Magnetic Imager (HMI). We then performed 1D hydrodynamic simulations of this event for different heating parameters and variations of the loop geometry (9000 simulations in total). We compared the resulting behaviour to simulations of TNE cycles that do not produce coronal rain.
Results. Our simulations show that both prominences and TNE cycles (with and without coronal rain) can form within the same magnetic structure. We show that the formation of coronal rain during TNE cycles depends on the asymmetry of the loop and of the heating. Asymmetric loops are overall less likely to produce coronal rain, regardless of the heating. In symmetric loops, coronal rain forms when the heating is also symmetric. In asymmetric loops, rain forms only when the heating compensates for the asymmetry.

Spectroscopic detection of periodic plasma flows in loops undergoing thermal non-equilibrium

Gabriel **Pelouze**, Frédéric Auchère, Karine Bocchialini, Clara Froment, Susanna Parenti, Elie Soubrié
A&A 634, A54 **2019**
https://arxiv.org/pdf/1912.02538.pdf
https://www.aanda.org/articles/aa/pdf/2020/02/aa35872-19.pdf
Context: Long-period intensity pulsations were recently detected in the EUV emission of coronal loops, and have been attributed to cycles of plasma evaporation and condensation driven by thermal non-equilibrium (TNE). Numerical simulations that reproduce this phenomenon also predict the formation of periodic flows of plasma at coronal temperatures along some of the pulsating loops. Aims: In this paper, we aim at detecting these predicted flows of coronal-temperature plasma in pulsating loops. Methods: To this end, we use time series of spatially resolved spectra from the EUV imaging spectrometer (EIS) onboard Hinode, and track the evolution of the Doppler velocity in loops in which intensity pulsations have previously been detected in images of SDO/AIA. Results: We measure signatures of flows that are compatible with the simulations, but only in a fraction of the observed events. We demonstrate that this low detection rate can be explained by line of sight ambiguities, combined with instrumental limitations such as low signal to noise ratio or insufficient cadence.

An Unreported White-light Prominence

Matt **Penn** and Hugh Hudson
RHESSI Science Nuggets #270 March **2016**
1998-11-22 2005-09-07 (X17)

Chromospheric counterparts of solar transition region unresolved fine structure loops

Tiago M. D. **Pereira**, Luc Rouppe van der Voort, Viggo H. Hansteen, Bart De Pontieu
A&A **2018**
https://arxiv.org/pdf/1803.04415.pdf
Low-lying loops have been discovered at the solar limb in transition region temperatures by the Interface Region Imaging Spectrograph (IRIS). They do not appear to reach coronal temperatures, and it has been suggested that they are the long-predicted unresolved fine structures (UFS). These loops are dynamic and believed to be visible during both heating and cooling phases. Making use of coordinated observations between IRIS and the Swedish 1-m Solar Telescope, we study how these loops impact the solar chromosphere. We show for the first time that there is indeed a chromospheric signal of these loops, seen mostly in the form of strong Doppler shifts and a conspicuous lack of chromospheric heating. In addition, we find that several instances have a inverse Y-shaped jet just above the loop, suggesting that magnetic reconnection is driving these events. Our observations add several puzzling details to the current knowledge of these newly discovered structures; this new information must be considered in theoretical models. **17 June 2014**

Parallel plasma loops and the energization of the solar corona

Hardi **Peter**, Lakshmi Pradeep Chitta, Feng Chen, David I. Pontin, Amy R. Winebarger, Leon Golub, Sabrina L. Savage, Laurel A. Rachmeler, Ken Kobayashi, David H. Brooks, Jonathan W.

Cirtain, Bart De Pontieu, David E. McKenzie, Richard J. Morton, Paola Testa, Sanjiv K. Tiwari, Robert W. Walsh, Harry P. Warren
ApJ **933** 153 **2022**
https://arxiv.org/pdf/2205.15919.pdf
https://iopscience.iop.org/article/10.3847/1538-4357/ac7219/pdf
The outer atmosphere of the Sun is composed of plasma heated to temperatures well in excess of the visible surface. We investigate short cool and warm (<1 MK) loops seen in the core of an active region to address the role of field-line braiding in energising these structures. We report observations from the High-resolution Coronal imager (Hi-C) that have been acquired in a coordinated campaign with the Interface Region Imaging Spectrograph (IRIS). In the core of the active region, the 172 A band of Hi-C and the 1400 A channel of IRIS show plasma loops at different temperatures that run in parallel. There is a small but detectable spatial offset of less than 1 arcsec between the loops seen in the two bands. Most importantly, we do not see observational signatures that these loops might be twisted around each other. Considering the scenario of magnetic braiding, our observations of parallel loops imply that the stresses put into the magnetic field have to relax while the braiding is applied: the magnetic field never reaches a highly braided state on these length-scales comparable to the separation of the loops. This supports recent numerical 3D models of loop braiding in which the effective dissipation is sufficiently large that it keeps the magnetic field from getting highly twisted within a loop. **May 29, 2018**

Hot Explosions in the Cool Atmosphere of the Sun
H. **Peter**, H. Tian, W. Curdt, D. Schmit, D. Innes, B. De Pontieu, J. Lemen, A. Title, P. Boerner, N. Hurlburt, T. D. Tarbell, J. P. Wuelser, J. Martínez-Sykora, L. Kleint, L. Golub, S. McKillop, K. K. Reeves, S. Saar, P. Testa, C. Kankelborg, S. Jaeggli, M. Carlsson, V. Hansteen
Science, 346, 1255726 (**2014**),
http://arxiv.org/pdf/1410.5842v1.pdf
The solar atmosphere was traditionally represented with a simple one-dimensional model. Over the past few decades, this paradigm shifted for the chromosphere and corona that constitute the outer atmosphere, which is now considered a dynamic structured envelope. Recent observations by IRIS (Interface Region Imaging Spectrograph) reveal that it is difficult to determine what is up and down even in the cool 6000-K photosphere just above the solar surface: this region hosts pockets of hot plasma transiently heated to almost 100,000 K. The energy to heat and accelerate the plasma requires a considerable fraction of the energy from flares, the largest solar disruptions. These IRIS observations not only confirm that the photosphere is more complex than conventionally thought, but also provide insight into the energy conversion in the process of magnetic reconnection.
Movie S1 (http://www2.mps.mpg.de/data/outgoing/peter/papers/2014-iris-eb/fig1-movie.mov)

Structure of solar coronal loops: from miniature to large-scale ⋆
H. **Peter**1, S. Bingert1, J. A. Klimchuk2, C. de Forest3, J. W. Cirtain4, L. Golub5, A. R. Winebarger4, K. Kobayashi6 and K. E. Korreck
A&A 556, A104 (**2013**)
Aims. We use new data from the High-resolution Coronal Imager (Hi-C) with its unprecedented spatial resolution of the solar corona to investigate the structure of coronal loops down to 0.2″.
Methods. During a rocket flight, Hi-C provided images of the solar corona in a wavelength band around 193 Å that is dominated by emission from Fe xii showing plasma at temperatures around 1.5 MK. We analyze part of the Hi-C field-of-view to study the smallest coronal loops observed so far and search for the possible substructuring of larger loops.
Results. We find tiny 1.5 MK loop-like structures that we interpret as miniature coronal loops. Their coronal segments above the chromosphere have a length of only about 1 Mm and a thickness of less than 200 km. They could be interpreted as the coronal signature of small flux tubes breaking through the photosphere with a footpoint distance corresponding to the diameter of a cell of granulation. We find that loops that are longer than 50 Mm have diameters of about 2″ or 1.5 Mm, which is consistent with previous observations. However, Hi-C really resolves these loops with some 20 pixels across the loop. Even at this greatly improved spatial resolution, the large loops seem to have no visible substructure. Instead they show a smooth variation in cross-section.
Conclusions. That the large coronal loops do not show a substructure on the spatial scale of 0.1″ per pixel implies that either the densities and temperatures are smoothly varying across these loops or it places an upper limit on the diameter of the strands the loops might be composed of. We estimate that strands that compose the 2″ thick loop would have to be thinner than 15 km. The miniature loops we find for the first time pose a challenge to be properly understood through modeling.

Constant cross section of loops in the solar corona⋆
H. **Peter** and S. Bingert
A&A 548, A1 (**2012**)

Context. The corona of the Sun is dominated by emission from loop-like structures. When observed in X-ray or extreme ultraviolet emission, these million K hot coronal loops show a more or less constant cross section.
Aims. In this study we show how the interplay of heating, radiative cooling, and heat conduction in an expanding magnetic structure can explain the observed constant cross section.
Methods. We employ a three-dimensional magnetohydrodynamics (3D MHD) model of the corona. The heating of the coronal plasma is the result of braiding of the magnetic field lines through footpoint motions and subsequent dissipation of the induced currents. From the model we synthesize the coronal emission, which is directly comparable to observations from, e.g., the Atmospheric Imaging Assembly on the Solar Dynamics Observatory (AIA/SDO).
Results. We find that the synthesized observation of a coronal loop seen in the 3D data cube does match actually observed loops in count rate and that the cross section is roughly constant, as observed. The magnetic field in the loop is expanding and the plasma density is concentrated in this expanding loop; however, the temperature is not constant perpendicular to the plasma loop. The higher temperature in the upper outer parts of the loop is so high that this part of the loop is outside the contribution function of the respective emission line(s). In effect, the upper part of the plasma loop is not bright and thus the loop actually seen in coronal emission appears to have a constant width.
Conclusions. From this we can conclude that the underlying field-line-braiding heating mechanism provides the proper spatial and temporal distribution of the energy input into the corona – at least on the observable scales.

MHD modeling of coronal loops: injection of high-speed chromospheric flows

A. **Petralia**, F. Reale, S. Orlando, J. A. Klimchuk
E-print, May **2014**; A&A, 567, A70, **2014**
http://arxiv.org/pdf/1405.2198v1.pdf
Observations reveal a correspondence between chromospheric type II spicules and bright upwardly moving fronts in the corona observed in the EUV band. However, theoretical considerations suggest that these flows are unlikely to be the main source of heating in coronal magnetic loops. We investigate the propagation of high-speed chromospheric flows into coronal magnetic flux tubes, and the possible production of emission in the EUV band. We simulate the propagation of a dense 10^4 K chromospheric jet upwards along a coronal loop, by means of a 2-D cylindrical MHD model, including gravity, radiative losses, thermal conduction and magnetic induction. The jet propagates in a complete atmosphere including the chromosphere and a tenuous cool (∼0.8 MK) corona, linked through a steep transition region. In our reference model, the jet's initial speed is 70 km/s, its initial density is 10^11 cm^−3, and the ambient uniform magnetic field is 10 G. We explore also other values of jet speed and density in 1-D, and of magnetic field in 2-D, and the jet propagation in a hotter (∼1.5 MK) background loop. While the initial speed of the jet does not allow it to reach the loop apex, a hot shock front develops ahead of it and travels to the other extreme of the loop. The shock front compresses the coronal plasma and heats it to about 10^6 K. As a result, a bright moving front becomes visible in the 171 A channel of the SDO/AIA mission. This result generally applies to all the other explored cases, except for the propagation in the hotter loop. For a cool, low-density initial coronal loop, the post-shock plasma ahead of upward chromospheric flows might explain at least part of the observed correspondence between type II spicules and EUV emission excess.

High frequency decayless waves with significant energy in Solar Orbiter/EUI observations

Elena **Petrova**, Norbert Magyar, Tom Van Doorsselaere, David Berghmans
ApJ **2022**
https://arxiv.org/pdf/2205.05319.pdf
High-frequency wave phenomena present a great deal of interest as one of the possible candidates to contribute to the energy input required to heat the corona as a part of the AC heating theory. However, the resolution of imaging instruments up until the Solar Orbiter have made it impossible to resolve the necessary time and spatial scales. The present paper reports on high-frequency transverse motions in a small loop located in a quiet Sun region of the corona. The oscillations were observed with the HRIEUV telescope (17.4 nm) of the EUI instrument onboard the Solar Orbiter. We detect two transverse oscillations in short loops with lengths of 4.5 Mm and 11 Mm. The shorter loop displays an oscillation with a 14 s period and the longer a 30 s period. Despite the high resolution, no definitive identification as propagating or standing waves is possible. The velocity amplitudes are found to be equal to 72 km/s and 125 km/s, respectively, for the shorter and longer loop. Based on that, we also estimated the values of the energy flux contained in the loops - the energy flux of the 14 s oscillation is 1.9 kW m^-2 and of the 30 s oscillation it is 6.5 kW m^-2 . While these oscillations have been observed in the Quiet Sun, their energy fluxes are of the same order as the energy input required to heat the active solar corona. Numerical simulations were performed in order to reproduce the observed oscillations. The correspondence of the numerical results to the observations provide support to the energy content estimates for the observations. Such high energy densities have not yet been observed in decayless coronal waves, and this is promising for coronal heating models based on wave damping. **2021 February 23**

Non-reflective Propagation of Kink Pulses in Magnetic Waveguides in the Solar Atmosphere

N. S. **Petrukhin**, M. S. Ruderman, E. Pelinovsky

Solar Phys. **2015**

We study the propagation of pulses of kink waves in magnetic-flux tubes. We use the thin-tube approximation and assume that the dependence of the phase speed on the distance along the tube is either linear or quadratic. In this case, the wave equation describing the propagation of kink waves reduces to the Klein–Gordon equation with constant coefficients. We present the general solution of the initial value–boundary value problem for this equation. Using this solution, we study the general properties of non-reflective pulse propagation. Then we apply the general results to the kink-pulse propagation in coronal magnetic loops. In particular, we suggest an alternative mechanism of small-amplitude decay-less kink oscillations in coronal loops.

Coronal Mass Ejections from Magnetic Systems Encompassing Filament Channels Without Filaments

Alexei A. **Pevtsov**, Olga Panasenco and Sara F. Martin

Solar Physics, Volume 277, Number 1, 185-201, **2012, File**

Well-developed filament channels may be present in the solar atmosphere even when there is no trace of filament material inside them. Such magnetic systems with filament channels without filaments can result in coronal mass ejections that might appear to have no corresponding solar surface source regions. In this case study, we analyze CMEs on **9 August 2001 and 3 March 2011** and trace their origins to magnetic systems with filament channels containing no obvious filament material on the days around the eruptions.

PROMINENCE SEISMOLOGY: WAVELET ANALYSIS OF FILAMENT OSCILLATIONS

Bala´zs **Pinte´r**, Rekha Jain, Durgesh Tripathi, Hiroaki Isobe

The Astrophysical Journal, 680:1560-1568, 2008

http://www.journals.uchicago.edu/doi/pdf/10.1086/588273

The temporal and spatial behavior of a large-amplitude filament oscillation is investigated using wavelet analysis. The extreme-ultraviolet (EUV) images of the phenomenon, which occurred on 2002 October 15, were taken from the EUV Imaging Telescope on board the Solar and Heliospheric Observatory (SOHO). The wavelet spectra, extracted from the intensity data, show that the filament oscillates as a rigid body, with a period of about 2.5-2.6 hr which is almost constant along the filament. The period slowly decreases with time until the filament erupts. No clear sign of the eruption is found in the wavelet spectrum prior to the eruption, that followed the filament oscillation. The axial component of the magnetic field is estimated between 1 and 5 G, which is believed to be reasonable for a polar crown filament of this kind.

Soft X-ray emission in kink-unstable coronal loops

R. F. **Pinto**, N. Vilmer, A. S. Brun

A&A, **2015**

http://arxiv.org/pdf/1401.0916v2.pdf

Context. Solar flares are associated with intense soft X-ray emission generated by the hot flaring plasma in coronal magnetic loops. Kink unstable twisted flux-ropes provide a source of magnetic energy which can be released impulsively and account for the heating of the plasma in flares. Aims. We investigate the temporal, spectral and spatial evolution of the properties of the thermal continuum X-ray emission produced in such kink-unstable magnetic flux-ropes and we discuss the results of the simulations with respect to solar flare observations. Methods. We compute the temporal evolution of the thermal X-ray emission in kink-unstable coronal loops based on a series of MHD numerical simulations. The numerical setup used consists of a highly twisted loop embedded in a region of uniform and untwisted background coronal magnetic field. We let the kink instability develop, compute the evolution of the plasma properties in the loop (density, temperature) without accounting for mass exchange with the chromosphere. We then deduce the X-ray emission properties of the plasma during the whole flaring episode. Results. During the initial (linear) phase of the instability plasma heating is mostly adiabatic (due to compression). Ohmic diffusion takes over as the instability saturates, leading to strong and impulsive heating (up to more than 20 MK), to a quick enhancement of X-ray emission and to the hardening of the thermal X-ray spectrum. The temperature distribution of the plasma becomes broad, with the emission measure depending strongly on temperature. Significant emission measures arise for plasma at temperatures higher than 9 MK. The magnetic flux-rope then relaxes progressively towards a lower energy state as it reconnects with the background flux. The loop plasma suffers smaller sporadic heating events but cools down globally by thermal conduction. The total thermal X-ray emission slowly fades away during this phase, and the high temperature component of emission measure distribution converges to the power-law distribution EM ∝ T^(−4.2). The amount of twist deduced directly from the X-ray emission patterns is considerably lower than the maximum magnetic twist in the simulated flux-ropes.

Coronal kink oscillations and photospheric driving: combining SolO/EUI and SST/CRISP high-resolution observations

Nicolas **Poirier** (1 and 2), Sanja Danilovic (3), Petra Kohutova (1 and 2), Carlos J. Díaz Baso (1 and 2), Luc Rouppe van der Voort (1 and 2), Daniele Calchetti (4), Jonas Sinjan (4)
A&A **2024**
https://arxiv.org/pdf/2412.14805
The driving and excitation mechanisms of decay-less kink oscillations in coronal loops remain under debate. We aim to quantify and provide simple observational constraints on the photospheric driving of oscillating coronal loops in a few typical active region configurations: sunspot, plage, pores and enhanced-network regions. We then aim to investigate the possible interplay between photospheric driving and properties of kink oscillations in connected coronal loops. We analyse two unique datasets of the corona and photosphere taken at a high resolution during the first coordinated observation campaign between Solar Orbiter and the Swedish 1-m Solar Telescope (SST). A local correlation tracking method is applied on the SST/CRISP data to quantify the photospheric motions at the base of coronal loops. The same loops are then analysed in the corona by exploiting data from the Extreme Ultraviolet Imager on Solar Orbiter, and by using a wavelet analysis to characterize the kink oscillations. Each photospheric region shows dynamics with an overall increase in strength going from pore, plage, enhanced-network to sunspot regions. Differences are also seen in the kink-mode amplitudes of the corresponding coronal loops. This suggests the photosphere is involved in the driving of coronal kink oscillations. However, the few samples available does not allow to further establish the excitation mechanism yet. Despite oscillating coronal loops being anchored in seemingly "static" strong magnetic field regions as seen from coronal EUV observations, photospheric observations provide evidence for a continuous and significant driving at their base. The precise connection between photospheric driving and coronal kink oscillations remains to be further investigated. This study finally provides critical constraints on photospheric driving that can be tested in existing numerical models of coronal loops. **19-20 Oct 2023**

Detailed imaging of coronal rays with Parker Solar Probe

Nicolas **Poirier**, Athanasios Kouloumvakos, Alexis P. Rouillard, Rui F. Pinto, Angelos Vourlidas, ...
ApJ **2020**
https://arxiv.org/pdf/1912.09345.pdf
The Wide-field Imager for Solar PRobe (WISPR) obtained the first high-resolution images of coronal rays at heights below 15 R⊙ when **Parker Solar Probe** (PSP) was located inside 0.25 AU during the first encounter. We exploit these remarkable images to reveal the structure of coronal rays at scales that are not easily discernible in images taken from near 1 AU. To analyze and interpret WISPR observations which evolve rapidly both radially and longitudinally, we construct a latitude versus time map using full WISPR dataset from the first encounter. From the exploitation of this map and also from sequential WISPR images we show the presence of multiple sub-structures inside streamers and pseudo-streamers. WISPR unveils the fine-scale structure of the densest part of streamer rays that we identify as the solar origin of the heliospheric plasma sheet typically measured in situ in the solar wind. We exploit 3-D magneto-hydrodynamic (MHD) models and we construct synthetic white-light images to study the origin of the coronal structures observed by WISPR. Overall, including the effect of the spacecraft relative motion towards the individual coronal structures we can interpret several observed features by WISPR. Moreover, we relate some coronal rays to folds in the heliospheric current sheet that are unresolved from 1 AU. Other rays appear to form as a result of the inherently inhomogeneous distribution of open magnetic flux tubes. **2018.11.01-06**

Investigating the Response of Loop Plasma to Nanoflare Heating Using RADYN Simulations

V. **Polito**1, P. Testa1, J. Allred2, B. De Pontieu3,4,5, M. Carlsson4,5, T. M. D. Pereira4,5,Milan Gošić3,6, and Fabio Reale7
2018 ApJ 856 178
http://sci-hub.tw/http://iopscience.iop.org/0004-637X/856/2/178/
We present the results of 1D hydrodynamic simulations of coronal loops that are subject to nanoflares, caused by either in situ thermal heating or nonthermal electron (NTE) beams. The synthesized intensity and Doppler shifts can be directly compared with Interface Region Imaging Spectrograph (IRIS) and Atmospheric Imaging Assembly (AIA) observations of rapid variability in the transition region (TR) of coronal loops, associated with transient coronal heating. We find that NTEs with high enough low-energy cutoff (E_C) deposit energy in the lower TR and chromosphere, causing blueshifts (up to ~20 km s−1) in the IRIS Si iv lines, which thermal conduction cannot reproduce. The E_C threshold value for the blueshifts depends on the total energy of the events (≈5 keV for 1024 erg, up to 15 keV for 1025 erg). The observed footpoint emission intensity and flows, combined with the simulations,

can provide constraints on both the energy of the heating event and E_C. The response of the loop plasma to nanoflares depends crucially on the electron density: significant Si iv intensity enhancements and flows are observed only for initially low-density loops (<109 cm−3). This provides a possible explanation of the relative scarcity of observations of significant moss variability. While the TR response to single heating episodes can be clearly observed, the predicted coronal emission (AIA 94 Å) for single strands is below current detectability and can only be observed when several strands are heated closely in time. Finally, we show that the analysis of the IRIS Mg ii chromospheric lines can help further constrain the properties of the heating mechanisms.

Non-thermal line broadening due to braiding-induced turbulence in solar coronal loops

D. I. **Pontin**1,2, H. Peter3 and L. P. Chitta3

A&A 639, A21 (**2020**)

https://www.aanda.org/articles/aa/pdf/2020/07/aa37582-20.pdf

Aims. Emission line profiles from solar coronal loops exhibit properties that are unexplained by current models. We investigate the non-thermal broadening associated with plasma heating in coronal loops that is induced by magnetic field line braiding.

Methods. We describe the coronal loop by a 3D magnetohydrodynamic model of the turbulent decay of an initially-braided magnetic field. From this, we synthesised the Fe XII line at 193 Å that forms around 1.5 MK.

Results. The key features of current observations of extreme ultraviolet (UV) lines from the corona are reproduced in the synthesised spectra: (i) Typical non-thermal widths range from 15 to 20 km s−1. (ii) The widths are approximately independent of the size of the field of view. (iii) There is a correlation between the line intensity and non-thermal broadening. (iv) Spectra are found to be non-Gaussian, with enhanced power in the wings of the order of 10–20%.

Conclusions. Our model provides an explanation that self-consistently connects the heating process to the observed non-thermal line broadening. The non-Gaussian nature of the spectra is a consequence of the non-Gaussian nature of the underlying velocity fluctuations, which is interpreted as a signature of intermittency in the turbulence.

Observable Signatures of Energy Release in Braided Coronal Loops

D. I. **Pontin**1, M. Janvier2, S. K. Tiwari3,4, K. Galsgaard5, A. R. Winebarger3, and J. W. Cirtain3

2017 ApJ 837 108

http://c.brightcove.com/article/10.3847/1538-4357/aa5ff9/pdf

We examine the turbulent relaxation of solar coronal loops containing non-trivial field line braiding. Such field line tangling in the corona has long been postulated in the context of coronal heating models. We focus on the observational signatures of energy release in such braided magnetic structures using MHD simulations and forward modeling tools. The aim is to answer the following question: if energy release occurs in a coronal loop containing braided magnetic flux, should we expect a clearly observable signature in emissions? We demonstrate that the presence of braided magnetic field lines does not guarantee a braided appearance to the observed intensities. Observed intensities may—but need not necessarily—reveal the underlying braided nature of the magnetic field, depending on the degree and pattern of the field line tangling within the loop. However, in all cases considered, the evolution of the braided loop is accompanied by localized heating regions as the loop relaxes. Factors that may influence the observational signatures are discussed. Recent high-resolution observations from Hi-C have claimed the first direct evidence of braided magnetic fields in the corona. Here we show that both the Hi-C data and some of our simulations give the appearance of braiding at a range of scales.

The Structure of Current Layers and Degree of Field-line Braiding in Coronal Loops

D. I. **Pontin** and G. Hornig

2015 ApJ 805 47

One proposed resolution to the long-standing problem of solar coronal heating involves the buildup of magnetic energy in the corona due to turbulent motions at the photosphere that braid the coronal field, and the subsequent release of this energy via magnetic reconnection. In this paper the ideal relaxation of braided magnetic fields modeling solar coronal loops is followed. A sequence of loops with increasing braid complexity is considered, with the aim of understanding how this complexity influences the development of small scales in the magnetic field, and thus the energy available for heating. It is demonstrated that the ideally accessible force-free equilibrium for these braided fields contains current layers of finite thickness. It is further shown that for any such braided field, if a force-free equilibrium exists then it should contain current layers whose thickness is determined by length scales in the field-line mapping. The thickness and intensity of the current layers follow scaling laws, and this allows us to extrapolate beyond the numerically accessible parameter regime and to place an upper bound on the braid complexity possible at coronal plasma parameters. At this threshold level the braided loop contains 1026–10^{28} ergs of available free magnetic energy, more than sufficient for a large nanoflare.

Role of compressive viscosity and thermal conductivity on the damping of slow waves in the coronal loops with and without heating cooling imbalance
Abhinav **Prasad**, A.K. Srivastava, T.J. Wang
Solar Phys. **297**, Article number: 5 **2022**
https://arxiv.org/pdf/2011.14519.pdf
https://link.springer.com/content/pdf/10.1007/s11207-021-01940-z.pdf
https://doi.org/10.1007/s11207-021-01940-z
In the present paper, we derive a new dispersion relation for slow magnetoacoustic waves invoking the effect of thermal conductivity, compressive viscosity, radiation and unknown heating term along with the consideration of heating cooling imbalance from linearized MHD equations. We solve the general dispersion relation to understand role of compressive viscosity and thermal conductivity in damping of the slow waves in coronal loops with and without heating cooling imbalance. We have analyzed wave damping for the range of loop length L=50-500 Mm, temperature T=5-30 MK, and density ρ=10−11-10−9 kg m−3. It was found that inclusion of compressive viscosity along with thermal conductivity significantly enhances the damping of fundamental mode oscillations in shorter (e.g., L=50 Mm) and super-hot (T>10 MK) loops. However, role of the viscosity in damping is insignificant in longer (e.g., L=500 Mm) and hot loops (T≤10 MK) where, instead, thermal conductivity along with the presence of heating cooling imbalance plays a dominant role. For the shorter loops at the super-hot regime of the temperature, increment in loop density substantially enhances damping of the fundamental modes due to thermal conductivity when the viscosity is absent, however, when the compressive viscosity is added the increase in density substantially weakens damping. Thermal conductivity alone is found to play a dominant role in longer loops at lower temperatures (T≤10 MK), while compressive viscosity dominates in damping at super-hot temperatures (T>10 MK) in shorter loops. The predicted scaling law between damping time (τ) and wave period (P) is found to better match to observed SUMER oscillations when heating cooling imbalance is taken into account in addition to thermal conductivity and compressive viscosity for the damping of the fundamental slow mode oscillations.

The Temperature-dependent Damping of Propagating Slow Magnetoacoustic Waves
S. Krishna **Prasad**, D. B. Jess, T. Van Doorsselaere
Frontiers in Astronomy and Space Sciences **2019**
https://arxiv.org/pdf/1908.00384.pdf
The rapid damping of slow magnetoacoustic waves in the solar corona has been extensively studied in previous years. Most studies suggest that thermal conduction is a dominant contributor to this damping, albeit with a few exceptions. Employing extreme-ultraviolet (EUV) imaging data from SDO/AIA, we measure the damping lengths of propagating slow magnetoacoustic waves observed in several fan-like loop structures using two independent methods. The dependence of the damping length on temperature has been studied for the first time. The results do not indicate any apparent decrease in damping length with temperature, which is in contrast to the existing viewpoint. Comparing with the corresponding theoretical values calculated from damping due to thermal conduction, it is inferred that thermal conduction is suppressed in hotter loops. An alternative interpretation that suggests thermal conduction is not the dominant damping mechanism, even for short period waves in warm active region loops, is also presented. **216-06-16**

Unravelling the components of a multi-thermal coronal loop using magnetohydrodynamic seismology
S. Krishna **Prasad**, D. B. Jess, J. A. Klimchuk, D. Banerjee
ApJ **834** 103 **2017**
https://arxiv.org/pdf/1611.04011v1.pdf
Coronal loops, constituting the basic building blocks of the active Sun, serve as primary targets to help understand the mechanisms responsible for maintaining multi-million Kelvin temperatures in the solar and stellar coronae. Despite significant advances in observations and theory, our knowledge on the fundamental properties of these structures is limited. Here, we present unprecedented observations of accelerating slow magnetoacoustic waves along a coronal loop that show differential propagation speeds in two distinct temperature channels, revealing the multi-stranded and multi-thermal nature of the loop. Utilizing the observed speeds and employing nonlinear force-free magnetic field extrapolations, we derive the actual temperature variation along the loop in both channels, and thus are able to resolve two individual components of the multi-thermal loop for the first time. The obtained positive temperature gradients indicate uniform heating along the loop, rather than isolated footpoint heating. **10 December 2011**

Frequency-dependent Damping in Propagating Slow Magneto-acoustic Waves
S. Krishna **Prasad**1, D. Banerjee1, and T. Van Doorsselaere
2014 ApJ 789 118

Propagating slow magneto-acoustic waves are often observed in polar plumes and active region fan loops. The observed periodicities of these waves range from a few minutes to a few tens of minutes and their amplitudes were found to decay rapidly as they travel along the supporting structure. Previously, thermal conduction, compressive viscosity, radiation, density stratification, and area divergence were identified to be some of the causes for change in the slow wave amplitude. Our recent studies indicate that the observed damping in these waves is frequency-dependent. We used imaging data from the Solar Dynamics Observatory/Atmospheric Imaging Assembly to study this dependence in detail and for the first time via observations we attempted to deduce a quantitative relation between the damping length and frequency of these oscillations. We developed a new analysis method to obtain this relation. The observed frequency dependence does not seem to agree with the current linear wave theory and it was found that the waves observed in the polar regions show a different dependence from those observed in the on-disk loop structures despite the similarity in their properties.

Oscillations in Active Region Fan Loops: Observations from EIS/Hinode and AIA/SDO

S. Krishna **Prasad**, D. Banerjee, Jagdev Singh

Solar Physics, November **2012**, Volume 281, Issue 1, pp 67-85

Active region fan loops in AR 11076 were studied, in search of oscillations, using high cadence spectroscopic observations from Extreme-ultraviolet Imaging Spectrometer (EIS) on board Hinode combined with imaging sequences from the Atmospheric Imaging Assembly (AIA) on board Solar Dynamics Observatory (SDO). Spectra from EIS were analyzed in two spectral windows, Fe xii 195.12 Å and Fe xiii 202.04 Å along with the images from AIA in the 171 Å and 193 Å channels. We find short (< 3 min) and long (≈ 9 min) periods at two different locations. Shorter periods show oscillations in all three line parameters and the longer ones only in intensity and Doppler shift but not in line width. Line profiles at both these locations do not show any visible blue-shifted component and can be fitted well with a single Gaussian function along with a polynomial background. Results using co-spatial and co-temporal data from AIA/SDO do not show any significant peaks corresponding to shorter periods, but longer periods are clearly observed in both 171 Å and 193 Å channels. Space-time analysis in these fan loops using images from AIA/SDO show alternate slanted ridges of positive slope, indicative of outward propagating disturbances. The apparent propagation speeds were estimated to be 83.5±1.8 km s−1 and 100.5±4.2 km s−1, respectively, in the 171 Å and 193 Å channels. Observed short-period oscillations are suggested to be caused by the simultaneous presence of more than one MHD mode whereas the long periods are suggested to be signatures of slow magneto-acoustic waves. In case of shorter periods, the amplitude of the oscillation is found to be higher in EIS lines with relatively higher temperature of formation. Longer periods, when observed from AIA, show a decrease of amplitude in hotter AIA channels, which might indicate damping due to thermal conduction owing to their acoustic nature. **5 June 2010**

Forward Modelling of a Brightening Observed by AIA

D. J. **Price**, Y. Taroyan, D. E. Innes, S. J. Bradshaw

Solar Phys. Volume 290, Issue 7, pp 1931-1945, **2015**

A comprehensive understanding of the different transient events is necessary for any eventual solution of the coronal heating problem. We present a cold loop whose heating caused a short-lived small-scale brightening that was observed by AIA. The loop was simulated using an adaptive hydrodynamic radiation code that considers the ions to be in a state of non-equilibrium. Forward modelling was used to create synthetic AIA intensity plots, which were tested against the observational data to confirm the simulated properties of the event. The hydrodynamic properties of the loop were determined. We found that the energy released by the heating event is within the canonical energy range of a nanoflare.

Physics of outflows near solar active regions

D. J. **Price** and Y. Taroyan

Ann. Geophys., 33, 25-29, **2015**

http://www.ann-geophys.net/33/25/2015/angeo-33-25-2015.pdf

Hinode/EIS observations have revealed outflows near active regions which remain unexplained. An outflow region observed by the EUV Imaging Spectrometer (EIS) that appears slightly redshifted at low temperatures and blueshifted at higher temperatures is presented. We conduct simulations and use those to create synthetic line profiles in order to replicate the observed line profiles of an apparent open structure. The results of the forward modelling support a scenario whereby long loops consisting of multiple strands undergo a cyclical process of heating and cooling on timescales of approximately 80 min. **20 February 2007**

Detection of Solar Filaments using Suncharts from Kodaikanal Solar Observatory Archive Employing a Clustering Approach

Aditya **Priyadarshi**, Manjunath Hegde, Bibhuti Kumar Jha, Subhamoy Chatterjee, Sudip Mandal, Mayukh Chowdhury, Dipankar Banerjee

ApJ **943** 140 **2023**

https://arxiv.org/pdf/2212.12176.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/acaefb/pdf

With over 100 years of solar observations, the Kodaikanal Solar Observatory (KoSO) is a one-of-a-kind solar data repository in the world. Among its many data catalogues, the `suncharts' at KoSO are of particular interest. These Suncharts (1904-2020) are coloured drawings of different solar features, such as sunspots, plages, filaments, and prominences, made on papers with a Stonyhurst latitude-longitude grid etched on them. In this paper, we analyze this unique data by first digitizing each suncharts using an industry-standard scanner and saving those digital images in high-resolution `.tif' format. We then examine the Cycle~19 and Cycle~20 data (two of the strongest cycles of the last century) with the aim of detecting filaments. To this end, we employed `k-means clustering' method and obtained different filament parameters such as position, tilt angle, length, and area. Our results show that filament length (and area) increases with latitude and the pole-ward migration is clearly dominated by a particular tilt sign. Lastly, we cross-verified our findings with results from KoSO digitized photographic plate database for the overlapping time period and obtained a good agreement between them. This work, acting as a proof-of-the-concept, will kick-start new efforts to effectively use the entire hand-drawn series of multi-feature, full-disk solar data and enable researchers to extract new sciences, such as the generation of pseudo magnetograms for the last 100 years.

Excitation of flare-induced waves in coronal loops and the effects of radiative cooling

Elena **Provornikova**, Leon Ofman, Tongjiang Wang

Advances in Space Research Volume 61, Issue 2, 15 January 2018, Pages 645-654

https://arxiv.org/pdf/1706.04219.pdf

EUV imaging observations from several space missions (SOHO/EIT, TRACE, and SDO/AIA) have revealed a presence of propagating intensity disturbances in solar coronal loops. These disturbances are typically interpreted as slow magnetoacoustic waves. Recent spectroscopic observations with Hinode/EIS of active region loops, however, revealed that the propagating intensity disturbances are associated with intermittent plasma upflows (or jets) at the footpoints which are presumably generated by magnetic reconnection. For this reason, whether these disturbances are waves or periodic flows is still being studied. This study is aimed at understanding the physical properties of observed disturbances by investigating the excitation of waves by hot plasma injections from below and the evolution of flows and wave propagation along the loop. We expand our previous studies based on isothermal 3D MHD models of active region to a more realistic model that includes full energy equation accounting for effects of radiative losses. Computations are initialized with an equilibrium state of a model active region using potential (dipole) magnetic field, gravitationally stratified density and temperature obtained from polytropic equation of state. We model an impulsive injection of hot plasma into the steady plasma outflow along the loops of different temperature, warm (~1 MK) and hot (~6 MK). The simulations show that hot jets launched at the coronal base excite slow magnetoacoustic waves that propagate along the loops to the high corona, while the injected hot flows decelerates rapidly with heights. The simulated results support that the observed coronal disturbances are mainly the wave features. We also find that the effect of radiative cooling on the damping of slow-mode waves in 1-6 MK coronal loops is small, in agreement with the previous conclusion based on 1D MHD models.

Observations of a Hybrid Double-Streamer/Pseudostreamer in the Solar Corona

Rachmeler, L. A., Platten, S. J., Bethge, C. W., Seaton, D. B., Yeates, A. R.

E-print, April **2014; 2014** ApJ 787 L3

http://arxiv.org/pdf/1312.3153v2.pdf

We report on the first observation of a single hybrid magnetic structure that contains both a pseudostreamer and a double helmet streamer. This structure was originally observed by the SWAP instrument aboard the PROBA2 satellite between **5 and 10~May~2013**. It consists of a pair of filament channels near the south pole of the sun. On the western edge of the structure, the magnetic morphology above the filaments is that of a side-by-side double helmet streamer, with open field between the two channels. On the eastern edge, the magnetic morphology is that of a coronal pseudostreamer without the central open field. We investigated this structure with multiple observations and modelling techniques. We describe the topology and dynamic consequences of such a unified structure.

Polarimetric Properties of Flux Ropes and Sheared Arcades in Coronal Prominence Cavities

L. A. **Rachmeler**, S. E. Gibson, J. B. Dove, C. R. DeVore, Y. Fan

Solar Phys (**2013**) 288:617–636

The coronal magnetic field is the primary driver of solar dynamic events. Linear and circular polarization signals of certain infrared coronal emission lines contain information about the magnetic field, and to access this information either a forward or an inversion method must be used. We study three coronal magnetic configurations that are applicable to polar-crown filament cavities by doing forward calculations to produce synthetic polarization data. We analyze these forward data to determine the distinguishing characteristics of each model. We conclude that it is possible to distinguish between cylindrical flux ropes, spheromak flux ropes, and sheared arcades using coronal polarization measurements. If one of these models is found to be consistent with observational measurements, it will mean positive identification of the magnetic morphology that surrounds certain quiescent filaments, which will lead to a better understanding of how they form and why they erupt.

Observations of apparent superslow wave propagation in solar prominences

J.O. **Raes**1 , T. Van Doorsselaere1 , M. Baes2 , and A.N. Wright3

A&A **2018**

https://arxiv.org/pdf/1706.04340.pdf

Phase mixing of standing continuum Alfv\'en waves and/or continuum slow waves in atmospheric magnetic structures such as coronal arcades can create the apparent effect of a wave propagating across the magnetic field. We observe a prominence with SDO/AIA on **2015 March 15** and find the presence of oscillatory motion. We aim to demonstrate that interpreting this motion as a magneto hydrodynamic (MHD) wave is faulty. We also connect the decrease of the apparent velocity over time with the phase mixing process, which depends on the curvature of the magnetic field lines. By measuring the displacement of the prominence at different heights to calculate the apparent velocity, we show that the propagation slows down over time, in accordance with the theoretical work of Kaneko et al. We also show that this propagation speed drops below what is to be expected for even slow MHD waves for those circumstances. We use a modified Kippenhahn-Schl\"uter prominence model to calculate the curvature of the magnetic field and fit our observations accordingly. Measuring three of the apparent waves, we get apparent velocities of 14, 8, and 4 km/s. Fitting a simple model for the magnetic field configuration, we obtain that the filament is located 103 Mm below the magnetic centre. We also obtain that the scale of the magnetic field strength in the vertical direction plays no role in the concept of apparent superslow waves and that the moment of excitation of the waves happened roughly one oscillation period before the end of the eruption that excited the oscillation. Some of the observed phase velocities are lower than expected for slow modes for the circumstances, showing that they rather fit with the concept of apparent superslow propagation. A fit with our magnetic field model allows for inferring the magnetic geometry of the prominence.

Stereoscopic observations reveal coherent morphology and evolution of solar coronal loops

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A&A **2024**

https://arxiv.org/pdf/2411.16943

Coronal loops generally trace magnetic lines of force in the upper solar atmosphere. Understanding the loop morphology and its temporal evolution has implications for coronal heating models that rely on plasma heating due to reconnection at current sheets. Simultaneous observations of coronal loops from multiple vantage points are best suited for this purpose. Here, we report a stereoscopic analysis of coronal loops in an active region based on observations from the Extreme Ultraviolet Imager on board the Solar Orbiter Spacecraft and the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory. Our stereoscopic analysis reveals that coronal loops have nearly circular cross-sectional widths and that they exhibit temporally coherent intensity variations along their lengths on timescales of around 30\,minutes. Results suggest that coronal loops can be best represented as three-dimensional monolithic or coherent plasma bundles that outline magnetic field lines. Therefore, at least on the scales resolved by Solar Orbiter, it is unlikely that coronal loops are manifestations of emission from the randomly aligned wrinkles in two-dimensional plasma sheets along the line-of-sight as proposed in the `coronal veil' hypothesis. **April 7, 2023**

Coronal loop physical parameters from the analysis of multiple observed transverse oscillations

A. Asensio **Ramos**1,2 and I. Arregui

A&A 554, A7 (**2013**)

The analysis of quickly damped transverse oscillations of solar coronal loops using magneto-hydrodynamic seismology allows us to infer physical parameters that are difficult to measure otherwise. Under the assumption that such damped oscillations are due to the resonant conversion of global modes into Alfvén oscillations of the tube surface, we carry out a global seismological analysis of a large set of coronal loops. A Bayesian hierarchical method is used to obtain distributions for coronal loop physical parameters by means of a global analysis of a large number of observations. The resulting distributions summarize global information and constitute data-favoured information that can be used for the inversion of individual events. The results strongly suggest that internal Alfvén travel times along the loop are longer than 100 s and shorter than 540 s with 95% probability. Likewise, the density contrast between the loop interior and the surrounding is larger than 2.3 and below 6.9 with 95% probability.

Signatures of red-shifted footpoints in the quiescent coronal loop system

Yamini K. **Rao**, Abhishek K. Srivastava, Pradeep Kayshap, Bhola N. Dwivedi

Annales Geophysicae **2019**

https://arxiv.org/pdf/1908.02865.pdf

We observed quiescent coronal loops using multi-wavelength observations from the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO) on **2016 April 13**. The flows at the footpoints of such loop systems are studied using spectral data from Interface Region Imaging Spectrograph (IRIS). The Doppler velocity distributions at the footpoints lying in the moss region show the negligible or small flows at Ni I, Mg II k3 and C II line corresponding to upper photospheric and chromospheric emissions. Significant red-shifts (downflows) ranging from (1 to 7) km/s are observed at Si IV (1393.78 A; log(T/K) = 4.8) which is found to be consistent with the existing results regarding dynamical loop systems and moss regions. Such downflows agree well with the impulsive heating mechanism reported earlier.

Plasma flows in the cool loop systems

Yamini K. **Rao**, Abhishek K. Srivastava, Pradeep Kayshap, Klaus Wilhelm, Bhola N. Dwivedi

ApJ **874** 56 **2019**

https://arxiv.org/pdf/1902.05237.pdf

https://doi.org/10.3847/1538-4357/ab06f5

We study the dynamics of low-lying cool loop systems for three datasets as observed by the Interface Region Imaging Spectrograph (IRIS). Radiances, Doppler shifts and line widths are investigated in and around observed cool loop systems using various spectral lines formed between the photosphere and transition region (TR). Footpoints of the loop threads are either dominated by blueshifts or redshifts. The co-spatial variation of velocity above the blue-shifted footpoints of various loop threads shows a transition from very small upflow velocities ranging from (-1 to +1) km/s in the Mg\,{\sc ii} k line (2796.20~\AA; formation temperature: log (T/K) = 4.0) to the high upflow velocities from (-10 to -20) km/s in Si\,{\sc iv}. Thus, the transition of the plasma flows from red-shift (downflows) to the blue-shift (upflows) is observed above the footpoints of these loop systems in the spectral line C\,{\sc ii} (1334.53~\AA; \log (T/K) = 4.3) lying between Mg\,{\sc ii} k and Si\,{\sc iv} (1402.77~\AA; log (T / K) = 4.8). This flow inversion is consistently observed in all three sets of the observational data. The other footpoint of loop system always remains red-shifted indicating downflowing plasma. The multi-spectral line analysis in the present paper provides a detailed scenario of the plasma flows inversions in cool loop systems leading to the mass transport and their formation. The impulsive energy release due to small-scale reconnection above loop footpoint seems to be the most likely cause for sudden initiation of the plasma flows evident at TR temperatures. **27 December 2013**

Role of Transients in the Sustainability of Solar Coronal Plumes

N.-E. **Raouafi**1 and G. Stenborg

2014 ApJ 787 118.

We report on the role of small-scale, transient magnetic activity in the formation and evolution of solar coronal plumes. Three plumes within equatorial coronal holes are analyzed over the span of several days based on the Solar Dynamic Observatory (SDO)/Atmospheric Imaging Assembly 171 Å and 193 Å images and SDO/Helioseismic and Magnetic Imager line-of-sight magnetograms. The focus is on the role of transient structures at the footpoints in sustaining coronal plumes for relatively long periods of time (i.e., several days). The appearance of plumes is a gradual and lengthy process. In some cases, the initial stages of plume formation are marked by the appearance of pillar-like structures whose footpoints are the sources of transient brightenings. In addition to nominal jets occurring prior to and during the development of plumes, the data show that a large number of small jets (i.e., "jetlets") and plume transient bright points (PTBPs) occur on timescales of tens of seconds to a few minutes. These features are the result of quasi-random cancellations of fragmented and diffuse minority magnetic polarity with the dominant unipolar magnetic field concentration over an extended period of time. They unambiguously reflect a highly dynamical evolution at the footpoints and are seemingly the main energy source for plumes. This suggests a tendency for plumes to be dependent on the occurrence of transients (i.e., jetlets, and PTBPs) resulting from low-rate magnetic reconnection. The decay phase of plumes is characterized by gradual fainting and multiple rejuvenations as a result of the dispersal of the unipolar magnetic concentration and its precipitation into multiple magnetic centers.

OBSERVATIONAL EVIDENCE FOR CORONAL TWISTED FLUX ROPE

N.-E. **Raouafi**
ApJ 691 L128-L132 **2009**
http://www.iop.org/EJ/abstract/1538-4357/691/2/L128
Multi-instrument data sets of NOAA AR10938 on **2007 January 16** (e.g., Hinode, STEREO, GOES, MLSO, and ISOON Hα) are utilized to study the fine structure and evolution of a magnetic loop system exhibiting multiple crossing threads, whose arrangement and individual shapes are very suggestive of individual field lines in a flux rope. The footpoints of the magnetic threads are closely rooted into pores and plage areas. A C-class flare recorded by GOES at approximately 2:35 UT near one of the footpoints of the multi-thread system (along with a wisp of loop material shown by EUV data) led to the brightening of the magnetic structure revealing its fine structure with several threads that indicate a high degree of linking (suggesting a left-handed helical pattern as shown by the filament structure formed later on). EUV observations by Hinode/EIS of hot spectral lines at 2:46 UT show a complex structure of coronal loops. The same features were observed about 20 minutes later in X-ray images from Hinode/XRT and about 30 minutes further in EUV images of STEREO/SECCHI/EUVI with much better resolution. Hα and 304 Å images revealed the presence of several filament fibrils in the same area. They evolved a few hours later into a denser structure seemingly showing a helical pattern, which persisted or several days forming a segment of a larger-scale filament. The present observations provide an important indication for a flux robe as a precursor of a solar filament.

Large-amplitude quasi-periodic pulsations as evidence of impulsive heating in hot transient loop systems detected in the EUV with SDO/AIA

Fabio **Reale**, Paola Testa, Antonino Petralia, Dmitrii Y. Kolotkov
ApJ **884** 131 **2019**
https://arxiv.org/pdf/1909.02847.pdf
https://doi.org/10.3847/1538-4357/ab4270
Short heat pulses can trigger plasma pressure fronts inside closed magnetic tubes in the corona. The alternation of condensations and rarefactions from the pressure modes drive large-amplitude pulsations in the plasma emission. Here we show the detection of such pulsations along magnetic tubes that brighten transiently in the hot 94A EUV channel of SDO/AIA. The pulsations are consistent with those predicted by hydrodynamic loop modeling, and confirm pulsed heating in the loop system. The comparison of observations and model provides constraints on the heat deposition: a good agreement requires loop twisting and pulses deposited close to the footpoints with a duration of 0.5 min in one loop, and deposited in the corona with a duration of 2.5 min in another loop of the same loop system. **12 November 2015**

3D MHD modeling of twisted coronal loops

F. **Reale**, S. Orlando, M. Guarrasi, A. Mignone, G. Peres, A. W. Hood, E. R. Priest
ApJ 830 21 **2016**
http://arxiv.org/pdf/1607.05500v1.pdf
We perform MHD modeling of a single bright coronal loop to include the interaction with a non-uniform magnetic field. The field is stressed by random footpoint rotation in the central region and its energy is dissipated into heating by growing currents through anomalous magnetic diffusivity that switches on in the corona above a current density threshold. We model an entire single magnetic flux tube, in the solar atmosphere extending from the high-beta chromosphere to the low-beta corona through the steep transition region. The magnetic field expands from the chromosphere to the corona. The maximum resolution is ~30 km. We obtain an overall evolution typical of loop models and realistic loop emission in the EUV and X-ray bands. The plasma confined in the flux tube is heated to active region temperatures (~3 MK) after ~2/3 hr. Upflows from the chromosphere up to ~100 km/s fill the core of the flux tube to densities above 10^9 cm^-3. More heating is released in the low corona than the high corona and is finely structured both in space and time.

"Coronal Loops: Observations and Modeling of Confined Plasma" (major update)

Fabio **Reale** **Review**
Living Reviews in Solar Physics, PUB.NO. lrsp-**2014**-4
http://www.livingreviews.org/lrsp-2014-4
Coronal loops are the building blocks of the X-ray bright solar corona. They owe their brightness to the dense confined plasma, and this review focuses on loops mostly as structures confining plasma. After a brief historical overview, the review is divided into two separate but not independent parts: the first illustrates the observational framework, the second reviews the theoretical knowledge. Quiescent loops and their confined plasma are considered and, therefore, topics such as loop oscillations and flaring loops (except for non-solar ones, which provide information on stellar loops) are not specifically addressed here. The observational section discusses the classification, populations, and the morphology of coronal loops, its relationship with the magnetic field, and the

loop stranded structure. The section continues with the thermal properties and diagnostics of the loop plasma, according to the classification into hot, warm, and cool loops. Then, temporal analyses of loops and the observations of plasma dynamics, hot and cool flows, and waves are illustrated. In the modeling section, some basics of loop physics are provided, supplying fundamental scaling laws and timescales, a useful tool for consultation. The concept of loop modeling is introduced and models are divided into those treating loops as monolithic and static, and those resolving loops into thin and dynamic strands. More specific discussions address modeling the loop fine structure and the plasma flowing along the loops. Special attention is devoted to the question of loop heating, with separate discussion of wave (AC) and impulsive (DC) heating. Large-scale models including atmosphere boxes and the magnetic field are also discussed. Finally, a brief discussion about stellar coronal loops is followed by highlights and open questions.

The role of radiative losses in the late evolution of pulse-heated coronal loops/strands

F. **Reale**, E. Landi

E-print, 22 May, **2012**, A&A 543, A90 (**2012**)

Radiative losses from optically thin plasma are an important ingredient for modeling plasma confined in the solar corona. Spectral models are continuously updated to include the emission from more spectral lines, with significant effects on radiative losses, especially around 1 MK. We investigate the effect of changing the radiative losses temperature dependence due to upgrading of spectral codes on predictions obtained from modeling plasma confined in the solar corona. The hydrodynamic simulation of a pulse-heated loop strand is revisited comparing results using an old and a recent radiative losses function. We find significant changes in the plasma evolution during the late phases of plasma cooling: when the recent radiative loss curve is used, the plasma cooling rate increases significantly when temperatures reach 1-2 MK. Such more rapid cooling occurs when the plasma density is larger than a threshold value, and therefore in impulsive heating models that cause the loop plasma to become overdense. The fast cooling has the effect of steepening the slope of the emission measure distribution of coronal plasmas with temperature at temperatures lower than ~2 MK. The effects of changes in the radiative losses curves can be important for modeling the late phases of the evolution of pulse-heated coronal loops, and, more in general, of thermally unstable optically thin plasmas.

Coronal Loops: Observations and Modeling of Confined Plasma **Review**

Fabio **Reale**

Living Reviews in Solar Physics

http://www.livingreviews.org/lrsp-2010-5 , **2010**

Coronal loops are the building blocks of the X-ray bright solar corona. They owe their brightness to the dense confined plasma, and this review focuses on loops mostly as structures confining plasma. After a brief historical overview, the review is divided into two separate but not independent parts: the first illustrates the observational framework, the second reviews the theoretical knowledge. Quiescent loops and their confined plasma are considered, and therefore topics such as loop oscillations and flaring loops (except for non-solar ones which provide information on stellar loops) are not specifically addressed here. The observational section discusses loop classification and populations, and then describes the morphology of coronal loops, its relationship with the magnetic field, and the concept of loops as multi-stranded structures. The following part of this section is devoted to the characteristics of the loop plasma and of its thermal structure in particular, according to the classification into hot, warm, and cool loops. Then, temporal analyses of loops and the observations of plasma dynamics and flows are illustrated. In the modeling section some basics of loop physics are provided, supplying some fundamental scaling laws and timescales, a useful tool for consultation. The concept of loop modeling is introduced and models are distinguished between those treating loops as monolithic and static, and those resolving loops into thin and dynamic strands. Then, more specific discussions address modeling the loop fine structure and the plasma flowing along the loops. Special attention is devoted to the question of loop heating, with separate discussion of wave (AC) and impulsive (DC) heating. Finally, a brief discussion about stellar X-ray emitting structures related to coronal loops is included and followed by conclusions and open questions.

Mass Flows in Expanding Coronal Loops

Jeffrey W. **Reep**, Roger B. Scott, Sherry Chhabra, John Unverferth, Kalman J. Knizhnik

ApJ **967** 53 **2024**

https://arxiv.org/pdf/2403.12358

https://iopscience.iop.org/article/10.3847/1538-4357/ad3c3c/pdf

An expansion of cross-sectional area directly impacts the mass flow along a coronal loop, and significantly alters the radiative and hydrodynamic evolution of that loop as a result. Previous studies have found that an area expansion from chromosphere to corona significantly lengthens the cooling time of the corona, and appears to suppress draining from the corona. In this work, we examine the fluid dynamics to understand how the mass flow rate, the energy balance, and the cooling and draining timescales are affected by a non-uniform area. We find that in loops with moderate or large expansion (cross-sectional area expansion factors of 2, 3, 10, 30, 100 from photosphere to apex), impulsive heating, for either direct thermal heating or electron beam heating, induces a steady flow into the corona, so that the coronal density continues to rise during the cooling phase, whereas a uniform loop drains during the cooling phase. The induced upflow carries energy into the corona, balancing the losses from thermal conduction, and continues until thermal conduction weakens enough so that it can no longer support the radiative losses of the transition region (TR). As a result, the plasma cools primarily radiatively until the onset of catastrophic collapse. The speed and duration of the induced upflow both increase in proportion to the rate of area expansion. We argue that observations of blue-shifted spectral lines, therefore, could place a constraint on a loop's area expansion.

Geometric Assumptions in Hydrodynamic Modeling of Coronal and Flaring Loops

Jeffrey W. **Reep**, Ignacio Ugarte-Urra, Harry P. Warren, Will T. Barnes

ApJ **933** 106 **2022**

https://arxiv.org/pdf/2203.04385

https://iopscience.iop.org/article/10.3847/1538-4357/ac7398/pdf

In coronal loop modeling, it is commonly assumed that the loops are semi-circular with a uniform cross-sectional area. However, observed loops are rarely semi-circular, and extrapolations of the magnetic field show that the field strength decreases with height, implying that the cross-sectional area should expand with height. In this work, we examine these two assumptions directly to understand how they affect the hydrodynamic and radiative response to strong, impulsive heating events. Both the magnitude and rate of area expansion impact the dynamics directly, and we show that an expanding cross-section significantly lengthens the time for a loop to cool and drain, increases upflow durations, and suppresses sound waves. An increase in the eccentricity of loops, on the other hand, only increases the draining timescale, and is a minor effect in general. Spectral line intensities are also strongly impacted by the variation in the cross-sectional area since they depend on both the volume of the emitting region as well as the density and ionization state. With a larger expansion, the density is reduced, so the lines at all heights are relatively reduced in intensity and, because of the increase of cooling times, the hottest lines remain bright for significantly longer. Future modeling work needs to include area expansion for an accurate picture of the hydrodynamics, and future observations are needed to provide tighter constraints on the magnitude, rate, and location of the expansion or lack thereof.

A Hydrodynamic Model of Alfvénic Wave Heating in a Coronal Loop and its Chromospheric Footpoints

Jeffrey W. **Reep**, Alexander J.B. Russell, Lucas A. Tarr, James E. Leake

ApJ **853** 101 **2017**

https://arxiv.org/pdf/1712.06171.pdf

Alfv\'enic waves have been proposed as an important energy transport mechanism in coronal loops, capable of delivering energy to both the corona and chromosphere and giving rise to many observed features, of flaring and quiescent regions. In previous work, we established that resistive dissipation of waves (ambipolar diffusion) can drive strong chromospheric heating and evaporation, capable of producing flaring signatures. However, that model was based on a simplified assumption that the waves propagate instantly to the chromosphere, an assumption which the current work removes. Via a ray tracing method, we have implemented traveling waves in a field-aligned hydrodynamic simulation that dissipate locally as they propagate along the field line. We compare this method to and validate against the magnetohydrodynamics code Lare3D. We then examine the importance of travel times to the dynamics of the loop evolution, finding that (1) the ionization level of the plasma plays a critical role in determining the location and rate at which waves dissipate; (2) long duration waves effectively bore a hole into the chromosphere, allowing subsequent waves to penetrate deeper than previously expected, unlike an electron beam whose energy deposition rises in height as evaporation reduces the mean-free paths of the electrons; (3) the dissipation of these waves drives a pressure front that propagates to deeper depths, unlike energy deposition by an electron beam.

THERMAL PROPERTIES OF A SOLAR CORONAL CAVITY OBSERVED WITH THE X-RAY TELESCOPE ON HINODE

Katharine K. **Reeves**1, Sarah E. Gibson2, Therese A. Kucera3, Hugh S. Hudson4,5 and Ryouhei Kano

2012 ApJ 746 146

Coronal cavities are voids in coronal emission often observed above high latitude filament channels. Sometimes, these cavities have areas of bright X-ray emission in their centers. In this study, we use data from the X-ray Telescope (XRT) on the Hinode satellite to examine the thermal emission properties of a cavity observed during **2008 July** that contains bright X-ray emission in its center. Using ratios of XRT filters, we find evidence for elevated temperatures in the cavity center. The area of elevated temperature evolves from a ring-shaped structure at the beginning of the observation, to an elongated structure two days later, finally appearing as a compact round source four days after the initial observation. We use a morphological model to fit the cavity emission, and find that a uniform structure running through the cavity does not fit the observations well. Instead, the observations are reproduced by modeling several short cylindrical cavity "cores" with different parameters on different days. These changing core parameters may be due to some observed activity heating different parts of the cavity core at different times. We find that core temperatures of 1.75 MK, 1.7 MK, and 2.0 MK (for **July 19, July 21, and July 23**, respectively) in the model lead to structures that are consistent with the data, and that line-of-sight effects serve to lower the effective temperature derived from the filter ratio.

Red and Blueshifts in Multi-stranded Coronal Loops: A New Temperature Diagnostic

S. **Regnier**, R. W. Walsh

2014

http://arxiv.org/pdf/1405.3450v1.pdf

[...] redshifts are predominantly observed in the core of active regions, while blueshifts are observed at the edge of active regions. [...] Using a nanoflare heating model for multi-stranded coronal loops (Sarkar and Walsh, 2008, 2009), we reproduce the above Dopplershift observations using spectral lines covering a broad range of temperature (from 0.25 MK to 5.6 MK). We first show that red- and blueshifts are ubiquitous in all wavelength ranges; redshifts/downflows dominating cool spectral lines (from O v to Si vii) and blueshifts/upflows dominating the hot lines (from Fe xv to Ca xvii). By computing the average Dopplershift, we derive a new temperature diagnostic for coronal loops: the temperature at which the average Dopplershift vanishes is the mean temperature along the coronal loop. In addition, the temperature estimate at the footpoints of the loop when the average Dopplershift vanishes is a lower bound of the temperature along the loop. To compare closely with observations, we thus model typical Hinode/EIS rasters with a spatial resolution of 1", an exposure time of 50s and a step of 3". Even if the raster reproduce the global features of up and downflows along the loop, we show that this type of raster cannot provide information on the heating mechanism. We also discuss the fact that observing a single spectral line can lead to false interpretation of the physical processes at play. For instance, an observed increased in blueshift velocity in the Fe xii channel can indicate a cooling event (decrease of energy input). We also investigate the existence of coronal loops having Dopplershifts of opposite signs which could characterise a unidirectional flow along the loop: about 50% of loops have opposite Dopplershifts at the footpoints for the spectral line closest to the mean temperature of the loop.

Structure and Dynamics of a Polar Crown Cavity as Observed by SDO/AIA

S. **Régnier**, R. W. Walsh and C. E. Alexander

UKSP Nuggets, Sept **2011**

http://www.uksolphys.org/?p=3253

13 June 2010

A new look at a polar crown cavity as observed by SDO/AIA Structure and dynamics⋆

S. **Régnier**, R. W. Walsh and C. E. Alexander

A&A 533, L1 (**2011**), **File**

Context. The Solar Dynamics Observatory (SDO) was launched in February 2010 and is now providing an unprecedented view of the solar activity at high spatial resolution and high cadence covering a broad range of temperature layers of the atmosphere.

Aims. We aim at defining the structure of a polar crown cavity and describing its evolution during the erupting process.

Methods. We use the high-cadence time series of SDO/AIA observations at 304 Å (50 000 K) and 171 Å (0.6 MK) to determine the structure of the polar crown cavity and its associated plasma, as well as the evolution of the cavity during the different phases of the eruption. We report on the observations recorded on **13 June 2010** located on the north-west limb.

Results. We observe coronal plasma shaped by magnetic field lines with a negative curvature (U-shape) sitting at the bottom of a cavity. The cavity is located just above the polar crown filament material. We thus observe the inner part of the cavity above the filament as depicted in the classical three part coronal mass ejection (CME) model composed of a filament, a cavity, and a CME front. The filament (in this case a polar crown filament) is part of the cavity, and it makes a continuous structuring from the filament to the CME front depicted by concentric ellipses (in a 2D cartoon).

Conclusions. We propose to define a polar crown cavity as a density depletion sitting above denser polar crown filament plasma drained down the cavity by gravity. As part of the polar crown filament, plasma at different temperatures (ranging from 50 000 K to 0.6 MK) is observed at the same location on the cavity dips and sustained by a competition between the gravity and the curvature of magnetic field lines. The eruption of the polar crown cavity as a solid body can be decomposed into two phases: a slow rise at a speed of 0.6 km s-1 and an acceleration phase at a mean speed of 25 km s-1.

The eruption of a small filament in the quiet Sun

D.B. **Ren** · Y.C. Jiang · J.Y. Yang · R.S. Zheng · Y. Bi · M. Wang
Astrophys Space Sci (**2008**) 318: 141–147, DOI 10.1007/s10509-008-9908-2
http://www.springerlink.com/content/wp2135251q063553/fulltext.pdf
We analyzed multi-wavelength observations of the eruption of a small-scale filament on the quiet Sun. The filament first became thicker, then broke into two, and eventually underwent a partial eruption with possible rotating motion. The eruption was followed by a small flare with three bright kernels on either side of the eruptive section in Hα and a small coronal dimming near one end of this section in EUV and soft X-ray. On the photosphere, MDI magnetograms show the flux emergence or motions and cancellation between opposite polarities before and during the filament eruption. We find that this small-scale filament shows the similar characteristics as the previous findings in the large-scale filament eruptions on the multi-wavelength, indicating the common nature.

Wave-like Formation of Hot Loop Arcades

Reva, A.; Shestov, S.; Zimovets, I.; Bogachev, S.; Kuzin, S.
Solar Phys. Volume 290, Issue 10, pp.2909-2921, **2015**
https://arxiv.org/pdf/1510.02319v1.pdf
We present observations of hot arcades made with the Mg xii spectroheliograph onboard the CORONAS-F mission, which provides monochromatic images of hot plasma in the Mg xii 8.42 Å resonance line. The arcades were observed to form above the polarity inversion line between active regions NOAA 09847 and 09848 at four successive episodes: at 09:18, 14:13, and 22:28 UT on **28 February 2002**, and at 00:40 UT on **1 March 200**2. The evolution of the arcades can be described as: a) a small flare (precursor) appeared near the edge of the still invisible arcade, b) the arcade brightened in a wave-like manner - closer loops brightened earlier, and c) the arcade intensity gradually decreased in {≈} 1 h. The estimated wave speed was {≈} 700 km s^{-1}, and the distance between the hot loops was {≈} 50 Mm. The arcades formed without visible changes in their magnetic structure. The arcades were probably heated up by the instabilities of the current sheet above the arcade, which were caused by a magnetohydrodynamic wave excited by the precursor.

Normal Modes of Transverse Coronal Loop Oscillations from Numerical Simulations. I. Method and Test Case

S. **Rial**1, I. Arregui2, R. Oliver1,3, and J. Terradas1,3
2019 ApJ 876 86
sci-hub.se/10.3847/1538-4357/ab1417
The purpose of this work is to develop a procedure to obtain the normal modes of a coronal loop from time-dependent numerical simulations with the aim of better understanding observed transverse loop oscillations. To achieve this goal, in this paper we present a new method and test its performance with a problem for which the normal modes can be computed analytically. In a follow-up paper, the application to the simulations of Rial et al. is tackled. The method proceeds iteratively and at each step consists of (i) a time-dependent numerical simulation followed by (ii) the Complex Empirical Orthogonal Function (CEOF) analysis of the simulation results. The CEOF analysis provides an approximation to the normal mode eigenfunctions that can be used to set up the initial conditions for the numerical simulation of the following iteration, in which an improved normal mode approximation is obtained. The iterative process is stopped once the global difference between successive approximate eigenfunctions is below a prescribed threshold. The equilibrium used in this paper contains material discontinuities that result in one eigenfunction with a jump across these discontinuities and two eigenfunctions whose normal derivatives are discontinuous there. After six iterations, the approximations to the frequency and eigenfunctions are accurate to $\lesssim$0.7% except for the eigenfunction with discontinuities, which displays a much larger error at these positions.

WAVE LEAKAGE AND RESONANT ABSORPTION IN A LOOP EMBEDDED IN A CORONAL ARCADE

S. **Rial**1, I. Arregui2, J. Terradas1, R. Oliver1, and J. L. Ballester
2013 ApJ 763 16
We investigate the temporal evolution of impulsively generated perturbations in a potential coronal arcade with an embedded loop. For the initial configuration we consider a coronal loop, represented by a density enhancement, which is unbounded in the ignorable direction of the arcade. The linearized time-dependent magnetohydrodynamic equations have been numerically solved in field-aligned coordinates and the time evolution of the initial perturbations has been studied in the zero-β approximation. For propagation constrained to the plane of the arcade, the considered initial perturbations do not excite trapped modes of the system. This weakness of the model is

overcome by the inclusion of wave propagation in the ignorable direction. Perpendicular propagation produces two main results. First, damping by wave leakage is less efficient because the loop is able to act as a better wave trap of vertical oscillations. Second, the consideration of an inhomogeneous corona enables the resonant damping of vertical oscillations and the energy transfer from the interior of the loop to the external coronal medium.

Acoustic wave properties in footpoints of coronal loops in 3D MHD simulations

Julia M. **Riedl**, Tom Van Doorsselaere, Fabio Reale, Marcel Goossens, Antonino Petralia, Paolo Pagano

ApJ **922** 225 **2021**

https://arxiv.org/pdf/2109.02971.pdf

https://doi.org/10.3847/1538-4357/ac23c7

Acoustic waves excited in the photosphere and below might play an integral part in the heating of the solar chromosphere and corona. However, it is yet not fully clear how much of the initially acoustic wave flux reaches the corona and in what form. We investigate the wave propagation, damping, transmission, and conversion in the lower layers of the solar atmosphere using 3D numerical MHD simulations. A model of a gravitationally stratified expanding straight coronal loop, stretching from photosphere to photosphere, is perturbed at one footpoint by an acoustic driver with a period of 370 seconds. For this period acoustic cutoff regions are present below the transition region (TR). About 2% of the initial energy from the driver reach the corona. The shape of the cutoff regions and the height of the TR show a highly dynamic behavior. Taking only the driven waves into account, the waves have a propagating nature below and above the cutoff region, but are standing and evanescent within the cutoff region. Studying the driven waves together with the background motions in the model reveals standing waves between the cutoff region and the TR. These standing waves cause an oscillation of the TR height. In addition, fast or leaky sausage body-like waves might have been excited close to the base of the loop. These waves then possibly convert to fast or leaky sausage surface-like waves at the top of the main cutoff region, followed by a conversion to slow sausage body-like waves around the TR.

Interplanetary Signatures of Unipolar Streamers and the Origin of the Slow Solar Wind

P. **Riley** and J. G. Luhmann

Solar Physics, Volume 277, Number 2, 355-373, **2012**

Unipolar streamers (also known as pseudo-streamers) are coronal structures that, at least in coronagraph images, and when viewed at the correct orientation, are often indistinguishable from dipolar (or “standard”) streamers. When interpreted with the aid of a coronal magnetic field model, however, they are shown to consist of a pair of loop arcades. Whereas dipolar streamers separate coronal holes of the opposite polarity and whose cusp is the origin of the heliospheric current sheet, unipolar streamers separate coronal holes of the same polarity and are therefore not associated with a current sheet. In this study, we investigate the interplanetary signatures of unipolar streamers. Using a global MHD model of the solar corona driven by the observed photospheric magnetic field for Carrington rotation 2060, we map the ACE trajectory back to the Sun. The results suggest that ACE fortuitously traversed through a large and well-defined unipolar streamer. We also compare heliospheric model results at 1 AU with ACE in-situ measurements for Carrington rotation 2060. The results strongly suggest that the solar wind associated with unipolar streamers is slow. We also compare predictions using the original Wang–Sheeley (WS) empirically determined inverse relationship between solar wind speed and expansion factor. Because of the very low expansion factors associated with unipolar streamers, the WS model predicts high speeds, in disagreement with the observations. We discuss the implications of these results in terms of theories for the origin of the slow solar wind. Specifically, premises relying on the expansion factor of coronal flux tubes to modulate the properties of the plasma (and speed, in particular) must address the issue that while the coronal expansion factors are significantly different at dipolar and unipolar streamers, the properties of the measured solar wind are, at least qualitatively, very similar.

Dependence of Coronal Loop Heating on the Characteristics of Slow Photospheric Motions

M.L. **Ritchie**, A.L. Wilmot-Smith, G. Hornig

2016 ApJ 824 19

http://arxiv.org/pdf/1508.05001v1.pdf

The Parker hypothesis (Parker (1972)) assumes that heating of coronal loops occurs due to reconnection, induced when photospheric motions braid field lines to the point of current sheet formation. In this contribution we address the question of how the nature of photospheric motions affects heating of braided coronal loops. We design a series of boundary drivers and quantify their properties in terms of complexity and helicity injection. We examine a series of long-duration full resistive MHD simulations in which a simulated coronal loop, consisting of initially uniform field lines, is subject to these photospheric flows. Braiding of the loop is continually driven until differences in behaviour induced by the drivers can be characterised. It is shown that heating is crucially dependent on the nature of the photospheric driver - coherent motions typically lead to fewer large energy release events, while more complex motions result in more frequent but less energetic heating events.

DETERMINING THE NORTH-SOUTH DISPLACEMENT OF THE HELIOSPHERIC CURRENT SHEET FROM CORONAL STREAMER OBSERVATIONS

E. **Robbrecht**1 and Y.-M. Wang

2012 ApJ 755 135

Inferences based on interplanetary field measurements have suggested a statistical tendency for the heliospheric current sheet (HCS) to be displaced southward of the heliographic equator during the past four solar cycles. Here, we use synoptic maps of white-light streamer structures to determine more directly the longitudinally averaged latitude of the HCS, after separating out the contribution of streamers without magnetic polarity reversals ("pseudostreamers"). We find a strong tendency for the HCS to be shifted southward by a few degrees during 2007-2011, but no significant shift during the 1996-1997 sunspot minimum. Fluctuations in the magnitude and direction of the north-south shifts often occur on timescales as short as one or two Carrington rotations, as a result of changes in the streamer structures due to active region emergence. The largest shifts occurred during 2010-2011 and were on the order of –6°. Such southward displacements are consistent with the overwhelming dominance of northern-hemisphere sunspot activity during the rising phase of the current solar cycle 24, resulting in a strong axisymmetric quadrupole component whose sign at the equator matched that of the north polar field; the symmetry-breaking effect of the quadrupole was further enhanced by the weakness of the polar fields.

Solar prominence modelling and plasma diagnostics at ALMA wavelengths

Andrew S **Rodger**, Nicolas Labrosse

Solar Phys. 292:130 **2017**

https://arxiv.org/pdf/1704.05385.pdf

Our aim is to test potential solar prominence plasma diagnostics as obtained with the new solar capability of the Atacama Large Millimeter / submillimeter Array (ALMA). We investigate the thermal and plasma diagnostic potential of ALMA for solar prominences through the computation of brightness temperatures at ALMA wavelengths. The brightness temperature, for a chosen line of sight, is calculated using densities of hydrogen and helium obtained from a radiative transfer code under non local thermodynamic equilibrium (NLTE) conditions, as well as the input internal parameters of the prominence model in consideration. Two distinct sets of prominence models were used: isothermal-isobaric fine-structure threads, and large-scale structures with radially increasing temperature distributions representing the prominence-to-corona transition region. We compute brightness temperatures over the range of wavelengths in which ALMA is capable of observing (0.32 - 9.6mm), however we particularly focus on the bands available to solar observers in ALMA cycles 4 and 5, namely 2.6 - 3.6mm (Band 3) and 1.1 - 1.4mm (Band 6). We show how the computed brightness temperatures and optical thicknesses in our models vary with the plasma parameters (temperature and pressure) and the wavelength of observation. We then study how ALMA observables such as the ratio of brightness temperatures at two frequencies can be used to estimate the optical thickness and the emission measure for isothermal and non-isothermal prominences. From this study we conclude that, for both sets of models, ALMA presents a strong thermal diagnostic capability, provided that the interpretation of observations is supported by the use of non-LTE simulation results.

A solar eruption triggered by the interaction between two magnetic flux systems with opposite magnetic helicity

P. **Romano**1, E. Pariat2, M. Sicari3 and F. Zuccarello3

A&A 525, A13 (**2011**), **File**

Context. In recent years the accumulation of magnetic helicity via emergence of new magnetic flux and/or shearing photospheric motions has been considered to play an important role in the destabilization processes that lead to eruptive phenomena occurring in the solar atmosphere.

Aims. In this paper we want to highlight a specific aspect of magnetic helicity accumulation, providing new observational evidence of the role played by the interaction of magnetic fields characterized by opposite magnetic helicity signs in triggering solar eruption.

Methods. We used 171 Å TRACE data to describe a filament eruption on **2001 Nov. 1** in active region NOAA 9682 and MDI full disk line-of-sight magnetograms to measure the accumulation of magnetic helicity in corona before the event. We used the local correlation tracking (LCT) and the differential affine velocity estimator (DAVE) techniques to determine the horizontal velocities and two methods for estimating the magnetic helicity flux.

Results. The chirality signatures of the filament involved in the eruption were ambiguous, and the overlying arcade visible during the main phase of the event was characterized by a mixing of helicity signs. However, the measures of the magnetic helicity flux allowed us to deduce that the magnetic helicity was positive in the whole active region where the event took place, while it was negative near the magnetic inversion line where the filament footpoints were located.

Conclusions. These results suggest that the filament eruption may be caused by magnetic reconnection between two magnetic field systems characterized by opposite signs of magnetic helicity. We also find that only the DAVE method allowed us to obtain the crucial information on the horizontal velocity field near the magnetic inversion line.

Magnetic helicity and active filament configuration:

P. **Romano**, F. Zuccarello, S. Poedts, A. Soenen and F. P. Zuccarello

A&A 506 (**2009**) 895-900**, File**

Context. The role of magnetic helicity in active filament formation and destabilization is still under debate.
Aims. Although active filaments usually show a sigmoid shape and a twisted configuration before and during their eruption, it is unclear which mechanism leads to these topologies. In order to provide an observational contribution to clarify these issues, we describe a filament evolution whose characteristics seem to be directly linked to the magnetic helicity transport in corona.
Methods. We applied different methods to determine the helicity sign and the chirality of the filament magnetic field. We also computed the magnetic helicity transport rate at the filament footpoints.
Results. All the observational signatures provided information on the positive helicity and sinistral chirality of the flux rope containing the filament material: its forward S shape, the orientation of its barbs, the bright and dark threads at 195 Å. Moreover, the magnetic helicity transport rate at the filament footpoints showed a clear accumulation of positive helicity.
Conclusions. The study of this event showed a correspondence between several signatures of the sinistral chirality of the filament and several evidences of the positive magnetic helicity of the filament magnetic field. We also found that the magnetic helicity transported along the filament footpoints showed an increase just before the change of the filament shape observed in H α images. We argued that the photospheric regions where the filament was rooted might be the preferential ways where the magnetic helicity was injected along the filament itself and where the conditions to trigger the eruption were yielded.

Photospheric flows around a quiescent filament:

S. **Rondi**, Th. Roudier, G. Molodij, V. Bommier, S. Keil, P. SЭtterlin, J. M. Malherbe, N. Meunier, B. Schmieder and P. Maloney

A&A 467 (**2007**) 1289-1298, File

Before the filament's eruptive phase, we observe both parasitic and normal polarities being swept by a continuously diverging horizontal flow located in the filament gap. The disappearance of the filament initiates in this gap. Such purely horizontal motions could lead to destabilization of the filament and could trigger the sudden filament disappearance.

Large-scale horizontal flows in the solar photosphere
III. Effects on filament destabilization

T. **Roudier**[1], M. Svanda[2, 3], N. Meunier[1, 4], S. Keil[5], M. Rieutord[1], J. M. Malherbe[6], S. Rondi[1], G. Molodij[6], V. Bommier[7], and B. Schmieder

A&A 480, 255-263 (2008)

*Aims.*We study the influence of large-scale photospheric motions on the destabilization of an eruptive filament, observed on October 6, 7, and 8, 2004, as part of an international observing campaign (JOP 178).
*Methods.*Large-scale horizontal flows were investigated from a series of MDI full-disc Dopplergrams and magnetograms. From the Dopplergrams, we tracked supergranular flow patterns using the local correlation tracking (LCT) technique. We used both LCT and manual tracking of isolated magnetic elements to obtain horizontal velocities from magnetograms.
*Results.*We find that the measured flow fields obtained by the different methods are well-correlated on large scales. The topology of the flow field changed significantly during the filament eruptive phase, suggesting a possible coupling between the surface flow field and the coronal magnetic field. We measured an increase in the shear below the point where the eruption starts and a decrease in shear after the eruption. We find a pattern in the large-scale horizontal flows at the solar surface that interact with differential rotation.
*Conclusions.*We conclude that there is probably a link between changes in surface flow and the disappearance of the eruptive filament.

An analytical model of prominence dynamics

Swati **Routh**, Snehanshu Saha, Atul Bhat, M.N.Sundar[a]

Advances in Space Research Volume 61, Issue 2, 15 January 2018, Pages 715-719

http://arxiv.org/pdf/1608.07674v1.pdf

Solar prominences are magnetic structures incarcerating cool and dense gas in an otherwise hot solar corona. Prominences can be categorized as quiescent and active. Their origin and the presence of cool gas (~104 K) within the hot (∼106K) solar corona remains poorly understood. The structure and dynamics of solar prominences was investigated in a large number of observational and theoretical (both analytical and numerical) studies. In this paper, an analytic model of quiescent solar prominence is developed and used to demonstrate that the prominence velocity increases exponentially, which means that some gas falls downward towards the solar surface, and that Alfvén waves are naturally present in the solar prominences. These theoretical predictions are consistent with the current observational data of solar quiescent prominences.

Diagnostics of the Prominence Plasma from Hα and Mg ii Spectral Observations

Guiping **Ruan**, Sonja Jejčič, Brigitte Schmieder, Pierre Mein, Nicole Mein, Petr Heinzel, Stanislav Gunár, and Yao Chen

2019 ApJ 886 134

https://doi.org/10.3847/1538-4357/ab4b50

The goal of this paper is to derive the physical conditions of the prominence observed on 2017 March 30. To do so, we use a unique set of data in Mg ii lines obtained with the space-borne Interface Region Imaging Spectrograph (IRIS) and in Hα line with the ground-based Multi-Channel Subtractive Double Pass spectrograph operating at the Meudon solar tower. Here, we analyze the prominence spectra of Mg ii h and k lines, and the Hα line in the part of the prominence which is visible in both sets of lines. We compute a grid of 1D NLTE (i.e., departures from the local thermodynamical equilibrium) models providing synthetic spectra of Mg ii k and h, and Hα lines in a large space of model input parameters (temperature, density, pressure, and microturbulent velocity). We compare Mg ii and Hα line profiles observed in 75 positions of the prominence with the synthetic profiles from the grid of models. These models allow us to compute the relationships between the integrated intensities and between the optical thickness in Hα and Mg ii k lines. The optical thickness τ Hα is between 0.05 and 2, and is between 3 and 200. We show that the relationship of the observed integrated intensities agrees well with the synthetic integrated intensities for models with a higher microturbulence (16 km s−1) and T around 8000 K, ne = 1.5 × 1010 cm−3, p = 0.05 dyne. In this case, large microturbulence values could be a way to take into account the large mixed velocities existing in the observed prominence.

On the Dynamic Nature of a Quiescent Prominence Observed by IRIS and MSDP Spectrographs

Guiping **Ruan**1,2,3, Brigitte Schmieder2, Pierre Mein2, Nicole Mein2, Nicolas Labrosse4, Stanislav Gunár2,5, and Yao Chen1

2018 ApJ 865 123

Quiescent solar prominences are generally considered to have a stable large-scale structure. However, they consist of multiple small-scale structures that are often significantly dynamic. To understand the nature of prominence plasma dynamics we use the high spatial, temporal, and spectral resolution observations obtained by Interface Region Imaging Spectrograph (IRIS) during a coordinated campaign with the Multichannel Subtractive Double Pass spectrograph at the Meudon Solar Tower. Detailed analysis of the IRIS observations of Mg ii lines, including the analysis of Dopplershift and line width obtained with two different methods (quantile method and Gaussian-fit method) are discussed in the frame of the dynamic nature of the structures. Large-scale coherent blueshift and redshift features are observed in Mg ii lines and Hα exhibiting a slow evolution during 1:40 hr of observations. We explain the presence of several significantly asymmetric peaks in the observed Mg ii line profiles by the presence of several prominence fine structures moving with different velocities located along the line of sight (LOS). In such a case, the decrease of the intensity of individual components of the observed spectra with the distance from the central wavelength can be explained by the Doppler dimming effect. We show that C ii line profiles may be used to confirm the existence of multi-components along the LOS.

Effect of siphon flow on resonant damping of kink oscillations in magnetic flux tubes

Michael S. **Ruderman**1,2 and Nikolai S. Petrukhin3

A&A 631, A31 (**2019**)

https://doi.org/10.1051/0004-6361/201936198

The effect of siphon flow on kink oscillations of magnetic flux tubes is studied in the thin tube and thin boundary layer (TTTB) approximation. The presence of a transitional layer results in oscillation damping due to resonance absorption. To calculate the damping rate we use the regular perturbation method with the ratio of transitional layer thickness to tube radius as a small parameter. We found a dependence of the ratio of decrement to the oscillation frequency, γ/ω1, on the ratio, χ, of flow velocity magnitude to the Alfvén speed in the tube core. The general theoretical results are applied to a particular case where the density radial dependence in the transitional layer is linear. We consider two models. In the first model, the radial dependence of the velocity amplitude is such that the resonance in the transitional layer occurs where the flow velocity is zero. In the second model, the flow velocity is non-zero in the whole transitional layer. In both cases, γ/ω1 is an increasing function of χ. In the first case, the presence of flow can lead to an increase in γ/ω1 by more than a factor of two. In the second model, we only carry out the calculation in the case where the plasma density inside the tube is much larger than the density of the surrounding plasma. In this model, the effect of flow is less pronounced than in the first model, and the presence of flow can increase γ/ω1 by a factor of 0.25 at most. We discuss the application of the obtained results to coronal and prominence seismology. We conclude that while for typical values of velocity in coronal loops the effect of flow is weak, it can be quite substantial in prominence seismology.

Kink oscillations of cooling coronal loops with variable cross-section

M. S. **Ruderman**1,2, A. A. Shukhobodskiy1,3 and R. Erdélyi

A&A 602, A50 (**2017**)

http://www.aanda.org.sci-hub.cc/articles/aa/abs/2017/06/aa30162-16/aa30162-16.html

We study kink waves and oscillations in a thin expanding magnetic tube in the presence of flow. The tube consists of a core region and a thin transitional region at the tube boundary. In this region the plasma density monotonically decreases from its value in the core region to the value outside the tube. Both the plasma density and velocity of background flow vary along the tube and in time. Using the multiscale expansions we derive the system of two equations describing the kink oscillations. When there is no transitional layer the oscillations are described by the first of these two equations. We use this equation to study the effect of plasma density variation with time on kink oscillations of an expanding tube with a sharp boundary. We assume that the characteristic time of the density variation is much greater than the characteristic time of kink oscillations. Then we use the Wentzel-Kramer-Brillouin (WKB) method to derive the expression for the adiabatic invariant, which is the quantity that is conserved when the plasma density varies. The general theoretical results are applied to the kink oscillations of coronal magnetic loops. We consider an expanding loop with the half-circle shape and assume that the plasma temperature inside a loop decays exponentially with time. We numerically calculated the dependences of the fundamental mode frequency, the ratio of frequencies of the first overtone and fundamental mode, and the oscillation amplitude on time. We obtained that the oscillation frequency and amplitude increase and the frequency ratio decreases due to cooling. The amplitude increase is stronger for loops with a greater expansion factor. This effect is also more pronounced for higher loops. However, it is fairly moderate even for loops that are quite high.

Damping of prominence longitudinal oscillations due to mass accretion

Michael S. **Ruderman** and Manuel Luna

A&A 591, A131 **2016**

http://www.iac.es/preprints/files/PP16028.pdf

http://arxiv.org/pdf/1605.03376v1.pdf

We study the damping of longitudinal oscillations of a prominence thread caused by the mass accretion. We suggested a simple model describing this phenomenon. In this model we considered a thin curved magnetic tube filled with the plasma. The prominence thread is in the central part of the tube and it consists of dense cold plasma. The parts of the tube at the two sides of the thread are filled with hot rarefied plasma. We assume that there are flows of rarefied plasma toward the thread caused by the plasma evaporation at the magnetic tube footpoints. Our main assumption is that the hot plasma is instantaneously accommodated by the thread when it arrives at the thread, and its temperature and density become equal to those of the thread. Then we derive the system of ordinary differential equations describing the thread dynamics. We solve this system of ordinary differential equations in two particular cases. In the first case we assume that the magnetic tube is composed of an arc of a circle with two straight lines attached to its ends such that the whole curve is smooth. A very important property of this model is that the equations describing the thread oscillations are linear for any oscillation amplitude. We obtain the analytical solution of the governing equations. Then we obtain the analytical expressions for the oscillation damping time and periods. We find that the damping time is inversely proportional to the accretion rate. The oscillation periods increase with time. We conclude that the oscillations can damp in a few periods if the inclination angle is sufficiently small, not larger that 10^\circ\/, and the flow speed is sufficiently large, not less that 30~km s-1. In the second model we consider the tube with the shape of an arc of a circle. The thread oscillates with the pendulum frequency dependent exclusively of the radius of curvature of the arc. The damping depends on the mass accretion rate and the initial mass of the threads, that is the mass of the thread at the moment when it is perturbed. First we consider small amplitude oscillations and use the linear description. Then we consider nonlinear oscillations and assume that the damping is slow, meaning that the damping time is much larger that the characteristic oscillation time. The thread oscillations are described by the solution of the nonlinear pendulum problem with slowly varying amplitude. The nonlinearity reduces the damping time, however this reduction is small. Again the damping time is inversely proportional to the accretion rate. We also obtain that the oscillation periods decrease with time. However even for the largest initial oscillation amplitude considered in our article the period reduction does not exceed 20%. We conclude that the mass accretion can damp the motion of the threads rapidly. Thus, this mechanism can explain the observed strong damping of large-amplitude longitudinal oscillations. In addition, the damping time can be used to determine the mass accretion rate and indirectly the coronal heating.

On the Ratio of Periods of the Fundamental Harmonic and First Overtone of Magnetic Tube Kink Oscillations

M. S. **Ruderman** , N. S. Petrukhin, E. Pelinovsky
Solar Phys. **2016**

We study kink oscillations of thin magnetic tubes. We assume that the density inside and outside the tube (and possibly also the cross-section radius) can vary along the tube. This variation is assumed to be of such a form that the kink speed is symmetric with respect to the tube centre and varies monotonically from the tube ends to the tube centre. Then we prove a theorem stating that the ratio of periods of the fundamental mode and first overtone is a monotonically increasing function of the ratio of the kink speed at the tube centre and the tube ends. In particular, it follows from this theorem that the period ratio is lower than two when the kink speed increases from the tube ends to its centre, while it is higher than two when the kink speed decreases from the tube ends to its centre. The first case is typical for non-expanding coronal magnetic loops, and the second for prominence threads. We apply the general results to particular problems. First we consider kink oscillations of coronal magnetic loops. We prove that, under reasonable assumptions, the ratio of the fundamental period to the first overtone is lower than two and decreases when the loop size increases. The second problem concerns kink oscillations of prominence threads. We consider three internal density profiles: generalised parabolic, Gaussian, and Lorentzian. Each of these profiles contain the parameter α that is responsible for its sharpness. We calculate the dependence of the period ratio on the ratio of the mean to the maximum density. For all considered values of α we find that a formula relating the period ratio and the ratio of the mean and maximum density suggested by Soler, Goossens, and Ballester (Astron. Astrophys. 575, A123, 2015) gives a sufficiently good approximation to the exact dependence.

Propagating kink waves in thin twisted magnetic tubes with continuous equilibrium magnetic field⋆

M. S. **Ruderman**
A&A 575, A130 (**2015**)

In this paper, we study kink waves in twisted magnetic tubes. In the equilibrium state there is the electrical current with constant density inside the tube directed along the tube axis. This current creates the azimuthal magnetic field with the magnitude proportional to the distance from the tube axis inside the tube and inversely proportional to this distance outside the tube. We derive the dispersion equations for propagating waves and for unstable perturbations in the long wavelength approximation. We show that there are no solutions to the dispersion equation determining the frequencies of unstable perturbations, which implies that there are no unstable long kink modes. We study the dispersion equation for propagating waves both in the case when the plasma density is larger than that in the surrounding plasma as well as when it is smaller. In the first case we obtain that, depending on the wave number, the dispersion equation for propagating waves has either no solutions, or one solution, or two solutions. In the case when there is one solution, in the approximation of very weak twist, the wave mode propagates with the phase speed slightly larger than the kink speed. This wave mode is called the accelerated kink wave. In the case when there are two solutions to the dispersion equation, one of the two solutions gives the frequency of a quasi-mode that is subjected to the Alfvén resonance outside the tube. The other solution gives the frequency of a true eigenmode of linear ideal MHD. In the approximation of very weak twist its phase speed is smaller than the kink speed. This mode is called the decelerated kink wave. In the case of rarefied tube, depending on the wave number, the dispersion equation has either one or three solutions. When there is only one solution, the mode frequency is very close to the Alfvén frequency far from the tube, so the wave mode practically coincides with the Alfvén wave. When there are three solutions, the largest frequency practically coincides with the Alfvén frequency far from the tube. Two other solutions almost coincide. In all cases the wave modes existing in the case of rarefied tube are quasi-modes that are subjected to the Alfvén resonance. A possible application of the obtained results to the solar atmospheric seismology is discussed.

Possible Cross-Section for a Coronal Loop of Given Shape?

M. S. **Ruderman**
Solar Phys., February **2015**, Volume 290, Issue 2, pp 423-435
http://link.springer.com/article/10.1007/s11207-014-0607-6

We aim to answer the question about the cross-section of a planar coronal loop with a prescribed shape. We restrict the analysis to coronal loops embedded in a planar potential magnetic field. Then we carry out the analysis in the leading-order approximation with respect to the small parameter ϵ equal to the ratio of the characteristic size of the loop cross-section to the loop length. We show that, in this approximation, the loop cross-section can be prescribed arbitrarily at one of its footpoints. Then the loop cross-section at any other point is obtained by stretching or compressing the prescribed loop cross-section in the direction that is perpendicular to the loop axis and in the plane of the loop. The variation of the coefficient of stretching or compression along the loop can be chosen arbitrarily. In particular, it follows from this result that we can consider a planar loop of arbitrary shape and assume that its cross-section is circular everywhere and has a constant radius.

Kink Oscillations of Thin Magnetic Tubes with Discontinuous Density

M. S. **Ruderman**

Solar Physics, July **2014**, Volume 289, Issue 7, pp 2473-2485

We consider kink oscillations of thin magnetic tubes with the equilibrium density discontinuous in the axial direction. The aim is to find out what boundary conditions have to be used at a contact discontinuity where the equilibrium density jumps. At a contact discontinuity perturbations of all quantities but the density have to be continuous. However, in the thin-tube approximation, all these conditions cannot be satisfied simultaneously. It is shown that in the thin-tube approximation, there is a boundary layer with the thickness of the order of the tube radius that embraces the contact discontinuity. In this boundary layer the variation of the loop displacement and its axial derivative is negligible. In contrast, the total pressure variation in the boundary layer is very strong. Hence, the correct boundary conditions at a contact discontinuity in the thin-tube approximation are the continuity of the tube displacement and its axial derivative.

Nonlinear Kink Oscillations of Coronal Magnetic Loops

M. S. **Ruderman**, M. Goossens

Solar Physics, June **2014**, Volume 289, Issue 6, pp 1999-2020

We studied nonlinear kink oscillations of a thin magnetic tube using the cold-plasma approximation. We assumed that the plasma density varies along the tube but does not vary in the radial direction. Using the regular perturbation method, we show that the nonlinearity does not affect the oscillation amplitude. We also calculated the nonlinear correction to the oscillation frequency, which is proportional to the oscillation amplitude squared. As an example, we considered nonlinear oscillations of a coronal magnetic loop of half-circle shape in an isothermal atmosphere with equal plasma temperatures inside and outside the loop.

Damping of coronal loop kink oscillations due to mode conversion⋆

M. S. **Ruderman**1 and J. Terradas

A&A 555, A27 (**2013**)

The damping of kink oscillations of a thin magnetic tube due to mode conversion, also called resonant absorption, is studied. The tube consists of a homogeneous core region and an inhomogeneous annulus, where the density monotonically decreases from its value in the core region to the value in the surrounding plasma. The annulus is assumed to be thin, so the study is carried out in the thin tube thin boundary approximation. The equation governing the amplitude variation of kink oscillations is derived. The initial value problem for this equation is solved to study the resonant damping. This means that, in particular, we study the transient state before the loop oscillates with the stationary or nearly stationary state. The results are compared with those of the direct numerical modelling, and the agreement is found to be fairly good. On the basis of the solution to the initial value problem for the governing equation, the damping time is calculated and compared with that given by the classical theory of resonant absorption. It is found that the classical theory underestimates the damping time, with the error increasing with the increase of the annulus thickness. However, the error is not large, so the damping time given by the classical theory of resonant absorption can be taken as a sufficiently good approximation.

Resonant damping of kink oscillations of cooling coronal magnetic loops

M. S. **Ruderman**

A&A 534, A78 (**2011**)

The simultaneous effect of amplification due to cooling and damping due to resonant absorption on the kink oscillations of coronal loops is studied. The governing equation describing the kink oscillations is derived in the thin tube thin boundary layer approximation. The cooling time is assumed to be much larger than the oscillation period, and the Wentzel-Kramers-Brillouin (WKB) method is used to obtain the equation describing the dependence of the oscillation amplitude on time. This equation is solved numerically for various values of determining parameters. In particular, the question if the amplification due to cooling can balance the resonant damping and produce undamped oscillation is addressed. The conclusion is that the amplification due to cooling is not very efficient and can balance the resonant damping only when the density contrast is not very large and the cooling is very fast with the characteristic cooling time of the order of the oscillation period.

Analysis of Overtones in Transverse Oscillations of Coronal Loops of an Active Region.

Safna Banu, K., Maurya, R.A.
Sol Phys 299, 168 (**2024**).
https://doi.org/10.1007/s11207-024-02411-x
We investigate the fundamental mode and overtones in the transverse oscillations of coronal loops associated with an active region using intensity observations taken by the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO). The fundamental periods of the two selected coronal loops are found to be 17.0 minutes and 15.2 minutes, respectively. The first loop oscillated in the first and second overtones, with periods of around 6.9 minutes and 4.3 minutes, respectively. However, the second loop was detected only with the first overtone of approximately 7.7 minutes period. The period ratios of the fundamental to the first overtones of these loops are 1.24 and 0.99, respectively, while the fundamental-to-second-overtone period ratio of the first loop is 1.33. Thus, the deviation of period ratios from unity helps estimate the density scale height and the loop expansion factor. We obtained a density scale height of 11 Mm for the second loop and a loop expansion factor of 1.5 for the first coronal loop, considering that coronal loops have a greater effect on the loop expansion factor than on longitudinal density stratification associated with a sigmoidal active region. Using their lengths and periods of oscillations, we estimated a reasonable average magnetic field strength within a range of 20−30 G in the coronal loops.

Three-dimensional reconstruction of the streamer belt and other large-scale structures of the solar corona - I. Method:
F. **Saez**, A. Llebaria, P. Lamy and D. Vibert
A&A 473 (2007) 265-277 (Section 'The Sun')
http://www.aanda.org/10.1051/0004-6361:20066777

Magnetic Field Dynamics and Varying Plasma Emission in Large-scale Coronal Loops
S. **Şahin**1, V. Yurchyshyn2, P. Kumar3, A. Kilcik1, K. Ahn2, and X. Yang2
2019 ApJ 873 75
https://doi.org/10.3847/1538-4357/ab04aa
In this study we report detailed observations of magnetic environment at four footpoints of two warm coronal loops observed on **2016 May 5** in NOAA AR 12542 (Loop I) and **2015 December 17** in NOAA AR 12470 (Loop II). These loops were connecting a plage region with sunspot periphery (Loop I) and a sunspot umbra (Loop II). We used Solar Dynamics Observatory (SDO) and Goode Solar Telescope (GST) data to describe the phenomenon and understand its causes. The study indicates loop brightening episodes were associated with magnetic flux emergence and cancellation processes observed in SDO's Helioseismic and Magnetic Imager and GST's Near InfraRed Imaging Spectrapolarimeter data. The observed activity was driven by magnetic reconnection between small-scale emerging dipoles and large-scale pre-existing fields, suggesting that the reconnection occurred in the lower chromosphere at reconnection events, gradually filled the loops and as it cooled the visible density front propagated from one footpoint of the loop to another at a rate of 90–110 km s−1. This study also indicates that at least some of the bright loops seen in SDO Atmospheric Imaging Assembly images rooted in sunspot umbra may be heated due to magnetic activity taking place at the remote (nonsunspot) footpoint.
RHESSI Science Nuggets #349 Apr **2019**
http://sprg.ssl.berkeley.edu/~tohban/wiki/index.php/Warm_UV_loops_heated_by_small-scale_cancellation_events

HMI observations of linear polarization in a coronal loop prominence system
Pascal **Saint-Hilaire**
HMI Science Nuggets, #10, March **2014**
http://hmi.stanford.edu/hminuggets/?p=591
We examine the polarization of light emitted by a loop prominence system, near the Fe I line (6173 Å). It has a linearly polarized component, at times up to the level expected from pure Thomson scattering.

Observations of Linear Polarization in a Solar Coronal Loop Prominence System Observed near 6173 Å
Pascal **Saint-Hilaire**, Jesper Schou, Juan-Carlos Martínez Oliveros, Hugh S. Hudson, Säm Krucker, Hazel Bain, Sébastien Couvidat
2014, ApJL, 786 L19
http://arxiv.org/pdf/1402.7016v1.pdf
White-light observations by the Solar Dynamics Observatory's Helioseismic and Magnetic Imager of a loop-prominence system occurring in the aftermath of an X-class flare on **2013 May 13** near the eastern solar limb show a linearly polarized component, reaching up to ~20% at an altitude of ~33 Mm, about the maximal amount

expected if the emission were due solely to Thomson scattering of photospheric light by the coronal material. The mass associated with the polarized component was 8.2×1014 g. At 15 Mm altitude, the brightest part of the loop was 3(+/-0.5)% linearly polarized, only about 20% of that expected from pure Thomson scattering, indicating the presence of an additional unpolarized component at wavelengths near Fe I (617.33 nm), probably thermal emission. We estimated the free electron density of the white-light loop system to possibly be as high as 1.8×1012 cm−3.

Generation of a secondary shock wave during the oblique collision between a current sheet and a fast magnetosonic shock wave

J. I. **Sakai** and Y. Tanaka

A&A 468, 1075-1081 (**2007**)

It is shown that the fast magnetosonic shock with initial Alfvén Mach $M_A = 5.6$ compresses the current sheet, resulting in strong deformation of the current sheet. In the later stage a secondary fast magnetosonic shock wave can be generated almost perpendicular to the current sheet, and it propagates away to the opposite side of the original shock. This newly generated shock wave may emit a type II radio burst. The simulation results may be applied to a split of electromagnetic wave emissions when a shock wave associated with CMEs collides obliquely with a coronal streamer. For weak initial Alfvén Mach $M_A = 2.8$, a secondary shock wave does not appear, while the current sheet can be deformed and become unstable for tearing-like modes associated with magnetic reconnection.

Subarcsecond imaging of a solar active region filament with ALMA and IRIS

João M. Da Silva **Santos**, Stephen White, Stephen White, Kevin Reardon, Gianna Cauzzi, Stanislav Gunár, Petr Heinzel, Jorrit Leenaarts, and Jorrit Leenaarts

Front. Astron. Space Sci. 9: 898115. **2022**

https://www.frontiersin.org/articles/10.3389/fspas.2022.898115/pdf

https://arxiv.org/pdf/2204.13178.pdf

Quiescent filaments appear as absorption features on the solar disk when observed in chromospheric lines and at continuum wavelengths in the millimeter (mm) range. Active region (AR) filaments are their small-scale, low-altitude analogues, but they could not be resolved in previous mm observations. This spectral diagnostic can provide insight into the details of the formation and physical properties of their fine threads, which are still not fully understood. Here, we shed light on the thermal structure of an AR filament using high-resolution brightness temperature (Tb) maps taken with ALMA Band 6 complemented by simultaneous IRIS near-UV spectra, Hinode/SOT photospheric magnetograms, and SDO/AIA extreme-UV images. Some of the dark threads visible in the AIA 304 Å passband and in the core of Mg ii resonance lines have dark (Tb << 5,000 K) counterparts in the 1.25 mm maps, but their visibility significantly varies across the filament spine and in time. These opacity changes are possibly related to variations in temperature and electron density in filament fine structures. The coolest Tb values (<< 5,000 K) coincide with regions of low integrated intensity in the Mg ii h and k lines. ALMA Band 3 maps taken after the Band 6 ones do not clearly show the filament structure, contrary to the expectation that the contrast should increase at longer wavelengths based on previous observations of quiescent filaments. The ALMA maps are not consistent with isothermal conditions, but the temporal evolution of the filament may partly account for this. **13 April 2019**

CESRA # 3325 Jun **2022** https://www.astro.gla.ac.uk/users/eduard/cesra/?p=3325

Transverse oscillations in a coronal loop triggered by a jet

S. **Sarkar**, V. Pant, A. K. Srivastava, D. Banerjee

Solar Phys. Volume 291, Issue 11, pp 3269–3288 **2016**

https://arxiv.org/pdf/1611.04063v1.pdf

We detect and analyse transverse oscillations in a coronal loop, lying at the south east limb of the Sun as seen from the \textit{{Atmospheric Imaging Assembly}} (AIA) onboard \textit{{Solar Dynamics Observatory}} (SDO). The jet is believed to trigger transverse oscillations in the coronal loop. The jet originates from a region close to the coronal loop on **19 th September 2014** at 02:01:35 UT. The length of the loop is estimated to be between 377-539~Mm. Only one complete oscillation is detected with an average period of about 32±5~min. Using MHD seismologic inversion techniques, we estimate the magnetic field inside the coronal loop to be between 2.68−4.5~G. The velocity of the hot and cool components of the jet is estimated to be 168~km~s−1 and 43~km~s−1, respectively. The energy density of the jet is found to be greater than the energy density of the oscillating coronal loop. Therefore, we conclude that the jet {triggered} transverse oscillations in the coronal loop. To our knowledge, this is the first coronal loop seismology study using the properties of a jet propagation {to trigger} oscillations.

In situ measurements of the variable slow solar wind near sector boundaries

E. **Sanchez-Diaz** (IRAP), A. Rouillard, B. Lavraud (IRAP), E. Kilpua (FMI), J. Davies

ApJ 2019

https://arxiv.org/ftp/arxiv/papers/1911/1911.09683.pdf

The release of density structures at the tip of the coronal helmet streamers, likely as a consequence of magnetic reconnection, contributes to the mass flux of the slow solar wind. In situ measurements in the vicinity of the heliospheric plasma sheet of the magnetic field, protons and suprathermal electrons reveal details of the processes at play during the formation of density structures near the Sun. In a previous article, we exploited remote-sensing observations to derive a 3-D picture of the dynamic evolution of a streamer. We found evidence of the recurrent and continual release of dense blobs from the tip of the streamers. In the present paper, we interpret in situ measurements of the slow solar wind during solar maximum. Through both case and statistical analysis, we show that in situ signatures (magnetic field magnitude, smoothness and rotation, proton density and suprathermal electrons, in the first place) are consistent with the helmet streamers producing, in alternation, high-density regions (mostly disconnected) separated by magnetic flux ropes (mostly connected to the Sun). This sequence of emission of dense blobs and flux ropes also seems repeated at smaller scales inside each of the high-density regions. These properties are further confirmed with in situ measurements much closer to the Sun using Helios observations. We conclude on a model for the formation of dense blobs and flux ropes that explains both the in situ measurements and the remote-sensing observations presented in our previous studies. **2010 January 30, 2011 April 27, 2011 May 19, 2013 July 08**

Table 1. List of crossings of highly-tilted HCSs not contaminated by CMEs during solar cycle 24

Subarcsecond imaging of a solar active region filament with ALMA and IRIS

J. M. da Silva **Santos**, S. M. White, K. Reardon, G. Cauzzi, S. Gunár, P. Heinzel, J. Leenaarts

Front. Astron. Space Sci. 2022

https://arxiv.org/pdf/2204.13178.pdf

Quiescent filaments appear as absorption features on the solar disk when observed in chromospheric lines and at continuum wavelengths in the millimeter (mm) range. Active region (AR) filaments are their small-scale, low-altitude analogues, but they could not be resolved in previous mm observations. This spectral diagnostic can provide insight into the details of the formation and physical properties of their fine threads, which are still not fully understood. Here, we shed light on the thermal structure of an AR filament using high-resolution brightness temperature (Tb) maps taken with ALMA Band 6 complemented by simultaneous IRIS near-UV spectra, Hinode/SOT photospheric magnetograms, and SDO/AIA extreme-UV images. Some of the dark threads visible in the AIA 304 Å passband and in the core of Mg II resonance lines have dark (Tb<5000K) counterparts in the 1.25 mm maps, but their visibility significantly varies across the filament spine and in time. These opacity changes are possibly related to variations in temperature and electron density in filament fine structures. The coolest Tb values (<5000 K) coincide with regions of low integrated intensity in the Mg II h and k lines. ALMA Band 3 maps taken after the Band 6 ones do not clearly show the filament structure, contrary to the expectation that the contrast should increase at longer wavelengths based on previous observations of quiescent filaments. The ALMA maps are not consistent with isothermal conditions, but the temporal evolution of the filament may partly account for this. **April 13, 2019**

Modelling solar low-lying cool loops with optically thick radiative losses

C. **Sasso**, V. Andretta, D. Spadaro

A&A 583, A54 **2015**

http://arxiv.org/pdf/1508.05792v1.pdf

We investigate the increase of the DEM (differential emission measure) towards the chromosphere due to small and cool magnetic loops (height ≲8~Mm, T≲105~K). In a previous paper we analysed the conditions of existence and stability of these loops through hydrodynamic simulations, focusing on their dependence on the details of the optically thin radiative loss function used. In this paper, we extend those hydrodynamic simulations to verify if this class of loops exists and it is stable when using an optically thick radiative loss function. We study two cases: constant background heating and a heating depending on the density. The contribution to the transition region EUV output of these loops is also calculated and presented. We find that stable, quasi-static cool loops can be obtained by using an optically thick radiative loss function and a background heating depending on the density. The DEMs of these loops, however, fail to reproduce the observed DEM for temperatures between 4.6<logT<4.8. We also show the transient phase of a dynamic loop obtained by considering constant heating rate and find that its average DEM, interpreted as a set of evolving dynamic loops, reproduces quite well the observed DEM.

Magnetic structure of an activated filament in a flaring active region⋆

C. **Sasso**1,2, A. Lagg1 and S. K. Solanki
A&A 561, A98 (**2014**)
Aims. While the magnetic field in quiescent prominences has been widely investigated, less is known about the field in activated prominences. We report observational results on the magnetic field structure of an activated filament in a flaring active region. In particular, we studied its magnetic structure and line-of-sight flows during its early activated phase, shortly before it displayed signs of rotation.
Methods. We inverted the Stokes profiles of the chromospheric He i 10 830 Å triplet and the photospheric Si i 10 827 Å line observed in this filament by the Vacuum Tower Telescope on Tenerife. Using these inversion results, we present and interpret the first maps of the velocity and magnetic field obtained in an activated filament, both in the photosphere and the chromosphere.
Results. Up to five different magnetic components are found in the chromospheric layers of the filament, while outside the filament a single component is sufficient to reproduce the observations. Magnetic components displaying an upflow are preferentially located towards the centre of the filament, while the downflows are concentrated along its periphery. Moreover, the upflowing gas is associated with an opposite-polarity magnetic configuration with respect to the photosphere, while the downflowing gas is associated with a same-polarity configuration.
Conclusions. The activated filament has a very complex structure. Nonetheless, it is compatible with a flux rope, albeit a distorted one, in the normal configuration. The observations are best explained by a rising flux rope in which part of the filament material is still stably stored (upflowing material, rising with the field), while the rest is no longer stably stored and flows down along the field lines. **2005 May 18**

Multicomponent He I 10 830 Å profiles in an active filament
C. **Sasso**1,2, A. Lagg1, and S. K. Solanki1,3
A&A 526, A42 (**2011**)
Aims.We present new spectropolarimetric observations of the chromospheric He i 10 830 Å multiplet observed in a filament during its phase of activity.
Methods.The data were recorded with the new Tenerife Infrared Polarimeter (TIP-II) at the German Vacuum Tower Telescope (VTT) on **2005 May 18**. We inverted the He Stokes profiles using multiple atmospheric components.
Results.The observed He Stokes profiles display a remarkably wide variety of shapes. Most of the profiles show very broad Stokes *I* absorptions and complex and spatially variable Stokes *V* signatures. The inversion of the profiles shows evidence of different atmospheric blue- and redshifted components of the He i lines within the resolution element (~1 arcsec), with supersonic velocities of up to ~100 km s^{-1}. Up to five different atmospheric components are found in the same profile. We show that even these complex profiles can be reliably inverted.

SWAP Observations of the Long-term, Large-scale Evolution of the Extreme-ultraviolet Solar Corona
Daniel B. **Seaton**1, Anik De Groof1,2, Paul Shearer3, David Berghmans1, and Bogdan Nicula
2013 ApJ 777 72
The Sun Watcher with Active Pixels and Image Processing (SWAP) EUV solar telescope on board the Project for On-Board Autonomy 2 spacecraft has been regularly observing the solar corona in a bandpass near 17.4 nm since 2010 February. With a field of view of 54 × 54 arcmin, SWAP provides the widest-field images of the EUV corona available from the perspective of the Earth. By carefully processing and combining multiple SWAP images, it is possible to produce low-noise composites that reveal the structure of the EUV corona to relatively large heights. A particularly important step in this processing was to remove instrumental stray light from the images by determining and deconvolving SWAP's point-spread function from the observations. In this paper, we use the resulting images to conduct the first-ever study of the evolution of the large-scale structure of the corona observed in the EUV over a three year period that includes the complete rise phase of solar cycle 24. Of particular note is the persistence over many solar rotations of bright, diffuse features composed of open magnetic fields that overlie polar crown filaments and extend to large heights above the solar surface. These features appear to be related to coronal fans, which have previously been observed in white-light coronagraph images and, at low heights, in the EUV. We also discuss the evolution of the corona at different heights above the solar surface and the evolution of the corona over the course of the solar cycle by hemisphere.

Vector magnetic field measurements along a cooled stereo-imaged coronal loop
Thomas A. **Schad**, Matthew J. Penn, Haosheng Lin, Philip G. Judge
ApJ 833 5 **2016**
https://arxiv.org/pdf/1610.05332v1.pdf
The variation of the vector magnetic field along structures in the solar corona remains unmeasured. Using a unique combination of spectropolarimetry and stereoscopy, we infer and compare the vector magnetic field structure and three-dimensional morphology of an individuated coronal loop structure undergoing a thermal instability. We analyze spectropolarimetric data of the He I 10830 {\AA} triplet (1s2s3S1−1s2p3P2,1,0) obtained at the Dunn Solar Telescope with the Facility Infrared Spectropolarimeter on 19 September 2011. Cool coronal loops are identified by their prominent drainage signatures in the He I data (redshifts up to 185 km sec−1). Extinction of EUV

background radiation along these loops is observed by both the Atmospheric Imaging Assembly onboard the Solar Dynamics Observatory and the Extreme Ultraviolet Imager onboard spacecraft A of the Solar Terrestrial Relations Observatory, and is used to stereoscopically triangulate the loop geometry up to heights of 70 Mm (0.1Rsun) above the solar surface. The He I polarized spectra along this loop exhibit signatures indicative of atomic-level polarization as well as magnetic signatures through the Hanle and Zeeman effects. Spectropolarimetric inversions indicate that the magnetic field is generally oriented along the coronal loop axis, and provide the height dependence of the magnetic field intensity. The technique we demonstrate is a powerful one that may help better understand the thermodynamics of coronal fine structure magnetism.

A Bayesian Approach to Period Searching in Solar Coronal Loops

Bryan **Scherrer**1 and David McKenzie

2017 ApJ 837 24

We have applied a Bayesian generalized Lomb–Scargle period searching algorithm to movies of coronal loop images obtained with the Hinode X-ray Telescope (XRT) to search for evidence of periodicities that would indicate resonant heating of the loops. The algorithm makes as its only assumption that there is a single sinusoidal signal within each light curve of the data. Both the amplitudes and noise are taken as free parameters. It is argued that this procedure should be used alongside Fourier and wavelet analyses to more accurately extract periodic intensity modulations in coronal loops. The data analyzed are from XRT Observation Program #129C: "MHD Wave Heating (Thin Filters)," which occurred during **2006 November 13** and focused on active region 10293, which included coronal loops. The first data set spans approximately 10 min with an average cadence of 2 s, 2" per pixel resolution, and used the Al-mesh analysis filter. The second data set spans approximately 4 min with a 3 s average cadence, 1" per pixel resolution, and used the Al-poly analysis filter. The final data set spans approximately 22 min at a 6 s average cadence, and used the Al-poly analysis filter. In total, 55 periods of sinusoidal coronal loop oscillations between 5.5 and 59.6 s are discussed, supporting proposals in the literature that resonant absorption of magnetic waves is a viable mechanism for depositing energy in the corona.

Explaining Inverted Temperature Loops in the Quiet Solar Corona with Magnetohydrodynamic Wave Mode Conversion

Avery J. **Schiff**, Steven R. Cranmer

ApJ **831** 10 **2016**

http://arxiv.org/pdf/1608.04398v1.pdf

Coronal loops trace out bipolar, arch-like magnetic fields above the Sun's surface. Recent measurements that combine rotational tomography, extreme ultraviolet imaging, and potential-field extrapolation have shown the existence of large loops with inverted temperature profiles; i.e., loops for which the apex temperature is a local minimum, not a maximum. These "down loops" appear to exist primarily in equatorial quiet regions near solar minimum. We simulate both these and the more prevalent large-scale "up loops" by modeling coronal heating as a time-steady superposition of: (1) dissipation of incompressible Alfven-wave turbulence, and (2) dissipation of compressive waves formed by mode conversion from the initial population of Alfven waves. We found that when a large percentage (> 99%) of the Alfven waves undergo this conversion, heating is greatly concentrated at the footpoints and stable "down loops" are created. In some cases we found loops with three maxima that are also gravitationally stable. Models that agree with the tomographic temperature data exhibit higher gas pressures for "down loops" than for "up loops," which is consistent with observations. These models also show a narrow range of Alfven wave amplitudes: 3 to 6 km/s at the coronal base. This is low in comparison to typical observed amplitudes of 20 to 30 km/s in bright X-ray loops. However, the large-scale loops we model are believed to comprise a weaker diffuse background that fills much of the volume of the corona. By constraining the physics of loops that underlie quiescent streamers, we hope to better understand the formation of the slow solar wind.

THE CORONAL LOOP INVENTORY PROJECT: EXPANDED ANALYSIS AND RESULTS

J. T. **Schmelz**1,2,3, G. M. Christian3, and R. A. Chastain3

2016 ApJ 831 199

https://arxiv.org/pdf/1705.09360.pdf

We have expanded upon earlier work that investigates the relative importance of coronal loops with isothermal versus multithermal cross-field temperature distributions. These results are important for determining if loops have substructure in the form of unresolved magnetic strands. We have increased the number of loops targeted for temperature analysis from 19 to 207 with the addition of 188 new loops from multiple regions. We selected all loop segments visible in the 171 Å images of the Atmospheric Imaging Assembly (AIA) that had a clean background. Eighty-six of the new loops were rejected because they could not be reliably separated from the background in other AIA filters. Sixty-one loops required multithermal models to reproduce the observations. Twenty-eight loops were effectively isothermal, that is, the plasma emission to which AIA is sensitive could not be distinguished from isothermal emission, within uncertainties. Ten loops were isothermal. Also, part of our inventory was one small flaring loop, one very cool loop whose temperature distribution could not be constrained by the AIA data, and one loop with inconclusive results. Our survey can confirm an unexpected result from the pilot study: we found no isothermal loop segments where we could properly use the 171-to-193 ratio method, which would be similar to the analysis done for many loops observed with TRACE and EIT. We recommend caution to observers who assume the loop plasma is isothermal, and hope that these results will influence the direction of coronal heating models and the effort modelers spend on various heating scenarios.

THE CORONAL LOOP INVENTORY PROJECT

J. T. **Schmelz**, S. Pathak, G. M. Christian, R. S. S. Dhaliwal, and K. S. Paul

2015 ApJ 813 71

Most coronal physicists now seem to agree that loops are composed of tangled magnetic strands and have both isothermal and multithermal cross-field temperature distributions. As yet, however, there is no information on the relative importance of each of these categories, and we do not know how common one is with respect to the other. In this paper, we investigate these temperature properties for all loop segments visible in the 171-Å image of AR 11294, which was observed by the Atmospheric Imaging Assembly (AIA) on **2011 September 15**. Our analysis revealed 19 loop segments, but only 2 of these were clearly isothermal. Six additional segments were effectively isothermal, that is, the plasma emission to which AIA is sensitive could not be distinguished from isothermal emission, within measurement uncertainties. One loop had both isothermal transition region and multithermal coronal solutions. Another five loop segments require multithermal plasma to reproduce the AIA observations. The five remaining loop segments could not be separated reliably from the background in the crucial non-171-Å AIA images required for temperature analysis. We hope that the direction of coronal heating models and the efforts modelers spend on various heating scenarios will be influenced by these results.

The Flow-chart Loop: Temperature, Density, and Cooling Observables Supporting Nanoflare Coronal Heating Models

J. T. **Schmelz**, S. Pathak, R. S. Dhaliwal, G. M. Christian, and C. B. Fair

2014 ApJ 795 139

We have tested three controversial properties for a target loop observed with the Atmospheric Imaging Assembly: (1) overdense loops; (2) long-lifetime loops; and (3) multithermal loops. Our loop is overdense by a factor of about 10 compared to results expected from steady uniform heating models. If this were the only inconsistency, our loop could still be modeled as a single strand, but the density mismatch would imply that the heating must be impulsive. Moving on to the second observable, however, we find that the loop lifetime is at least an order of magnitude greater than the predicted cooling time. This implies that the loop cannot be composed of a single flux tube, even if the heating were dynamic, and must be multi-stranded. Finally, differential emission measure analysis shows that the cross-field temperature of the target loop is multithermal in the early and middle phases of its lifetime, but effectively isothermal before it fades from view. If these multithermal cooling results are found to be widespread, our results could resolve the original coronal loop controversy of "isothermal" versus "multithermal" cross-field temperatures. That is, the cross-field temperature is not always "multithermal" nor is it always "isothermal," but might change as the loop cools. We find that the existence and evolution of this loop is consistent with predictions of nanoflare heating.

ATMOSPHERIC IMAGING ASSEMBLY OBSERVATIONS OF CORONAL LOOPS: CROSS-FIELD TEMPERATURE DISTRIBUTIONS

J. T. **Schmelz**, B. S. Jenkins, and S. Pathak

2013 ApJ 770 14

We construct revised response functions for the Atmospheric Imaging Assembly (AIA) using the new atomic data, ionization equilibria, and coronal abundances available in CHIANTI 7.1. We then use these response functions in multithermal analysis of coronal loops, which allows us to determine a specific cross-field temperature distribution without ad hoc assumptions. Our method uses data from the six coronal filters and the Monte Carlo solutions available from our differential emission measure (DEM) analysis. The resulting temperature distributions are not consistent with isothermal plasma. Therefore, the observed loops cannot be modeled as single flux tubes and must be composed of a collection of magnetic strands. This result is now supported by observations from the High-resolution Coronal Imager, which show fine-scale braiding of coronal strands that are reconnecting and releasing energy. Multithermal analysis is one of the major scientific goals of AIA, and these results represent an important step toward the successful achievement of that goal. As AIA DEM analysis becomes more straightforward, the solar community will be able to take full advantage of the state-of-the-art spatial, temporal, and temperature resolution of the instrument.

ISOTHERMAL AND MULTITHERMAL ANALYSIS OF CORONAL LOOPS OBSERVED WITH ATMOSPHERIC IMAGING ASSEMBLY. II. 211 Å SELECTED LOOPS

J. T. **Schmelz**1,2, B. T. Worley1, D. J. Anderson1, S. Pathak1, J. A. Kimble1, B. S. Jenkins1 and S. H. Saar

2011 ApJ 739 33

An important component of coronal loop analysis involves conflicting results on the cross-field temperature distribution. Are loops isothermal or multithermal? The Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory was designed in part to answer this question. AIA has a series of coronal filters that peak at different temperatures and cover the entire active region temperature range. These properties should make AIA ideal for multithermal analysis, but recent results have shown that the response functions of two of the filters, AIA 94 and 131 Å, are missing a significant number of low-temperature emission lines. Here we analyze coronal loops from several active regions that were chosen in the 211 Å channel of AIA, which has a peak response temperature of log T = 6.3. The differential emission measure (DEM) analysis of the 12 loops in our sample reveals that using data from the 131 Å AIA filter distorts the results, and we have no choice but to do the analysis without these data. The 94 Å data do not appear to be as important, simply because the chosen loops are not visible in this channel. If we eliminate the 131 Å data, however, we find that our DEM analysis is not well constrained on the cool temperature end of six of our loops. The information revealed by our 211 selected loops indicates that additional atomic data are required in order to pin down the cross-field temperature distribution.

ISOTHERMAL AND MULTITHERMAL ANALYSIS OF CORONAL LOOPS OBSERVED WITH AIA

J. T. **Schmelz**, B. S. Jenkins, B. T. Worley, D. J. Anderson, S. Pathak and J. A. Kimble

2011 ApJ 731 49

The coronal filters in the Atmospheric Imaging Assembly (AIA) aboard the Solar Dynamics Observatory peak at different temperatures; the series covers the entire active region temperature range, making AIA ideal for multithermal analysis. Here, we analyze coronal loops from several active regions that have been observed by AIA. We have specifically targeted cool loops (or at least loops with a cool component) that were chosen in the 171 Å channel of AIA, which has a peak response temperature of log T = 5.8. We wanted to determine if the loops could be described as isothermal or multithermal. We find that several of our 12 loops have narrow temperature distributions, which may be consistent with isothermal plasma; these can be modeled with a single flux tube. Other loops have intermediate-width temperature distributions, appear well-constrained, and should be multi-stranded. The remaining loops, however, have unrealistically broad differential emission measures. We find that this problem is the result of missing low-temperature lines in the AIA 131 Å channel. If we repeat the analysis without the 131 Å data, these loops also appear to be well-constrained and multi-stranded.

ATMOSPHERIC IMAGING ASSEMBLY MULTITHERMAL LOOP ANALYSIS: FIRST RESULTS **SDO**

J. T. **Schmelz**1,2, J. A. Kimble1, B. S. Jenkins1, B. T. Worley1, D. J. Anderson1, S. Pathak1, and S. H. Saar2

Astrophysical Journal Letters, 725:L34–L37, **2010**

The Atmospheric Imaging Assembly (AIA) on board the *Solar Dynamics Observatory* has state-of-the-art spatial resolution and shows the most detailed images of coronal loops ever observed. The series of coronal filters peak at different temperatures, which span the range of active regions. These features represent a significant improvement over earlier coronal imagers and make AIA ideal for multithermal analysis. Here, we targeted a 171 Å coronal loop in AR 11092 observed by AIA on **2010 August 3**. Isothermal analysis using the 171-to-193 ratio gave a temperature of log $T \approx 6.1$, similar to the results of Extreme ultraviolet Imaging Spectrograph (EIT) and *TRACE*. Differential emission measure analysis, however, showed that the plasma was multithermal, not isothermal, with the bulk of the emission measure at log $T > 6.1$. The result from the isothermal analysis, which is the average of the true plasma distribution weighted by the instrument response functions, appears to be deceptively low. These results have potentially serious implications: EIT and *TRACE* results, which use the same isothermal method, show substantially smaller temperature gradients than predicted by standard models for loops in hydrodynamic equilibrium and have been used as strong evidence in support of footpoint heating models. These implications may have to be re-examined in the wake of new results from AIA.

Multi-stranded and Multi-thermal Solar Coronal Loops: Evidence from Hinode X-ray Telescope and EUV Imaging Spectrometer Data

J. T. **Schmelz**, S. H. Saar, K. Nasraoui, V. L. Kashyap, M. A. Weber, E. E. DeLuca and L. Golub

2010 ApJ 723 1180-1187

Data from the X-Ray Telescope (XRT) and the EUV Imaging Spectrometer (EIS) on the Japanese/USA/UK Hinode spacecraft were used to investigate the spatial and thermal properties of an isolated quiescent coronal loop. We constructed differential emission measure (DEM) curves using Monte Carlo based, iterative forward fitting algorithms. We studied the loop as a whole, in segments, in transverse cuts, and point-by-point, always with some form of background subtraction, and find that the loop DEM is neither isothermal nor extremely broad, with approximately 96% of the EM between 6.2 $\leq$log T$\leq$ 6.7, and an EM-weighted temperature of log T = 6.48 ± 0.16. We find evidence for a gradual change in temperature along the loop, with log T increasing only by 0.1 from the footpoints to the peak. The combine XRT-EIS data set does a good job of constraining the temperature distribution for coronal loop plasma. Our studies show that the strong constraints at high and low temperatures provided by the combined data set are crucial for obtaining reasonable solutions. These results confirm that the observations of at least some loops are not consistent with isothermal plasma, and therefore cannot be modeled with a single flux tube and must be multi-stranded. **13 May 2007**

Reconstruction of a helical prominence in 3D from IRIS spectra and images

B. **Schmieder**, M. Zapiór A. López Ariste, P. Levens, N. Labrosse, R. Gravet

A&A 606, A30 **2017**

https://arxiv.org/pdf/1706.08078.pdf

Movies of prominences obtained by space instruments e.g. the Solar Optical Telescope (SOT) aboard the {\it Hinode} satellite and the Interface Region Imaging Spectrograph (IRIS) with high temporal and spatial resolution revealed the tremendous dynamical nature of prominences. { Knots of plasma belonging to prominences} appear to travel along both vertical and horizontal thread-like loops, with highly dynamical nature.

The aim of the paper is to reconstruct the 3D shape of a helical prominence observed over two and a half hours by IRIS.

From the IRIS \ion{Mg}{ii} k spectra we compute Doppler shifts of the plasma inside the prominence and from the slit-jaw images (SJI){ we derive the transverse field in the plane of the sky. Finally we obtain the velocity vector field of the knots in 3D.

We reconstruct the real trajectories of nine knots travelling along ellipses.

The spiral-like structure of the prominence observed in the plane of the sky is mainly due to the projection effect of long arches of threads (up to 8 ×104 km). Knots run along more or less horizontal threads with velocities reaching 65 km s−1. The dominant driving force is the gas pressure. **17 July 2014**

Magnetic Field and Plasma Diagnostics from Coordinated Prominence Observations

B. **Schmieder**,1 P. Levens,2 K. Dalmasse,3 N. Mein,1 P. Mein,1 A. Lopez-Ariste,4 N. Labrosse,2 and P. Heinzel5

Ground-based Solar Observations in the Space Instrumentation Era

ASP Conference Series, Vol. 504, p. 119, **2016**

http://aspbooks.org/publications/504/119.pdf

We study the magnetic field in prominences from a statistical point of view, by using THEMIS in the MTR mode, performing spectropolarimetry of the He I D3 line. Combining these measurements with spectroscopic data from IRIS, Hinode/EIS as well as ground-based telescopes, such as the Meudon Solar Tower, we infer the temperature, density, and flow velocities of the plasma. There are a number of open questions that we aim to answer: - What is the general direction of the magnetic field in prominences? Is the model using a single orientation of magnetic field always valid for atypical prominences? %- Does this depend on the location of the filament on the disk (visible in Hα, in He II 304 Å) over an inversion line between weak or strong network ? - Are prominences in a weak environment field dominated by gas pressure? - Measuring the Doppler shifts in Mg II lines (with IRIS) and in Hα can tell us if there are substantial velocities to maintain vertical rotating structures, as has been suggested for tornado-like prominences. We present here some results obtained with different ground-based and space-based instruments in this framework. **September 24, 2013**,

Open questions on prominences from coordinated observations by IRIS, Hinode, SDO/AIA, THEMIS, and the Meudon/MSDP

Brigitte **Schmieder**, Hui Tian, Arturo Lopez Ariste, Nicole Mein, Pierre Mein, Kevin Dalmasse, Leon Golub

A&A, 569, A85 **2014**

http://arxiv.org/pdf/1407.3171v1.pdf

Context. A large prominence was observed on **September 24, 2013**, for three hours (12:12 UT -15:12 UT) with the newly launched (June 2013) Interface Region Imaging Spectrograph (IRIS), THEMIS (Tenerife), the Hinode Solar Optical Telescope (SOT), the Solar Dynamic Observatory Atmospheric Imaging Assembly (SDO/AIA), and the Multichannel Subtractive Double Pass spectrograph (MSDP) in the Meudon Solar Tower.

Aims. The aim of this work is to study the dynamics of the prominence fine structures in multiple wavelengths to understand their formation.
Methods. The spectrographs IRIS and MSDP provided line profiles with a high cadence in Mg II and in Halpha lines.
Results. The magnetic field is found to be globally horizontal with a relatively weak field strength (8-15 Gauss). The Ca II movie reveals turbulent-like motion that is not organized in specific parts of the prominence. On the other hand, the Mg II line profiles show multiple peaks well separated in wavelength. Each peak corresponds to a Gaussian profile, and not to a reversed profile as was expected by the present non-LTE radiative transfer modeling.
Conclusions. Turbulent fields on top of the macroscopic horizontal component of the magnetic field supporting the prominence give rise to the complex dynamics of the plasma. The plasma with the high velocities (70 km/s to 100 km/s if we take into account the transverse velocities) may correspond to condensation of plasma along more or less horizontal threads of the arch-shape structure visible in 304 A. The steady flows (5 km/s) would correspond to a more quiescent plasma (cool and prominence-corona transition region) of the prominence packed into dips in horizontal magnetic field lines. The very weak secondary peaks in the Mg II profiles may reflect the turbulent nature of parts of the prominence.

Proper horizontal photospheric flows in a filament channel

B. **Schmieder**, T. Roudier, N. Mein, P. Mein, J. M. Malherbe and R. Chandra

A&A 564, A104 (**2014**)

Context. An extended filament in the central part of the active region NOAA 11106 crossed the central meridian on **Sept. 17, 2010** in the southern hemisphere. It has been observed in Hα with the THEMIS telescope in the Canary Islands and in 304 Å with the EUV imager (AIA) onboard the Solar Dynamic Observatory (SDO).
Counterstreaming along the Hα threads and bright moving blobs (jets) along the 304 Å filament channel were observed during 10 h before the filament erupted at 17:03 UT.
Aims. The aim of the paper is to understand the coupling between magnetic field and convection in filament channels and relate the horizontal photospheric motions to the activity of the filament.
Methods. An analysis of the proper photospheric motions using SDO/HMI continuum images with the new version of the coherent structure tracking (CST) algorithm developed to track granules, as well as the large scale photospheric flows, was performed for three hours. Using corks, we derived the passive scalar points and produced a map of the cork distribution in the filament channel. Averaging the velocity vectors in the southern hemisphere in each latitude in steps of 3.5 arcsec, we defined a profile of the differential rotation.
Results. Supergranules are clearly identified in the filament channel. Diverging flows inside the supergranules are similar in and out of the filament channel. Converging flows corresponding to the accumulation of corks are identified well around the Hα filament feet and at the edges of the EUV filament channel. At these convergence points, the horizontal photospheric velocity may reach 1 km s-1, but with a mean velocity of 0.35 km s-1. In some locations, horizontal flows crossing the channel are detected, indicating eventually large scale vorticity.
Conclusions. The coupling between convection and magnetic field in the photosphere is relatively strong. The filament experienced the convection motions through its anchorage points with the photosphere, which are magnetized areas (ends, feet, lateral extensions of the EUV filament channel). From a large scale point-of-view, the differential rotation induced a shear of 0.1 km s-1 in the filament. From a small scale point-of-view, any convective motions favored the interaction of the parasitic polarities responsible for the anchorages of the filament to the photosphere with the surrounding network and may explain the activity of the filament.

Propagating Waves Transverse to the Magnetic Field in a Solar Prominence

B. **Schmieder**, T.A. Kucera, K. Knizhnik, M. Luna, A. Lopez-Ariste, and D.Toot

E-print, Sept **2013**; **2013** ApJ 777 108

We report an unusual set of observations of waves in a large prominence pillar which consist of pulses propagating perpendicular to the prominence magnetic field. We observe a huge quiescent prominence with the Solar Dynamics Observatory (SDO) Atmospheric Imaging Assembly (AIA) in EUV on **2012 October 10** and only a part of it, the pillar, which is a foot or barb of the prominence, with the Hinode Solar Optical Telescope (SOT) (in Ca II and Hα lines), Sac Peak (in Hα, Hβ and Na-D3 lines), THEMIS (?T?lescope H?liographique pour l? Etude du Magn?tisme et des Instabilit?s Solaires?) with the MTR (MulTi-Raies) spectropolarimeter (in He D3 line). The THEMIS/MTR data indicates that the magnetic field in the pillar is essentially horizontal and the observations in the optical domain show a large number of horizontally aligned features on a much smaller scale than the pillar as a whole. The data is consistent with a model of cool prominence plasma trapped in the dips of horizontal field lines. The SOT and Sac Peak data over the 4 hour observing period show vertical oscillations appearing as wave pulses. These pulses, which include a Doppler signature, move vertically, perpendicular to the field direction, along thin quasi-vertical columns in the much broader pillar. The pulses have a velocity of propagation of about 10 km s−1, a period about 300 sec, and a wavelength around 2000 km. We interpret these waves in terms of fast magneto-sonic waves and discuss possible wave drivers.

ERRATUM: B. Schmieder et al. **2014** ApJ 781 129

Solar filament eruptions and their physical role in triggering Coronal Mass Ejections

Schmieder B., Demoulin P., Aulanier G. Review

E-print, Dec **2012**; Advances in Space Research, v. 51, No. 11, p. 1967-1980, **2013, File**

Solar filament eruptions play a crucial role in triggering coronal mass ejections (CMEs). More than 80 % of eruptions lead to a CME. This correlation has been studied extensively during the past solar cycles and the last long solar minimum. The statistics made on events occurring during the rising phase of the new solar cycle 24 is in agreement with this finding. Both filaments and CMEs have been related to twisted magnetic fields. Therefore, nearly all the MHD CME models include a twisted flux tube, called a flux rope. Either the flux rope is present long before the eruption, or it is built up by reconnection of a sheared arcade from the beginning of the eruption. In order to initiate eruptions, different mechanisms have been proposed: new emergence of flux, and/or dispersion of the external magnetic field, and/or reconnection of field lines below or above the flux rope. These mechanisms reduce the downward magnetic tension and favor the rise of the flux rope. Another mechanism is the kink instability when the configuration is twisted too much. In this paper we open a forum of discussions revisiting observational and theoretical papers to understand which mechanisms trigger the eruption. We conclude that all the above quoted mechanisms could bring the flux rope to an unstable state. However, the most efficient mechanism for CMEs is the loss-of-equilibrium or torus instability, when the flux rope has reached an unstable threshold determined by a decay index of the external magnetic field.

27 May 2005, 4-7 Dec 2007, 17 September 2010, 3 November 2010, 23 January 2012,

Velocity vectors of a quiescent prominence observed by Hinode/SOT and the MSDP (Meudon)*

B. **Schmieder**1, R. Chandra1, A. Berlicki2 and P. Mein1

A&A 514, A68 (**2010**)

Context. The dynamics of prominence fine structures present a challenge to our understanding of the formation of cool plasma prominence embedded in the hot corona.

Aims. Observations performed by the high resolution Hinode/SOT telescope allow us to compute velocities perpendicular to the line-of-sight or transverse velocities. Combining simultaneous observations obtained in Hα with Hinode/SOT and the MSDP spectrograph operating in the Meudon solar tower, we derive the velocity vectors of a quiescent prominence.

Methods. The velocities perpendicular to the line-of-sight are measured using a time-slice technique and the Doppler shifts velocity using the bisector method.

Results. The Doppler shifts of bright threads derived from the MSDP show counterstreaming of the order of 5 km s-1 in the prominence and reaching 15 km s-1 at the edges of the prominence. Even though they are minimum values because of seeing effects, they are of the same order as the transverse velocities.

Conclusions. These measurements are very important because they suggest that the vertical structures detected by SOT may not be true vertical magnetic structures in the sky plane. The vertical structures could be a pile up of dips in more or less horizontal magnetic field lines in a 3D perspective, as proposed by many MHD modelers. In our analysis, we also calibrate the Hinode Hα data using MSDP observations obtained simultaneously.

Solar prominences

Brigitte **Schmieder**, Guillaume Aulanier and Tibor TËorËok

Proceedings of the International Astronomical Union / Volume 4 / Symposium S257, pp 223 – 232, Published online: 16 Март **2009, File**

Solar filaments (or prominences) are magnetic structures in the corona. They can be represented by twisted flux ropes in a bipolar magnetic environment. In such models, the dipped field lines of the flux rope carry the filament material and parasitic polarities in the filament channel are responsible for the existence of the lateral feet of prominences. **Review**

Magnetic causes of the eruption of a quiescent filament

B. **Schmieder**1, V. Bommier2, Y. Kitai3, T. Matsumoto3, T.T. Ishii3,
M. Hagino3, H. Li4, L. Golub5

E-print, Nov 2007, Solar Phys. (**2008**) 247: 321–333

During the JOP178 campaign in August 2006, we observed the disappearance of our target, a large quiescent filament located at S25°, after an observation time of three days (24 August to 26 August). Multi-wavelength instruments were operating: THEMIS/MTR ("MulTi-Raies") vector magnetograph, TRACE ("Transition Region and Coronal Explorer") at 171 Å and 1600 Å and Hida Domeless Solar telescope. Counterstreaming flows (+/−10 km s-1) in the filament were detected more than 24 hours before its eruption. A slow rise of the global structure started during this time period with a velocity estimated to be of the order of 1 kms-1. During the hour before the eruption (26 August around 09:00 UT) the velocity reached 5 kms-1. The filament eruption is suspected to be responsible for a slow CME observed by LASCO around 21:00 UT on 26 August. No brightening in H〈 or in coronal lines, no new emerging polarities in the filament channel, even with the high polarimetry sensitivity of THEMIS, were detected. We measured a relatively large decrease of the photospheric magnetic field strength of the network (from 400 G to 100 G), whose downward magnetic tension provides stability to the underlying stressed filament magnetic fields. According to some MHD models based on turbulent photospheric diffusion, this gentle decrease of magnetic strength (the tension) could act as the destabilizing mechanism which first leads to the slow filament rise and its fast eruption.

Prominence Mass Supply and the Cavity

Donald J. **Schmit**1, S. Gibson2, M. Luna3,4, J. Karpen5, and D. Innes

2013 ApJ 779 156

A prevalent but untested paradigm is often used to describe the prominence-cavity system: the cavity is under-dense because it is evacuated by supplying mass to the condensed prominence. The thermal non-equilibrium (TNE) model of prominence formation offers a theoretical framework to predict the thermodynamic evolution of the prominence and the surrounding corona. We examine the evidence for a prominence-cavity connection by comparing the TNE model with diagnostics of dynamic extreme ultraviolet (EUV) emission surrounding the prominence, specifically prominence horns. Horns are correlated extensions of prominence plasma and coronal plasma which appear to connect the prominence and cavity. The TNE model predicts that large-scale brightenings will occur in the Solar Dynamics Observatory Atmospheric Imaging Assembly 171 Å bandpass near the prominence that are associated with the cooling phase of condensation formation. In our simulations, variations in the magnitude of footpoint heating lead to variations in the duration, spatial scale, and temporal offset between emission enhancements in the other EUV bandpasses. While these predictions match well a subset of the horn observations, the range of variations in the observed structures is not captured by the model. We discuss the implications of our one-dimensional loop simulations for the three-dimensional time-averaged equilibrium in the prominence and the cavity. Evidence suggests that horns are likely caused by condensing prominence plasma, but the larger question of whether this process produces a density-depleted cavity requires a more tightly constrained model of heating and better knowledge of the associated magnetic structure.

DIAGNOSING THE PROMINENCE-CAVITY CONNECTION

Donald J. **Schmit**1,2 and Sarah Gibson

2013 ApJ 770 35

Prominences and cavities are ubiquitously observed together, but the physical link between these disparate structures has not been established. We address this issue by using dynamic emission in the extreme ultraviolet to probe the connections of these structures. The SDO/AIA observations show that the cavity exhibits excessive emission variability compared to the surrounding quiet-Sun streamer, particularly in the 171 Å bandpass. We find that this dynamic emission takes the form of coherent loop-like brightening structures which emanate from the prominence into the central cavity. The geometry of these structures, dubbed prominence horns, generally mimics the curvature of the cavity boundary. We use a space-time statistical analysis of two cavities in multiple AIA bandpasses to constrain the energetic properties of 45 horns. In general, we find there is a positive correlation between the light curves of the horns in the 171 Å and 193 Å bandpasses; however, the 193 Å emission is a factor of five weaker. There is also a strong correlation between structural changes to the prominence as viewed in the He II 304 Å bandpass and the enhanced 171 Å emission. In that bandpass, the prominence appears to extend several megameters along the 171 Å horn where we observe co-spatial, co-temporal 304 Å and 171 Å emission dynamics. We present these observations as evidence of the magnetic and energetic connection between the prominence and the cavity. Further modeling work is necessary to explain the physical source and consequences of these events, particularly in the context of the traditional paradigm: the cavity is underdense because it supplies mass to the overdense prominence.

SLOW MAGNETOACOUSTIC WAVE OSCILLATION OF AN EXPANDING CORONAL LOOP

J. M. **Schmidt**1,2 and L. Ofman

2011 ApJ 739 75

We simulated an expanding loop or slow coronal mass ejection (CME) in the solar corona dimensioned with size parameters taken from real coronal expanding loops observed with the STEREO spacecraft. We find that the loop expands to Sun's size within about one hour, consistent with slow CME observations. At the top of the loop, plasma is being blown off the loop, enabled with the reconnection between the loop's flux rope magnetic field and the radial magnetic field of the Sun, thus yielding feeding material for the formation of the slow solar wind. This mechanism is in accordance with the observed blob formation of the slow solar wind. We find wave packets traveling with local sound speed downward toward the footpoints of the loop, already seen in coronal seismology observations and simulations of stationary coronal loops. Here, we generalize these results for an expanding medium. We also find a reflection of the wave packets, identified as slow magnetoacoustic waves, at the footpoints of the loop. This confirms the formation of standing waves within the coronal loop. In particular, the reflected waves can partly escape the loop top and contribute to the heating of the solar wind. The present study improves our understanding on how loop material can emerge to form blobs, major ingredients of slow CMEs, and how the release of the wave energy stored in slow magnetoacoustic waves, and transported away from the Sun within expanding loops, contributes to the acceleration and formation of the slow solar wind.

FORWARD MODELING CAVITY DENSITY: A MULTI-INSTRUMENT DIAGNOSTIC

D. J. **Schmit**1,2 and S. E. Gibson

2011 ApJ 733 1

The thermodynamic properties of coronal prominence cavities present a unique probe into the energy and mass budget of prominences. Using a three-dimensional morphological model, we forward model the polarization brightness and extreme-ultraviolet (EUV) emission of a cavity and its surrounding streamer. Using a genetic algorithm, we find the best-fit density model by comparing the models to Mauna Loa Solar Observatory MK4 and Hinode EUV Imaging Spectrometer data. The effect of temperature variations on the derived density is also measured. We have measured the density inside a cavity down to 1.05 R with height-dependent error bars. Our forward modeling technique compensates for optically thin projection effects. This method provides a complementary technique to traditional line ratio diagnostics that is useful for diffuse off-limb coronal structures.

LARGE-SCALE FLOWS IN PROMINENCE CAVITIES

D. J. **Schmit**, S. E. Gibson2, S. Tomczyk2, K. K. Reeves3, Alphonse C. Sterling4,9, D. H. Brooks5, D. R. Williams6, and D. Tripathi

Astrophysical Journal, 700:L96–L98, **2009** August

Regions of rarefied density often form cavities above quiescent prominences. We observed two different cavities with the Coronal Multichannel Polarimeter on **2005 April 21** and with *Hinode/*EIS on **2008 November 8**. Inside both of these cavities, we find coherent velocity structures based on spectral Doppler shifts. These flows have speeds of 5–10 km s−1, occur over length scales of tens of megameters, and persist for at least 1 hr. Flows in cavities are an example of the nonstatic nature of quiescent structures in the solar atmosphere.

Magnetic Field Topology and the Thermal Structure of the Corona over Solar Active Regions

Carolus J. **Schrijver**, Marc L. DeRosa, and Alan M. Title

2010 ApJ 719 1083-1096

Solar extreme ultraviolet (EUV) images of quiescent active-region coronae are characterized by ensembles of bright 1-2 MK loops that fan out from select locations. We investigate the conditions associated with the formation of these persistent, relatively cool, loop fans within and surrounding the otherwise 3-5 MK coronal environment by combining EUV observations of active regions made with TRACE with global source-surface potential-field models based on the full-sphere photospheric field from the assimilation of magnetograms that are obtained by the Michelson Doppler Imager (MDI) on SOHO. We find that in the selected active regions with largely potential-field configurations these fans are associated with (quasi-)separatrix layers (QSLs) within the strong-field regions of magnetic plage. Based on the empirical evidence, we argue that persistent active-region cool-loop fans are primarily related to the pronounced change in connectivity across a QSL to widely separated clusters of magnetic flux, and confirm earlier work that suggested that neither a change in loop length nor in base field strengths across such topological features are of prime importance to the formation of the cool-loop fans. We discuss the hypothesis that a change in the distribution of coronal heating with height may be involved in the phenomenon of relatively cool coronal loop fans in quiescent active regions.

Driving Major Solar Flares and Eruptions: A Review

Carolus J. **Schrijver**

Advances in Space Research

Volume 43, Issue 5, 2 March **2009**, Pages 739-755; **File**

This review focuses on the processes that energize and trigger M- and X-class solar flares and associated flux-rope destabilizations. Numerical modeling of specific solar regions is hampered by uncertain coronal-field reconstructions and by poorly understood magnetic reconnection; these limitations result in uncertain estimates of field topology, energy, and helicity. The primary advances in understanding field destabilizations therefore come from the combination of generic numerical experiments with interpretation of sets of observations. These suggest a critical role for the emergence of twisted flux ropes into pre-existing strong field for many, if not all, of the active regions that produce M- or X-class flares. The flux and internal twist of the emerging ropes appear to play as important a role in determining whether an eruption will develop predominantly as flare, confined eruption, or CME, as do the properties of the embedding field. Based on reviewed literature, I outline a scenario for major flares and eruptions that combines flux-rope emergence, mass draining, near-surface reconnection, and the interaction with the surrounding field. Whether deterministic forecasting is in principle possible remains to be seen: to date no reliable such forecasts can be made. Large-sample studies based on long-duration, comprehensive observations of active regions from their emergence through their flaring phase are needed to help us better understand these complex phenomena.

Observations and modeling of the early acceleration phase of erupting filaments involved in coronal mass ejections

Carolus J. **Schrijver,** Christopher Elmore, Bernhard Kliem, Tibor T¨or¨ok, and Alan M. Title

E-print, Oct 2007, Ap. J. 674:586-595, **2008** February 10;   **File**

We examine the early phases of two near-limb filament destabilizations involved in coronal mass ejections on 16 June and 27 July 2005, using high-resolution, high-cadence observations made with the Transition Region and Coronal Explorer (TRACE), complemented by coronagraphic observations by Mauna Loa and the SOlar and Heliospheric Observatory (SOHO). *The filaments' heights above the solar limb in their rapid-acceleration phases are best characterized by a height dependence h(t)~ t^m with m near, or slightly above, 3 for both events. Such profiles are incompatible with published results for breakout, MHD-instability, and catastrophe models.* We show numerical simulations of the torus instability that approximate this height evolution in case a substantial initial velocity perturbation is applied to the developing instability. We argue that the sensitivity of magnetic instabilities to initial and boundary conditions requires higher fidelity modeling of all proposed mechanisms if observations of rise profiles are to be used to differentiate between them. **The observations show no significant delays between the motions of the filament and of overlying loops: the filaments seem to move as part of the overall coronal field until several minutes after the onset of the rapid-acceleration phase.**

A Comparative Evaluation of Automated Solar Filament Detection

M. A. **Schuh**, J. M. Banda, P. N. Bernasconi, R. A. Angryk, P. C. H. Martens

Solar Physics, July **2014**, Volume 289, Issue 7, pp 2503-2524

We present a comparative evaluation for automated filament detection in Hα solar images. By using metadata produced by the Advanced Automated Filament Detection and Characterization Code (AAFDCC) module, we adapted our trainable feature recognition (TFR) module to accurately detect regions in solar images containing filaments. We first analyze the AAFDCC module's metadata and then transform it into labeled datasets for machine-learning classification. Visualizations of data transformations and classification results are presented and accompanied by statistical findings. Our results confirm the reliable event reporting of the AAFDCC module and establishes our TFR module's ability to effectively detect solar filaments in Hα solar images.

Flute oscillations of cooling coronal loops with variable cross-section

Daria **Shukhobodskaia**1, Alexander A. Shukhobodskiy2 and Robert Erdélyi1,3,4

A&A 649, A36 (**2021**)

https://www.aanda.org/articles/aa/pdf/2021/05/aa40314-21.pdf

https://doi.org/10.1051/0004-6361/202140314

We consider fluting oscillations in a thin straight expanding magnetic flux tube in the presence of a background flow. The tube is divided into a core region that is wrapped in a thin transitional region, where the damping takes place. The method of multiple scales is used for the derivation of the system of governing equations. This system is applicable to study both standing and propagating waves. Furthermore, the system of equations is obtained for magnetic tubes with a sharp boundary. An adiabatic invariant is derived using the Wentzel-Kramer-Brillouin method for a magnetic flux tube with slowly varying density, and the theoretical results are then used to investigate the effect of cooling on flute oscillations of a curved flux tube semi-circular in shape. We have analysed numerically the dependencies of the dimensionless amplitude for a range of values of the expansion factor and the ratio of internal to external plasma densities at an initial time. We find that the amplitude increases due to cooling and is higher for a higher expansion factor. Higher values of the wave number lead to localisation of the oscillation closer to the boundary. Finally, we show that the higher the value of the ratio of internal to external plasma densities, the higher the amplification of oscillation due to cooling. Therefore, we conclude that the wave number, density ratio, and the variation of tube expansion are all relevant parameters in the cooling process of an oscillating flux tube.

The Effect of Thermal Nonequilibrium on Helmet Streamers

Michael J. **Schlenker**1,2, Spiro K. Antiochos2, Peter J. MacNeice2, and Emily I. Mason2

2021 ApJ 916 115
https://doi.org/10.3847/1538-4357/ac069d
Solar loops in which the coronal heating scale is short compared to the loop length are known to be susceptible to thermal nonequilibrium (TNE). We investigate the effects of this process on the largest loops in the corona, those of a helmet streamer. Our numerical study uses a 2.5D MHD code that includes the full magnetic field dynamics as well as the detailed plasma thermodynamics. The simulation model is axisymmetric, consisting of an equatorial streamer belt and two polar coronal holes. As in previous 1D loop studies, we find that TNE occurs in coronal loops with sufficiently large length, but in contrast to these studies, we find that the process also drives substantial magnetic dynamics, especially near the top of the streamer where the plasma beta becomes of order unity. From the simulation results we determine predictions for spectroscopic and imaging observations of both the hot and cool helmet streamer plasma. Simulations are preformed using different scale heights for the heating and different numerical resolution in order to determine the dependence of our findings on these important parameters. We conclude that TNE in streamers may explain several puzzling observations, such as the ubiquitous blueshifts observed at the edges of active regions. We also discuss the implications of our results for the solar wind.

The diversity of spectral shapes of hydrogen Lyman lines and Mg II lines in a quiescent prominence

P. **Schwartz** (1), S. Gunar (2), J. Koza (1), P. Heinzel (2, 3) ((1)
A&A **2024**
https://arxiv.org/pdf/2401.09992.pdf
Broad sets of spectroscopic observations comprising multiple lines represent an excellent opportunity for diagnostics of the properties of the prominence plasma and the dynamics of their fine structures. However, they also bring significant challenges when they are compared with synthetic spectra provided by radiative transfer modeling. In this work, we provide a statistical spectroscopic analysis of a unique dataset of coordinated prominence observations in the Lyman lines (Ly_alpha to Ly_delta) and the Mg II k and h lines. The observed data were obtained by the Solar Ultraviolet Measurements of Emitted Radiation (SUMER) spectrograph on board of the Solar and Heliospheric Observatory (SoHO) satellite and the Interface Region Imaging Spectrograph (IRIS) on **22 October 2013**. We focus on the following profile characteristics: the shape of the observed line profiles based on the number of distinct peaks, the integrated line intensity, the center-to-peak ratio describing the depth of the reversal of two-peaked profiles, and the asymmetry of these peaks. We show that the presence of noise has a negligible effect on the integrated intensity of all observed lines, but it significantly affects the classification of spectral profiles using the number of distinct peaks, the reversal depth, and also the peak asymmetry. We also demonstrate that by taking the influence of noise into account, we can assess which profile characteristics in which spectral lines are suitable for diagnostics of different properties of the observed prominence.

2D non-LTE modelling of a filament observed in the H_alpha line with the DST/IBIS spectropolarimeter

P. **Schwartz** (1), S. Gunar (2), J. M. Jenkins (3), D. M. Long (3), P. Heinzel (2), D. P. Choudhary
A&A 631, A146 **2019**
https://arxiv.org/pdf/1910.03607.pdf
https://doi.org/10.1051/0004-6361/201935358
We study a fragment of a large quiescent filament observed on **May 29, 2017** by the Interferometric BIdimensional Spectropolarimeter (IBIS) mounted at the Dunn Solar Telescope. We focus on its quiescent stage prior to its eruption. We analyse the spectral observations obtained in the Hα line to derive the thermodynamic properties of the plasma of the observed fragment of the filament. We used a 2D filament model employing radiative transfer computations under conditions that depart from the local thermodynamic equilibrium. We employed a forward modelling technique in which we used the 2D model to producesynthetic H_alpha line profiles that we compared with the observations. We then found the set of model input parameters, which produces synthetic spectra with the best agreement with observations. Our analysis shows that one part of the observed fragment of the filament is cooler, denser, and more dynamic than its other part that is hotter, less dense, and more quiescent. The derived temperatures in the first part range from 6,000 K to 10,000$ K and in the latter part from 11,000 K to 14,000 K. The gas pressure is 0.2-0.4 dyn/cm}^{2} in the first part and around 0.15 dyn/cm}^{2} in the latter part. The more dynamic nature of the first part is characterised by the line-of-sight velocities with absolute values of 6-7 km/s and microturbulent velocities of 8-9 km/s. On the other hand, the latter part exhibits line-of-sight velocities with absolute values 0-2.5 km/s and microturbulent velocities of 4-6 km/s.

Prominence Visibility in Hinode/XRT images

Pavol **Schwartz**, Sonja Jejcic, Petr Heinzel, Ulrich Anzer, Patricia R. Jibben
2015 *ApJ* **807** 97
http://arxiv.org/pdf/1506.06078v1.pdf

In this paper we study the soft X-ray (SXR) signatures of one particular prominence. The X-ray observations used here were made by the Hinode/XRT instrument using two different filters. Both of them have a pronounced peak of the response function around 10 A. One of them has a secondary smaller peak around 170 A, which leads to a contamination of SXR images. The observed darkening in both of these filters has a very large vertical extension. The position and shape of the darkening corresponds nicely with the prominence structure seen in SDO/AIA images. First we have investigated the possibility that the darkening is caused by X-ray absorption. But detailed calculations of the optical thickness in this spectral range show clearly that this effect is completely negligible. Therefore the alternative is the presence of an extended region with a large emissivity deficit which can be caused by the presence of cool prominence plasmas within otherwise hot corona. To reproduce the observed darkening one needs a very large extension along the line-of-sight of the region amounting to around 105 km. We interpret this region as the prominence spine, which is also consistent with SDO/AIA observations in EUV. **22 Jun 2010**

Non-LTE modelling of prominence fine structures using hydrogen Lyman-line profiles

P. **Schwartz**, S. Gunár2† and W. Curdt

A&A 577, A92 (**2015**)

Aims. We perform a detailed statistical analysis of the spectral Lyman-line observations of the quiescent prominence observed on **May 18, 2005**.

Methods. We used a profile-to-profile comparison of the synthetic Lyman spectra obtained by 2D single-thread prominence fine-structure model as a starting point for a full statistical analysis of the observed Lyman spectra. We employed 2D multi-thread fine-structure models with random positions and line-of-sight velocities of each thread to obtain a statistically significant set of synthetic Lyman-line profiles. We used for the first time multi-thread models composed of non-identical threads and viewed at line-of-sight angles different from perpendicular to the magnetic field.

Results. We investigated the plasma properties of the prominence observed with the SoHO/SUMER spectrograph on May 18, 2005 by comparing the histograms of three statistical parameters characterizing the properties of the synthetic and observed line profiles. In this way, the integrated intensity, Lyman decrement ratio, and the ratio of intensity at the central reversal to the average intensity of peaks provided insight into the column mass and the central temperature of the prominence fine structures.

Total mass of six quiescent prominences estimated from their multi-spectral observations

P. **Schwartz**1, 2, P. Heinzel1, P. Kotrč1, F. Fárník1, Yu. A. Kupryakov1, 3, E. E. DeLuca4 and L. Golub

A&A 574, A62 (**2015**)

http://www.aanda.org/articles/aa/pdf/2015/02/aa24880-14.pdf

Context. Total masses of six solar prominences were estimated using prominence multi-spectral observations (in EUV, X-rays, Hα, and Ca II H). The observations were made during the observing campaign from April through June 2011.

Aims. The aim of the work was to apply a complex method for the prominence mass estimations that can be used later for other prominences observed during the observing campaign.

Methods. Our method is based on the fact that intensity of the EUV solar corona at wavelengths below 912 Å is reduced by the absorption in resonance continua of hydrogen and helium (photoionisation) and at the same time also by a deficit of the coronal emissivity in volume occupied by the cool prominence plasma. Both mechanisms contribute to intensity decrease simultaneously. The observations in X-rays allow us to separate these mechanisms from each other. Coronal emission behind a prominence is not estimated by any temporal or spatial interpolation, but by using a new method based on comparing the ratio of the optical thickness at 193 Å and 211 Å determined from the observations with the theoretical ratio.

Results. Values of the total mass estimated for six prominences are between 2.9×10^{11} and 1.7×10^{12} kg. The column density of hydrogen is of the order of 10^{18}–10^{19} cm^{-2}. Our results agree with results of other authors.

Conclusions. The method is now ready to be used for all 30 prominences observed during the campaign. Then in the near future it will be possible to obtain a statistics of the total mass of quiescent solar prominences. **10-13/06/2009**,

Study of an Extended EUV Filament Using SoHO/SUMER Observations of the Hydrogen Lyman Lines

P. **Schwartz**, B. Schmieder, P. Heinzel, P. Kotrč

Solar Phys., 281(2), 707-728, **2012**

A filament and its channel close to the solar disk were observed in the complete hydrogen Lyman spectrum, and in several EUV lines by the SUMER (Solar Ultraviolet Measurement of Emitted Radiation) and CDS (Coronal Diagnostic Spectrometer) spectrographs on the SoHO satellite, and in Hα by ground-based telescopes during a multi-instrument campaign in May 2005. It was a good opportunity to get an overview of the volume and the density of the cold plasma in the filament channel; these are essential parameters for coronal mass ejections. We found that the width of the filament depends on the wavelength in which the filament is observed (around 15 arcsec in Hα, 30 arcsec in Lα, and 60 arcsec in EUV). In Lα the filament is wider than in Hα because cool plasma, not visible in Hα, is optically thick at the Lα line center, and its presence blocks the coronal emission. We have derived physical plasma properties of this filament fitting the Lyman spectra and Hα profiles by using a 1D isobaric NLTE model. The vertical temperature profile of the filament slab is flat (T≈7000 K) with an increase to ≈ 20 000 K at the top and the bottom of the slab. From an analysis of the Lα and Hα source functions we have concluded that these lines are formed over the whole filament slab. We have estimated the geometrical filling factor in the filament channel. Its low value indicates the presence of multi-threads. **27 May 2005**

Study of an extended EUV filament using SoHO/SUMER observations of the hydrogen Lyman lines

P. **Schwartz**[1], P. Heinzel[1], B. Schmieder[2] and U. Anzer,
A&A 459, 651-661 (**2006**)

The Dynamic Formation of Pseudostreamers

Roger B. **Scott**1, David I. Pontin2,3, Spiro K. Antiochos4, C. Richard DeVore4, and Peter F. Wyper5
2021 ApJ 913 64
https://iopscience.iop.org/article/10.3847/1538-4357/abec4f/pdf
https://doi.org/10.3847/1538-4357/abec4f
Streamers and pseudostreamers structure the corona at the largest scales, as seen in both eclipse and coronagraph white-light images. Their inverted-goblet appearance encloses broad coronal loops at the Sun and tapers to a narrow radial stalk away from the star. The streamer associated with the global solar dipole magnetic field is long-lived, predominantly contains a single arcade of nested loops within it, and separates opposite-polarity interplanetary magnetic fields with the heliospheric current sheet (HCS) anchored at its apex. Pseudostreamers, on the other hand, are transient, enclose double arcades of nested loops, and separate like-polarity fields with a dense plasma sheet. We use numerical magnetohydrodynamic simulations to calculate, for the first time, the formation of pseudostreamers in response to photospheric magnetic-field evolution. Convective transport of a minority-polarity flux concentration, initially positioned under one side of a streamer, through the streamer boundary into the adjacent preexisting coronal hole forms the pseudostreamer. Interchange magnetic reconnection at the overlying coronal null point(s) governs the development of the pseudostreamer above—and of a new satellite coronal hole behind—the moving minority polarity. The reconnection dynamics liberate coronal-loop plasma that can escape into the heliosphere along so-called separatrix-web ("S-Web") arcs, which reach far from the HCS and the solar equatorial plane, and can explain the origin of high-latitude slow solar wind. We describe the implications of our results for in situ and remote-sensing observations of the corona and heliosphere as obtained, most recently, by Parker Solar Probe and Solar Orbiter.
2017 August 21

THE RESPONSE OF A THREE-DIMENSIONAL SOLAR ATMOSPHERE TO WAVE-DRIVEN JETS

E. **Scullion**1,2, R. Erdélyi2, V. Fedun2 and J. G. Doyle
2011 ApJ 743 14
Global oscillations from the solar interior are, mainly, pressure-driven (p-modes) oscillations with a peak power of a five-minute period. These oscillations are considered to manifest in many phenomena in the lower solar atmosphere, most notably, in spicules. These small-scale jets may provide the key to understanding the powering mechanisms of the transition region (TR) and lower corona. Here, we simulate the formation of wave-driven (type-I) spicule phenomena in three dimensions and the transmission of acoustic waves from the lower chromosphere and into the corona. The outer atmosphere oscillates in response to the jet formation, and in turn, we reveal the formation of a circular seismic surface wave, which we name as a Transition Region Quake (TRQ). The TRQ forms as a consequence of an upward propelling spicular wave train that repeatedly punctures and energizes the TR. The steep density gradient enables the TRQ to develop and radially fan outward from the location where the spicular plasma column impinges the TR. We suggest the TRQ formation as a formidable mechanism in continuously sustaining part of the energy budget of the TR. We present a supporting numerical model which allow us to determine the level of energy dumping at the TR by upward-propagating p-modes. Upon applying a wavelet analysis on our simulations we identify the presence of a chromospheric cavity which resonates with the jet propagation and leaves behind an oscillatory wake with a distinctive periodicity. Through our numerical analysis we also discover type-I spicule turbulence leading to a convection-based motion in the low corona.

Increase in the amplitude of line-of-sight velocities of the small-scale motions in a solar filament before eruption

Daikichi **Seki**, Kenichi Otsuji, Hiroaki Isobe, Takako T. Ishii, Takahito Sakaue, Kumi Hirose

APJL **2017**

https://arxiv.org/pdf/1705.09041.pdf

We present a study on the evolution of the small scale velocity field in a solar filament as it approaches to the eruption. The observation was carried out by the Solar Dynamics Doppler Imager (SDDI) that was newly installed on the Solar Magnetic Activity Research Telescope (SMART) at Hida Observatory. The SDDI obtains a narrow-band full disk image of the sun at 73 channels from Hα - 9.0 \AA\ to Hα + 9.0 \AA, allowing us to study the line-of-sight (LOS) velocity of the filament before and during the eruption. The observed filament is a quiescent filament that erupted on **2016 November 5**. We derived the LOS velocity at each pixel in the filament using the Becker's cloud model, and made the histograms of the LOS velocity at each time. The standard deviation of the LOS velocity distribution can be regarded as a measure for the amplitude of the small scale motion in the filament. We found that the standard deviation on the previous day of the eruption was mostly constant around 2-3 km s^{-1}, and it slightly increased to 3-4 km s^{-1} on the day of the eruption. It shows further increase with a rate of 1.1 m s^{-2} about three hours before eruption and again with a rate of 2.8 m s^{-2} about an hour before eruption. From this result we suggest the increase in the amplitude of the small scale motions in a filament can be regarded as a precursor of the eruption.

THE ROLE OF ACTIVE REGION LOOP GEOMETRY. I. HOW CAN IT AFFECT CORONAL SEISMOLOGY?

M. **Selwa**[1,2,5], L. Ofman[1,2,,6], and S. K. Solanki[3,4]

Astrophysical Journal, 726:42 (10pp), **2011**

We present numerical results of coronal loop oscillation excitation using a three-dimensional (3D) MHD model of an idealized active region (AR) field. The AR is initialized as a potential dipole magnetic configuration with gravitationally stratified density and contains a loop with a higher density than its surroundings.We study different ways of excitation of vertical kink oscillations of this loop by velocity: as an initial condition, and as an impulsive excitation with a pulse of a given position, duration, and amplitude. We vary the geometry of the loop in the 3D MHD model and find that it affects both the period of oscillations and the synthetic observations (difference images) that we get from oscillations. Due to the overestimated effective length of the loop in the case of loops which have maximum separation between their legs above the footpoints (>50% of observed loops), the magnetic field obtained from coronal seismology can also be overestimated. The 3DMHD model shows how the accuracy of magnetic field strength determined from coronal seismology can be improved.We study the damping mechanism of the oscillations and find that vertical kink waves in 3D stratified geometry are damped mainly due to wave leakage in the horizontal direction.

3D numerical simulations of coronal loops oscillations

M. **Selwa** and L. Ofman

Ann. Geophys., 27, 3899-3908, **2009**

www.ann-geophys.net/27/3899/2009/

We present numerical results of 3-D MHD model of a dipole active region field containing a loop with a higher density than its surroundings. We study different ways of excitation of vertical kink oscillations by velocity perturbation: as an initial condition, and as an impulsive excitation with a pulse of a given position, duration, and amplitude. These properties are varied in the parametric studies. We find that the amplitude of vertical kink oscillations is significantly amplified in comparison to horizontal kink oscillations for exciters located centrally (symmetrically) below the loop, but not if the exciter is located a significant distance to the side of the loop. This explains why the pure vertical kink mode is so rarely observed in comparison to the horizontally polarized one. We discuss the role of curved magnetic field lines and the pulse overlapping at one of the loop's footpoints in 3-D active regions (AR's) on the excitation and the damping of slow standing waves. We find that footpoint excitation becomes more efficient in 3-D curved loops than in 2-D curved arcades and that slow waves can be excited within an interval of time that is comparable to the observed one wave-period due to the combined effect of the pulse inside and outside the loop. Additionally, we study the effect of AR topology on the excitation and trapping of loop oscillations. We find that a perturbation acting directly on a single loop excites oscillations, but results in an increased leakage compared to excitation of oscillations in an AR field by an external source.

Variation of temperature and non-thermal velocity with height in fan loops

Aishawnnya **Sharma**, Durgesh Tripathi

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https://doi.org/10.1093/mnras/stad2359

We study the variation of temperature and non-thermal velocity with height in fan loops. For this purpose, we have used the observations recorded by the Extreme Ultraviolet Imaging Spectrometer onboard Hinode. We have employed the emission measure (EM)-loci method to estimate the temperatures of different coronal fan loops and then compute the non-thermal velocities using the obtained temperatures in Si VII 275.35 Å and Fe VIII 185.21 Å lines. The EM-loci analysis provides nearly iso-thermal temperature along the fan loops. We obtain the peak temperatures in the range logT(K) = 5.85–5.95 for fan loops, and the subtraction of thermal broadening gives the non-thermal velocities in the range ≈5–15 and 11–29 km s^{-1} for Si VII 275.35 Å and Fe VIII 185.21 Å, respectively. Our method provides quantitative accuracy in the measurement of non-thermal velocity, which is an important parameter in understanding the dynamics of heating of the solar atmosphere.

Wave amplitude modulation in fan loops as observed by AIA/SDO

Aishawnnya **Sharma**, Durgesh Tripathi, Robertus Erdelyi, G. R. Gupta, G. A. Ahmed

A&A **2020**

https://arxiv.org/pdf/2004.05797.pdf

We perform multiwavelength time-distance analysis of a fan loop system anchored in an isolated sunspot region AR 12553. The active region was observed by the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory. We measure the phase speeds of the propagating intensity disturbances by employing cross-correlation analysis, as well as by obtaining the slopes in xt-plots. We obtain original as well as de-trended light curves at different heights of the time-distance maps and characterize them by performing Fouriér and Wavelet analysis, respectively. The time-distance maps reveal clear propagation of intensity oscillations in all the coronal EUV channels except AIA 94 and 335~Å. We determine the nature of the intensity disturbances as slow magnetoacoustic waves by measuring their phase speeds. The time-distance maps, as well as the de-trended light curves, show an increase and decrease in the amplitude of propagating 3-min oscillations over time. The amplitude variations appear most prominent in AIA 171~Å, though other EUV channels also show such signatures. Fouriér power spectrum yield the presence of significant powers with several nearby frequencies between 2--3 minutes (5--8 mHz), along with many other smaller peaks between 2--4 minutes. Wavelet analysis shows an increase and decrease of oscillating power around 3-min simultaneous to the amplitude variations. We obtain the modulation period to be in the range of 20--30 minutes. Our results provide the viability of occurrence of phenomenon like `Beat' among the nearby frequencies giving rise to the observed amplitude modulation. However, we cannot, at this stage, rule out the possibility that the modulation may be driven by variability of an underlying unknown source. **June 16, 2016**

USING CORONAL CELLS TO INFER THE MAGNETIC FIELD STRUCTURE AND CHIRALITY OF FILAMENT CHANNELS

N. R. **Sheeley**, Jr.1, S. F. Martin2, O. Panasenco2,3, and H. P. Warren

2013 ApJ 772 88

http://arxiv.org/pdf/1306.2273v3.pdf

Coronal cells are visible at temperatures of ~1.2 MK in Fe XII coronal images obtained from the Solar Dynamics Observatory and Solar Terrestrial Relations Observatory spacecraft. We show that near a filament channel, the plumelike tails of these cells bend horizontally in opposite directions on the two sides of the channel like fibrils in the chromosphere. Because the cells are rooted in magnetic flux concentrations of majority polarity, these observations can be used with photospheric magnetograms to infer the direction of the horizontal field in filament channels and the chirality of the associated magnetic field. This method is similar to the procedure for inferring the direction of the magnetic field and the chirality of the fibril pattern in filament channels from Hα observations. However, the coronal cell observations are easier to use and provide clear inferences of the horizontal field direction for heights up to ~50 Mm into the corona.

A STREAMER EJECTION WITH RECONNECTION CLOSE TO THE SUN

N. R. **Sheeley**, Jr., H. P. Warren, and Y.-M. Wang

The Astrophysical Journal, 671:926Y935, **2007** December 10

http://www.journals.uchicago.edu/doi/pdf/10.1086/522940

We previously described coronal events that expand gradually outward over an interval of 1-2 days and then suddenly tear apart in the coronagraph's 2-6 R_ field of view to form an outgoing flux rope and an inward system of collapsing loops. Now, we combine LASCO white-light images of the outer corona with spectrally resolved EIT images of the inner corona to describe a similar event for which the separation occurs closer to the Sun. The evolution of this 2006 July 1-2 event had four phases: (1) an expansion phase in which magnetic loops rise slowly upward and increase the amount of open flux in the adjacent polar coronal hole and in the low-latitude hole of opposite polarity; (2) a stretching phase in which the legs of the rising loops pinch together to form a current sheet; (3) a transition phase in which field line reconnection produces an outgoing flux rope and a hot cusp of new loops; and (4) an end phase in which the reconnected loops become visible at lower temperatures, and the outgoing flux rope plows through the slow material ahead of it to form a traveling bow wave. During this time, the photospheric field was relatively weak and unchanging, as if the eruption had a nonmagnetic origin. We suppose that coronal heating gradually overpowers magnetic tension and causes the streamer to separate into a system of collapsing loops and a flux rope that is carried outward in the solar wind.

IN/OUT PAIRS AND THE DETACHMENT OF CORONAL STREAMERS

N. R. **Sheeley**, Jr. and Y.-M. Wang

The Astrophysical Journal, 655:1142Y1156, 2007 February 1

http://www.journals.uchicago.edu/doi/pdf/10.1086/510323

We previously described coronal events that originate in the 2Y6 R_ field of view of the LASCO white-light coronagraph and involve the simultaneous ejection of material inward toward the Sun and outward away from it. Now, in a study of more than 160 in /out pairs, we have found that these features are density enhancements at the leading and trailing edges of depletions that occur when slowly rising coronal structures separate from the Sun. The outward component is shaped like a large arch with both ends attached to the Sun, and the inward component is often resolved into loops. We also found about 60 additional events in which the outward components began near the edge of the occulting disk and inward components were not visible, as if these events were in/out pairs that originated below the 2 R_ radius of the occulting disk.We conclude that in/out pairs belong to a broad class of streamer detachments, which include ‘‘streamer blowout’’ coronal mass ejections, and we suppose that all of these events occur when rising magnetic loops reconnect to produce an outgoing helical flux rope and an ingoing arcade of collapsing loops.

Time-dependent Ionization in a Steady Flow in an MHD Model of the Solar Corona and Wind

Chengcai **Shen**1, John C. Raymond1, Zoran Mikić2, Jon A. Linker2, Katharine K. Reeves1, andNicholas A. Murphy1

2017 ApJ 850 26

Time-dependent ionization is important for diagnostics of coronal streamers and pseudostreamers. We describe time-dependent ionization calculations for a three-dimensional magnetohydrodynamic (MHD) model of the solar corona and inner heliosphere. We analyze how non-equilibrium ionization (NEI) influences emission from a pseudostreamer during the Whole Sun Month interval (Carrington rotation CR1913, 1996 August 22 to September 18). We use a time-dependent code to calculate NEI states, based on the plasma temperature, density, velocity, and magnetic field in the MHD model, to obtain the synthetic emissivities and predict the intensities of the Lyα, O vi, Mg x, and Si xii emission lines observed by the SOHO/Ultraviolet Coronagraph Spectrometer (UVCS). At low coronal heights, the predicted intensity profiles of both Lyα and O vilines match UVCS observations well, but the Mg x and Si xii emission are predicted to be too bright. At larger heights, the O vi and Mg x lines are predicted to be brighter for NEI than equilibrium ionization around this pseudostreamer, and Si xii is predicted to be fainter for NEI cases. The differences of predicted UVCS intensities between NEI and equilibrium ionization are around a factor of 2, but neither matches the observed intensity distributions along the full length of the UVCS slit. Variations in elemental abundances in closed field regions due to the gravitational settling and the FIP effect may significantly contribute to the predicted uncertainty. The assumption of Maxwellian electron distributions and errors in the magnetic field on the solar surface may also have notable effects on the mismatch between observations and model predictions.

On a small-scale EUV wave: the driving mechanism and the associated oscillating filament

Yuandeng **Shen**, Yu Liu, Zhanjun Tian, Zhining Qu

ApJ **2017**

https://arxiv.org/pdf/1711.04905.pdf

We present observations of a small-scale Extreme-ultraviolet (EUV) wave that was associated with a mini-filament eruption and a GOES B1.9 micro-fare in the quiet Sun region. The initiation of the event was due to the photospheric magnetic emergence and cancellation in the eruption source region, which first caused the ejection of a small plasma ejecta, then the ejecta impacted on a nearby mini-filament and thereby led to the filament's eruption and the associated fare. During the filament eruption, an EUV wave at a speed of 182 { 317 km/s was formed ahead of an expanding coronal loop, which propagated faster than the expanding loop and showed obvious deceleration and refection during the propagation. In addition, the EUV wave further resulted in the transverse oscillation of a remote filament whose period and damping time are 15 and 60 minutes, respectively. Based on the observational results, we propose that the small-scale EUV wave should be a fast-mode magnetosonic wave that was driven by the the expanding coronal loop. Moreover, with the application of filament seismology, it is estimated that the radial magnetic field strength is about 7 Gauss. The observations also suggest that small-scale EUV waves associated with miniature solar eruptions share similar driving mechanism and observational characteristics with their large-scale counterparts. **March 21, 2016**

Fine Magnetic Structure and Origin of Counter-Streaming Mass Flows in a Quiescent Solar Prominence

Yuandeng **Shen**, Yu Liu, Ying D. Liu, P. F. Chen, Jiangtao Su, Zhi Xu, Zhong Liu
2015 *ApJL* **814** L17
http://arxiv.org/pdf/1511.02489v1.pdf
We present high-resolution observations of a quiescent solar prominence which was consisted of a vertical and a horizontal foot encircled by an overlying spine, and counter-streaming mass flows were ubiquitous in the prominence. While the horizontal foot and the spine were connecting to the solar surface, the vertical foot was suspended above the solar surface and supported by a semicircular bubble structure. The bubble first collapsed and then reformed at a similar height, finally, it started to oscillate for a long time. We find that the collapsing and oscillation of the bubble boundary were tightly associated with a flare-like feature located at the bottom of the bubble. Based on the observational results, we propose that the prominence should be composed of an overlying horizontal spine encircling a low-lying horizontal and a vertical foot, in which the horizontal foot was consisted of shorter field lines running partially along the spine and with the both ends connecting to the solar surface, while the vertical foot was consisted of piling-up dips due to the sagging of the spine fields and supported by a bipolar magnetic system formed by parasitic polarities (i.e., the bubble). The upflows in the vertical foot were possibly caused by the magnetic reconnection at the separator between the bubble and the overlying dips, which intruded into the persistent downflow field and formed the picture of counter-streaming mass flows. In addition, the counter-streaming flows in the horizontal foot were possibly caused by the imbalanced pressure at the both ends.
24 May 2014

Simultaneous Transverse Oscillations of a Prominence and a Filament and Longitudinal Oscillation of another Filament Induced by a Single Shock Wave

Yuandeng **Shen**, Ying D. Liu, P. F. Chen, Kiyoshi Ichimoto
ApJ, 795 130 **2014**
http://arxiv.org/pdf/1409.1304v1.pdf
We present the first stereoscopic and Doppler observations of simultaneous transverse oscillations of a prominence and a filament and longitudinal oscillation of another filament launched by a single shock wave. Using H-alpha Doppler observations, we derive the three-dimensional oscillation velocities at different heights along the prominence axis. The results indicate that the prominence has a larger oscillation amplitude and damping time at higher altitude, but the periods at different heights are the same (i.e., 13.5 minutes). This suggests that the prominence oscillates like a linear vertical rigid body with one end anchored on the Sun. One of the filaments shows weak transverse oscillation after the passing of the shock, which is possibly due to the low altitude of the filament and the weakening (due to reflection) of the shock wave before the interaction. Large amplitude longitudinal oscillation is observed in the other filament after the passing of the shock wave. The velocity amplitude and period are about 26.8 km/s and 80.3 minutes, respectively. We propose that the orientation of a filament or prominence relative to the normal vector of the incoming shock should be an important factor for launching transverse or longitudinal filament oscillations. In addition, the restoring forces of the transverse prominence are most likely due to the coupling of gravity and magnetic tension of the supporting magnetic field, while that for the longitudinal filament oscillation is probably the resultant force of gravity and magnetic pressure. **August 09, 2011**

A Chain of Winking (Oscillating) Filaments Triggered by an Invisible Extreme-Ultraviolet Wave

Yuandeng **Shen**, Kiyoshi Ichimoto, Takako T. Ishii, Zhanjun Tian, Ruijuan Zhao, Kazunari Shibata
2014 ApJ 786 151
http://arxiv.org/pdf/1403.7705v1.pdf
Winking (oscillating) filaments have been observed for many years. However, observations of successive winking filaments in one event have not been reported yet. In this paper, we present the observations of a chain of winking filaments and a subsequent jet that are observed right after the X2.1 are in AR11283. The event also produced an Extreme-ultraviolet (EUV) wave that has two components: upward dome-like wave (850 km/s) and lateral surface wave (554 km/s) which was very weak (or invisible) in imaging observations. By analyzing the temporal and spatial relationships between the oscillating filaments and the EUV waves, we propose that all the winking filaments and the jet were triggered by the weak (or invisible) lateral surface EUV wave. The oscillation of the filaments last for two or three cycles, and their periods, Doppler velocity amplitudes, and damping times are 11 - 22 minutes, 6 - 14 km/s, and 25 - 60 minutes, respectively. We further estimate the radial component magnetic field and the maximum kinetic energy of the filaments, and they are 5 - 10 Gauss and ~ 10^19 J, respectively. The estimated maximum kinetic energy is comparable to the minimum energy of ordinary EUV waves, suggesting that EUV waves can

efficiently launch filament oscillations on their path. Based on our analysis results, we conclude that the EUV wave is a good agent for triggering and connecting successive but separated solar activities in the solar atmosphere, and it is also important for producing solar sympathetic eruptions. **2011-09-06**

A time series of filament eruptions observed by three eyes from space: from failed to successful eruptions

Yuandeng **Shen**, Yu Liu, and Rui Liu

E-print, July **2013**; Research in Astronomy and Astrophysics Volume 11 Number 5, **2011**

We present stereoscopic observations of six sequential eruptions of a filament in the active region NOAA 11045 on **2010 Feb 8**, with the advantage of the STEREO twin viewpoints in combination with Earth's viewpoint from SOHO instruments and ground-based telescopes. The last one of the six eruptions is a coronal mass ejection, but the others are not. The flare in this successful one is more intense than in the others. Moreover, the velocity of filament material in the successful one is also the largest among them. Interestingly, all the filament velocities are found to be proportional to the power of their flares. We calculate magnetic field intensity at low altitude, the decay indexes of the external field above the filament, and the asymmetry properties of the overlying fields before and after the failed eruptions and find little difference between them, indicating the same coronal confinement exists for both the failed and successful eruptions. The results suggest that, besides the confinement of the coronal magnetic field, the energy released in the low corona should be another crucial element affecting a failed or successful filament eruption. That is, a coronal mass ejection can only be launched if the energy released exceeds some critical value, given the same initial coronal conditions.

Sympathetic Partial and Full Filament Eruptions Observed in One Solar Breakout Event

Yuandeng **Shen**, Yu Liu, Jiangtao Su

ApJ, **2012**, 750, 12, **File**

We report two sympathetic solar eruptions including a partial and a full flux rope eruption in a quadrupolar magnetic region where a large and a small filament resided above the middle and the east neutral lines, respectively. The large filament first rose slowly at a speed of 8 km/s for 23 minutes; it then accelerated to 102 km/s. Finally, this filament erupted successfully and caused a coronal mass ejection. During the slow rising phase, various evidence for breakout-like external reconnection has been identified at high and low temperature lines. The eruption of the small filament started around the end of the large filament's slow rising. This filament erupted partially, and no associated coronal mass ejection could be detected. Based on a potential field extrapolation, we find that the topology of the three-dimensional coronal field above the source region is composed of three low-lying lobes and a large overlying flux system, and a null point located between the middle lobe and the overlying antiparallel flux system. We propose a possible mechanism within the framework of the magnetic breakout model to interpret the sympathetic filament eruptions, in which the magnetic implosion mechanism is thought to be a possible link between the sympathetic eruptions, and the external reconnection at the null point transfers field lines from the middle lobe to the lateral lobes and thereby leads to the full (partial) eruption of the observed large (small) filament. Other possible mechanisms are also discussed briefly. We conclude that the structural properties of coronal fields are important for producing sympathetic eruptions. **Хорошее Введение - Review**

ON A CORONAL BLOWOUT JET: THE FIRST OBSERVATION OF A SIMULTANEOUSLY PRODUCED BUBBLE-LIKE CME AND A JET-LIKE CME IN A SOLAR EVENT

Yuandeng **Shen**1,2,3, Yu Liu1,3, Jiangtao Su3,4 and Yuanyong Deng3

2012 ApJ 745, 164

The coronal blowout jet is a peculiar category among various jet phenomena, in which the sheared base arch, often carrying a small filament, experiences a miniature version of blowout eruption that produces large-scale coronal mass ejection (CME). In this paper, we report such a coronal blowout jet with high-resolution multi-wavelength and multi-angle observations taken from Solar Dynamics Observatory, Solar Terrestrial Relations Observatory, and Big Bear Solar Observatory. For the first time, we find that simultaneous bubble-like and jet-like CMEs were dynamically related to the blowout jet that showed cool and hot components next to each other. Our observational results indicate that (1) the cool component resulted from the eruption of the filament contained within the jet's base arch, and it further caused the bubble-like CME; (2) the jet-like CME was associated with the hot component, which was the outward moving heated plasma generated by the reconnection of the base arch and its ambient open field lines. On the other hand, bifurcation of the jet's cool component was also observed, which resulted from the uncoupling of the erupting filament's two legs that were highly twisted at the very beginning. Based on these results, we propose a model to interpret the coronal blowout jet, in which the external reconnection not only produces the jet-like CME, but also leads to the rising of the filament. Subsequently, internal reconnection starts underneath the rising filament and thereby causes the bubble-like CME.

Horizontally Polarized Kink Oscillations Supported by Solar Coronal Loops in an Asymmetric Environment

Mijie **Shi**, Bo Li, Shengju Yuan

A&A **2024**

https://arxiv.org/pdf/2402.11181.pdf

Kink oscillations are ubiquitously observed in solar coronal loops, their understanding being crucial in the contexts of coronal seismology and atmospheric heating. We study kink modes supported by a straight coronal loop embeded in an asymmetric environment using three-dimensional magnetohydrodynamic (MHD) simulations. We implement the asymmetric effect by setting different exterior densities below and above the loop interior, and initiate the simulation using a kink-like velocity perturbation perpendicular to the loop plane, mimicking the frequently measured horizontally polarized kink modes. We find that the external velocity fields show fan blade structures propagating in the azimuthal direction as a result of the successive excitation of higher azimuthal Fourier modes. Resonant absorption and phase mixing can still occur despite an asymmetric environment, leading to the development of small scales at loop boundaries. These small scales nonetheless develop asymmetrically at the upper and lower boundaries due to the different gradients of the Alfven speed. These findings enrich our understanding of kink modes in coronal loops embedded within an asymmetric environment, providing insights helpful for future high-resolution observations.

Forward Modeling of Simulated Transverse Oscillations in Coronal Loops and the Influence of Background Emission

Mijie **Shi**, Tom Van Doorsselaere, Patrick Antolin, Bo Li

ApJ **922** 60 **2021**

https://arxiv.org/pdf/2109.02338.pdf

https://doi.org/10.3847/1538-4357/ac2497

We simulate transverse oscillations in radiatively cooling coronal loops and forward-model their spectroscopic and imaging signatures, paying attention to the influence of background emission. The transverse oscillations are driven at one footpoint by a periodic velocity driver. A standing kink wave is subsequently formed and the loop cross-section is deformed due to the Kelvin-Helmholtz instability, resulting in energy dissipation and heating at small scales. Besides the transverse motions, a long-period longitudinal flow is also generated due to the ponderomotive force induced slow wave. We then transform the simulated straight loop to a semi-torus loop and forward-model their spectrometer and imaging emissions, mimicking observations of Hinode/EIS and SDO/AIA. We find that the oscillation amplitudes of the intensity are different at different slit positions, but are roughly the same in different spectral lines or channels. X-t diagrams of both the Doppler velocity and the Doppler width show periodic signals. We also find that the background emission dramatically decreases the Doppler velocity, making the estimated kinetic energy two orders of magnitude smaller than the real value. Our results show that background subtraction can help recover the real oscillation velocity. These results are helpful for further understanding transverse oscillations in coronal loops and their observational signatures. However, they cast doubt on the spectroscopically estimated energy content of transverse waves using the Doppler velocity.

The First 3D Coronal Loop Model Heated by MHD Waves against Radiative Losses

Mijie **Shi**, Tom Van Doorsselaere, Mingzhe Guo, Konstantinos Karampelas, Bo Li, Patrick Antolin

ApJ **2021**

https://arxiv.org/pdf/2101.01019.pdf

In the quest to solve the long-standing coronal heating problem, it has been suggested half a century ago that coronal loops could be heated by waves. Despite the accumulating observational evidence of the possible importance of coronal waves, still no 3D MHD simulations exist that show significant heating by MHD waves. Here we report on the first 3D coronal loop model heating the plasma against radiative cooling. The coronal loop is driven at the footpoint by transverse oscillations and subsequently the induced Kelvin-Helmholtz instability deforms the loop cross-section and generates small-scale structures. Wave energy is transfered to smaller scales where it is dissipated, overcoming the internal energy losses by radiation. These results open up a new avenue to address the coronal heating problem.

Synthetic Extreme-ultraviolet Emissions Modulated by Leaky Fast Sausage Modes in Solar Active Region Loops

Mijie **Shi**, Bo Li, Zhenghua Huang, Shao-Xia Chen

ApJ **883** 196 **2019**

https://arxiv.org/pdf/1908.07131.pdf

https://doi.org/10.3847/1538-4357/ab3d42

We study the extreme-ultraviolet (EUV) emissions modulated by leaky fast sausage modes (FSMs) in solar active region loops and examine their observational signatures via spectrometers like EIS. After computing fluid variables of leaky FSMs with MHD simulations, we forward-model the intensity and spectral properties of the Fe X 185~Å~and Fe XII 195~Å~lines by incorporating non-equilibrium ionization (NEI) in the computations of the relevant ionic fractions. The damping times derived from the intensity variations are then compared with the wave values, namely the damping times directly found from our MHD simulations. Our results show that in the equilibrium ionization cases, the density variations and the intensity variations can be either in phase or in anti-phase, depending on the loop temperature. NEI considerably impacts the intensity variations but has only marginal effects on the derived Doppler velocity or Doppler width. We find that the damping time derived from the intensity can largely reflect the wave damping time if the loop temperature is not drastically different from the nominal formation temperature of the corresponding emission line. These results are helpful for understanding the modulations to the EUV emissions by leaky FSMs and hence helpful for identifying FSMs in solar active region loops.

Non-equilibrium Ionization Effects on Extreme-ultraviolet Emissions Modulated by Standing Sausage Modes in Coronal Loops

Mijie **Shi**1,2, Bo Li1, Tom Van Doorsselaere3, Shao-Xia Chen1, and Zhenghua Huang

2019 ApJ 870 99

Forward-modeling the emission properties in various passbands is important for confidently identifying magnetohydrodynamic waves in the structured solar corona. We examine how non-equilibrium ionization (NEI) affects the extreme-ultraviolet (EUV) emissions modulated by standing fast sausage modes (FSMs) in coronal loops, taking the Fe ix 171 Å and Fe xii 193 Å emission lines as examples. Starting with the expressions for linear FSMs in straight cylinders, we synthesize the specific intensities and spectral profiles for the two spectral lines by incorporating the self-consistently derived ionic fractions in the relevant contribution functions. We find that relative to the case where equilibrium ionization (EI) is assumed, NEI considerably impacts the intensity modulations, but shows essentially no effect on the Doppler velocities or widths. Furthermore, NEI may affect the phase difference between intensity variations and those in Doppler widths for Fe xii193 Å when the line of sight is oblique to the loop axis. While this difference is 180° when EI is assumed, it is ~90° when NEI is incorporated for the parameters we choose. We conclude that in addition to viewing angles and instrumental resolutions, NEI further complicates the detection of FSMs in spectroscopic measurements of coronal loops in the EUV passband.

Unusual Migration of Prominence Activities in the Southern Hemisphere during Cycles 23–24

M. **Shimojo**

Publ. Astron. Soc. Japan 65, No SP1, S16 [6 pages] (**2013**)

http://pasj.asj.or.jp/v65/sp1/65S016/65S016.pdf

The solar activity in Cycles 23–24 shows differences from the previous cycles that were observed with modern instruments, e.g., long cycle duration and a small number of sunspots. To appreciate the anomalies further, we investigated the prominence eruptions and disappearances observed with the Nobeyama Radioheliograph for over 20 years. Consequently, we found that the occurrence of prominence activities in the northern hemisphere is normal because the period of the number variation is 11 years, and the migration of the producing region of the prominence activities traces the migration of 11 years ago. On the other hand, the migration in the southern hemisphere significantly
differs from that in the northern hemisphere and the previous cycles. The prominence activities occurred over _50₁ latitude in spite of the late decay phase of Cycle 23, and the number of prominence activities in the higher latitude region (over _65₁) is very small, even near the solar maximum of Cycle 24. The results suggest that the anomalies of the global magnetic field distribution started at the solar maximum of Cycle 23. A comparison of the butterfly diagram of the prominence activities with the magnetic butterfly diagram indicates that the timing of “the rush to the pole” and the polar magnetic field closely relates to unusual migration. Considering that the rush to the pole is made of the sunspots, the hemispheric asymmetry of the sunspots and the strength of the polar magnetic fields are essential for understanding the anomalies of the prominence activities.

On the Existence of Long-Period Decayless Oscillations in Short Active Region Loops

Arpit Kumar **Shrivastav**, Vaibhav Pant, Rohan Kumar, David Berghmans, Tom Van Doorsselaere, Dipankar Banerjee, Elena Petrova, Daye Lim

ApJ **2024**

https://arxiv.org/pdf/2411.15646

Decayless kink oscillations, characterized by their lack of decay in amplitude, have been detected in coronal loops of varying scales in active regions, quiet Sun and coronal holes. Short-period (< 50 s) decayless oscillations have been detected in short loops (< 50 Mm) within active regions. Nevertheless, long-period decayless oscillations in these loops remain relatively unexplored and crucial for understanding the wave modes and excitation mechanisms of decayless oscillations. We present the statistical analysis of decayless oscillations from two active regions observed by the Extreme Ultraviolet Imager (EUI) onboard Solar Orbiter. The average loop length and period of the detected oscillations are 19 Mm and 151 seconds, respectively. We find 82 long-period and 23 short-period oscillations in these loops. We do not obtain a significant correlation between loop length and period. We discuss the possibility of different wave modes in short loops, although standing waves can not be excluded from possible wave modes. Furthermore, a different branch exists for active region short loops in the loop length vs period relation, similar to decayless waves in short loops in quiet Sun and coronal holes. The magnetic fields derived from MHD seismology, based on standing kink modes, show lower values for multiple oscillations compared to previous estimates for long loops in active regions. Additionally, the comparison of period distributions in short loops across different coronal regions indicates that different excitation mechanisms may trigger short-period kink oscillations in active regions compared to the quiet Sun and coronal holes**. 2022-03-17, 2022-10-13**

On the Effect of Coronal Rain on Decayless Kink Oscillations of Coronal Loops

Arpit Kumar **Shrivastav**, Vaibhav Pant, Patrick Antolin

A&A 689, A295 **2024**

https://arxiv.org/pdf/2405.07177

https://www.aanda.org/articles/aa/pdf/2024/09/aa49677-24.pdf

Decayless kink oscillations are ubiquitously observed in active region coronal loops with an almost constant amplitude for several cycles. Decayless kink oscillations of coronal loops triggered by coronal rain have been analysed, but the impact of coronal rain formation in an already oscillating loop is unclear. As kink oscillations can help diagnose the local plasma conditions, it is important to understand how these are affected by coronal rain phenomena. In this study, we present the analysis of an event of coronal rain that occurred on **25 April 2014** and was simultaneously observed by \textit{Slit-Jaw Imager} (SJI) onboard \textit{Interface Region Imaging Spectrograph} (IRIS) and \textit{Atmospheric Imaging Assembly} (AIA) onboard \textit{Solar Dynamic Observatory} (SDO). The oscillation properties of the coronal loop in AIA are investigated before and after the appearance of coronal rain in SJI. We find signatures of decayless oscillations before and after coronal rain at similar positions to those during coronal rain. The individual cases show a greater amplitude and period during coronal rain. The mean period is increased by 1.3 times during coronal rain, while the average amplitude is increased by 2 times during rain, in agreement with the expected density increase from coronal rain. The existence of the oscillations in the same loop at the time of no coronal rain indicates the presence of a footpoint driver. The properties of the observed oscillations during coronal rain can result from the combined contribution of coronal rain and a footpoint driver. The oscillation amplitude associated with coronal rain is approximated to be 0.14 Mm. The properties of decayless oscillations are considerably affected by coronal rain, and without prior knowledge of coronal rain in the loop, a significant discrepancy can arise from coronal seismology with respect to the true values.

A Statistical Investigation of Decayless Oscillations in Small-scale Coronal Loops Observed by Solar Orbiter/EUI

Arpit Kumar **Shrivastav**, Vaibhav Pant, David Berghmans, Andrei N. Zhukov, Tom Van Doorsselaere, Elena Petrova, Dipankar Banerjee, Daye Lim, Cis Verbeeck

A&A 685, A36 **2024**

https://arxiv.org/pdf/2304.13554.pdf

https://www.aanda.org/articles/aa/pdf/2024/05/aa46670-23.pdf

Decayless kink oscillations are omnipresent in the solar atmosphere and a viable candidate for coronal heating. Though there have been extensive studies of decayless oscillations in coronal loops with a few hundred Mm lengths, the properties of these oscillations in small-scale (∼10 Mm) loops are yet to be explored. In this study, we present the properties of decayless oscillations in small loops embedded in the quiet corona and coronal holes. We use high resolution observations from the Extreme Ultraviolet Imager onboard Solar Orbiter with pixel scales of 210 km and 5 s cadence or better. We find 42 oscillations in 33 coronal loops with loop lengths varying between 3 to 23 Mm. The average displacement amplitude is found to be 136 km. The oscillations period has a range of 27 to 276 s, and the velocity amplitudes range from 2.2 to 19.3 km s−1. The observed kink speeds are lower than those observed in active region coronal loops. The variation of loop length with the period does not indicate a strong correlation. Coronal seismology technique indicated an average magnetic field value of 2.1 G. We estimate the energy flux with a broad range of 0.6-314 W m−2. Moreover, we note that the short-period decayless oscillations are not prevalent in the quiet Sun and coronal holes. Therefore, our study suggests that decayless oscillations in small-scale coronal loops are unlikely to provide enough energy to heat the quiet Sun and accelerate solar wind in the coronal holes.
2021-09-14, 2022-03-30

Significance of Cooling Effect On Comprehension of Kink Oscillations of Coronal Loops

Daria **Shukhobodskaia**, Alexander Shukhobodskiy, Chris Nelson, Michael Ruderman, and

Robertus Erdelyi
Front. Astron. Space Sci., Volume 7, id.106 **2020** |
https://www.frontiersin.org/articles/10.3389/fspas.2020.579585/full https://doi.org/10.3389/fspas.2020.579585
Kink oscillations of coronal loops have been widely studied, both observationally and theoretically, over the past few decades. It has been shown that the majority of observed driven coronal loop oscillations appear to damp with either exponential or Gaussian profiles and a range of mechanisms have been proposed to account for this. However, some driven oscillations seem to evolve in manners which cannot be modeled with purely Gaussian or exponential profiles, with amplification of oscillations even being observed on occasions. Recent research has shown that incorporating the combined effects of coronal loop expansion, resonant absorption, and cooling can cause significant deviations from Gaussian and exponential profiles in damping profiles, potentially explaining increases in oscillation amplitude through time in some cases. In this article, we analyze 10 driven kink oscillations in coronal loops to further investigate the ability of expansion and cooling to explain complex damping profiles. Our results do not rely on fitting a periodicity to the oscillations meaning complexities in both temporal (period changes) and spatial (amplitude changes) can be accounted for in an elegant and simple way. Furthermore, this approach could also allow us to infer some important diagnostic information (such as, for example, the density ratio at the loop foot-points) from the oscillation profile alone, without detailed measurements of the loop and without complex numerical methods. Our results imply the existence of correlations between the density ratio at the loop foot-points and the amplitudes and periods of the oscillations. Finally, we compare our results to previous models, namely purely Gaussian and purely exponential damping profiles, through the calculation of $\chi 2$ values, finding the inclusion of cooling can produce better fits in some cases. The current study indicates that thermal evolution should be included in kink-mode oscillation models in the future to help us to better understand oscillations that are not purely Gaussian or exponential.

Resonant damping of kink oscillations of thin cooling and expanding coronal magnetic loops

A. A. **Shukhobodskiy**1,2, M. S. Ruderman1,3 and R. Erdélyi1,4
A&A 619, A173 (**2018**)
sci-hub.tw/10.1051/0004-6361/201833714
We have considered resonant damping of kink oscillations of cooling and expanding coronal magnetic loops. We derived an evolutionary equation describing the dependence of the oscillation amplitude on time. When there is no resonant damping, this equation reduces to the condition of conservation of a previously derived adiabatic invariant. We used the evolutionary equation describing the amplitude to study the competition between damping due to resonant absorption and amplification due to cooling. Our main aim is to investigate the effect of loop expansion on this process. We show that the loop expansion acts in favour of amplification. We found that, when there is no resonant damping, the larger the loop expansion the faster the amplitude growths. When the oscillation amplitude decays due to resonant damping, the loop expansion reduces the damping rate. For some values of parameters the loop expansion can fully counterbalance the amplitude decay and turn the amplitude evolution into amplification.

MULTIPLE PLASMA EJECTIONS AND INTERMITTENT NATURE OF MAGNETIC RECONNECTION IN SOLAR CHROMOSPHERIC ANEMONE JETS

K. A. P. **Singh**1, H. Isobe2, N. Nishizuka3, K. Nishida1, and K. Shibata
2012 ApJ 759 33
The recent discovery of chromospheric anemone jets with the Solar Optical Telescope (SOT) on board Hinode has shown an indirect evidence of magnetic reconnection in the solar chromosphere. However, the basic nature of magnetic reconnection in chromosphere is still unclear. We studied nine chromospheric anemone jets from SOT/Hinode using Ca II H filtergrams, and we found multiple bright, plasma ejections along the jets. In most cases, the major intensity enhancements (larger than 30% relative to the background intensity) of the loop correspond to the timing of the plasma ejections. The typical lifetime and size of the plasma ejecta are about 20-60 s and 0.3-1.5 Mm, respectively. The height-time plot of jet shows many sub-structures (or individual jets) and the typical lifetime of the individual jet is about one to five minutes. Before the onset of the jet activity, a loop appears in Ca II H and gradually increases in size, and after few minutes several jets are launched from the loop. Once the jet activity starts and several individual jets are launched, the loop starts shrinking with a speed of ~4 km s–1. In some events, a downward moving blob with a speed of ~35 km s–1 was observed, associated with the upward moving plasma along one of the legs of the loop hosting the jets. The upward moving plasma gradually developed into jets. Multiple plasma ejections in chromospheric anemone jet show the strongly time-dependent as well as intermittent nature of magnetic reconnection in the solar chromosphere.

Chromospheric Anemone Jets and Magnetic Reconnection in Partially Ionized Solar Atmosphere

K.A.P **Singh**, K. Shibata, N. Nishizuka, and H. Isobe
Physics of Plasmas, Volume 18, 111210 (**2011**)

The solar optical telescope onboard Hinode with temporal resolution of less than 5 s and spatial resolution of 150 km has observed the lower solar atmosphere with an unprecedented detail. This has led to many important findings, one of them is the discovery of chromospheric anemone jets in the solar chromosphere. The chromospheric anemone jets are ubiquitous in solar chromosphere and statistical studies show that the typical length, life time and energy of the chromospheric anemone jets are much smaller than the coronal events (e.g., jets/flares/CMEs). Among various observational parameters, the apparent length and maximum velocity shows good correlation. The velocity of chromospheric anemone jets is comparable to the local Alfvén speed in the lower solar chromosphere. Since the discovery of chromospheric anemone jets by Hinode, several evidences of magnetic reconnection in chromospheric anemone jets have been found and these observations are summarized in this paper. These observations clearly suggest that reconnection occurs quite rapidly as well as intermittently in the solar chromosphere. In the solar corona, anomalous resistivity arises due to various collisionless processes. Previous MHD simulations show that reconnection becomes fast as well as strongly time-dependent due to anomalous resistivity. Such processes would not arise in the solar chromosphere which is fully collisional and partially-ionized. So, it is unclear how the rapid and strongly time-dependent reconnection would occur in the solar chromosphere. It is quite likely that the Hall and ambipolar diffusion are present in the solar chromosphere and they could play an important role in driving such rapid, strongly time-dependent reconnection in the solar chromosphere.

Predictions of DKIST/DL-NIRSP Observations for an Off-limb Kink-unstable Coronal Loop

B. **Snow**1,2,3, G. J. J. Botha2, E. Scullion2, J. A. McLaughlin2, P. R. Young2,4,5, and S. A. Jaeggli6

2018 ApJ 863 172

http://iopscience.iop.org/article/10.3847/1538-4357/aad3bc/pdf

Synthetic intensity maps are generated from a 3D kink-unstable flux rope simulation using several DKIST/DL-NIRSP spectral lines to make a prediction of the observational signatures of energy transport and release. The reconstructed large field-of-view intensity mosaics and single tile sit-and-stare high-cadence image sequences show detailed, fine-scale structure and exhibit signatures of wave propagation, redistribution of heat, flows, and fine-scale bursts. These fine-scale bursts are present in the synthetic Doppler velocity maps and can be interpreted as evidence for small-scale magnetic reconnection at the loop boundary. The spectral lines reveal the different thermodynamic structures of the loop, with the hotter lines showing the loop interior and braiding and the cooler lines showing the radial edges of the loop. The synthetic observations of DL-NIRSP are found to preserve the radial expansion, and hence the loop radius can be measured accurately. The electron number density can be estimated using the intensity ratio of the Fe xiiilines at 10747 and 10798 Å. The estimated density from this ratio is correct to within ±10% during the later phases of the evolution; however, it is less accurate initially when line-of-sight density inhomogeneities contribute to the Fe xiii intensity, resulting in an overprediction of the density by ≈30%. The identified signatures are all above a conservative estimate for instrument noise and therefore will be detectable. In summary, we have used forward modeling to demonstrate that the coronal off-limb mode of DKIST/DL-NIRSP will be able to detect multiple independent signatures of a kink-unstable loop and observe small-scale transient features including loop braiding/twisting and small-scale reconnection events occurring at the radial edge of the loop.

The role of lateral magnetic reconnection in solar eruptive events

A. **Soenen**1,2, A. Bemporad3, C. Jacobs1,2, and S. Poedts

Ann. Geophys., 27, 3941-3948, **2009, File**

On **10–11 December 2005** a slow CME occurred in between two coronal streamers in the Western Hemisphere. SOHO/MDI magnetograms show a multipolar magnetic configuration at the photosphere consisting of a complex of active regions located at the CME source and two bipoles at the base of the lateral coronal streamers. White light observations reveal that the expanding CME affects both of the lateral streamers and induces the release of plasma within or close to them. These transient phenomena are possibly due to magnetic reconnections induced by the CME expansion that occurs either inside the streamer current sheet or between the CME flanks and the streamer. Our observations show that CMEs can be associated to not only a single reconnection process at a single location in the corona, but also to many reconnection processes occurring at different times and locations around the flux rope. Numerical simulations are used to demonstrate that the observed lateral reconnections can be reproduced. The observed secondary reconnections associated to CMEs may facilitate the CME release by globally decreasing the magnetic tension of the corona. Future CME models should therefore take into account the lateral reconnection effect.

Resonances in a Coronal Loop Driven by Torsional Alfvén Waves Propagating from the Photosphere

Roberto **Soler**1,2, Jaume Terradas1,2, Ramón Oliver1,2, and José Luis Ballester1,2

2021 ApJ 909 190

https://doi.org/10.3847/1538-4357/abdec5

There is increasing evidence that magnetohydrodynamic waves play an important role in the propagation and dissipation of energy in the solar atmosphere. Here we investigate how torsional Alfvén waves driven at the photosphere can transport energy to an overlying coronal magnetic loop and explore their ability to heat the plasma. We consider a coronal loop whose feet are embedded in the partially ionized chromosphere. A broadband driver at the photosphere excites torsional Alfvén waves that propagate upward to the coronal loop. By means of numerical computations under the stationary-state assumption, we study the transmission of wave energy to the loop and the heating associated with ohmic diffusion and ion–neutral collisions. We find that wave transmission to the loop is heavily affected by the presence of cavity resonances when the frequency of the driver matches an eigenfrequency of the loop. A tremendous amount of wave energy is channeled to the coronal loop for those particular frequencies. The transmitted energy surpasses by many orders of magnitude the requirements to balance thermal radiation. However, dissipation is so weak in the coronal plasma that only a tiny percentage of the energy budget is converted into heat, which is not enough to compensate for radiative losses. Most of the energy simply leaks back to the chromosphere. Conversely, dissipation is much more efficient in the lower atmosphere, and wave heating can locally balance a significant fraction of radiation in the chromosphere. We argue that nonlinear effects such as turbulence triggered by the Kelvin–Helmholtz instability should enhance the heating efficiency at coronal heights.

The role of Alfvén wave heating in solar prominences

Roberto **Soler**, Jaume Terradas, Ramon Oliver, Jose Luis Ballester

A&A 592, A28 **2016**

http://arxiv.org/pdf/1605.07048v1.pdf

Observations have shown that magnetohydrodynamic waves over a large frequency range are ubiquitous in solar prominences. The waves are probably driven by photospheric motions and may transport energy up to prominences suspended in the corona. Dissipation of wave energy can lead to heating of the cool prominence plasma, so contributing to the local energy balance within the prominence. Here we discuss the role of Alfv\'en wave dissipation as a heating mechanism for the prominence plasma. We consider a slab-like quiescent prominence model with a transverse magnetic field embedded in the solar corona. The prominence medium is modelled as a partially ionized plasma composed of a charged ion-electron single fluid and two separate neutral fluids corresponding to neutral hydrogen and neutral helium. Friction between the three fluids acts as a dissipative mechanism for the waves. The heating caused by externally-driven Alfv\'en waves incident on the prominence slab is analytically explored. We find that the dense prominence slab acts as a resonant cavity for the waves. The fraction of incident wave energy that is channelled into the slab strongly depends upon the wave period, P. Using typical prominence conditions, we obtain that wave energy trapping and associated heating are negligible when $P \gtrsim 100$ s, so that it is unlikely that those waves have a relevant influence on prominence energetics. When 1 s $\lesssim P \lesssim 100$ s the energy absorption into the slab shows several sharp and narrow peaks, that can reach up to 100%, when the incident wave frequency matches a cavity resonance of the slab. Wave heating is enhanced at those resonant frequencies. Conversely, when $P \lesssim 1$ s cavity resonances are absent, but the waves are heavily damped by the strong dissipation. We estimate that wave heating may compensate for about 10% of radiative losses of the prominence plasma.

Damped transverse oscillations of interacting coronal loops

Roberto **Soler**, Manuel Luna

A&A 582, A120 **2015**

http://arxiv.org/pdf/1509.01487v1.pdf

Damped transverse oscillations of magnetic loops are routinely observed in the solar corona. This phenomenon is interpreted as standing kink magnetohydrodynamic waves, which are damped by resonant absorption owing to plasma inhomogeneity across the magnetic field. The periods and damping times of these oscillations can be used to probe the physical conditions of the coronal medium. Some observations suggest that interaction between neighboring oscillating loops in an active region may be important and can modify the properties of the oscillations compared to those of an isolated loop. Here we theoretically investigate resonantly damped transverse oscillations of interacting non-uniform coronal loops. We provide a semi-analytic method, based on the T-matrix theory of scattering, to compute the frequencies and damping rates of collective oscillations of an arbitrary configuration of parallel cylindrical loops. The effect of resonant damping is included in the T-matrix scheme in the thin boundary approximation. Analytic and numerical results in the specific case of two interacting loops are given as an application.

Prominence seismology using the period ratio of transverse thread oscillations

R. **Soler**, M. Goossens, J. L. Ballester

A&A, 575, A123 **2015**

http://arxiv.org/pdf/1501.05238v1.pdf

The ratio of the period of the fundamental mode to that of the first overtone of kink oscillations, from here on the "period ratio", is a seismology tool that can be used to infer information about the spatial variation of density along solar magnetic flux tubes. The period ratio is 2 in longitudinally homogeneous thin tubes, but it differs from 2 due to longitudinal inhomogeneity. In this paper we investigate the period ratio in longitudinally inhomogeneous prominence threads and explore its implications for prominence seismology. We numerically solve the two-dimensional eigenvalue problem of kink oscillations in a model of a prominence thread. We take into account three nonuniform density profiles along the thread. In agreement with previous works that used simple piecewise constant density profiles, we find that the period ratio is larger than 2 in prominence threads. When the ratio of the central density to that at the footpoints is fixed, the period ratio depends strongly on the form of the density profile along the thread. The more concentrated the dense prominence plasma near the center of the tube, the larger the period ratio. However, the period ratio is found to be independent of the specific density profile when the spatially averaged density in the thread is the same for all the profiles. An empirical fit of the dependence of the period ratio on the average density is given and its use for prominence seismology is discussed.

The behavior of transverse waves in nonuniform solar flux tubes. II. Implications for coronal loop seismology

Roberto **Soler**, Marcel Goossens, Jaume Terradas, Ramon Oliver

E-print, Dec **2013**; **2014** ApJ 781 111

Seismology of coronal loops using observations of damped transverse oscillations in combination with results from theoretical models is a tool to indirectly infer physical parameters in the solar atmospheric plasma. Existing seismology schemes based on approximations to the period and damping time of kink oscillations are often used beyond their theoretical range of applicability. These approximations assume that the variation of density across the loop is confined to a nonuniform layer much thinner than the radius of the loop, but the results of the inversion problem often do not satisfy this preliminary hypothesis. Here, we determine the accuracy of the analytic approximations to the period and damping time, and its impact on seismology estimates, when largely nonuniform loops are considered. We find that the accuracy of the approximations when used beyond their range of applicability is strongly affected by the form of the density profile across the loop, that is observationally unknown and so must be arbitrarily imposed as part of the theoretical model. The error associated with the analytic approximations can be larger than 50% even for relatively thin nonuniform layers. This error directly affects the accuracy of approximate seismology estimates compared to actual numerical inversions. In addition, assuming different density profiles can produce noncoincident intervals of the seismic variables in inversions of the same event. The ignorance about the true shape of density variation across the loop is an important source of error that may dispute the reliability of parameters seismically inferred assuming an ad hoc density profile.

Damped kink oscillations of flowing prominence threads

R. **Soler**1, M. S. Ruderman2 and M. Goossens

A&A 546, A82 (**2012**)

Transverse oscillations of thin threads in solar prominences are frequently reported in high-resolution observations. Two typical features of the observations are that the oscillations are damped in time and that simultaneous mass flows along the threads are detected. Flows cause the dense threads to move along the prominence magnetic structure while the threads are oscillating. The oscillations have been interpreted in terms of standing magnetohydrodynamic (MHD) kink waves of the magnetic flux tubes, which support the threads. The damping is most likely due to resonant absorption caused by plasma inhomogeneity. The technique of seismology uses the observations combined with MHD wave theory to estimate prominence physical parameters. This paper presents a theoretical study of the joint effect of flow and resonant absorption on the amplitude of standing kink waves in prominence threads. We find that flow and resonant absorption can either be competing effects on the amplitude or both can contribute to damp the oscillations depending on the instantaneous position of the thread within the prominence magnetic structure. The amplitude profile deviates from the classic exponential profile of resonantly damped kink waves in static flux tubes. Flow also introduces a progressive shift of the oscillation period compared to the static case, although this effect is in general of minor importance. We test the robustness of seismological estimates by using synthetic data aiming to mimic real observations. The effect of the thread flow can significantly affect the estimation of the transverse inhomogeneity length scale. The presence of random background noise adds uncertainty to this estimation. Caution needs to be paid to the seismological estimates that do not take the influence of flow into account.

Stability of thermal modes in cool prominence plasmas

R. **Soler**1, J. L. Ballester2 and S. Parenti

A&A 540, A7 (**2012**)

Magnetohydrodynamic thermal modes may play an important role in the formation, plasma condensation, and evolution of solar prominences. Unstable thermal modes due to unbalance between radiative losses and heating can lead to rapid plasma cooling and condensation. An accurate description of the radiative loss function is therefore crucial for this process. We study the stability of thermal modes in unbounded and uniform plasmas with properties akin to those in solar prominences. Effects of partial ionization are taken into account. Three different parametrizations of the radiative loss function are used. By means of a normal mode analysis, we investigate linear nonadiabatic perturbations superimposed on the equilibrium state. We find an approximate instability criterion for thermal modes, while the exact linear growth rate is obtained by numerically solving the general dispersion relation. The stability of thermal disturbances is compared for the three different loss functions that we consider. Using up-to-date computations of radiative losses derived from the CHIANTI atomic database, we find that thermal modes may be unstable in prominences for lower temperatures than those predicted with previously existing loss functions. Thermal instability can take place for temperatures as low as about 15 000 K. The obtained linear growth rates indicate that this instability might have a strong impact on the dynamics and evolution of cool prominence condensations.

Magnetohydrodynamic Waves in Partially Ionized Prominence Plasmas

Roberto **Soler**, Jose Luis Ballester

E-print, Jan **2012**; Astrophysics and Space Science Proceedings

Prominences or filaments are cool clouds of partially ionized plasma living in the solar corona. Ground- and space-based observations have confirmed the presence of oscillatory motions in prominences and they have been interpreted in terms of magnetohydrodynamic (MHD) waves. Existing observational evidence points out that these oscillatory motions are damped in short spatial and temporal scales by some still not well known physical mechanism(s). Since prominences are partially ionized plasmas, a potential mechanism able to damp these oscillations could be ion-neutral collisions. Here, we will **review** the work done on the effects of partial ionization on MHD waves in prominence plasmas.

Kink oscillations of flowing threads in solar prominences

R. **Soler**1,2 and M. Goossens

A&A 531, A167 (**2011**)

Context. Recent observations by Hinode/SOT show that MHD waves and mass flows are simultaneously present in the fine structure of solar prominences.

Aims. We investigate standing kink magnetohydrodynamic (MHD) waves in flowing prominence threads from a theoretical point of view. We model a prominence fine structure as a cylindrical magnetic tube embedded in the solar corona with its ends line-tied in the photosphere. The magnetic cylinder is composed of a region with dense prominence plasma, which is flowing along the magnetic tube, whereas the rest of the flux tube is occupied by coronal plasma.

Methods. We use the WKB approximation to obtain analytical expressions for the period and the amplitude of the fundamental mode as functions of the flow velocity. In addition, we solve the full problem numerically by means of time-dependent simulations.

Results. We find that both the period and the amplitude of the standing MHD waves vary in time as the prominence thread flows along the magnetic structure. The fundamental kink mode is a good description for the time-dependent evolution of the oscillations, and the analytical expressions in the WKB approximation are in agreement with the full numerical results.

Conclusions. The presence of flow modifies the period of the oscillations with respect to the static case. However, for realistic flow velocities this effect might fall within the error bars of the observations. The variation of the amplitude due to the flow leads to apparent damping or amplification of the oscillations, which could modify the real rate of attenuation caused by an additional damping mechanism.

THE THERMAL INSTABILITY OF SOLAR PROMINENCE THREADS

R. **Soler**, J. L. Ballester and M. Goossens

2011 ApJ 731 39

The fine structure of solar prominences and filaments appears as thin and long threads in high-resolution images. In Hα observations of filaments, some threads can be observed for only 5-20 minutes before they seem to fade and eventually disappear, suggesting that these threads may have very short lifetimes. The presence of an instability might be the cause of this quick disappearance. Here, we study the thermal instability of prominence threads as an explanation of their sudden disappearance from Hα observations. We model a prominence thread as a magnetic tube with prominence conditions embedded in a coronal environment. We assume a variation of the physical properties in the transverse direction so that the temperature and density continuously change from internal to external values in an inhomogeneous transitional layer representing the particular prominence-corona transition region (PCTR) of the thread. We use the nonadiabatic and resistive magnetohydrodynamic equations, which include terms due to thermal conduction parallel and perpendicular to the magnetic field, radiative losses, heating, and magnetic diffusion. We combine both analytical and numerical methods to study linear perturbations from the equilibrium state, focusing on unstable thermal solutions. We find that thermal modes are unstable in the PCTR for temperatures higher than 80,000 K, approximately. These modes are related to temperature disturbances that can lead to changes in the equilibrium due to rapid plasma heating or cooling. For typical prominence parameters, the instability timescale is of the order of a few minutes and is independent of the form of the temperature profile within the PCTR of the thread. This result indicates that thermal instability may play an important role for the short lifetimes of threads in the observations.

SEISMOLOGY OF STANDING KINK OSCILLATIONS OF SOLAR PROMINENCE FINE STRUCTURES

R. **Soler**, I. Arregui, R. Oliver, and J. L. Ballester

Astrophysical Journal, 722:1778–1792, **2010**

We investigate standing kink magnetohydrodynamic (MHD) oscillations in a prominence fine structure modeled as a straight and cylindrical magnetic tube only partially filled with the prominence material and with its ends fixed at two rigid walls representing the solar photosphere. The prominence plasma is partially ionized and a transverse inhomogeneous transitional layer is included between the prominence thread and the coronal medium. Thus, ion-neutral collisions and resonant absorption are the damping mechanisms considered. Approximate analytical expressions of the period, the damping time, and their ratio are derived for the fundamental mode in the thin tube and thin boundary approximations. We find that the dominant damping mechanism is resonant absorption, which provides damping ratios in agreement with the observations, whereas ion-neutral collisions are irrelevant for damping. The values of the damping ratio are independent of both the prominence thread length and its position within the magnetic tube, and coincide with the values for a tube fully filled with the prominence plasma. The implications of our results in the context of the MHD seismology technique are discussed, pointing out that the reported short-period (2–10 minutes) and short-wavelength (700–8000 km) thread oscillations may not be consistent with a standing mode interpretation and could be related to propagating waves. Finally, we show that the inversion of some prominence physical parameters, e.g., Alf´en speed, magnetic field strength, transverse inhomogeneity length scale, etc., is possible using observationally determined values of the period and damping time of the oscillations along with the analytical approximations of these quantities.

RESONANTLY DAMPED KINK MAGNETOHYDRODYNAMIC WAVES IN A PARTIALLY IONIZED FILAMENT THREAD

R. Soler, R. Oliver and J. L. Ballester

ApJ 707 662-670, **2009**

Transverse oscillations of solar filament and prominence threads have been frequently reported. These oscillations have the common features of being of short period (2-10 minutes) and being damped after a few periods. The observations are interpreted as kink magnetohydrodynamic (MHD) wave modes, whereas resonant absorption in the Alfvén continuum and ion-neutral collisions are candidates to be the damping mechanisms. Here, we study both analytically and numerically the time damping of kink MHD waves in a cylindrical, partially ionized filament thread embedded in a coronal environment. The thread model is composed of a straight and thin, homogeneous filament plasma, with a transverse inhomogeneous transitional layer where the plasma physical properties vary continuously from filament to coronal conditions. The magnetic field is homogeneous and parallel to the thread axis. We find that the kink mode is efficiently damped by resonant absorption for typical wavelengths of filament oscillations, the damping times being compatible with the observations. Partial ionization does not affect the process of resonant absorption, and the filament plasma ionization degree is only important for the damping for wavelengths much shorter than those observed. To our knowledge, this is the first time that the phenomenon of resonant absorption is studied in a partially ionized plasma.

MAGNETOHYDRODYNAMIC WAVES IN A PARTIALLY IONIZED FILAMENT THREAD

R. **Soler**, R. Oliver, and J. L. Ballester

ApJ 699 1553-1562, **2009**

Oscillations and propagating waves are commonly seen in high-resolution observations of filament threads, i.e., the fine-structures of solar filaments/prominences. Since the temperature of prominences is typically of the order of 10^4 K, the prominence plasma is only partially ionized. In this paper, we study the effect of neutrals on the wave propagation in a filament thread modeled as a partially ionized homogeneous magnetic flux tube embedded in an homogeneous and fully ionized coronal plasma. Ohmic and ambipolar magnetic diffusion are considered in the basic resistive magnetohydrodynamic (MHD) equations. We numerically compute the eigenfrequencies of kink, slow, and Alfvén linear MHD modes and obtain analytical approximations in some cases. We find that the existence of propagating modes is constrained by the presence of critical values of the longitudinal wavenumber. In particular, the lower and upper frequency cutoffs of kink and Alfvén waves owe their existence to magnetic diffusion parallel and perpendicular to magnetic field lines, respectively. The slow mode only has a lower frequency cutoff, which is caused by perpendicular magnetic diffusion and is significantly affected by the ionization degree. In addition, ion-neutral collision is the most efficient damping mechanism for short wavelengths, while ohmic diffusion dominates in the long-wavelength regime.

Damping of Filament Thread Oscillations: Effect of the Slow Continuum

R. **Soler**, R. Oliver, J. L. Ballester, and M. Goossens

ApJL, 695, L166-L170, **2009** doi: 10.1088/0004-637X/695/2/L166

Transverse oscillations of small amplitude are commonly seen in high-resolution observations of filament threads, i.e., the fine structures of solar filaments/prominences, and are typically damped in a few periods. Kink wave modes supported by the thread body offer a consistent explanation of these observed oscillations. Among the proposed mechanisms to explain the kink mode damping, resonant absorption in the Alfvén continuum seems to be the most efficient as it produces damping times of about three periods. However, for a nonzero-β plasma and typical prominence conditions, the kink mode is also resonantly coupled to slow (or cusp) continuum modes, which could further reduce the damping time. In this Letter, we explore for the first time both analytically and numerically the effect of the slow continuum on the damping of transverse thread oscillations. The thread model is composed of a homogeneous and straight cylindrical plasma, an inhomogeneous transitional layer, and the homogeneous coronal plasma. We find that the damping of the kink mode due to the slow resonance is much less efficient than that due to the Alfvén resonance.

Thread Displacement and Intensity Oscillations in a Quiescent Prominence

Yuxiang **Song**1,2, Zongjun Ning1,2, Dong Li1,2, Fanpeng Shi1,2, Jun Xu1,2, and Yuzhi Yang1,2

2024 ApJ 975 280

https://iopscience.iop.org/article/10.3847/1538-4357/ad813c/pdf

In this paper, we investigate the thread displacement and intensity oscillations in a quiescent prominence observed by New Vacuum Solar Telescope at the Hα line center on **2019 October 31**. Each individual thread is traced by the local maximum intensity among its width at various times. In total, 35 threads are detected at six heights parallel to the solar surface. We find 29/35 threads exhibiting the displacement oscillation. A sinusoidal function is used to fit them, and a mean period of 26 minutes is identified. By slicing the same thread at different positions, we find that the oscillation of the thread is very likely a standing wave, but it could also be a long-wavelength propagating wave. After integrating the intensity along the thread width, we also find 8/35 threads presenting their intensity oscillation with a mean period of 7.7 minutes. In total, 7/35 threads exhibit both the displacement and the intensity oscillations.

Interactions between Filament Fibrils and a Network Field

Zhiping **Song**1,2, Jun Zhang1, and Yue Fang1

2023 ApJ 943 114

https://iopscience.iop.org/article/10.3847/1538-4357/acaefc/pdf

Filaments are common structures in the solar atmosphere, and usually interact with their surrounding magnetic fields. However, interactions between filaments and network fields are rare. Here, we report interactions between filament fibrils and a nearby network field in the quiet Sun by employing observations from the New Vacuum Solar Telescope (NVST) and Solar Dynamics Observatory. NVST Hα images show that several filament fibrils separated from the main body of the filament, and moved sideward. While a fibril met the network field, the movement of the fibril segment corresponding to the network field slowed down. Subsequently, weak extremely ultraviolet brightenings appeared near the interface of the filament and the network field, and then the fibril materials began to converge toward the network field. Meanwhile, continuous redshift signal enhancements appeared in the corresponding Dopplergrams, accompanying the convergences of the fibril materials. About 10 and 35 minutes later, two other similar processes occurred again. These observations imply that the network field blocks movements of the filament fibrils and weak magnetic reconnections between the blocked fibrils and the network field take place. We suggest that new field lines developed due to the magnetic reconnections, along which fibril materials fell down into the lower solar atmosphere. These results provide a new picture of filament material drainage. **21 Feb 2019**

A giant dark channel across the solar equator consisting of two filament channels with different chiralities

Zhiping **Song**, Yijun Hou, Jun Zhang

ApJ **871** 7 **2019**

https://arxiv.org/pdf/1811.10148.pdf

http://iopscience.iop.org/article/10.3847/1538-4357/aaf426/pdf

Solar filaments are the largest magnetic structure that can be physically traced to the chromosphere. The structure and evolution of solar filaments are important for our understanding of solar atmosphere physics. In this work, we investigate a giant dark channel crossing the solar equator, which consists of two filament channels with different chiralities. From 2016 April 22 to April 27, this giant dark channel occupied the solar disk. Within this giant channel, a filament channel with dextral chirality was detected in the northern hemisphere, and another filament channel with sinistral chirality was observed in the southern hemisphere. At the junction of the two filament channels, a cusp structure was observed associated with active region (AR) 12532 near the solar equator. The extrapolated three-dimensional magnetic fields reveal that this cusp structure was composed of two sets of field lines belonging to two different filament channels and was rooted on the AR positive-polarity fields. In addition, dark material flows from filaments in the two channels to the cusp structure were detected as well as the flux emergence and cancellation around the cusp footpoints. On 2016 May 21, after a solar rotation, the cusp structure had disappeared, and the giant dark channel broke in the middle where another AR, 12546, had emerged completely. We propose that the magnetic flux emergence and cancellation around the cusp region resulted in the disappearance of the cusp structure and the break of the giant dark channel. **2016 April 22-27**

A Model of the Solar Chromosphere: Structure and Internal Circulation

P. **Song**

2017 ApJ 846 92

http://iopscience.iop.org/article/10.3847/1538-4357/aa85e1/pdf

A model of the solar chromosphere that consists of two fundamentally different regions, a lower region and an upper region, is proposed. The lower region is covered mostly by weak locally closed magnetic field and small network areas of extremely strong, locally open field. The field in the upper region is relatively uniform and locally open, connecting to the corona. The chromosphere is heated by strong collisional damping of Alfvén waves, which are driven by turbulent motions below the photosphere. The heating rate depends on the field strength, wave power from the photosphere, and altitude in the chromosphere. The waves in the internetwork area are mostly damped in the lower region, supporting radiation in the lower chromosphere. The waves in the network area, carrying more Poynting flux, are only weakly damped in the lower region. They propagate into the upper region. As the thermal pressure decreases with height, the network field expands to form the magnetic canopy where the damping of the waves from the network area supports radiation in the whole upper region. Because of the vertical stratification and horizontally nonuniform distribution of the magnetic field and heating, one circulation cell is formed in each of the upper and lower regions. The two circulation cells distort the magnetic field and reinforce the funnel-canopy-shaped magnetic geometry. The model is based on classical processes and is semi-quantitative. The estimates are constrained according to observational knowledge. No anomalous process is invoked or needed. Overall, the heating mechanism is able to damp 50% of the total wave energy.

The Origin of Solar Filament Plasma Inferred from in situ Observations of Elemental Abundances

Hongqiang **Song**, Yao Chen, Bo Li, Leping Li, Liang Zhao, Jiansen He, Die Duan, Xin Cheng, Jie Zhang

ApJL **836** L11 **2017**

https://arxiv.org/pdf/1702.01215.pdf

Solar filaments/prominences are one of the most common features in the corona, which may lead to energetic coronal mass ejections (CMEs) and flares when they erupt. Filaments are about one hundred times cooler and denser than the coronal material, and physical understanding of their material origin remains controversial. Two types of scenarios have been proposed: one argues that the filament plasma is brought into the corona from photosphere or chromosphere through a siphon or evaporation/injection process, while the other suggests that the material condenses from the surrounding coronal plasma due to thermal instability. The elemental abundance analysis is a reasonable clue to constrain the models, as the siphon or evaporation/injection model would predict that the filament material abundances are close to the photospheric or chromospheric ones, while the condensation model should have coronal abundances. In this letter, we analyze the elemental abundances of a magnetic cloud that contains the ejected filament material. The corresponding filament eruption occurred on **1998 April 29**, accompanying an M6.8 class soft X-ray flare located at the heliographic coordinates S18E20 (NOAA 08210) and a fast halo CME with the linear velocity of 1374 km s^{-1} near the Sun. We find that the abundance ratios of elements with low and high First Ionization Potential such as Fe/O, Mg/O, and Si/O are 0.150, 0.050, and 0.070, respectively, approaching their corresponding photospheric values 0.065, 0.081, and 0.066, which does not support the coronal origin of the filament plasma.

Quasi-Periodic Releases of Streamer Blobs and Velocity Variability of the Slow SolarWind near the Sun

H.Q. **Song** · Y. Chen · K. Liu · S.W. Feng · L.D. Xia

Solar Phys (**2009**) 258: 129–140

We search for persistent and quasi-periodic release events of streamer blobs during 2007 with the *Large Angle Spectrometric Coronagraph* on the *Solar and Heliospheric Observatory* and assess the velocity of the slow solar wind along the plasma sheet above the corresponding streamer by measuring the dynamic parameters of blobs. We find ten quasiperiodic release events of streamer blobs lasting for three to four days. In each day of these events, we observe three – five blobs. The results are in line with previous studies using data observed near the last solar minimum. Using the measured blob velocity as a proxy for that of the mean flow, we suggest that the velocity of the background slow solar wind near the Sun can vary significantly within a few hours. This provides an observational manifestation of the large velocity variability of the slow solar wind near the Sun.

MHD modelling of coronal streamers and their oscillations⋆

D. **Sorokina**1, T. Van Doorsselaere1, D.-C. Talpeanu2 and S. Poedts1,3

A&A 682, A168 (**2024**)

https://www.aanda.org/articles/aa/pdf/2024/02/aa47623-23.pdf

Context. The present work investigates solar coronal dynamics in particular streamer waves. Streamer waves are transverse oscillations of the streamer stalk, often generated by the passage of a coronal mass ejection (CME). Recent observational studies infer that the streamer wave is an eigenmode of the streamer plasma slab and an excellent candidate for coronal seismology.

Aims. In the present work, we aim to numerically investigate the theoretical concepts of the physics and properties of streamer waves and to complement the observational statistical analysis of these events.

Methods. We used the magnetohydrodynamics (MHD) module of MPI-AMRVAC. An adaptive mesh refinement scheme was employed to achieve high resolution for the streamer structure. All the simulations were computed on the same base grid with the same numerical methods. We considered a dipole magnetic field on the Sun and a uniformly accelerating solar wind. We introduced a θ-velocity perturbation within our computational domain in the plane of a streamer to excite the transverse motion.

Results. A numerical model for the streamer wave phenomena was constructed in the framework of 2.5D MHD. We performed a parameter study and identified a sensitivity of the streamer dynamics to the background solar wind speed, the characteristics of the perturbation, and the input parameters for the model, such as temperature and magnetic field. We performed a statistical analysis and compared the obtained modelling results with the database of such events from observations from three different coronagraphs. We observed a narrow range of phase speeds and a correlation between wavelength and period. This is consistent with the observations and supports the idea that the streamer wave is an eigenmode of the streamer plasma slab. The measured phase speed is consistently significantly higher than the speed calculated from the measured period and wavelength. The simple fit, when the difference between these two speeds is exactly the background solar wind speed, only matches a small fraction of the data. The obtained results indicate that further investigation is required into the Doppler shift effect in the MHD theory for coronal seismology.

Fast downflows in a chromospheric filament

K. **Sowmya**, A. Lagg, S. K. Solanki, J. S. Castellanos Durán

Proceedings of IAUS 354 **2019**)

https://arxiv.org/pdf/1912.06586.pdf

An active region filament in the upper chromosphere is studied using spectropolarimetric data in He I 10830 A from the GREGOR telescope. A Milne-Eddingon based inversion of the Unno-Rachkovsky equations is used to retrieve the velocity and the magnetic field vector of the region. The plasma velocity reaches supersonic values closer to the feet of the filament barbs and coexist with a slow velocity component. Such supersonic velocities result from the acceleration of the plasma as it drains from the filament spine through the barbs. The line-of-sight magnetic fields have strengths below 200 G in the filament spine and in the filament barbs where fast downflows are located, their strengths range between 100 - 700 G. **17 June 2014**

Inference of Magnetic Field in the Coronal Streamer Invoking Kink Wave Motions generated by Multiple EUV Waves

A.K. **Srivastava**, Talwinder Singh, Leon Ofman, B.N. Dwivedi

Mon. Not. R. Astron. Soc. **2016** **File**

http://arxiv.org/pdf/1606.00337v1.pdf

Using MHD seismology by observed kink waves, the magnetic field profile of a coronal streamer has been investigated. STEREO-B/EUVI temporal image data on **7 March 2012** shows an evolution of two consecutive EUV waves that interact with the footpoint of a coronal streamer evident in the co-spatial and co-temporal STEREO-B/COR-I observations. The evolution of EUV waves is clearly evident in STEREO-B/EUVI, and its energy exchange with coronal streamer generates kink oscillations. We estimate the phase velocities of the kink wave perturbations by tracking it at different heights of the coronal streamer. We also estimate the electron densities inside and outside the streamer using SSI of polarized brightness images in STEREO-B/COR-1 observations. Taking into account the MHD theory of kink waves in a cylindrical waveguide, their observed properties at various heights, and density contrast of the streamer, we estimate the radial profile of magnetic field within this magnetic structure. Both the kink waves diagnose the exponentially decaying radial profiles of the magnetic field in coronal steamer upto 3 solar radii. Within the limit of uncertainties in the measurements, it is indicated that coronal magnetic field of the streamer varies slowly in time at various heights, although its nature always remains exponentially decaying. It is seen that during the evolution of second kink motion in the streamer, it increases in brightness, and also in areal extent slightly, which may be associated with the decreased photospheric magnetic flux at its footpoint. As a result, the magnetic field profile produced by the second kink wave is reduced within the streamer compared to the one diagnosed by the first one. The precisely estimated magnetic field profiles with the uncertainty less than 10% match well with the empirical profile and various observational estimations of the outer coronal magnetic field.

Observations of intensity oscillations in a prominence-like cool loop system as observed by SDO/AIA: evidence of multiple harmonics of fast magnetoacoustic waves

Srivastava, A. K.; Dwivedi, B. N.; Kumar, Mukul

Astrophysics and Space Science, Volume 345, Issue 1, pp.25-32, **2013**

Using SDO/AIA 304 ? channel, we study the evolution of weak intensity oscillations in a prominence like cool loop system observed at North-West limb on **7 March 2011**. We use the standard wavelet tool to produce statistically significant power spectra of AIA 304 ? normalized fluxes derived respectively near the apex and footpoint of the fluxtube. We find periodicities of ≈667 s and ≈305 s respectively near apex and above footpoint with significance level >98 %. Observed statistically significant periodicities in the tube of projected length ≈170 Mm and width ≈10 Mm, are interpreted as most likely signature of evolution of various harmonics of tubular fast magnetoacoustic waves. Sausage modes are unlikely though they are compressive as they need bulky and highly denser loop system for their evolution for sustaining such large periods. We interpret the observed periodicities as multiple harmonics (fundamental and first) of fast magnetoacoustic kink waves that can generate some weak density perturbations (thus intensity oscillations) in the tube and can be observed pertaining to periodic variation in plasma column depth as tube is oblique in projection with respect to line-of-sight. The period ratio P 1/ P 2=2.18 is observed in the fluxtube, which is the signature of the magnetic field divergence of the cool loop system. We estimate tube expansion factor as 1.27 which is typical of EUV bipolar loops in the solar atmosphere. We estimate the lower bound average magnetic fields ranging from ≈9 to 90 Gauss depending upon typical densities as 109-1011 cm-3 in the observed prominence-like cool loop system. We also observe the first signature of lowering fundamental mode period by a factor 0.85 due to cooling of this loop system.

Discovery of the Sausage-Pinch Instability in Solar Corona

Abhi K. **Srivastava**1, R. Erdélyi2, V. Fedun2, P. Kayshap1, N.C. Joshi1, D. Tripathi

UKSP nugget 34, **2013.** http://www.uksolphys.org/?p=6158

A wide range of MHD instabilities have been observed in recent years in association with various solar dynamical processes. An instability known as the sausage instability (m = 0) mode, which is theoretically investigated in astrophysical plasma [7,9,10], has – to the best of our knowledge - not yet been observed in the solar atmosphere (although it is worth mentioning that sausage oscillations of the stable flux-tubes are well-observed [11,12,13]). In this nugget, we outline in brief the discovery of the sausage-pinch instability in the solar corona, in an activated partial filament eruption observed by SDO/AIA.

These types of magnetic instabilities can act as canonical plasma processes to trigger large-scale solar eruptions**.**
12 September 2011

OBSERVATIONAL EVIDENCE OF SAUSAGE-PINCH INSTABILITY IN SOLAR CORONA BY SDO/AIA

A. K. **Srivastava**1, R. Erdélyi2, Durgesh Tripathi3, V. Fedun2,4, N. C. Joshi1, and P. Kayshap

2013 ApJ 765 L42

We present the first observational evidence of the evolution of sausage-pinch instability in active region 11295 during a prominence eruption using data recorded on **2011 September 12** by the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO). We have identified a magnetic flux tube visible in AIA 304 Å that shows curvatures on its surface with variable cross-sections as well as enhanced brightness. These curvatures evolved and thereafter smoothed out within a timescale of a minute. The curved locations on the flux tube exhibit a radial outward enhancement of the surface of about 1-2 Mm (a factor of two larger than the original thickness of the flux tube) from the equilibrium position. AIA 193 Å snapshots also show the formation of bright knots and narrow regions in-between at the four locations as that of 304 Å along the flux tube where plasma emission is larger compared to the background. The formation of bright knots over an entire flux tube as well as the narrow regions in <60 s may be the morphological signature of the sausage instability. We also find the flows of confined plasma (propagation of brightness) in these bright knots along the field lines, which indicates the dynamicity of the flux tube that probably causes the dominance of the longitudinal field component over short temporal scales. The observed longitudinal motion of the plasma frozen in the magnetic field lines further vanishes the formed curvatures and plasma confinements as well as growth of instability to stabilize the flux tube.

The Na I and Sr II Resonance Lines in Solar Prominences

Goetz **Stellmacher**, Eberhard Wiehr

Solar Phys. 292:83 **2017**

https://arxiv.org/pdf/1705.02475.pdf

We estimate the electron density, n_e, and its spatial variation in quiescent prominences from the observed emission ratio of the resonance lines Na I 5890 (D2) and Sr II 4078. For a bright prominence (tau_alpha ~ 25) we obtain a mean n_e ~ 2*10^10 /cm^3; for a faint one (tau_alpha ~ 4) n_e ~ 4*10^10 /cm^3 on two consecutive days with moderate internal fluctuation and no systematic variation with height above the solar limb. The thermal and non-thermal contributions to the line broadening, T_kin and V_nth, required to deduce n_e from the emission ratio NaI/SrII cannot be unambiguously determined from observed widths of lines from atoms of different mass. The reduced widths, Delta-lambda_D / lambda_0, of Sr II 4078 show an excess over those from NaD2 and H-delta, assuming the same T_kin and V_nth. We attribute this excess broadening to higher non-thermal broadening induced by interaction of ions with the prominence magnetic field. This is suggested by the finding of higher macro-shifts of SrII4078 as compared to those from NaD2.

30 Aug-3 Sept 2015

Non-thermal line-broadening in solar prominences

G. **Stellmacher**1 and E. Wiehr

A&A 581, A141 (**2015**)

http://arxiv.org/pdf/1605.07923v1.pdf

Aims. We show that the line broadening in quiescent solar prominences is mainly due to non-thermal velocities.
Methods. We have simultaneously observed a wide range of optically thin lines in quiescent prominences, selected for bright and narrow Mg b emission without line satellites from macro-shifts.
Results. We find a ratio of reduced widths, $\Delta\lambda D/\lambda 0$, of $H\gamma$ and $H\delta$ of 1.05 ± 0.03, which can hardly be attributed to saturation, since both are optically thin for the prominences observed: $\tau\gamma \leq 0.3$, $\tau\delta \leq 0.15$. We confirm the ratio of reduced widths of He 4772 (triplet) and He 5015 (singlet) of 1.1 ± 0.05 at higher significance and detect a width ratio of Mg b2 and Mg 4571 (both from the triplet system) of 1.3 ± 0.1.
Conclusions. The discrepant widths of lines from different atoms, and even from the same atom, cannot be represented by a unique pair [Tkin; Vnth]. Values of Tkin deduced from observed line radiances using models indicate low temperatures down to Tkin ≈ 5000 K. Non-thermal velocities, related to different physical states of the respective emitting prominence region, seem to be the most important line broadening mechanism.

OBSERVATIONS FROM SDO, HINODE, AND STEREO OF A TWISTING AND WRITHING START TO A SOLAR-FILAMENT-ERUPTION CASCADE

Alphonse C. **Sterling**1,3, Ronald L. Moore1, and Hirohisa Hara

2012 ApJ 761 69, **File**

We analyze data from SDO (AIA, HMI), Hinode (SOT, XRT, EIS), and STEREO (EUVI) of a solar eruption sequence of **2011 June 1** near 16:00 UT, with an emphasis on the early evolution toward eruption. Ultimately, the sequence consisted of three emission bursts and two filament ejections. SDO/AIA 304 Å images show absorbing-material strands initially in close proximity which over ~20 minutes form a twisted structure, presumably a flux rope with ~1029 erg of free energy that triggers the resulting evolution. A jump in the filament/flux rope's displacement (average velocity ~20 km s–1) and the first burst of emission accompanies the flux-rope formation. After ~20 more minutes, the flux rope/filament kinks and writhes, followed by a semi-steady state where the flux rope/filament rises at (~5 km s–1) for ~10 minutes. Then the writhed flux rope/filament again becomes MHD unstable and violently erupts, along with rapid (50 km s–1) ejection of the filament and the second burst of emission. That ejection removed a field that had been restraining a second filament, which subsequently erupts as the second filament ejection accompanied by the third (final) burst of emission. Magnetograms from SDO/HMI and Hinode/SOT, and other data, reveal several possible causes for initiating the flux-rope-building reconnection, but we are not able to say which is dominant. Our observations are consistent with magnetic reconnection initiating the first burst and the flux-rope formation, with MHD processes initiating the further dynamics. Both filament ejections are consistent with the standard model for solar eruptions.

INSIGHTS INTO FILAMENT ERUPTION ONSET FROM SOLAR DYNAMICS OBSERVATORY OBSERVATIONS

Alphonse C. **Sterling**1,3, Ronald L. Moore1 and Samuel L. Freeland

2011 ApJ 731 L3; **File**

We examine the buildup to and onset of an active region filament confined eruption of **2010 May 12**, using EUV imaging data from the Solar Dynamics Observatory (SDO) Atmospheric Imaging Array and line-of-sight magnetic data from the SDO Helioseismic and Magnetic Imager. Over the hour preceding eruption the filament undergoes a slow rise averaging ~3 km s–1, with a step-like trajectory. Accompanying a final rise step ~20 minutes prior to eruption is a transient preflare brightening, occurring on loops rooted near the site where magnetic field had canceled over the previous 20 hr. Flow-type motions of the filament are relatively smooth with speeds ~50 km s–1 prior to the preflare brightening and appear more helical, with speeds ~50-100 km s–1, after that brightening. After a final plateau in the filament's rise, its rapid eruption begins, and concurrently an outer shell "cocoon" of the filament material increases in emission in hot EUV lines, consistent with heating in a newly formed magnetic flux rope. The main flare brightenings start ~5 minutes after eruption onset. The main flare arcade begins between the legs of an envelope-arcade loop that is nearly orthogonal to the filament, suggesting that the flare results from reconnection among the legs of that loop. This progress of events is broadly consistent with flux cancellation leading to formation of a helical flux rope that subsequently erupts due to onset of a magnetic instability and/or runaway tether cutting.

Hinode Observations of the Onset Stage of a Solar Filament Eruption

A. C. **Sterling**, R. L. Moore, T. E. Berger, M. Bobra, J. M. Davis, P. Jibben, R. Kano, L. L. Lundquist, D. Myers, N. Narukage, T. Sakao, K. Shibasaki, R. A. Shine, T. D. Tarbell, and M. Weber

Publ. Astron. Soc. Japan 59, pp.S823-S829 **(2007) File**

[Abstract], [HTML], [PDF(1832kb)], [PS.gz(10203kb)] (Movie1, Movie2, Movie3)

class B2.5 level on **2007 March 2 at 05:29UT**,

We used Hinode X-Ray Telescope (XRT) and Solar Optical Telescope (SOT) filtergraph (FG) Stokes-V magnetogram observations, to study the early onset of a solar eruption that includes an erupting filament that we observe in TRACE EUV images. The filament undergoes a slow rise for at least 20min prior to its fast eruption and strong soft X-ray (SXR) flaring; such slow rises have been previously reported, and the new Hinode data elucidate the physical processes occurring during this period. XRT images show that during the slow-rise phase, an SXR sigmoid forms from apparent reconnection low in the sheared core field traced by the filament, and there is a low-level intensity peak in both EUV and SXRs during the slow rise. MDI and SOT FG Stokes-V magnetograms show that the pre-eruption filament is along a neutral line between opposing-polarity enhanced network cells, and the SOT magnetograms show that these opposing fields are flowing together and canceling for at least six hours prior to eruption. From the MDI data we measured the canceling network fields to be _ 40 G, and we estimated that _10^{19} Mx of flux canceled during the five hours prior to eruption; this is only _5% of the total flux spanned by the eruption and flare, but apparently its tether-cutting cancellation was enough to destabilize the sigmoid field holding the filament and resulted in that field's eruption.

NEW EVIDENCE FOR THE ROLE OF EMERGING FLUX IN A SOLAR FILAMENT'S SLOW RISE PRECEDING ITS CME-PRODUCING FAST ERUPTION

Alphonse C. **Sterling**, Louise K. Harra, and Ronald L. Moore

The Astrophysical Journal, 669:1359-1371, **2007, File**

We observe the eruption of a large-scale (_300,000 km) **quiet-region solar filament** (**2001 February 28**) leading to an Earth-directed ‘‘halo’’ coronal mass ejection (CME), using data from EIT, CDS, MDI, and LASCO on SOHO and from SXT on Yohkoh. Initially the filament shows a slow (_1 km s_{-1} projected against the solar disk) and approximately constant velocity rise for about 6 hr, before erupting rapidly, reaching a velocity of _8 kms_{-1} over the next_25 minutes. CDS Doppler data show Earth-directed filament velocities ranging from <20 km s_{-1} (the noise limit) during the slow-rise phase, to _100 km s_{-1} early in the eruption. Beginning within 10 hr prior to the start of the slow rise, localized new magnetic flux emerged near one end of the filament. Near the start of and during the slow-rise phase, soft X-ray (SXR) microflaring occurred repeatedly at the flux-emergence site, and the magnetic arcade over the filament progressively brightened in a fan of illumination in SXRs. These observations are consistent with ‘‘tether-weakening’’ reconnection occurring between the newly emerging flux and the overlying arcade field containing the filament, and apparently this reconnection is the cause of the filament's slow rise. We cannot, however, discern whether the transition from slow rise to fast eruption was caused by a final episode of tether-weakening reconnection, or by one or some combination of other possible mechanisms allowed by the observations.

Intensity ''dimmings'' and ''brightenings'' occurring both near to and relatively far from the location of the filament are possible signatures of the expansion (''opening'') of the erupting field and its reconnection with overarching field during the eruption.

Slow-Rise and Fast-Rise Phases of an Erupting Solar Filament, and Flare Emission Onset
Alphonse C. **Sterling** and Ronald L. Moore
Ap. J. 630, No. 2, 1148-1159, **2005**

Solar Magnetized ''Tornadoes': Evidence for Rotational Motion in a Tornado-like Prominence
Yang **Su**, Peter G?m?ry, Astrid Veronig, Manuela Temmer, Tongjiang Wang, Kamalam Vanninathan, Weiqun Gan, Youping Li
2014 ApJL 785 L2
http://arxiv.org/pdf/1312.5226v1.pdf
https://iopscience.iop.org/article/10.1088/2041-8205/785/1/L2/pdf
Su et al. (2012) proposed a new explanation for filament formation and eruption, where filament barbs are rotating magnetic structures driven by underlying vortices on the surface. Such structures have been noticed as "tornado-like prominences" when they appear above the limb. They may play a key role as the source of plasma and twists in filament. However, no observations have successfully identified rotational motion of the magnetic structure itself from other motions such as oscillation and plasma flow. Here we report the first solid evidence of rotational motions in a tornado-like prominence obtained from spectroscopic observations in two coronal lines in the frame of a specifically designed Hinode/EIS observing program. The opposite velocities at the two sides of the prominence and their time evolution, together with the periodic motions evident in SDO/AIA images, indicate a rotational motion with a speed of ∼5 km/s. The data also revealed the existence of both cold and million-degree-hot plasma in the prominence leg, supporting the so-called ``prominence-corona transition region". **14 September 2013**

ROTATING MOTIONS AND MODELING OF THE ERUPTING SOLAR POLAR-CROWN PROMINENCE ON 2010 DECEMBER 6
Yingna **Su** and Adriaan van Ballegooijen
2013 ApJ 764 91
A large polar-crown prominence composed of different segments spanning nearly the entire solar disk erupted on **2010 December 6**. Prior to the eruption, the filament in the active region part split into two layers: a lower layer and an elevated layer. The eruption occurs in several episodes. Around 14:12 UT, the lower layer of the active region filament breaks apart: One part ejects toward the west, while the other part ejects toward the east, which leads to the explosive eruption of the eastern quiescent filament. During the early rise phase, part of the quiescent filament sheet displays strong rolling motion (observed by STEREO-B) in the clockwise direction (viewed from east to west) around the filament axis. This rolling motion appears to start from the border of the active region, then propagates toward the east. The Atmospheric Imaging Assembly (AIA) observes another type of rotating motion: In some other parts of the erupting quiescent prominence, the vertical threads turn horizontal, then turn upside down. The elevated active region filament does not erupt until 18:00 UT, when the erupting quiescent filament has already reached a very large height. We develop two simplified three-dimensional models that qualitatively reproduce the observed rolling and rotating motions. The prominence in the models is assumed to consist of a collection of discrete blobs that are tied to particular field lines of a helical flux rope. The observed rolling motion is reproduced by continuous twist injection into the flux rope in Model 1 from the active region side. Asymmetric reconnection induced by the asymmetric distribution of the magnetic fields on the two sides of the filament may cause the observed rolling motion. The rotating motion of the prominence threads observed by AIA is consistent with the removal of the field line dips in Model 2 from the top down during the eruption.

SIMULTANEOUS OBSERVATION OF SOLAR OSCILLATIONS ASSOCIATED WITH CORONAL LOOPS FROM THE PHOTOSPHERE TO THE CORONA
J. T. **Su**1, Y. Liu2, S. Liu1, Y. Z. Zhang1, H. Zhao1, H. Q. Xu1, and W. B. Xie
2013 ApJ 762 42
The solar oscillations along one coronal loop in AR 11504 are observed simultaneously in white light emission and Doppler velocity by SDO/HMI, and in UV and EUV emissions by SDO/AIA. The technique of the time-distance diagram is used to detect the propagating oscillations of the emission intensities along the loop. We find that although all the oscillation signals were intercorrelated, the low chromospheric oscillation correlated more closely to the oscillations of the transition region and corona than to those of the photosphere. Situated above the sunspot, the oscillation periods were ~3 minutes in the UV/EUV emissions; however, moving away from the sunspot and into the quiet Sun, the periods became longer, e.g., up to ~5 minutes or more. In addition, along another loop we observe

both the high-speed outflows and oscillations, which roughly had a one-to-one corresponding relationship. This indicates that the solar periodic oscillations may modulate the magnetic reconnections between the loops of the high and low altitudes that drive the high-speed outflows along the loop.

OBSERVATION OF HIGH-SPEED OUTFLOWS IN CORONAL LOOPS ASSOCIATED WITH PHOTOSPHERIC MAGNETIC FIELD EVOLUTION

J. T. **Su**1, Y. Liu2, Y. D. Shen2, S. Liu1, and X. J. Mao

2012 ApJ 760 82

Using SDO/AIA instruments, we provide an EUV observation of two adjacent loop strands (Loops 1 and 2) with one side of their footpoints rooted in the boundaries of active region (AR) NOAA 11158 and the other side in the quiet-Sun regions. The AR footpoints of Loop 1 were located in monopolar magnetic areas and those of Loop 2 in mixed polar areas (SDO/HMI magnetograms). There were no apparent outflows found in Loop 1 in 10 hr of observations, whereas in Loop 2, the outflows were detected throughout the whole observation with an average speed of 120-150 km s–1. We find clear evidence of magnetic reconnections occurring in the AR footpoints of Loop 2 (the opposite magnetic polarities came close and then a part of them disappeared) and magnetic flux dispersal in the quiet-Sun footpoints (a patch of positive polarities decayed with time). Furthermore, with Hinode/SOT observations, there were no significant Ca II H brightenings detected at the loop footpoints of Loop 2 at the chromospheric heights in response to those of the AIA 171 Å and 304 Å channels when four strong outflow events took place in the loops, which seem to differ from the conclusions of previous studies. In other studies, the rapid coronal outflows along the coronal loops were found to originate from the chromosphere through transient events (e.g., type II spicules).

OBSERVATIONS AND MAGNETIC FIELD MODELING OF A SOLAR POLAR CROWN PROMINENCE

Yingna **Su** and Adriaan van Ballegooijen

2012 ApJ 757 168

We present observations and magnetic field modeling of the large polar crown prominence that erupted on **2010 December 6**. Combination of Solar Dynamics Observatory (SDO)/Atmospheric Imaging Assembly (AIA) and STEREO_Behind/EUVI allows us to see the fine structures of this prominence both at the limb and on the disk. We focus on the structures and dynamics of this prominence before the eruption. This prominence contains two parts: an active region part containing mainly horizontal threads and a quiet-Sun part containing mainly vertical threads. On the northern side of the prominence channel, both AIA and EUVI observe bright features which appear to be the lower legs of loops that go above then join in the filament. Filament materials are observed to frequently eject horizontally from the active region part to the quiet-Sun part. This ejection results in the formation of a dense-column structure (concentration of dark vertical threads) near the border between the active region and the quiet Sun. Using the flux rope insertion method, we create nonlinear force-free field models based on SDO/Helioseismic and Magnetic Imager line-of-sight magnetograms. A key feature of these models is that the flux rope has connections with the surroundings photosphere, so its axial flux varies along the filament path. The height and location of the dips of field lines in our models roughly replicate those of the observed prominence. Comparison between model and observations suggests that the bright features on the northern side of the channel are the lower legs of the field lines that turn into the flux rope. We suggest that plasma may be injected into the prominence along these field lines. Although the models fit the observations quiet well, there are also some interesting differences. For example, the models do not reproduce the observed vertical threads and cannot explain the formation of the dense-column structure.

SOLAR MAGNETIZED "TORNADOES:" RELATION TO FILAMENTS

Yang **Su**1, Tongjiang Wang2,3, Astrid Veronig1, Manuela Temmer1, and Weiqun Gan

2012 ApJL 756 L41

https://iopscience.iop.org/article/10.1088/2041-8205/756/2/L41/pdf

Solar magnetized "tornadoes," a phenomenon discovered in the solar atmosphere, appear as tornado-like structures in the corona but are rooted in the photosphere. Like other solar phenomena, solar tornadoes are a feature of magnetized plasma and therefore differ distinctly from terrestrial tornadoes. Here we report the first analysis of solar "tornadoes" (two papers which focused on different aspects of solar tornadoes were published in the Astrophysical Journal Letters and Nature, respectively, during the revision of this Letter). A detailed case study of two events indicates that they are rotating vertical magnetic structures probably driven by underlying vortex flows in the photosphere. They usually exist as a group and are related to filaments/prominences, another important solar phenomenon whose formation and eruption are still mysteries. Solar tornadoes may play a distinct role in the supply of mass and twists to filaments. These findings could lead to a new explanation of filament formation and eruption.

EXTREME-ULTRAVIOLET MULTI-WAVELENGTH OBSERVATIONS OF QUASI-PERIODIC PULSATIONS IN A SOLAR POST-FLARE CUSP-SHAPE LOOP WITH SDO/AIA

J. T. **Su**1, Y. D. Shen2, and Y. Liu

2012 ApJ 754 43

We present extreme-ultraviolet multi-wavelength observations with the SDO/AIA instruments of quasi-periodic pulsations (QPPs) propagating along a cusp-shaped loop formed after an M2.2 flare on the Sun. Our motivation is to detect whether there were slow-mode magnetoacoustic waves propagating along its protruding flux tube. To this end, with fast Fourier transform we extract the short (<3 minutes) and long (>3 minutes) period components of the QPPs from time-space diagrams of the tube slices. We find that velocity differences did exist among the short/long-period components of different wavelengths, but only one event in the long-period ones showed they were greater than the measurement errors (e.g., 65 km s–1), which were 330 km s–1 detected in 171 Å, 590 km s–1 in 211 Å, and 180 km s–1 in 304 Å. The intensity modulation in all wavelengths is found to be very large, e.g., ~60% of the emission trend for an event in the 171 Å passband, which would be an order of magnitude higher than the perturbation of the plasma density in the slow-mode magnetoacoustic waves. Moreover, only the QPPs with upward velocities of 50-300 km s–1 are found in the tube, and the downward ones of several tens of kilometers are never unambiguously detected. Therefore, most of the QPP events under study were likely the episodic outflows along the tube, and the one with a supersonic speed of 590 km s–1 may be a kink wave

STRUCTURE AND DYNAMICS OF QUIESCENT FILAMENT CHANNELS OBSERVED BY *HINODE/*XRT AND *STEREO/*EUVI

Yingna **Su**, Adriaan van Ballegooijen, and Leon Golub

Astrophysical Journal, 721:901–910, **2010** September

We present a study of the structure and dynamics of quiescent filament channels observed by *Hinode/*XRT and *STEREO/*EUVI at the solar minimum 23/24 from 2006 November to 2008 December. For 12 channels identified on the solar disk (Group I channels), we find that the morphology of the structure on the two sides of the channel is asymmetric in bothX-rays and EUV: the eastern side has curved features while thewestern side has straight features. We interpret the results in terms of a magnetic flux rope model. The asymmetry in the morphology is due to the variation in axial flux of the flux rope along the channel, which causes the field lines from one polarity to turn into the flux rope (curved feature),while the field lines from the other polarity are connected to very distant sources (straight).

For most of the 68 channels identified by cavities at the east and west limbs (Group II channels), the asymmetry cannot be clearly identified, which is likely due to the fact that the axial flux may be relatively constant along such channels. Corresponding cavities are identified only for 5 of the 12 Group I channels, while Group II channels are identified for all of the 68 cavity pairs. The studied filament channels are often observed as dark channels in X-rays and EUV. Sheared loops within Group I channels are often seen in X-rays, but are rarely seen in Group II channels as shown in the X-ray Telescope daily synoptic observations. A survey of the dynamics of studied filament channels shows that filament eruptions occur at an average rate of 1.4 filament eruptions per channel per solar rotation.

Observation of Interactions and Eruptions of Two Filaments

Jiangtao **Su**, Yu Liu, Hiroki Kurokawa, Xinjie Mao, Shangbin Yang, Hongqi Zhang and Haimin Wang

BBSO, Number: 1339, 2007; Solar Phys. 242(1-2), 53-63, **2007**.

We present new observations of interactions of two close, but distinct, Hα filaments and their successive eruptions on **5 November 1998**. The magnetic fields of the filaments are both of the sinistral type. The interactions between the two filaments were initiated mainly by an active filament of one of them. Before the filament eruptions, two dark plasma ejections and chromospheric brightenings were observed. They indicate that possible magnetic reconnections had occurred between the two filaments. During the first filament eruption, salient dark mass motions transferring from the left erupting filament into the right one were observed. The right filament erupted 40 minutes later. This second filament eruption may have been the result of a loss of stability due to the sudden mass injection from the left filament. Based on the Hα observations, we have created a sketch for understanding the interactions between two filaments and accompanying activities. The traditional theory of filament merger requires that the filaments share the same filament channel and that the reconnection occur between head and head, as simulated by **Devore, Antiochos, and Aulanier (2005, 2006).** Our interpretation is that the external bodily magnetic reconnection between flux ropes of the same chirality is another possible way for two filament bodies to coalesce.

The magnetic field configuration of a solar prominence inferred from spectropolarimetric observations in the He I 10830 A triplet

David Orozco **Suárez**, Andrés Asensio Ramos, Javier Trujillo Bueno

A&A, **2014**

http://arxiv.org/pdf/1403.7976v1.pdf

Context: The determination of the magnetic field vector in quiescent solar prominences is possible by interpreting the Hanle and Zeeman effects in spectral lines. However, observational measurements are scarce and lack high spatial resolution. Aims: To determine the magnetic field vector configuration along a quiescent solar prominence by interpreting spectropolarimetric measurements in the He I 1083.0 nm triplet obtained with the Tenerife Infrared Polarimeter installed at the German Vacuum Tower Telescope of the Observatorio del Teide. Methods. The He I 1083.0 nm triplet Stokes profiles are analyzed with an inversion code that takes into account the physics responsible of the polarization signals in this triplet. The results are put into a solar context with the help of extreme ultraviolet observations taken with the Solar Dynamic Observatory and the Solar Terrestrial Relations Observatory satellites. Results: For the most probable magnetic field vector configuration, the analysis depicts a mean field strength of 7 gauss. We do not find local variations in the field strength except that the field is, in average, lower in the prominence body than in the prominence feet, where the field strength reaches 25 gauss. The averaged magnetic field inclination with respect to the local vertical is 77 degrees. The acute angle of the magnetic field vector with the prominence main axis is 24 degrees for the sinistral chirality case and 58 degrees for the dextral chirality. These inferences are in rough agreement with previous results obtained from the analysis of data acquired with lower spatial resolutions.

Magnetic thread twisting in a simulated solar atmosphere

C. **Sumner** and Y. Taroyan

A&A 666, A111 (**2022**)

https://doi.org/10.1051/0004-6361/202243695

https://www.aanda.org/articles/aa/pdf/2022/10/aa43695-22.pdf

Context. Plasma inflows accompany a variety of processes in the solar atmosphere such as heating of coronal loops and formation of prominences.

Aims. We model a stratified solar atmosphere, within which a simulated prominence thread experiences density accumulation via a plasma inflow designed to mimic the formation process. We aim to investigate the interaction of such a system with torsional perturbations, and the possible consequences.

Methods. The linearised equations of motion and induction are integrated to analyse the spatial and temporal evolution of torsional perturbations that are randomly driven at the photospheric footpoints.

Results. Our results demonstrate that magnetic threads will experience twist amplification. Different sources and sinks of energy and the corresponding amplification mechanisms are identified. Threads reaching chromospheric heights are most susceptible to magnetic twisting with the maximum twist occurring near their footpoints. The amplifying twists are associated with a standing wave behaviour along the simulated threads.

Conclusions. Our work suggests that torsional perturbations may be amplified within prominence threads, with strong magnetic twists forming at the footpoints. The amplification process is facilitated by small length scales in the background magnetic field. On the other hand, a small length scale in the background density inhibits growth. Possible consequences of the amplified twists, including their role in supporting the dense plasma within a prominence structure are discussed.

Amplification of magnetic field twisting by a stagnation point flow

Chloe **Sumner** and Youra Taroyan

A&A 642, A181 (**2020**)

https://www.aanda.org/articles/aa/pdf/2020/10/aa38761-20.pdf

Context. Flows are a common feature of many processes occurring in the solar atmosphere, such as the formation of prominences where evaporated plasma from the chromosphere condensates along thin prominence threads that are seen to twist and oscillate.

Aim. We aim to investigate the twisting of these threads by plasma condensation during their formation.

Methods. We introduce a simple model with fixed critical points where the flow speed matches the Alfvén speed. This allows us to study the problem separately in the sub-Alfvénic and super-Alfvénic regimes. The temporal and spatial evolution of small amplitude initial twists along a thread is investigated analytically and numerically.

Results. Analytical solutions are constructed in terms of the generalised hypergeometric functions. The solutions grow in time, despite the absence of any influxes of energy or magnetic fields. These results are confirmed numerically: We find oscillations with an amplifying amplitude and increasing period in the sub-Alfvénic regime. In the super-Alfvénic regime, we find twist amplification without any accompanying oscillations. An interesting result is the convergence of the twists at the critical points that leads to the formation of steep gradients and small scales. Energy is transferred from the flow to the amplifying twists.

Conclusions. Magnetic field lines may be twisted by a stagnation point flow without the influx of any azimuthal field or energy. This twisting could assist in the formation of topology that is able to support the growth of prominences. The formation of steep gradients and small scales at the critical point is a new phenomenon which requires further investigation in the non-linear regime with the inclusion of magnetic diffusion.

Formation of an Intermediate Filament Driven by Small-scale Magnetic Reconnection

Xia **Sun**1,2, Xiaoli Yan2,3, Hongfei Liang1, Zhike Xue2,3, Jincheng Wang2,3, Liheng Yang2,3, Zhe Xu2,3, Liping Yang2, Yang Peng2, Qiaoling Li2,4Show full author list

2023 ApJ 944 161

https://iopscience.iop.org/article/10.3847/1538-4357/acaa3e/pdf

We present the formation process of a filament in NOAA active region 12765 from **2020 June 5 to 8**, using observations from the New Vacuum Solar Telescope, the Solar Dynamics Observatory, and the Global Oscillation Network Group. We found that intermittent small-scale magnetic reconnection occurs at the northern part of the filament, and the small-scale magnetic reconnection shows the characteristics of the oscillatory reconnections. During the magnetic reconnection process, a large amount of material is continuously injected into the filament channel. Furthermore, there are bidirectional inflow and outflow, current sheets, and bright cusp-shaped structures. The velocities of the material injections range from 17 to 183 km s−1 with an average velocity of about 57 km s−1. A total of 53 material injections were found from 03:10 UT on 2020 June 5 to 00:10 UT on June 8. The total mass carried by the injection events is about 7.39 × 1014 g, and the total kinetic energy released through magnetic reconnection is approximately 3.09 × 1021 J. The projection area of the filament increased from less than 1 × 102 Mm2 to around 7 × 102 Mm2. We conclude that the filament is formed by direct material injection into the filament channel due to the small-scale magnetic reconnections.

Hot prominence detected in the core of a Coronal Mass Ejection: III. Plasma filling factor from UVCS Lyman-α and Lyman-β observations

R. **Susino**, A. Bemporad, S. Jejčič, P. Heinzel

A&A **2018**

https://arxiv.org/pdf/1805.12465.pdf

This work deals with the study of an erupting prominence embedded in the core of a CME and focuses on the derivation of the prominence plasma filling factor. We explore two methods to measure the prominence plasma filling factor that are based on the combination of visible-light and ultraviolet spectroscopic observations. Theoretical relationships for resonant scattering and collisional excitation are used to evaluate the intensity of the H I Lyman-{\alpha} and Lyman-{\beta} lines, in two prominence points where simultaneous and cospatial LASCO-C2 and UVCS data were available. Thermodynamic and geometrical parameters assumed for the calculation are provided by both observations and the results of a detailed 1D non-LTE radiative-transfer model of the prominence, developed in our previous work (Heinzel 2016). The filling factor is derived from the comparison between the calculated and the measured intensities of the two lines. The results are then checked against the non-LTE model in order to verify the reliability of the methods. The resulting filling factors are consistent with the model in both the prominence points when the separation of the radiative and collisional components of the total intensity, required to estimate the filling factor, is performed using both the line intensities. An exploration of the parameter space shows that the results are weakly sensitive to the plasma velocity, but they depends more strongly on the assumed kinetic temperatures. The combination of visible-light and ultraviolet Lyman-{\alpha} and Lyman-{\beta} data can be used to approximately estimate the geometrical filling factor in erupting prominences, but the proposed techniques are reliable only for emission that is optically thin in the lines considered, condition that is not in general representative of prominence plasma. **August 2, 2000**

Orientation of the linear polarization plane of H-alpha emission in prominences

E.Z. **Suyunova**, I.S. Kim, A.R. Osokin

Proceedings of the All-Russian annual conference "Solar and Solar-Terrestrial Physics-2014", **2014**, St Petersburg State University, p. 403-406

http://arxiv.org/ftp/arxiv/papers/1502/1502.04637.pdf

2D distributions of deviations of the polarization plane from the direction tangential to the solar limb (angle \chi) and the sign of \chi are presented for H{\alpha} prominences of **March 29, 2006**. The obtained values of \chi are in agreement with non-eclipse coronagraphic measurements and indicate the existence of longitudinal magnetic fields. The 2D distributions of the sign of \chi show the existence of both {\guillemotleft}+{\guillemotright} and {\guillemotleft}-{\guillemotright} polarities for each prominence. An interpretation in the frame of the existence of oppositely directed magnetic fields is noted.

EUV flickering of solar coronal loops: a new diagnostic of coronal heating

E. **Tajfirouze**1, F.Reale12, G. Peres12, P. Testa

ApJL 817 L11 **2016**
http://arxiv.org/pdf/1601.03935v1.pdf
A previous work of ours found the best agreement between EUV light curves observed in an active region core (with evidence of super-hot plasma) and those predicted from a model with a random combination of many pulse-heated strands with a power-law energy distribution. We extend that work by including spatially resolved strand modeling and by studying the evolution of emission along the loops in the EUV 94 A and 335 A channels of the Atmospheric Imaging Assembly on-board the Solar Dynamics Observatory. Using the best parameters of the previous work as the input of the present one, we find that the amplitude of the random fluctuations driven by the random heat pulses increases from the bottom to the top of the loop in the 94 A channel and, viceversa, from the top to the bottom in the 335 A channel. This prediction is confirmed by the observation of a set of aligned neighbouring pixels along a bright arc of an active region core. Maps of pixel fluctuations may therefore provide easy diagnostics of nano-flaring regions.

Study of the three-dimensional shape and dynamics of coronal loops observed by Hinode/EIS

P. **Syntelis**, C. Gontikakis, M.K. Georgoulis, C.E. Alissandrakis, K. Tsinganos
E-print, 1 June, **2012**; Solar Phys., October **2012**, Volume 280, Issue 2, pp 475-489
We study plasma flows along selected coronal loops in NOAA Active Region 10926, observed on 3 December 2006 with Hinode's EUV Imaging Spectrograph (EIS). From the shape of the loops traced on intensity images and the Doppler shifts measured along their length we compute their three-dimensional (3D) shape and plasma flow velocity using a simple geometrical model. This calculation was performed for loops visible in the Fe VIII 185 Ang., Fe X 184 Ang., Fe XII 195 Ang., Fe XIII 202 Ang., and Fe XV 284 Ang. spectral lines. In most cases the flow is unidirectional from one footpoint to the other but there are also cases of draining motions from the top of the loops to their footpoints. Our results indicate that the same loop may show different flow patterns when observed in different spectral lines, suggesting a dynamically complex rather than a monolithic structure. We have also carried out magnetic extrapolations in the linear force-free field approximation using SOHO/MDI magnetograms, aiming toward a first-order identification of extrapolated magnetic field lines corresponding to the reconstructed loops. In all cases, the best-fit extrapolated lines exhibit left-handed twist $\alpha < 0$), in agreement with the dominant twist of the region.

EUV Flickering of Solar Coronal Loops: A New Diagnostic of Coronal Heating

Tajfirouze, E.; Reale, F.; Peres, G.; Testa, P.
ApJL 817, Issue 2, article id. L11, 6 pp. (**2016**)
http://arxiv.org/pdf/1601.03935v1.pdf
A previous work of ours found the best agreement between EUV light curves observed in an active region core (with evidence of super-hot plasma) and those predicted from a model with a random combination of many pulse-heated strands with a power-law energy distribution. We extend that work by including spatially resolved strand modeling and by studying the evolution of emission along the loops in the EUV 94 " and 335 " channels of the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory. Using the best parameters of the previous work as the input of the present one, we find that the amplitude of the random fluctuations driven by the random heat pulses increases from the bottom to the top of the loop in the 94 " channel and from the top to the bottom in the 335 " channel. This prediction is confirmed by the observation of a set of aligned neighboring pixels along a bright arc of an active region core. Maps of pixel fluctuations may therefore provide easy diagnostics of nanoflaring regions.

Shock-Cloud Interaction in the Solar Corona

Takuya **Takahashi**
ApJ **2017**
https://arxiv.org/pdf/1701.07001v1.pdf
Flare associated coronal shock waves sometimes interact with solar prominences leading to large amplitude prominence oscillations. Such prominence activation gives us unique opportunity to track time evolution of shock-cloud interaction in cosmic plasmas. Although the dynamics of interstellar shock-cloud interaction is extensively studied, coronal shock-solar prominence interaction is rarely studied in the context of shock-cloud interaction. Associated with X5.4 class solar flare occurred on **7 March, 2012**, a globally propagated coronal shock wave interacted with a polar prominence leading to large amplitude prominence oscillation. In this paper, we studied bulk acceleration and excitation of internal flow of the shocked prominence using three-dimensional MHD simulations. We studied eight magnetohydrodynamic (MHD) simulation runs with different mass density structure of the prominence, and one hydrodynamic simulation run, and compared the result. In order to compare observed motion of activated prominence with corresponding simulation, we also studied prominence activation by injection of triangular shaped coronal shock. We found that magnetic tension force mainly accelerate (and then decelerate) the

prominence. The internal flow, on the other hand, is excited during the shock front sweeps through the the prominence and damps almost exponentially. We construct phenomenological model of bulk momentum transfer from shock to the prominence, which agreed quantitatively with all the simulation results. Based on the phenomenological prominence-activation model, we diagnosed physical parameters of coronal shock wave. The estimated energy of the coronal shock is several percent of total energy released during the X5.4 flare.

Prominence Activation by Coronal Fast Mode Shock

Takuya **Takahashi**, Ayumi Asai, Kazunari Shibata

2015 *ApJ* **801** 37

http://arxiv.org/pdf/1501.01592v1.pdf

An X5.4 class flare occurred in active region (AR) NOAA11429 on **2012 March 7**. The flare was associated with very fast coronal mass ejection (CME) with its velocity of over 2500 km/s. In the images taken with STEREO-B/COR1, a dome-like disturbance was seen to detach from expanding CME bubble and propagated further. A Type-II radio burst was also observed at the same time. On the other hand, in EUV images obtained by SDO/AIA, expanding dome-like structure and its foot print propagating to the north were observed. The foot print propagated with its average speed of about 670 km/s and hit a prominence located at the north pole and activated it. While the activation, the prominence was strongly brightened. On the basis of some observational evidence, we concluded that the foot print in AIA images and the ones in COR1 images are the same, that is MHD fast mode shock front. With the help of a linear theory, the fast mode mach number of the coronal shock is estimated to be between 1.11 and 1.29 using the initial velocity of the activated prominence. Also, the plasma compression ratio of the shock is enhanced to be between 1.18 and 2.11 in the prominence material, which we consider to be the reason of the strong brightening of the activated prominence. The applicability of linear theory to the shock problem is tested with nonlinear MHD simulation.

Dynamic and Thermal Disappearance of Prominences and Their Geoeffectiveness

Lela **Taliashvili** · Zadig Mouradian · Jorge Páez

Solar Phys (**2009**) 258: 277–295

This paper is a qualitative study of 42 events of solar filament/prominence sudden disappearances (“disparitions brusques”; henceforth DBs) around two solar minima, 1985 – 1986 and 1994. The studied events were classified as 17 thermal and 25 dynamic disappearances. Associated events, *i.e.* coronal mass ejections (CMEs), type II bursts, evolution of nearby coronal holes, as well as solar wind speed, and geomagnetic disturbances are discussed. We have found that about 50% of the thermal DBs with adjacent (within 15° from the DB) coronal holes were associated with CMEs within a selected time window. All the studied thermal disappearances with adjacent coronal holes or accompanied by dynamic disappearances were associated with weak and medium geomagnetic storms. Also, nearly 64% of dynamic DBs were associated with CMEs. Ten (40%) dynamic disappearances were associated with intense geomagnetic storms, even when no CMEs was reported, six (24%) dynamic disappearances corresponded to extreme storms, and five (20%) corresponded to medium geomagnetic storms. The extreme geomagnetic storms appeared to be related to combined events, involving dynamic disappearances with adjacent coronal holes or including thermal disappearances. Furthermore, the geomagnetic activity (Dst index) increased if the source was close to the central meridian (±30°). The highest interplanetary magnetic field (B), longest duration, lowest southward direction B_z component, and lowest Dst were highly correlated for all studied events. The Sun – Earth transit time computed from the starting time of the sudden disappearance and the time its effect was measured at Earth was about 4.3 days and was mainly well correlated with the solar wind speed measured *in situ* (daily value).

Coronal heating in multiple magnetic threads

K. V. **Tam**1,2, A. W. Hood1, P. K. Browning3 and P. J. Cargill

A&A 580, A122 (**2015**)

http://www.aanda.org/articles/aa/pdf/2015/08/aa25995-15.pdf

Context. Heating the solar corona to several million degrees requires the conversion of magnetic energy into thermal energy. In this paper, we investigate whether an unstable magnetic thread within a coronal loop can destabilise a neighbouring magnetic thread.

Aims. By running a series of simulations, we aim to understand under what conditions the destabilisation of a single magnetic thread can also trigger a release of energy in a nearby thread.

Methods. The 3D magnetohydrodynamics code, Lare3d, is used to simulate the temporal evolution of coronal magnetic fields during a kink instability and the subsequent relaxation process. We assume that a coronal magnetic loop consists of non-potential magnetic threads that are initially in an equilibrium state.

Results. The non-linear kink instability in one magnetic thread forms a helical current sheet and initiates magnetic reconnection. The current sheet fragments, and magnetic energy is released throughout that thread. We find that,

under certain conditions, this event can destabilise a nearby thread, which is a necessary requirement for starting an avalanche of energy release in magnetic threads.
Conclusions. It is possible to initiate an energy release in a nearby, non-potential magnetic thread, because the energy released from one unstable magnetic thread can trigger energy release in nearby threads, provided that the nearby structures are close to marginal stability.

Solar Prominences – An Intriguing Phenomenon

Einar **Tandberg-Hanssen**

Solar Phys (**2011**) 269: 237–251, **File**

The article starts with an autobiographical account, where the author relates how his several study-trips abroad gradually led him to the study of solar physics in general, and prominences particularly.
The article then treats the historical development of prominence research, from the "speculative" period, before the introduction of photography and spectroscopy around 1860.
These techniques led to a new understanding of the nature of prominences as "hot clouds in the solar atmosphere". However, it was only after about 1960, when the magnetic field in prominences could be measured, that the more complete picture of prominences could be understood, a view greatly helped by space missions, the result of which was the realization that the solar atmosphere is crisscrossed by electric currents that lead to magnetic flux tubes of nearly all imaginable sizes.
The article ends with a discussion of the *disparition-brusque* phenomenon, and the closely related coronal mass ejections.
Historical review.

Triggering of twists in solar prominence threads

Y. **Taroyan**1 and R. Soler2

A&A 631, A144 (**2019**)

https://www.aanda.org/articles/aa/pdf/2019/11/aa36465-19.pdf

Context. Magnetic twists are commonly associated with solar prominences. Twists are believed to play an important role in supporting the dense plasma against gravity as well as in prominence eruptions and coronal mass ejections, which may have a severe impact on the Earth and its near environment.
Aims. We used a simple model to mimic the formation of a prominence thread by plasma condensation with the aim of investigating the possibility of triggering twists during this process.
Methods. Temporal and spatial evolution of torsional Alfvénic perturbations driven by random photospheric motions was analysed using the linearised governing equations of motion and induction.
Results. We find that small amplitude perturbations are exponentially amplified in time as they propagate along the condensing thread. Mechanisms contributing to the rapid growth are explored. The result of the amplification process is the generation of large amplitude axisymmetric twists along the thread.
Conclusions. Magnetic twists may be triggered along a prominence thread when it is permeated by a converging flow, for example, during the evaporation and condensation of plasma along the thread. This may lead to the generation of vortices in the non-linear regime.

Alfvén instability of steady state flux tubes II. Upflows in stratified atmospheres

Y. **Taroyan**

A&A 575, A104 (**2015**)

Context. MHD instabilities play an important role in the dynamics and energetics of the solar atmosphere.
Aims. An open vertical magnetic flux tube is permeated by an upflow in a stratified atmosphere with variable temperature. The stability of the tube is investigated with respect to small-amplitude torsional perturbations generated at the footpoint by random convective motions.
Methods. A steady state equilibrium incorporating the effects of a vertical body force, heating, and losses is derived analytically. The governing equations for torsional motions are integrated with a fourth-order Runge-Kutta method and matched with the analytical solutions in the upper regions to obtain a numerical dispersion relation. The dependence of the eigenmode frequencies on different parameters is analysed. Unstable modes are found for a range of Alfvén and flow speeds in the photosphere, as well as expansion factors of the flux tubes. Both supersonic and subsonic flows are considered.
Results. It is shown that torsional perturbations are exponentially amplified in time if a section of the tube exists where the upflowing plasma decelerates and the tube expands. The flow speeds required for the instability are sub-Alfvénic.
Conclusions. The instability may be important for understanding the abundance of Alfvén waves seen in recent observations and the associated heating in magnetic regions of the solar atmosphere.

Forward-Modeling of Doppler Shifts in EUV Spectral Lines

Y. **Taroyan**, S. J. Bradshaw

Solar Physics, June **2014**, Volume 289, Issue 6, pp 1959-1970

The interpretation of red- and blueshifts in EUV spectral observations remains a challenge that could provide important clues to the heating processes in the solar atmosphere. Hinode/EUV Imaging Spectrometer (EIS) observations near the footpoints of coronal loops show blueshifts for emission lines with temperatures above 1 MK and redshifts for lines below 1 MK. The implications are addressed through numerical modeling of loop dynamics. The simulation results are converted into synthetic EIS observations. A single one-dimensional loop cannot reproduce the observed behavior. However, persistent red- and blueshifts can be understood as a collective spectral signature of a bundle of 10 or more loops that have an average temperature of around 1 MK and evolve in a similar way: small-scale heating events occur randomly along each loop on a timescale of several minutes. Strong blueshifts are accompanied by low intensities. The power-law index of the energy distribution has a minor role in determining the average Doppler shifts.

Power spectrum analysis of limb and disk spicule using Hinode Ca H line broadband filter

Ehsan **Tavabi**

Astrophysics and Space Science, **2014**

http://arxiv.org/pdf/1403.6660v1.pdf

We present observations of a solar quiet region obtained using Hinode Solar Optical telescope (SOT) in Ca II H line with broadband filter taken on November 2006. We study offlimb and on disk spicules to find a counterpart of limb spicule on the disk. This investigation shows a strong correspondence between the limb and near limb spicules (ondisk spicules that historically were called dark or bright mottles especially when observed in Halpha rather cool line) from the dynamical behavior (e.g., periodicity). An excellent time sequence of images obtained near the equatorial region with a cadence of 8 s was selected for analysis. 1D Fourier power spectra made at different positions on the disk and above the limb are shown. We take advantage of the so-called madmax operator to reduce effects of overlapping and improve the visibility of these hair like features.

A definite signature with strong power in the 3 min. (5.5 mHz) and 5 min. (3.5 mHz) oscillations for both places exist. A full range of oscillations was found and the high frequency intensity fluctuation (greater than 10 mHz or less than 100 sec.) corresponding to the occurrence of the so- called type II spicules and, even more impressively, dominant peaks of Fourier power spectra are seen in a wide range of frequencies and for all places of on and off disk spicules, in rough agreement with what historical works were reporting regarding the disk mottles and limb spicules. Also, some statistically significant behavior, based on power spectrum computed for different positions, is discussed. The power for all kind of power spectra are decreasing with the increasing distance from the limb, except for photospheric oscillations (5 min. or p mode), which show a dominate peak for on disk power spectra.

Performance Testing of an Off-Limb Solar Adaptive Optics System

G.E. **Taylor**, D. Schmidt, J. Marino, T.R. Rimmele, R.T.James McAteer

Solar Phys. **2015**

Long-exposure spectro-polarimetry in the near-infrared is a preferred method to measure the magnetic field and other physical properties of solar prominences. In the past, it has been very difficult to observe prominences in this way with sufficient spatial resolution to fully understand their dynamical properties. Solar prominences contain highly transient structures, visible only at small spatial scales; hence they must be observed at sub-arcsecond resolution, with a high temporal cadence. An adaptive optics (AO) system capable of directly locking on to prominence structure away from the solar limb has the potential to allow for diffraction-limited spectro-polarimetry of solar prominences. We show the performance of the off-limb AO system and its expected performance at the desired science wavelength Ca II 8542 ?.

One dimensional prominence threads: I. Equilibrium models

J. **Terradas**, M. Luna, R. Soler, R. Oliver, M. Carbonell, J. L Ballester

A&A 653, A95 **2021**

https://arxiv.org/pdf/2106.06327.pdf

https://www.aanda.org/articles/aa/pdf/2021/09/aa39905-20.pdf

Threads are the building blocks of solar prominences and very often show longitudinal oscillatory motions that are strongly attenuated with time. The damping mechanism responsible for the reported oscillations is not fully understood yet. To understand the oscillations and damping of prominence threads it is mandatory to investigate first the nature of the equilibrium solutions that arise under static conditions and under the presence of radiative losses, thermal conduction and background heating. This provides the basis to calculate the eigenmodes of the thread models. The nonlinear ordinary differential equations for hydrostatic and thermal equilibrium under the presence of gravity are solved using standard numerical techniques and simple analytical expressions are derived under certain approximations. The solutions to the equations represent a prominence thread, i.e., a dense and cold plasma region of a certain length that connects with the corona through a prominence corona transition region (PCTR). The solutions can also match with a chromospheric-like layer if a spatially dependent heating function localised around the footpoints is considered. We have obtained static solutions representing prominence threads and have investigated in detail the dependence of these solutions on the different parameters of the model. Among other results, we have shown that multiple condensations along a magnetic field line are possible, and that the effect of partial ionisation in the model can significantly modify the thermal balance in the thread and therefore their length. This last parameter is also shown to be comparable to that reported in the observations when the radiative losses are reduced for typical thread temperatures.

Solar prominences embedded in flux ropes: morphological features and dynamics from 3D MHD simulations

J. **Terradas**, R. Soler, M. Luna, R. Oliver, J. L. Ballester, A. N. Wright

ApJ **820** 125 **2016**

http://arxiv.org/pdf/1512.07096v1.pdf

The temporal evolution of a solar prominence inserted in a three-dimensional magnetic flux rope is investigated numerically. Using the model of Titov Demoulin (1999) under the regime of weak twist, the cold and dense prominence counteracts gravity by modifying the initially force-free magnetic configuration. In some cases a quasi-stationary situation is achieved after the relaxation phase, characterized by the excitation of standing vertical oscillations. These oscillations show a strong attenuation with time produced by the mechanism of continuum damping due to the inhomogeneous transition between the prominence and solar corona. The characteristic period of the vertical oscillations does not depend strongly on the twist of the flux rope. Nonlinearity is the responsible for triggering the Kelvin-Helmholtz instability associated to the vertical oscillations and that eventually produces horizontal structures. Contrary to other configurations in which the longitudinal axis of the prominence is permeated by a perpendicular magnetic field, like in unsheared arcades, the orientation of the prominence along the flux rope axis prevents the development of Rayleigh-Taylor instabilities and therefore the appearance of vertical structuring along this axis.

On the support of neutrals against gravity in solar prominences

J. **Terradas**, R. Soler, R. Oliver, \& J. L., Ballester

ApJL **802** L28 **2015**

http://arxiv.org/pdf/1503.05354v1.pdf

Cool and dense prominences found in the solar atmosphere are known to be partially ionized because of their relative low temperature. In this Letter, we address the long-standing problem of how the neutral component of the plasma in prominences is supported against gravity. Using the multiple fluid approach we solve the time-dependent equations in two dimensions considering the frictional coupling between the neutral and ionized components of the magnetized plasma representative of a solar prominence embedded in a hot coronal environment. We demonstrate that given an initial density enhancement in the two fluids, representing the body of the prominence, the system is able to relax in the vicinity of magnetic dips to a stationary state in which both neutrals and ionized species are dynamically suspended above the photosphere. Two different coupling processes are considered in this study, collisions between ions and neutrals and charge exchange interactions. We find that for realistic conditions ions are essentially static while neutrals have a very small downflow velocity. The coupling between ions and neutrals is so strong at the prominence body that the behavior is similar to that of a single fluid with an effective density equal to the sum of the ion and neutral species. We also find that the charge exchange mechanism is about three times more efficient sustaining neutrals than elastic scattering of ions with neutrals.

Morphology and dynamics of solar prominences from 3D MHD simulations

J. **Terradas**, R. Soler, M. Luna, R. Oliver, J. L. Ballester

ApJ **799** 94 **2015**

http://arxiv.org/pdf/1412.7438v1.pdf

In this paper we present a numerical study of the time evolution of solar prominences embedded in sheared magnetic arcades. The prominence is represented by a density enhancement in a background stratified atmosphere and is connected to the photosphere through the magnetic field. By solving the ideal magnetohydrodynamic (MHD) equations in three dimensions we study the dynamics for a range of parameters representative of real prominences. Depending on the parameters considered, we find prominences that are suspended above the photosphere, i.e., detached prominences, but also configurations resembling curtain or hedgerow prominences whose material continuously connects to the photosphere. The plasma$-\beta$ is an important parameter that determines the shape of the structure. In many cases magnetic Rayleigh-Taylor (MRT) instabilities and oscillatory phenomena develop. Fingers and plumes are generated, affecting the whole prominence body and producing vertical structures in an essentially horizontal magnetic field. However, magnetic shear is able to reduce or even to suppress this instability.

Magnetohydrodynamic Waves in Two-dimensional Prominences Embedded in Coronal Arcades

J. **Terradas**, R. Soler, A. J. Díaz, R. Oliver, and J. L. Ballester

2013 ApJ 778 49

Solar prominence models used so far in the analysis of MHD waves in two-dimensional structures are quite elementary. In this work, we calculate numerically magnetohydrostatic models in two-dimensional configurations under the presence of gravity. Our interest is in models that connect the magnetic field to the photosphere and include an overlying arcade. The method used here is based on a relaxation process and requires solving the time-dependent nonlinear ideal MHD equations. Once a prominence model is obtained, we investigate the properties of MHD waves superimposed on the structure. We concentrate on motions purely two-dimensional, neglecting propagation in the ignorable direction. We demonstrate how, by using different numerical tools, we can determine the period of oscillation of stable waves. We find that vertical oscillations, linked to fast MHD waves, are always stable and have periods in the 4-10 minute range. Longitudinal oscillations, related to slow magnetoacoustic-gravity waves, have longer periods in the range of 28-40 minutes. These longitudinal oscillations are strongly influenced by the gravity force and become unstable for short magnetic arcades.

Transverse kink oscillations in the presence of twist

J. **Terradas**1 and M. Goossens

A&A 548, A112 (**2012**)

Context. Magnetic twist is thought to play an important role in coronal loops. The effects of magnetic twist on stable magnetohydrodynamic (MHD) waves is poorly understood because they are seldom studied for relevant cases.
Aims. The goal of this work is to study the fingerprints of magnetic twist on stable transverse kink oscillations.
Methods. We numerically calculated the eigenmodes of propagating and standing MHD waves for a model of a loop with magnetic twist. The azimuthal component of the magnetic field was assumed to be small in comparison to the longitudinal component. We did not consider resonantly damped modes or kink instabilities in our analysis.
Results. For a nonconstant twist the frequencies of the MHD wave modes are split, which has important consequences for standing waves. This is different from the degenerated situation for equilibrium models with constant twist, which are characterised by an azimuthal component of the magnetic field that linearly increases with the radial coordinate.
Conclusions. In the presence of twist standing kink solutions are characterised by a change in polarisation of the transverse displacement along the tube. For weak twist, and in the thin tube approximation, the frequency of standing modes is unaltered and the tube oscillates at the kink speed of the corresponding straight tube. The change in polarisation is linearly proportional to the degree of twist. This has implications with regard to observations of kink modes, since the detection of this variation in polarisation can be used as an indirect method to estimate the twist in oscillating loops.

The role of Rayleigh-Taylor instabilities in filament threads

J. **Terradas**, R. Oliver and J. L. Ballester

A&A 541, A102 (**2012**)

Context. Many solar filaments and prominences show short-lived horizontal threads lying parallel to the photosphere.
Aims. In this work the possible link between Rayleigh-Taylor instabilities and thread lifetimes is investigated.
Methods. This is done by calculating the eigenmodes of a thread modelled as a Cartesian slab under the presence of gravity. An analytical dispersion relation is derived using the incompressible assumption for the magnetohydrodynamic (MHD) perturbations.
Results. The system allows a mode that is always stable, independently of the value of the Alfvén speed in the thread. The character of this mode varies from being localised at the upper interface of the slab when the magnetic field is weak, to having a global nature and resembling the transverse kink mode when the magnetic field is strong. On the contrary, the slab model permits another mode that is unstable and localised at the lower interface when the magnetic field is weak. The growth rates of this mode can be very short, of the order of minutes for typical thread conditions. This Rayleigh-Taylor unstable mode becomes stable when the magnetic field is increased, and in the limit of strong magnetic field it is essentially a sausage magnetic mode.
Conclusions. The gravity force might have a strong effect on the modes of oscillation of threads, depending on the value of the Alfvén speed. In the case of threads in quiescent filaments, where the Alfvén speed is presumably low,

very short lifetimes are expected according to the slab model. In active region prominences, the stabilising effect of the magnetic tension might be enough to suppress the Rayleigh-Taylor instability for a wide range of wavelengths.

TRANSVERSE OSCILLATIONS OF FLOWING PROMINENCE THREADS OBSERVED WITH *HINODE*

J. **Terradas**,1,2 I. Arregui,2 R. Oliver,2 and J. L. Ballester2

The Astrophysical Journal, 678: L153–L156, **2008**

http://www.journals.uchicago.edu/doi/pdf/10.1086/588728

Recent observations with the *Hinode* Solar Optical Telescope display an active region prominence whose fine threads oscillate in the vertical direction as they move along a path parallel to the photosphere. A seismological analysis of this event is carried out by taking advantage of the small radius of these structures compared to the total length of magnetic field lines, i.e., by using the thin-tube approximation. This analysis reveals that the oscillatory period is only slightly modified by the existence of the flow and that the difference between the period of a flowing thread and a static one is below the error bars of these observations. Moreover, although it is not possible to obtain values of the physical parameters, a lower bound for the Alfve´n speed (ranging between 120 and 350 km s) is obtained for each of the threads. Such Alfve´n speeds agree with the intense magnetic fields $_{-1}$ and large densities usually found in active region prominences.

Evidence of Non-Thermal Particles in Coronal Loops Heated Impulsively by Nanoflares

Paola **Testa** (1), Bart De Pontieu (2,3), Joel Allred (4), Mats Carlsson (3), Fabio Reale (5), Adrian Daw (4), Viggo Hansteen (3), Juan Martinez-Sykora (6), Wei Liu (2,7), Ed DeLuca (1), Leon Golub (1), Sean McKillop (1), Kathy Reeves (1), Steve Saar (1), Hui Tian (1), Jim Lemen (2), Alan Title (2), Paul Boerner (2), Neal Hurlburt (2), Ted Tarbell (2), J.P. Wuelser (2), Lucia Kleint (2,6), Charles Kankelborg (8), Sarah Jaeggli (8)

Science, **2014**

Movies are available at: http://www.lmsal.com/~ptesta/iris_science_mov/

http://arxiv.org/pdf/1410.6130v1.pdf

The physical processes causing energy exchange between the Sun's hot corona and its cool lower atmosphere remain poorly understood. The chromosphere and transition region (TR) form an interface region between the surface and the corona that is highly sensitive to the coronal heating mechanism. High resolution observations with the Interface Region Imaging Spectrograph (IRIS) reveal rapid variability (about 20 to 60 seconds) of intensity and velocity on small spatial scales at the footpoints of hot dynamic coronal loops. The observations are consistent with numerical simulations of heating by beams of non-thermal electrons, which are generated in small impulsive heating events called "coronal nanoflares". The accelerated electrons deposit a sizable fraction of their energy in the chromosphere and TR. Our analysis provides tight constraints on the properties of such electron beams and new diagnostics for their presence in the nonflaring corona. 2013-11-09

Fast magnetohydrodynamic waves in a solar coronal arcade

Hope **Thackray** and Rekha Jain

A&A 608, A108 (**2017**)

https://www.aanda.org/articles/aa/pdf/2017/12/aa31193-17.pdf

Aims. Our aim is to investigate detailed properties of fast magnetohydrodynamic (MHD) modes of a three-dimensional waveguide for a cylindrical magnetic arcade.

Methods. We derive governing equations and dispersion relations for different density profiles and numerically solve them to obtain discrete eigenvalues for fast modes and the corresponding eigenfunctions.

Results. We find that small changes in the density structure in the vicinity of the field lines can lead to drastic effects on propagating solutions and, under certain conditions, two evanescent waves arise.

Conclusions. We investigate coronal loop oscillations in an arcade as fast MHD modes of oscillations. We find that coronal loops with slightly different density structures can exhibit different oscillatory behaviour and some eigenmodes can be present or absent depending on this density structure. Though the model has a simple potential field, the role of a cylindrical waveguide in conjunction with differing density structures is demonstrated clearly. Multiple-wavelength observations at several points in the coronal loop arcades is suggested for correct mode identification; this is crucial for unraveling the plasma properties of the oscillating loops.

3D Reconstruction of a Rotating Erupting Prominence

W. T. **Thompson**, B. Kliem and T. Török

Solar Physics, Volume 276, Numbers 1-2, 241-259, **2012, File**

A bright prominence associated with a coronal mass ejection (CME) was seen erupting from the Sun on **9 April 2008**. This prominence was tracked by both the Solar Terrestrial Relations Observatory (STEREO) EUVI and COR1 telescopes, and was seen to rotate about the line of sight as it erupted; therefore, the event has been nicknamed the "Cartwheel CME." The threads of the prominence in the core of the CME quite clearly indicate the structure of a weakly to moderately twisted flux rope throughout the field of view, up to heliocentric heights of 4 solar radii. Although the STEREO separation was 48°, it was possible to match some sharp features in the later part of the eruption as seen in the 304 Å line in EUVI and in the Hα-sensitive bandpass of COR1 by both STEREO Ahead and Behind. These features could then be traced out in three-dimensional space, and reprojected into a view in which the eruption is directed toward the observer. The reconstructed view shows that the alignment of the prominence to the vertical axis rotates as it rises up to a leading-edge height of ≈2.5 solar radii, and then remains approximately constant. The alignment at 2.5 solar radii differs by about 115° from the original filament orientation inferred from Hα and EUV data, and the height profile of the rotation, obtained here for the first time, shows that two thirds of the total rotation are reached within ≈0.5 solar radii above the photosphere. These features are well reproduced by numerical simulations of an unstable moderately twisted flux rope embedded in external flux with a relatively strong shear field component.

Strong rotation of an erupting quiescent polar crown prominence

W.T. **Thompson**

Journal of Atmospheric and Solar-Terrestrial Physics, Volume 73, Issue 10, **2011**, Pages 1138-1147

On **5–6 June 2007**, a large quiescent polar crown prominence was observed to erupt by the two Solar Terrestrial Relations Observatory (STEREO) spacecraft. This eruption was particularly visible in the 304 Å channel of the Extreme Ultraviolet Imager (EUVI) telescopes. A detailed analysis of the fine structures in the images allows the three-dimensional structure of the erupting prominence to be derived. The prominence is seen to undergo substantial rotation of at least 90 along the radial axis as it rises, with indications that additional rotation occurred before the prominence rose into the STEREO fields of view. Two temporary structures ("spurs") are seen to form at an angle to the main spine of the prominence, and are interpreted as signs of reconnection. These reconnection events contribute to the overall rotation of the prominence. A significant fraction of the prominence material is drained through new field lines caused by one of the reconnection events, resulting in only a weak coronal mass ejection event observed by the STEREO and SOHO coronagraphs. The eruption is interpreted as being initiated by the helical kink instability, with subsequent modification by the reconnection events.

Can Multi-Threaded Flux Tubes in Coronal Arcades Support a Magnetohydrodynamic Avalanche?

James **Threlfall**, Jack Reid, Alan Hood

Solar Phys. **2021**

https://arxiv.org/pdf/2107.08758

Magnetohydrodynamic (MHD) instabilities allow energy to be released from stressed magnetic fields, commonly modelled in cylindrical flux tubes linking parallel planes, but, more recently, also in curved arcades containing flux tubes with both footpoints in the same photospheric plane. Uncurved cylindrical flux tubes containing multiple individual threads have been shown to be capable of sustaining an MHD avalanche, whereby a single unstable thread can destabilise many. We examine the properties of multi-threaded coronal loops, wherein each thread is created by photospheric driving in a realistic, curved coronal arcade structure (with both footpoints of each thread in the same plane). We use three-dimensional MHD simulations to study the evolution of single- and multi-threaded coronal loops, which become unstable and reconnect, while varying the driving velocity of individual threads. Experiments containing a single thread destabilise in a manner indicative of an ideal MHD instability and consistent with previous examples in the literature. The introduction of additional threads modifies this picture, with aspects of the model geometry and relative driving speeds of individual threads affecting the ability of any thread to destabilise others. In both single- and multi-threaded cases, continuous driving of the remnants of disrupted threads produces secondary, aperiodic bursts of energetic release.

Successive Two-sided Loop Jets Caused by Magnetic Reconnection between Two Adjacent Filamentary Threads

Zhanjun **Tian**1,2,3, Yu Liu1,4,5, Yuandeng Shen1,2,4,5,6, Abouazza Elmhamdi7, Jiangtao Su3,4,6, Ying D. Liu2,3, and Ayman. S. Kordi7

2017 ApJ 845 94

We present observational analysis of two successive two-sided loop jets observed by the ground-based New Vacuum Solar Telescope and the space-borne Solar Dynamics Observatory. The two successive two-sided loop jets manifested similar evolution processes and both were associated with the interaction of two small-scale adjacent filamentary threads, magnetic emerging, and cancellation processes at the jet's source region. High temporal and high spatial resolution observations reveal that the two adjacent ends of the two filamentary threads are rooted in opposite magnetic polarities within the source region. The two threads approached each other, and then an obvious brightening patch is observed at the interaction position. Subsequently, a pair of hot plasma ejections are observed heading in opposite directions along the paths of the two filamentary threads at a typical speed for two-sided loop jets of the order 150 km s−1. Close to the end of the second jet, we report the formation of a bright hot loop structure at the source region, which suggests the formation of new loops during the interaction. Based on the observational results, we propose that the observed two-sided loop jets are caused by magnetic reconnection between the two adjacent filamentary threads, largely different from the previous scenario that a two-sided loop jet is generated by magnetic reconnection between an emerging bipole and the overlying horizontal magnetic fields.

PERSISTENT DOPPLER SHIFT OSCILLATIONS OBSERVED WITH HINODE/EIS IN THE SOLAR CORONA: SPECTROSCOPIC SIGNATURES OF ALFVÉNIC WAVES AND RECURRING UPFLOWS
Hui **Tian**1,6, Scott W. McIntosh1, Tongjiang Wang2,3, Leon Ofman2,3, Bart De Pontieu4, Davina E. Innes5, and Hardi Peter
2012 ApJ 759 144
Using data obtained by the EUV Imaging Spectrometer on board Hinode, we have performed a survey of obvious and persistent (without significant damping) Doppler shift oscillations in the corona. We have found mainly two types of oscillations from February to April in 2007. One type is found at loop footpoint regions, with a dominant period around 10 minutes. They are characterized by coherent behavior of all line parameters (line intensity, Doppler shift, line width, and profile asymmetry), and apparent blueshift and blueward asymmetry throughout almost the entire duration. Such oscillations are likely to be signatures of quasi-periodic upflows (small-scale jets, or coronal counterpart of type-II spicules), which may play an important role in the supply of mass and energy to the hot corona. The other type of oscillation is usually associated with the upper part of loops. They are most clearly seen in the Doppler shift of coronal lines with formation temperatures between one and two million degrees. The global wavelets of these oscillations usually peak sharply around a period in the range of three to six minutes. No obvious profile asymmetry is found and the variation of the line width is typically very small. The intensity variation is often less than 2%. These oscillations are more likely to be signatures of kink/Alfvén waves rather than flows. In a few cases, there seems to be a π/2 phase shift between the intensity and Doppler shift oscillations, which may suggest the presence of slow-mode standing waves according to wave theories. However, we demonstrate that such a phase shift could also be produced by loops moving into and out of a spatial pixel as a result of Alfvénic oscillations. In this scenario, the intensity oscillations associated with Alfvénic waves are caused by loop displacement rather than density change. These coronal waves may be used to investigate properties of the coronal plasma and magnetic field.

A Statistical Study of Propagating MHD Kink Waves in the Quiescent Corona
Ajay K. **Tiwari**1,2, Richard J. Morton1, and James A. McLaughlin1
2021 ApJ 919 74
https://arxiv.org/pdf/2105.12451.pdf
https://iopscience.iop.org/article/10.3847/1538-4357/ac10c4/pdf
https://doi.org/10.3847/1538-4357/ac10c4
The Coronal Multi-channel Polarimeter (CoMP) has opened up exciting opportunities to probe transverse MHD waves in the Sun's corona. The archive of CoMP data is utilized to generate a catalog of quiescent coronal loops that can be used for studying propagating kink waves. The catalog contains 120 loops observed between 2012 and 2014. This catalog is further used to undertake a statistical study of propagating kink waves in the quiet regions of the solar corona, investigating phase speeds, loop lengths, footpoint power ratio (a measure of wave power entering the corona through each footpoint of a loop) and equilibrium parameter (which provides a measure of the change in wave amplitude) values. The statistical study enables us to establish the presence of a relationship between the rate of damping and the length of the coronal loop, with longer coronal loops displaying weaker wave damping. We suggest the reason for this behavior is related to a decreasing average density contrast between the loop and ambient plasma as loop length increases. The catalog presented here will provide the community with the foundation for the further study of propagating kink waves in the quiet solar corona. **19-July-2012**
Table

Are the Brightest Coronal Loops Always Rooted in Mixed-polarity Magnetic Flux?
Sanjiv K. **Tiwari**1,2, Caroline L. Evans3,4, Navdeep K. Panesar1,2, Avijeet Prasad5, and Ronald L. Moore5,6

2021 ApJ 908 151
https://doi.org/10.3847/1538-4357/abd176
https://arxiv.org/pdf/2102.10146.pdf
A recent study demonstrated that freedom of convection and strength of magnetic field in the photospheric feet of active-region (AR) coronal loops, together, can engender or quench heating in them. Other studies stress that magnetic flux cancellation at the loop-feet potentially drives heating in loops. We follow 24 hr movies of a bipolar AR, using extreme ultraviolet images from the Atmospheric Imaging Assembly/Solar Dynamics Observatory (SDO) and line-of-sight (LOS) magnetograms from the Helioseismic and Magnetic Imager (HMI)/SDO, to examine magnetic polarities at the feet of 23 of the brightest coronal loops. We derived Fe xviii emission (hot-94) images (using the Warren et al. method) to select the hottest/brightest loops, and confirm their footpoint locations via non-force-free field extrapolations. From 6" × 6" boxes centered at each loop foot in LOS magnetograms we find that ~40% of the loops have both feet in unipolar flux, and ~60% of the loops have at least one foot in mixed-polarity flux. The loops with both feet unipolar are ~15% shorter lived on average than the loops having mixed-polarity foot-point flux, but their peak-intensity averages are equal. The presence of mixed-polarity magnetic flux in at least one foot in the majority of the loops suggests that flux cancellation at the footpoints may drive most of the heating. But the absence of mixed-polarity magnetic flux (to the detection limit of HMI) in ~40% of the loops suggests that flux cancellation may not be necessary to drive heating in coronal loops—magnetoconvection and field strength at both loop feet possibly drive much of the heating, even in the cases where a loop foot presents mixed-polarity magnetic flux.

New Evidence that Magnetoconvection Drives Solar-Stellar Coronal Heating

Sanjiv K. **Tiwari**, Julia K. Thalmann, Navdeep K. Panesar, Ronald L. Moore, Amy R. Winebarger
ApJL **2017**
https://arxiv.org/pdf/1706.08035.pdf
How magnetic energy is injected and released in the solar corona, keeping it heated to several million degrees, remains elusive. Coronal heating generally increases with increasing magnetic field strength. From comparison of a non-linear force-free model of the three-dimensional active-region coronal field to observed extreme-ultraviolet loops, we find that (1) umbra-to-umbra coronal loops, despite being rooted in the strongest magnetic flux, are invisible, and (2) the brightest loops have one foot in an umbra or penumbra and the other foot in another sunspot's penumbra or in unipolar or mixed-polarity plage. The invisibility of umbra-to-umbra loops is new evidence that magnetoconvection drives solar-stellar coronal heating: evidently the strong umbral field at \underline{both} ends quenches the magnetoconvection and hence the heating. Broadly, our results indicate that, depending on the field strength in both feet, the photospheric feet of a coronal loop on any convective star can either engender or quench coronal heating in the loop's body. **01/02-April-2014, 07-July-2014**

Tilt Angles of Solar Filaments over the Period 1919-2014

A. G. **Tlatov**, K.M. Kuzanyan, V.V. Vasil'yeva
2016
http://arxiv.org/pdf/1601.02342v1.pdf
The spatial and temporal distributions of solar filaments were analyzed using data from the Meudon Observatory for the period 1919-2003 and the Kislovodsk Mountain Astronomical Station for the period 1979-2014. We scanned Hα solar synoptic charts on which the filaments were isolated and digitized. The data on each filament comprise its location, length, area, and other geometrical characteristics. The temporal distributions of the number and total length of the filaments have been obtained. We also found latitudinal migration of filament locations with the solar cycle, and analyzed the longitudinal distribution and asymmetry of filaments in the northern and southern hemispheres, and other properties of their distribution. The tilt angles of filaments with respect the solar equator (τ) were analyzed. On average, the eastern tips of filaments are closer to the poles than the western ones (τ∼10∘). On the other hand, the filaments in the polar regions (θ>50∘, where θ is the latitude) usually have negative tilts (τ<0∘). The tilt angles vary with the phases of the 11 year sunspot cycle and are at their highest values in the epoch of the activity maximum. In the century-long modulation of the solar activity (Gleissberg cycle), the mean tilt angles of filaments in the mid-latitude zone (θ∼±40∘) were maximum in the middle of the 20th century in solar sunspot cycles 18-19. We hereby propose using the statistical properties of solar filaments as an additional coherent measure of manifestation of the solar cycle which covers all latitudes and for which almost a century long systematically calibrated data series is available.
See ASP Conference Series, Vol. 504 http://aspbooks.org/publications/504/241.pdf

THE NON-RADIAL PROPAGATION OF CORONAL STREAMERS WITHIN A SOLAR CYCLE

A. G. **Tlatov**

Astrophysical Journal, 714:805–809, **2010** May

We have analyzed the shape of the solar corona using the data of daily observations with Mark-III/IV (1980–2008) and *SOHO/*LASCO-2 (1996–2009) telescopes. The angles of deviation of coronal rays from the radial direction $\otimes\theta$ vary cyclically, reaching the maximum deviation toward the solar equator at the minimum of the solar activity. We consider the relations between the angles of deviation of coronal rays and the parameters of the heliospheric current sheet, and discuss the hypothesis according to which the variations of the inclination $\otimes\theta$ of coronal rays can affect the parameters of the solar wind and the indices of geomagnetic perturbations at the minima of the solar activity cycles.

A MODEL FOR MAGNETICALLY COUPLED SYMPATHETIC ERUPTIONS

T. **Török**1, O. Panasenco2, V. S. Titov1, Z. Mikić1, K. K. Reeves3, M. Velli4, J. A. Linker1 and G. De Toma

2011 ApJ 739 L63, **File**

Sympathetic eruptions on the Sun have been observed for several decades, but the mechanisms by which one eruption can trigger another remain poorly understood. We present a three-dimensional MHD simulation that suggests two possible magnetic trigger mechanisms for sympathetic eruptions. We consider a configuration that contains two coronal flux ropes located within a pseudo-streamer and one rope located next to it. A sequence of eruptions is initiated by triggering the eruption of the flux rope next to the streamer. The expansion of the rope leads to two consecutive reconnection events, each of which triggers the eruption of a flux rope by removing a sufficient amount of overlying flux. The simulation qualitatively reproduces important aspects of the global sympathetic event on **2010 August 1** and provides a scenario for the so-called twin filament eruptions. The suggested mechanisms are also applicable for sympathetic eruptions occurring in other magnetic configurations.

FILAMENT INTERACTION MODELED BY FLUX ROPE RECONNECTION

T. **T¨or¨ok**1,2, R. Chandra1,3, E. Pariat1, P. D´emoulin1, B. Schmieder1, G. Aulanier1, M. G. Linton4, and C. H. Mandrini5

Astrophysical Journal, 728:65 (6pp), **2011; File**

Hα observations of solar active region NOAA 10501 on **2003 November 20** revealed a very uncommon dynamic process: during the development of a nearby flare, two adjacent elongated filaments approached each other, merged at their middle sections, and separated again, thereby forming stable configurations with new footpoint connections. The observed dynamic pattern is indicative of “slingshot” reconnection between two magnetic flux ropes. We test this scenario by means of a three-dimensional zero β magnetohydrodynamic simulation, using a modified version of the coronal flux rope model by Titov and D´emoulin as the initial condition for the magnetic field. To this end, a configuration is constructed that contains two flux ropes which are oriented side-by-side and are embedded in an ambient potential field. The choice of the magnetic orientation of the flux ropes and of the topology of the potential field is guided by the observations. Quasi-static boundary flows are then imposed to bring the middle sections of the flux ropes into contact. After sufficient driving, the ropes reconnect and two new flux ropes are formed, which now connect the former adjacent flux rope footpoints of opposite polarity. The corresponding evolution of filament material is modeled by calculating the positions of field line dips at all times. The dips follow the morphological evolution of the flux ropes, in qualitative agreement with the observed filaments.

The writhe of helical structures in the solar corona

T. **Török**1,2, M. A. Berger2,3, and B. Kliem2,4,5

A&A 516, A49 **(2010), File**

Context. Helicity is a fundamental property of magnetic fields, conserved in ideal MHD. In flux rope geometry, it consists of twist and writhe helicity. Despite the common occurrence of helical structures in the solar atmosphere, little is known about how their shape relates to the writhe, which fraction of helicity is contained in writhe, and how much helicity is exchanged between twist and writhe when they erupt.

Aims. Here we perform a quantitative investigation of these questions relevant for coronal flux ropes.

Methods. The decomposition of the writhe of a curve into local and nonlocal components greatly facilitates its computation.We use it to study the relation between writhe and projected S shape of helical curves and to measure writhe and twist in numerical simulations of flux rope instabilities. The results are discussed with regard to filament eruptions and coronal mass ejections (CMEs).

Results. (1) We demonstrate that the relation between writhe and projected S shape is *not* unique in principle, but that the ambiguity does not affect low-lying structures, thus supporting the established empirical rule which

associates stable forward (reverse) S shaped structures low in the corona with positive (negative) helicity. (2) Kink-unstable erupting flux ropes are found to transform a far smaller fraction of their twist helicity into writhe helicity than often assumed. (3) Confined flux rope eruptions tend to show stronger writhe at low heights than ejective eruptions (CMEs). This argues against suggestions that the writhing facilitates the rise of the rope through the overlying field. (4) Erupting filaments which are S shaped already before the eruption and keep the sign of their axis writhe (which is expected if field of one chirality dominates the source volume of the eruption), must reverse their S shape in the course of the rise. Implications for the occurrence of the helical kink instability in such events are discussed. (5) The writhe of rising loops can easily be estimated from the angle of rotation about the direction of ascent, once the apex height exceeds the footpoint separation significantly.
Conclusions. Writhe can straightforwardly be computed for numerical data and can often be estimated from observations. It is useful in interpreting S shaped coronal structures and in constraining models of eruptions.

Transient Formation of Loops in the Core of an Active Region

Durgesh **Tripathi**

ApJ **2021**

https://arxiv.org/pdf/2101.06622.pdf

We study the formation of transient loops in the core of the AR 11890. For this purpose, we have used the observations recorded by the Atmospheric Imaging Assembly (AIA) and the Interface Region Imaging Spectrograph (IRIS). For photospheric field configuration, we have used the line-of-sight (LOS) magnetograms obtained from the Helioseismic and Magnetic Imager (HMI). The transient is simultaneously observed in all the UV and EUV channels of AIA and the three slit-jaw images from IRIS. The co-existence of the transient in all AIA and IRIS SJI channels suggests the transient's multi-thermal nature. The transient consists of short loops located at the base of the transient as well as longe loops. A differential emission measure (DEM) analysis shows that the transient has a clumpy structure. The highest emission observed at the base is within the temperature bin of logT=6.65−6.95. We observe the longer loops at a similar temperature, albeit very feeble. Using LOS magnetograms, we conclude that the magnetic reconnection may have caused the transient. Our observations further suggest that the physics of the formation of such transients may be similar to those of typical coronal jets, albeit in different topological configurations. Such multi-wavelength observations shed light on the formation of hot plasma in the solar corona and provide further essential constraints on modeling the thermodynamics of such transients. **8 Nov 2013**
*We note that the transient loop system studied here resembles the structure similar to those described by **Hanaoka (1997)** using the observations recorded by the Soft X-ray Telescope (SXT; Tsuneta et al. 1991) onboard Yohkoh. These were referred to as "**double loop configuration of solar flares**".*

OBSERVATIONS OF PLASMA UPFLOW IN A WARM LOOP WITH HINODE/EIS

Durgesh **Tripathi**1, Helen E. Mason2, Giulio Del Zanna2, and Steven Bradshaw

2012 ApJ 754 L4

A complete understanding of Doppler shift in active region loops can help probe the basic physical mechanism involved into the heating of those loops. Here, we present observations of upflows in coronal loops detected in a range of temperatures (log T = 5.8-6.2). The loop was not discernible above these temperatures. The speed of upflow was strongest at the footpoint and decreased with height. The upflow speed at the footpoint was about 20 km s–1 in Fe VIII, which decreased with temperature, being about 13 km s–1 in Fe X, about 8 km s–1 in Fe XII, and about 4 km s–1 in Fe XIII. To the best of our knowledge, this is the first observation providing evidence of upflow of plasma in coronal loop structures at these temperatures. We interpret these observations as evidence of chromospheric evaporation in quasi-static coronal loops.

Large Amplitude Oscillations in Prominences

D. **Tripathi** · H. Isobe · R. Jain

2009; File

Since the first reports of oscillations in prominences in 1930s there have been major theoretical and observational advances to understand the nature of these oscillatory phenomena leading to a whole new field of so called "prominence seismology". There are two types of oscillatory phenomena observed in prominences; "small amplitude oscillations" (2-3 km s−1) which are quite common and "large amplitude oscillations" (>20 km s−1) for which observations are scarce. Large amplitude oscillations have been found as "winking filament" in H_ as well as motion in the sky plane in H_, EUV, micro-wave and He 10830 observations. Historically, it was suggested that the large amplitude oscillations in prominences were triggered by disturbances such as fast-mode MHD waves (Moreton wave) produced by remote flares. Recent observations show, in addition, that near-by flares or jets can also create such large amplitude oscillations in prominences. Large amplitude oscillations, which are observed both in transverse as well as longitudinal direction, have a range of periods varying from tens of minutes to a couple of hours. Using the observed period of oscillation and simple theoretical models, the obtained magnetic field in prominences has shown quite a good agreement with directly measured one and therefore, justifies prominences seismology as a powerful diagnostic tool. On rare occasions, when the large amplitude oscillations have been observed before or during the eruption, the oscillations may be applied to diagnose the stability and the eruption mechanism. Here we review the recent developments and understanding in the observational properties of large amplitude oscillations and their trigger mechanisms and stability in the context of prominence seismology.

Partially-erupting prominences: a comparison between observations and model-predicted observables

D. **Tripathi**1, S. E. Gibson2, J. Qiu3, L. Fletcher4, R.Liu5, H. Gilbert5, H. E. Mason1

E-print, Feb **2009, File**; A&A, 498, 295-305 (**2009**), DOI: 10.1051/0004-6361/200809801

Aims.We investigate several partially-erupting prominences to study their relationship with other CME-associated phenomena and compare these observations with observables predicted by a model of partially-expelled-flux-ropes (Gibson & Fan, 2006a, b).

Methods.We studied 6 selected events with partially-erupting prominences using multi-wavelength observations recorded by the Extremeultraviolet Imaging Telescope (EIT), Transition Region and Coronal Explorer (TRACE), Mauna Loa Solar Observatory (MLSO), Big Bear Solar Observatory (BBSO), and soft X-ray telescope (SXT). The observational features associated with partially-erupting prominences were then compared with the predicted observables from the model.

Results. The partially-expelled-flux-rope (PEFR) model can explain the partial eruption of these prominences, and in addition predicts a variety of other CME-related observables that provide evidence of internal reconnection during eruption. We find that all of the partially-erupting prominences studied in this paper exhibit indirect evidence of internal reconnection. Moreover, all cases showed evidence of at least one observable unique to the PEFR model, e.g., dimmings external to the source region and/or a soft X-ray cusp overlying a reformed sigmoid.

Conclusions.The PEFR model provides a plausible mechanism to explain the observed evolution of partially-erupting-prominence-associated CMEs in our study.

On the propagation of brightening after filament/prominence eruptions, as seen by SoHO-EIT

D. **Tripathi**, H. Isobe1,2, and H. E. Mason1

A&A, 2006, **file**; A&A, v. 453, Issue 3, pp.1111-1116, **2006**.

When the prominences/filaments erupted having one point fixed - asymmetric eruption - the brightening propagated along the neutral line together with the expansion/separation from the polarity inversion line (PIL) as expected from the standard models. However in case of symmetric eruptions, the brightening propagated towards both end points starting at the middle. When the prominence/filament erupted faster then the speed of the propagating brightening was faster and vice-versa.

Foot-point brightening

Observation of a bright coronal downflow by SOHO/EIT

D. **Tripathi**?1, S. K. Solanki1, R. Schwenn1, V. Bothmer2, M. Mierla1, G. Stenborg3

Astronomy and Astrophysics, Volume 449, Issue 1, April I **2006**, pp.369-378, **File**

A distinct coronal downflow has been discovered in the course of a prominence eruption associated coronal mass ejection (CME) on 05-Mar-2000.

On the relationship between coronal waves associated with a CME on 5 March 2000

D. **Tripathi** and N.-E.Raouafi

E-print, Aug. 2007, File; Astronomy and Astrophysics, Volume 473, Issue 3, pp.951-957, **2007**

a clear deflection and kink in a streamer

Spatial and temporal correlations show that the deflection and the propagation of the kink in the streamer (based on the LASCO data), and plasma heating and spectral line broadening (based on the UVCS data), are basically due to a CME-driven shock wave. The spatial and temporal correlations between the EIT wave and the shock wave provide strong evidence in favor of the interpretation that the EIT waves are indeed the counterpart of CME-driven shock waves in the lower corona. Although, we cannot rule out the possibility that the EIT waves are just a manifestation of the stretching of the field lines due to the outward propagation of the CMEs.

Корональные волны при эрупции волокна вне АО.

A bright coronal downflow seen in multi-wavelength observations: evidence of a bifurcating flux-rope?

D. **Tripathi**, S.K. Solanki, H.E. Mason, D.F. Webb

E-print, July **2007**

To study the origin and characteristics of a bright coronal downflow seen after a coronal mass ejection associated with erupting prominences on 5~March 2000.

The origin of the downflow was likely to have been magnetic reconnection taking place inside the erupting flux rope that led to its bifurcation.

The Magnetic Properties of Heating Events on High-Temperature Active Region Loops

Ignacio **Ugarte-Urra**, Nicholas A. Crump, Harry P. Warren, Thomas Wiegelmann

ApJ **877** 129 **2019**

https://arxiv.org/pdf/1904.11976.pdf

Understanding the relationship between the magnetic field and coronal heating is one of the central problems of solar physics. However, studies of the magnetic properties of impulsively heated loops have been rare. We present results from a study of 34 evolving coronal loops observed in the Fe XVIII line component of AIA/SDO 94 A filter images from three active regions with different magnetic conditions. We show that the peak intensity per unit cross-section of the loops depends on their individual magnetic and geometric properties. The intensity scales proportionally to the average field strength along the loop (Bavg) and inversely with the loop length (L) for a combined dependence of (Bavg/L)0.52±0.13. These loop properties are inferred from magnetic extrapolations of the photospheric HMI/SDO line-of-sight and vector magnetic field in three approximations: potential and two Non Linear Force-Free (NLFF) methods. Through hydrodynamic modeling (EBTEL model) we show that this behavior is compatible with impulsively heated loops with a volumetric heating rate that scales as ϵH∼B0.3±0.2avg/L0.2±0.20.1. **2011/02/12, 2011/04/15, 2011/11/08**

IS ACTIVE REGION CORE VARIABILITY AGE DEPENDENT?

Ignacio **Ugarte-Urra**[1] and Harry P. Warren

2012 ApJ 761 21

The presence of both steady and transient loops in active region cores has been reported from soft X-ray and extreme-ultraviolet observations of the solar corona. The relationship between the different loop populations, however, remains an open question. We present an investigation of the short-term variability of loops in the core of two active regions in the context of their long-term evolution. We take advantage of the nearly full Sun observations of STEREO and Solar Dynamics Observatory spacecraft to track these active regions as they rotate around the Sun multiple times. We then diagnose the variability of the active region cores at several instances of their lifetime using EIS/Hinode spectral capabilities. We inspect a broad range of temperatures, including for the first time spatially and temporally resolved images of Ca XIV and Ca XV lines. We find that the active region cores become fainter and steadier with time. The significant emission measure at high temperatures that is not correlated with a comparable increase at low temperatures suggests that high-frequency heating is viable. The presence, however, during the early stages, of an enhanced emission measure in the "hot" (3.0-4.5 MK) and "cool" (0.6-0.9 MK) components suggests that low-frequency heating also plays a significant role. Our results explain why there have been recent studies supporting both heating scenarios.

Are Coronal Loops Projection Effects?

Vadim M. **Uritsky**[1,2] and James A. Klimchuk[2]

2024 ApJ 961 222

https://iopscience.iop.org/article/10.3847/1538-4357/ad0c53/pdf

We report results of an in-depth numerical investigation of three-dimensional projection effects that could influence the observed loop-like structures in an optically thin solar corona. Several archetypal emitting geometries are tested, including collections of luminous structures with circular cross sections of fixed and random size, and light-emitting structures with highly anisotropic cross sections, as well as two-dimensional stochastic current density structures generated by fully developed magnetohydrodynamic turbulence. A comprehensive set of statistical signatures is used to compare the line-of-sight (LOS) integrated emission signals predicted by the constructed numerical models with the loop profiles observed by the extreme ultraviolet telescope on board the flight 2.1 of the High-Resolution Coronal Imager (Hi-C). The results suggest that typical cross-sectional emission envelopes of the Hi-C loops are unlikely to have high eccentricity, and that the observed loops cannot be attributed to randomly oriented quasi-two-dimensional emitting structures, some of which would produce anomalously strong optical signatures due to an accidental LOS alignment, as expected in the "coronal veil" scenario proposed recently by Malanushenko et al. The possibility of apparent loop-like projections of very small (close to the resolution limit) or very large (comparable with the size of an active region) light-emitting sheets remains open, but the intermediate range of scales commonly associated with observed loop systems is most likely filled with true quasi-one-dimensional (roughly axisymmetric) structures embedded into the three-dimensional coronal volume.

THE PHYSICAL PROPERTIES OF CORONAL STREAMERS. II.

M. **Uzzo**,[1] L. Strachan,[1] and A. Vourlidas[2]

The Astrophysical Journal, 671:912Y925, 2007 December 10

http://www.journals.uchicago.edu/doi/pdf/10.1086/522909

(Uzzo, M., Strachan, L., Vourlidas, A., Ko, Y.-K., & Raymond, J. C. 2006, ApJ, 645, 720 (**Paper I**)

The Heating of Solar Coronal Loops by Alfven Wave Turbulence

Adriaan A. **van Ballegooijen**, Mahboubeh Asgari-Targhi, Alexander Voss

2017 *ApJ* **849** 46

https://arxiv.org/pdf/1710.05074.pdf

In this paper we further develop a model for the heating of coronal loops by Alfven wave turbulence (AWT). The Alfven waves are assumed to be launched from a collection of kilogauss flux tubes in the photosphere at the two ends of the loop. Using a three-dimensional magneto-hydrodynamic (MHD) model for an active-region loop, we investigate how the waves from neighboring flux tubes interact in the chromosphere and corona. For a particular combination of model parameters we find that AWT can produce enough heat to maintain a peak temperature of about 2.5 MK, somewhat lower than the temperatures of 3-4 MK observed in the cores of active regions. The heating rates vary strongly in space and time, but the simulated heating events have durations less than 1 minute and are unlikely to reproduce the observed broad Differential Emission Measure distributions of active regions. The simulated spectral line non-thermal widths are predicted to be about 27 km/s, which is high compared to the observed values. Therefore, the present AWT model does not satisfy the observational constraints. An alternative "magnetic braiding" model is considered in which the coronal field lines are subject to slow random footpoint motions, but we find that such long period motions produce much less heating than the shorter period waves launched within the flux tubes. We discuss several possibilities for resolving the problem of producing sufficiently hot loops in active regions.

TANGLED MAGNETIC FIELDS IN SOLAR PROMINENCES

A. A. van Ballegooijen and S. R. Cranmer

2010 ApJ 711 164-178

Solar prominences are an important tool for studying the structure and evolution of the coronal magnetic field. Here we consider so-called hedgerow prominences, which consist of thin vertical threads. We explore the possibility that such prominences are supported by tangled magnetic fields. A variety of different approaches are used. First, the dynamics of plasma within a tangled field is considered. We find that the contorted shape of the flux tubes significantly reduces the flow velocity compared to the supersonic free fall that would occur in a straight vertical tube. Second, linear force-free models of tangled fields are developed, and the elastic response of such fields to gravitational forces is considered. We demonstrate that the prominence plasma can be supported by the magnetic pressure of a tangled field that pervades not only the observed dense threads but also their local surroundings. Tangled fields with field strengths of about 10 G are able to support prominence threads with observed hydrogen density of the order of 10^{11} cm^{-3}. Finally, we suggest that the observed vertical threads are the result of Rayleigh-Taylor instability. Simulations of the density distribution within a prominence thread indicate that the peak density is much larger than the average density. We conclude that tangled fields provide a viable mechanism for magnetic support of hedgerow prominences.

Broadening of the differential emission measure by multi-shelled and turbulent loops

T. **Van Doorsselaere**1, P. Antolin2,3 and K. Karampelas1

A&A 620, A65 (**2018**)

Context. Broad differential emission measure (DEM) distributions in the corona are a sign of multi-thermal plasma along the line-of-sight. Traditionally, this is interpreted as evidence of multi-stranded loops. Recently, however, it has been shown that multi-stranded loops are unlikely to exist in the solar corona, because of their instability to transverse perturbations.

Aims. We aim to test if loop models subject to the transverse wave-induced Kelvin-Helmholtz (TWIKH) instability result in broad DEMs, potentially explaining the observations.

Methods. We took simulation snapshots and compute the numerical DEM. Moreover, we performed forward-modelling in the relevant AIA channels before reconstructing the DEM.

Results. We find that turbulent loop models broaden their initial DEM, because of the turbulent mixing. The width of the DEM is determined by the initial temperature contrast with the exterior.

Conclusions. We conclude that impulsively excited loop models have a rather narrow DEM, but that continuously driven models result in broad DEMs that are comparable to the observations.

Energy Propagation by Transverse Waves in Multiple Flux Tube Systems Using Filling Factors

T. **Van Doorsselaere**1, S. E. Gijsen1, J. Andries2, and G. Verth

2014 ApJ 795 18.

In the last few years, it has been found that transverse waves are present at all times in coronal loops or spicules. Their energy has been estimated with an expression derived for bulk Alfvén waves in homogeneous media, with correspondingly uniform wave energy density and flux. The kink mode, however, is localized in space with the energy density and flux dependent on the position in the cross-sectional plane. The more relevant quantities for the kink mode are the integrals of the energy density and flux over the cross-sectional plane. The present paper provides an approximation to the energy propagated by kink modes in an ensemble of flux tubes by means of combining the analysis of single flux tube kink oscillations with a filling factor for the tube cross-sectional area. This finally allows one to compare the expressions for energy flux of Alfvén waves with an ensemble of kink waves. We find that the correction factor for the energy in kink waves, compared to the bulk Alfvén waves, is between f and 2f, where f is the density filling factor of the ensemble of flux tubes.

Measurement of the polytropic index during solar coronal rain using a diagram of the electron density distribution as a function of the electron temperature

Z. M. **Vashalomidze** (1), T. V. Zaqarashvili (1,2,3), V. D. Kukhianidze (1)

Astrophysics, Vol. 62, No. 1, March, **2019**

https://arxiv.org/ftp/arxiv/papers/2110/2110.01313.pdf

A differential emission measure (DEM) method is used to evaluate the relationship of the electron density and temperature before and after a coronal rain event during an active sun over the period from 20:10 UT on **October 6 to 02:10 on October 7, 2011**. Observational data were obtained from SDO/AIA for six different extreme ultraviolet (EUV) spectral lines. 240 different coronal loops were analyzed during this time interval, and the average electron density and temperature were obtained using 171 Å (Fe IX) and 193 Å (Fe XII) filters. The relationship between the density and temperature made it possible to estimate the polytropic index in the solar corona before and after the coronal rain. The polytropic index after the termination of the coronal rain was estimated to be {\gamma} = 1.3{\pm}0.06, Which shows the usual thermodynamic properties of study-state coronal plasma. The polytropic index at the time of onset of the coronal rain was, however, estimated to be {\gamma} = 2.1{\pm}0.11, which indicates an unstable thermodynamic process, i.e., thermal instability. It is suggested that the coronal rain is the result of an unstable process, and the coronal plasma returns its stable state after the rain.

3D Temperatures and Densities of the Solar Corona via Multi-Spacecraft EUV Tomography: Analysis of Prominence Cavities

Alberto M. **Vásquez** · Richard A. Frazin · Farzad Kamalabadi

Solar Phys (2009) 256: 73–85, DOI 10.1007/s11207-009-9321-1

STEREO SCIENCE RESULTS AT SOLAR MINIMUM

Three-dimensional (3D) tomographic analysis of extreme ultraviolet (EUV) images is used to place empirical constraints on the corona’s temperature and density structure. The input data are images taken by the EUVI instrument on STEREO A and B spacecraft for Carrington Rotation 2069 (16 April to 13 May 2008). While the reconstructions are global, we demonstrate the capabilities of this method by examining specific structures in detail. Of particular importance are the results for coronal cavities and the surrounding helmet streamers, which our method allows to be analyzed without projection effects for the first time. During this rotation, both the northern and southern hemispheres exhibited stable polar crown filaments with overlying EUV cavities. These filaments and cavities were too low-lying to be well observed in white-light coronagraphs. Furthermore, due to projection effects, these cavities were not clearly discernible above the limb in EUV images, thus tomography offers the only option to study their plasma properties quantitatively. It is shown that, when compared to the surrounding helmet material, these cavities have lower densities (about 30%, on average) and broader local differential emission measures that are shifted to higher temperatures than the surrounding streamer plasma.

Filament Eruption in NOAA 11093 Leading to a Two-Ribbon M1.0 Class Flare and CME

P. **Vemareddy**, R. A. Maurya and A. Ambastha

Solar Physics, Volume 277, Number 2, 337-354, **2012; File**

We present a multi-wavelength analysis of an eruption event that occurred in active region NOAA 11093 on **7 August 2010**, using data obtained from SDO, STEREO, RHESSI, and the GONG Hα network telescope. From these observations, we inferred that an upward slow rising motion of an inverse S-shaped filament lying along the polarity inversion line resulted in a CME subsequent to a two-ribbon flare. Interaction of overlying field lines across the filament with the side-lobe field lines, associated EUV brightening, and flux emergence/cancelation around the filament were the observational signatures of the processes leading to its destabilization and the onset of eruption. Moreover, the time profile of the rising motion of the filament/flux rope corresponded well with flare characteristics, viz., the reconnection rate and hard X-ray emission profiles. The flux rope was accelerated to the maximum velocity as a CME at the peak phase of the flare, followed by deceleration to an average velocity of 590 km s^{-1}. We suggest that the observed emergence/cancelation of magnetic fluxes near the filament caused it to rise, resulting in the tethers to cut and reconnection to take place beneath the filament; in agreement with the tether-cutting model. The corresponding increase/decrease in positive/negative photospheric fluxes found in the post-peak phase of the eruption provides unambiguous evidence of reconnection as a consequence of tether cutting.

Statistical seismology of transverse waves in the solar corona

E. **Verwichte**1,2, T. Van Doorsselaere2, R. S. White1 and P. Antolin2
A&A 552, A138 (**2013**)
Context. Observations show that transverse oscillations commonly occur in solar coronal loops. The rapid damping of these waves has been attributed to resonant absorption. The oscillation characteristics carries information of the structuring of the corona. However, self-consistent seismological methods that extract information from individual oscillations are limited because there are fewer observables than unknown parameters in the model, and the problem is underdetermined. Furthermore, it has been shown that one-to-one comparisons of the observed scaling of period and damping times with wave damping theories are misleading.
Aims. We aim to investigate whether seismological information can be gained from the observed scaling laws in a statistical sense.
Methods. A statistical approach is used whereby scaling laws are produced by forward modelling using distributions of values for key loop cross-sectional structuring parameters. We study two types of observations: 1) transverse loops oscillations as seen mainly with TRACE and SDO and 2) running transverse waves seen with the Coronal Multichannel Polarimeter (CoMP).
Results. We demonstrate that the observed period-damping time scaling law does provide information about the physical damping mechanism, if observations are collected from as wide range of periods as possible and a comparison with theory is performed in a statistical sense. The distribution of the ratio of damping time over period, i.e. the quality factor, has been derived analytically and fitted to the observations. A minimum value for the quality factor of 0.65 has been found. From this, a constraint linking the ranges of possible values for the density contrast and inhomogeneity layer thickness is obtained for transverse loop oscillations. If the layer thickness is not constrained, then the density contrast is at most equal to 3. For transverse waves seen by CoMP, it is found that the ratio of maximum to minimum values for these two parameters has to be less than 2.06; i.e., the sampled values for the layer thickness and Alfvén travel time come from a relatively narrow distribution.
Conclusions. Now that more and more transverse loop oscillations have been analysed, a statistical approach to coronal seismology becomes possible. Using the observed data cloud, we have found restrictions to the loop's density contrast and inhomogeneity layer thickness. Surprisingly, for running waves, narrow distributions for loop parameters have been found.

CORONAL ALFVÉN SPEED DETERMINATION: CONSISTENCY BETWEEN SEISMOLOGY USING AIA/SDO TRANSVERSE LOOP OSCILLATIONS AND MAGNETIC EXTRAPOLATION
E. **Verwichte**1,2, T. Van Doorsselaere2, C. Foullon1, and R. S. White
2013 ApJ 767 16
Two transversely oscillating coronal loops are investigated in detail during a flare on the **2011 September 6** using data from the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory. We compare two independent methods to determine the Alfvén speed inside these loops. Through the period of oscillation and loop length, information about the Alfvén speed inside each loop is deduced seismologically. This is compared with the Alfvén speed profiles deduced from magnetic extrapolation and spectral methods using AIA bandpass. We find that for both loops the two methods are consistent. Also, we find that the average Alfvén speed based on loop travel time is not necessarily a good measure to compare with the seismological result, which explains earlier reported discrepancies. Instead, the effect of density and magnetic stratification on the wave mode has to be taken into account. We discuss the implications of combining seismological, extrapolation, and spectral methods in deducing the physical properties of coronal loops.

Some relationships between radiative and atmospheric quantities through 1D NLTE modeling of prominences in the Mg II lines
J.-C. **Vial**, P. Zhang and É. Buchlin
A&A 624, A56 (**2019**)
sci-hub.se/10.1051/0004-6361/201834249
Context. With more than four years of IRIS observations, and in order to avoid building customized diagnostics for each observation, it is useful to derive some simple relations between spectra and physical quantities. This is even more useful for the k and h lines of Mg II, which require complex non-local-thermodynamic-equilibrium NLTE treatments.
Aims. The aim of this work concerning prominences is to correlate observable spectral features in h and k lines of Mg II to physical quantities such as the density and the emission measure (EM) in the same way as similar correlations have been obtained in the hydrogen lines. In this way, and within approximations done on some parameters such as temperature, it is possible to build pixel by pixel an IRIS map of the above-mentioned quantities.
Methods. In order to simplify and shorten the modeling, we chose to compute one-dimensional (1D) isothermal and isobaric models that are treated with the PROM7 NLTE code available at MEDOC (IAS). We built a set of models with large ranges of temperature, pressure, and thickness. At all altitudes considered, we paid attention to the exact

computation of the incident radiation. Then we compared the emergent Mg II h and k intensities with the corresponding hydrogen and electron densities and EMs.
Results. From the NLTE computation, we derive correlations between the k and h emergent intensities on one hand and the densities and EM on the other hand. With some assumptions on the temperature, we obtain a unique relation between the k (and h) intensities and the EM that should be useful for deriving either the hydrogen and electron densities or the effective thickness of an observed prominence.
Conclusions. From NLTE modeling, we have provided a relationship between observable integrated intensities of the Mg II resonance lines and prominence plasma EM, which will contribute to a first-order analysis of long time series of spectroscopic observations, for example, with IRIS. We anticipate building more complex relations between the profiles and other plasma quantities.

The Balmer Lines of He II in the Blue Wing of the Hydrogen Lyman *α* Line Observed in a Quiescent Prominence

J.-C. **Vial**, G. Eurin, W. Curdt

Solar Physics February **2015**, Volume 290, Issue 2, pp 381-387

We revisit the prominence observations in the Lyman *α* line of Curdt *et al.* (*Astron. Astrophys.* **511**, L4, 2010) and focus on the bump in the blue wing of the line, which we identify with He II Balmer lines. We determine the transition candidates, derive an upper limit for the width of the profile and an associated non-thermal velocity close to 0 km s^{-1}, with the assumption that the kinetic temperature is equal to the formation temperature. We compare the total intensity with the corresponding H Lyman *α* intensity and find a ratio much lower than that measured by Ebadi, Vial, and Ajabshirizadeh (*Solar Phys.* **257**, 91, 2009) in other Lyman lines. We confirm this result with observations performed by Schwartz *et al.* (private communication, 2014), we discuss a possible interpretation, and suggest that this issue needs to be addressed closely in future observations. **9-15 June 2009**

Using SDO/AIA to Understand the Thermal Evolution of Solar Prominence Formation

Nicholeen M. **Viall**, Therese A. Kucera, and Judith T. Karpen

Astrophysical Journal, 905:15 **2020**

https://doi.org/10.3847/1538-4357/abc419

https://iopscience.iop.org/article/10.3847/1538-4357/abc419/pdf

We investigated the thermal properties of prominence formation using time series analysis of Solar Dynamics Observatory's Atmospheric Imaging Assembly (SDO/AIA) data. Here, we report the first time-lag measurements derived from SDO/AIA observations of a prominence and its cavity on the solar limb, made possible by AIA's different wave bands and high time resolution. With our time-lag analysis, which tracks the thermal evolution using emission formed at different temperatures, we find that the prominence cavity exhibited a mixture of heating and cooling signatures. This is in contrast to prior time-lag studies of multiple active regions that chiefly identified cooling signatures and very few heating signatures, which is consistent with nanoflare heating. We also computed time lags for the same pairs of SDO/AIA channels using output from a one-dimensional hydrodynamic model of prominence material forming through thermal nonequilibrium (TNE). We demonstrate that the SDO/AIA time lags for flux tubes undergoing TNE are predicted to be highly complex, changing with time and location along the flux tube, and are consistent with the observed time-lag signatures in the cavity surrounding the prominence. Therefore, the time-lag analysis is a sensitive indicator of the heating and cooling processes in different coronal regions. The time lags calculated for the simulated prominence flux tube are consistent with the behavior deduced from the AIA data, thus supporting the TNE model of prominence formation. Future investigations of time lags predicted by other models for the prominence mass could be a valuable method for discriminating among competing physical mechanisms. **2010 December 14**

EVIDENCE FOR WIDESPREAD COOLING IN AN ACTIVE REGION OBSERVED WITH THE SDO ATMOSPHERIC IMAGING ASSEMBLY

Nicholeen M. **Viall** and James A. Klimchuk

2012 ApJ 753 35

A well-known behavior of EUV light curves of discrete coronal loops is that the peak intensities of cooler channels or spectral lines are reached at progressively later times than hotter channels. This time lag is understood to be the result of hot coronal loop plasma cooling through these lower respective temperatures. However, loops typically comprise only a minority of the total emission in active regions (ARs). Is this cooling pattern a common property of AR coronal plasma, or does it only occur in unique circumstances, locations, and times? The new Solar Dynamics Observatory/Atmospheric Imaging Assembly (SDO/AIA) data provide a wonderful opportunity to answer this question systematically for an entire AR. We measure the time lag between pairs of SDO/AIA EUV channels using 24 hr of images of AR 11082 observed on **2010 June 19**. We find that there is a time-lag signal consistent with cooling plasma, just as is usually found for loops, throughout the AR including the diffuse emission between loops for the entire 24 hr duration. The pattern persists consistently for all channel pairs and choice of window length within the 24 hr time period, giving us confidence that the plasma is cooling from temperatures of greater than 3 MK, and sometimes exceeding 7 MK, down to temperatures lower than ~0.8 MK. This suggests that the bulk of the emitting coronal plasma in this AR is not steady; rather, it is dynamic and constantly evolving. These measurements provide crucial constraints on any model which seeks to describe coronal heating.

High spatial resolution VAULT H-Lyα observations and multiwavelength analysis of an active region filament⋆

J.-C. **Vial**1, K. Olivier1, A. A. Philippon1, A. Vourlidas2 and V. Yurchyshyn

A&A 541, A108 (**2012**)

Context. The search for the fine structure of prominences has received considerable new attention thanks to the Swedish Solar Telescope (SST) Hα pictures that provide an unsurpassed spatial resolution. Recently, it has been shown that the filaments' coronal environment, at least for quiescent filaments, is perturbed by either cool absorbing material (in the EUV) or an "emissivity blocking" (actually a lack of transition region and coronal material).
Aims. The aim is to assess the fine structure in an active region filament and to determine the nature of the EUV absorption or lack of emission phenomena, using the very optically thick line H-Lyα, formed at a temperature higher than Hα.
Methods. We performed a multiwavelength study where high-resolution imaging in the H-Lyα line (VAULT) was analysed and compared with observations of an active region filament in Hα (BBSO) and EUV lines (EIT and TRACE).
Results. As for the SST data, small-scale structures were detected at a typical scale of about one to two arcseconds with, for some cuts, an indication of fine scales down to 0.4 arcsec in the optically thick H-Lyα line. The filament intensity relative to the intensity of the (active) region it is embedded in is about 0.2 in H-Lyα. This ratio (Lymanα ratio intensity or "LRI") is the lowest value compared to other lines, e.g. Hα. The filament environment was also investigated and evidence of an UV extension was found. The comparison of spatial cuts in different lines across the filament shows evidence of strong absorption, and consequently of cool plasma on one side of the filament, but not on the other (that side is obscured by the filament itself).
Conclusions. The absence of very fine structure in H-Lyα compared to Hα is explained by the formation temperature of the H-Lyα line (~20 000 K), where the transition regions of the thin threads begin to merge. From the detection of H-Lyα absorption on the observable side of the filament side, we derive the presence of absorbing (cool) material and possibly also of emissivity blocking (or coronal void). This poses the question whether these absorption effects are typical of active region filaments.

Variation of the electron flux spectrum along a solar flare loop as inferred from STIX hard X-ray observations

Anna **Volpara**, Paolo Massa, Sam Krucker, A Gordon Emslie, Michele Piana, Anna Maria Massone

A&A 684, A185 (**2024**)

https://arxiv.org/pdf/2311.07148.pdf

Regularized imaging spectroscopy was introduced for the construction of electron flux images at different energies from count visibilities recorded by the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI). In this work we seek to extend this approach to data from the Spectrometer/Telescope for Imaging X-rays (STIX) on-board the Solar Orbiter mission. Our aims are to demonstrate the feasibility of regularized imaging spectroscopy as a method for analysis of STIX data, and also to show how such analysis can lead to insights into the physical processes affecting the nonthermal electrons responsible for the hard X-ray emission observed by STIX. STIX records imaging data in an intrinsically different manner from RHESSI. Rather than sweeping the angular frequency plane in a set of concentric circles (one circle per detector), STIX uses 30 collimators, each corresponding to a specific angular frequency. In this paper we derive an appropriate modification of the previous computational approach for the analysis of the visibilities observed by STIX. This approach also allows for the observed count data to be placed into non-uniformly-spaced energy bins. We show that the regularized imaging spectroscopy approach is not only feasible for analysis of the visibilities observed by STIX, but also more reliable. Application of the regularized imaging spectroscopy technique to several well-observed flares reveals details of the variation of the electron flux spectrum throughout the flare sources. We conclude that the visibility-based regularized imaging spectroscopy approach is well-suited to analysis of STIX data. We also use STIX electron flux spectral images to track, for the first time, the behavior of the accelerated electrons during their path from the acceleration site in the solar corona toward the chromosphere . **2021-05-08, 2022-09-29**

Large amplitude oscillatory motion along a solar filament

B. **Vrsnak**, A.M. Veronig, J.K. Thalmann, T. Zic

E-print, July **2007**

Negative-energy Waves in the Vertical Threads of a Solar Prominence

Jincheng **Wang**1,2, Dong Li3,2, Chuan Li4,5,6, Yijun Hou7,2, Zhike Xue1,2, Zhe Xu1,2, Liheng Yang1,2, and Qiaoling Li8

2024 ApJL 965 **L28**

https://arxiv.org/pdf/2404.03199.pdf

https://iopscience.iop.org/article/10.3847/2041-8213/ad3af8/pdf

Solar prominences, intricate structures on the Sun's limb, have been a subject of fascination owing to their threadlike features and dynamic behaviors. Utilizing data from the New Vacuum Solar Telescope, Chinese Hα Solar Explorer, and Solar Dynamics Observatory, this study investigates the transverse swaying motions observed in the vertical threads of a solar prominence during its eruption onset on **2023 May 11**. The transverse swaying motions were observed to propagate upward, accompanied by upflowing materials at an inclination of 31° relative to the plane of the sky. These motions displayed small-amplitude oscillations with corrected velocities of around 3–4 km s−1 and periods of 13–17 minutes. Over time, the oscillations of swaying motion exhibited an increasing pattern in displacement amplitudes, oscillatory periods, and projected velocity amplitudes. Their phase velocities are estimated to be about 26–34 km s−1. An important finding is that these oscillations' phase velocities are comparable to the upward flow velocities, measured to be around 30–34 km s−1. We propose that this phenomenon is associated with negative-energy wave instabilities, which require comparable velocities of the waves and flows, as indicated by our findings. This phenomenon may contribute to the instability and observed disruption of the prominence. By using prominence seismology, the Alfvén speed and magnetic field strength of the vertical threads have been estimated to be approximately 21.5 km s−1 and 1–3G, respectively. This study reveals the dynamics and magnetic properties of solar prominences, contributing to our understanding of their behavior in the solar atmosphere.

Coronal Loop Detection Using Multiscale Convolutional Neural Networks

Yunzhi **Wang**3,1,2, Bo Liang3,1, and Song Feng4,1,2

2024 ApJS 270 4

https://iopscience.iop.org/article/10.3847/1538-4365/ad09b6/pdf

Solar magnetic fields play an important role in many solar activities, such as the solar wind, coronal mass ejections, and coronal oscillation. Coronal loops are curvilinear structures in the solar atmosphere and are closely related to coronal magnetic fields, so the study of their structure is very important. However, it is difficult to identify coronal loops accurately because of the complexity of their features. Therefore, we propose a two-stage detection method, using multiscale convolutional neural networks, to identify coronal loops. The regions including initial coronal loops are first marked by a improved Res-UNet model. The loop structures in the region are then detected using a improved dense extreme inception network for edge detection model. We selected the coronal images observed by the Transition and Coronal Explorer and the Atmospheric Imaging Assembly of the Solar Dynamics Observatory in the 171 Å channel to illustrate the detection processing. Meanwhile, we also compared the accuracy of our method to others. The results demonstrate that our proposed method has a high recognition rate and good robustness over previous identification methods and can be used to study the physical characteristics of coronal loops.

A formation mechanism for the large plumes in the prominence

Jincheng **Wang**, Xiaoli Yan, Zhike Xue, Liheng Yang, Qiaoling Li, Hechao Chen, Chun Xia, Zhong Liu

A&A 659, A76 **2022**

https://arxiv.org/pdf/2202.08521.pdf

https://www.aanda.org/articles/aa/pdf/2022/03/aa42584-21.pdf

https://doi.org/10.1051/0004-6361/202142584

To understand the formation mechanism of large plumes in solar prominences, we investigate the formation process of two such phenomena. We studied the dynamic and thermal properties of two large plumes using observations from New Vacuum Solar Telescope, the Solar Dynamic Observatory, and the Solar Terrestrial Relations Observatory-Ahead. We find that two large plumes observed with high-resolution data are quite different from previously studied small-scale plumes. They are born at the top of a prominence bubble with a large projected area of 10-20 Mm^2 . Before the occurrence of each large plume, the bubble expands and takes on a quasi-semicircular appearance. Meanwhile, the emission intensity of extreme-ultra-violet (EUV) bands increases in the bubble. A small-scale filament is found to erupt in the bubble during the second large plume. At the point at which the height of the bubble is comparable with half the width of the bubble, the bubble becomes unstable and generates the plumes. During the formation of plumes, two side edges of the top of the bubble, which are dominated by opposite Doppler signals, approach each other. The large plume then emerges and keeps rising up with a constant speed of about 13-15 km/s. These two large plumes have temperatures of 1.3 x 10^6 Kelvin and densities of 2.0 x 10^9 cm^-3, two orders hotter and one order less dense than the typical prominence. We also find that the bubble is a hot, low-density volume instead of a void region beneath the cold and dense prominence. Therefore, we conclude that these two large plumes are the result of the breakup of the prominence bubble triggered by an enhancement of thermal pressure; they separate from the bubble, most likely by magnetic reconnection. **2021 April 14,**

Slow-Mode Magnetoacoustic Waves in Coronal Loops **Review**

Tongjiang **Wang**, Leon Ofman, Ding Yuan, Fabio Reale, Dmitrii Y. Kolotkov, Abhishek K. Srivastava

Space Science Reviews **217**, Article number: 34 **2021**

https://arxiv.org/pdf/2102.11376.pdf

https://doi.org/10.1007/s11214-021-00811-0

Rapidly decaying long-period oscillations often occur in hot coronal loops of active regions associated with small (or micro-) flares. This kind of wave activity was first discovered with the SOHO/SUMER spectrometer from Doppler velocity measurements of hot emission lines, thus also often called "SUMER" oscillations. They were mainly interpreted as global (or fundamental mode) standing slow magnetoacoustic waves. In addition, increasing evidence has suggested that the decaying harmonic type of pulsations detected in light curves of solar and stellar flares are likely caused by standing slow-mode waves. The study of slow magnetoacoustic waves in coronal loops has become a topic of particular interest in connection with coronal seismology. We review recent results from SDO/AIA and Hinode/XRT observations that have detected both standing and reflected intensity oscillations in hot flaring loops showing the physical properties (e.g., oscillation periods, decay times, and triggers) in accord with the SUMER oscillations. We also review recent advances in theory and numerical modeling of slow-mode waves focusing on the wave excitation and damping mechanisms. MHD simulations in 1D, 2D and 3D have been dedicated to understanding the physical conditions for the generation of a reflected propagating or a standing wave by impulsive heating. Various damping mechanisms and their analysis methods are summarized. Calculations based on linear theory suggest that the non-ideal MHD effects such as thermal conduction, compressive viscosity, and optically thin radiation may dominate in damping of slow-mode waves in coronal loops of different physical conditions. Finally, an overview is given of several important seismological applications such as determination of transport coefficients and heating function.

Determination of transport coefficients by coronal seismology of flare-induced slow-mode waves: Numerical parametric study of 1D loop model

Tongjiang **Wang**, Leon Ofman

ApJ **2019**

https://arxiv.org/pdf/1909.10910.pdf

Recent studies of a flaring loop oscillation event on 2013 December 28 observed by the Atmospheric Imaging Assembly (AIA) of the Solar Dynamics Observatory (SDO) have revealed the suppression of thermal conduction and significant enhancement of compressive viscosity in hot (∼10 MK) plasma. In this study we aim at developing a new coronal seismology method for determining the transport coefficients based on a parametric study of wave properties using a 1D nonlinear MHD loop model in combination with the linear theory. The simulations suggest a two-step scheme: we first determine the effective thermal conduction coefficient from the observed phase shift between temperature and density perturbations as this physical parameter is insensitive to the unknown viscosity; then from the loop model with the obtained thermal conduction coefficient, we determine the effective viscosity coefficient from the observed decay time using the parametric modeling. With this new seismology technique we are able to quantify the suppression of thermal conductivity by a factor of about 3 and the enhancement of viscosity coefficient by a factor of 10 in the studied flaring loop. Using the loop model with these refined transport coefficients, we study the excitation of slow magnetoacoustic waves by launching a flow pulse from one footpoint. The simulation can self-consistently produce the fundamental standing wave on a timescale in agreement with the observation.

Formation of an active region filament driven by a series of jets

Jincheng **Wang**, Xiaoli Yan, ZhongQuan Qu, Satoru UeNo, Kiyoshi Ichimoto, Linhua Deng, Wenda Cao, Zhong Liu

ApJ **2018**

https://arxiv.org/pdf/1807.00992.pdf

We present a formation process of a filament in active region NOAA 12574 during the period from **2016 August 11 to 12**. Combining the observations of GONG Hα, Hida spectrum and SDO/AIA 304 A, the formation process of the filament is studied. It is found that cool material (T∼104 K) is ejected by a series of jets originating from the western foot-point of the filament. Simultaneously, the magnetic flux emerged from the photosphere in the vicinity of the western foot-point of the filament. These observations suggest that cool material in the low atmosphere can be directly injected into the upper atmosphere and the jets are triggered by the magnetic reconnection between pre-existing magnetic fields and new emerging magnetic fields. Detailed study of a jet at 18:02 UT on August 11 with GST/BBSO TiO observations reveals that some dark threads appeared in the vicinity of the western foot-point after the jet and the projection velocity of plasma along the filament axis was about 162.6±5.4 km/s. Using with DST/Hida observations, we find that the injected plasma by a jet at 00:42 UT on August 12 was rotating. Therefore, we conclude that the jets not only supplied the material for the filament, but also injected the helicity into the filament simultaneously. Comparing the quantity of mass injection by the jets with the mass of the filament, we conclude that the estimated mass loading by the jets is sufficient to account for the mass in the filament.

Gradual Streamer Expansions and the Relationship between Blobs and Inflows

Y.-M. **Wang** and P. Hess

2018 ApJ 859 135 10.3847/1538-4357/aabfd5

Coronal helmet streamers show a continual tendency to expand outward and pinch off, giving rise to flux ropes that are observed in white light as "blobs" propagating outward along the heliospheric current/plasma sheet. The blobs form within the r ~ 2–6 R ⊙ heliocentric range of the Large Angle and Spectrometric Coronagraph (LASCO) C2 instrument, but the expected inward-moving counterparts are often not detected. Here we show that the height of blob formation varies as a function of the underlying photospheric field, with the helmet streamer loops expanding to greater heights when active regions (ARs) emerge underneath them. When the pinch-offs occur at r ~ 3–4 R ⊙, diverging inward/outward tracks sometimes appear in height–time maps constructed from LASCO C2 running-difference images. When the underlying photospheric field is weak, the blobs form closer to the inner edge of the C2 field of view and only the outward tracks are clearly visible. Conversely, when the emergence of large ARs leads to a strengthening of the outer coronal field and an increase in the total white-light radiance (as during late 2014), the expanding helmet-streamer loops pinch off beyond r ~ 4 R ⊙, triggering strong inflow streams whose outgoing counterparts are usually very faint. We deduce that the visibility of the blobs and inflows depends on the amount of material that the diverging components sweep up within the 2–6 R ⊙ field of view. We also note that the rate of blob production tends to increase when a helmet streamer is "activated" by underlying flux emergence.

Effect of transport coefficients on excitation of flare-induced standing slow-mode waves in coronal loops

Tongjiang **Wang**, Leon Ofman, Xudong Sun, Sami K Solanki, Joseph M Davila

ApJ **2018**

https://arxiv.org/pdf/1805.03282.pdf

Standing slow-mode waves have been recently observed in flaring loops by the Atmospheric Imaging Assembly (AIA) of the Solar Dynamics Observatory (SDO). By means of the coronal seismology technique transport coefficients in hot (~10 MK) plasma were determined by Wang et al.(2015, Paper I), revealing that thermal conductivity is nearly suppressed and compressive viscosity is enhanced by more than an order of magnitude. In this study we use 1D nonlinear MHD simulations to validate the predicted results from the linear theory and investigate the standing slow-mode wave excitation mechanism. We first explore the wave trigger based on the magnetic field extrapolation and flare emission features. Using a flow pulse driven at one footpoint we simulate the wave excitation in two types of loop models: model 1 with the classical transport coefficients and model 2 with the seismology-determined transport coefficients. We find that model 2 can form the standing wave pattern (within about one period) from initial propagating disturbances much faster than model 1, in better agreement with the observations. Simulations of the harmonic waves and the Fourier decomposition analysis show that the scaling law between damping time (τ) and wave period (P) follows $\tau \propto P2$ in model 2, while $\tau \propto P$ in model 1. This indicates that the largely enhanced viscosity efficiently increases the dissipation of higher harmonic components, favoring the quick formation of the fundamental standing mode. Our study suggests that observational constraints on the transport coefficients are important in understanding both, the wave excitation and damping mechanisms. **2013 December 28**

Extending Counter-Streaming Motion from an Active Region Filament to Sunspot Light Bridge

Haimin **Wang**, Rui Liu, Qin Li, Chang Liu, Na Deng, Yan Xu, Ju Jing, Yuming Wang, Wenda Cao

2018 ApJL 852 L18

https://arxiv.org/pdf/1712.06783.pdf

We analyze the high-resolution observations from the 1.6m telescope at Big Bear Solar Observatory that cover an active region filament. Counter-streaming motions are clearly observed in the filament. The northern end of the counter-streaming motions extends to a light bridge, forming a spectacular circulation pattern around a sunspot, with clockwise motion in the blue wing and counterclockwise motion in the red wing as observed in Halpha off-bands. The apparent speed of the flow is around 10 to 60 km/s in the filament, decreasing to 5 to 20 km/s in the light bridge. The most intriguing results are the magnetic structure and the counter-streaming motions in the light bridge. Similar to those in the filament, magnetic fields show a dominant transverse component in the light bridge. However, the filament is located between opposite magnetic polarities, while the light bridge is between strong fields of the same polarity. We analyze the power of oscillations with the image sequences of constructed Dopplergrams, and find that the filament's counter-streaming motion is due to physical mass motion along fibrils, while the light bridge's counter-streaming motion is due to oscillation in the direction along the line-of-sight. The oscillation power peaks around 4 minutes. However, the section of the light bridge next to the filament also contains a component of the extension of the filament in combination with the oscillation, indicating that some strands of the filament are extended to and rooted in that part of the light bridge. **2015 June 20**

Dynamics of a prominence-horn structure during its evaporation in the solar corona
Bing **Wang**, Yao Chen, Jie Fu, Bo Li, Xing Li, Wei Liu
ApJL **827** L33 **2016**
http://arxiv.org/pdf/1608.04095v1.pdf
The physical connection among and formation mechanisms of various components of the prominence-horn cavity system remain elusive. Here we present observations of such a system, focusing on a section of the prominence that rises and separates gradually from the main body. This forms a configuration sufficiently simple to yield clues to the above issues. It is characterized by embedding horns, oscillations, and a gradual disappearance of the separated material. The prominence-horn structure exhibits a large amplitude longitudinal oscillation with a period of ~150 minutes and an amplitude of ~30 Mm along the trajectory defined by the concave horn structure. The horns also experience a simultaneous transverse oscillation with a much smaller amplitude (~3 Mm) and shorter period (~10-15 minutes), likely representative of a global mode of the large-scale magnetic structure. The gradual disappearance of the structure indicates that the horn, an observational manifestation of the field-aligned transition region separating the cool and dense prominence from the hot and tenuous corona, is formed due to the heating and diluting process of the central prominence mass, while most previous studies suggest that it is the opposite process, i.e., the cooling and condensation of coronal plasmas, to form the horn. This study also demonstrates how the prominence transports magnetic flux to the upper corona, a process essential for the gradual build-up of pre-eruption magnetic energy.
July 7-10, 2011

Waves in Solar Coronal Loops **Review**
Tongjiang **Wang**
Geophysical Monograph Series, Vol. 216. ISBN: 978-1-119-05495-5. Wiley, **2016**, Chapter 23
p.395-418 **2018**
https://arxiv.org/pdf/1803.11329.pdf
Recent observations have revealed the ubiquitous presence of magnetohydrodynamic (MHD) waves and oscillations in the solar corona. The aim of this review is to present recent progress in the observational study of four types of wave (or oscillation) phenomena mainly occurring in active region coronal loops, including (i) flare-induced slow mode oscillations, (ii) fast kink mode oscillations, (iii) propagating slow magnetoacoustic waves, and (iv) ubiquitous propagating kink (Alfvenic) waves. This review not only comprehensively outlines various aspects of these waves and coronal seismology, but also highlights the topics that are newly emerging or hotly debated, thus can provide readers a useful guidance on further studies of their interested topics.

Waves in Solar Coronal Loops **Review**
Wang, Tongjiang
Wiley Book **2016**
http://onlinelibrary.wiley.com/doi/10.1002/9781119055006.ch23/summary
The corona is visible in the optical band only during a total solar eclipse or with a coronagraph. Coronal loops are believed to be plasma-filled closed magnetic flux anchored in the photosphere. Based on the temperature regime, they are generally classified into cool, warm, and hot loops. The magnetized coronal structures support propagation of various types of magnetohydrodynamics (MHD) waves. This chapter reviews the recent progress made in studies based on observations of four types of wave phenomena mainly occurring in coronal loops of active regions, including: flare-excited slow-mode waves; impulsively excited kink-mode waves; propagating slow magnetoacoustic waves; and ubiquitous propagating kink (Alfvénic) waves. This review not only comprehensively discusses these waves and coronal seismology but also topics that are newly emerging or hotly debated in order to provide the reader with useful guidance on further studies.

THE EVOLUTION OF THE ELECTRIC CURRENT DURING THE FORMATION AND ERUPTION OF ACTIVE-REGION FILAMENTS
Jincheng **Wang**1,2, Xiaoli Yan1,3, Zhongquan Qu1, Zhike Xue1, Yongyuan Xiang1, and Hao Li1
2016 ApJ 817 156
We present a comprehensive study of the electric current related to the formation and eruption of active region filaments in NOAA **AR 11884**. The vertical current on the solar surface was investigated by using vector magnetograms (VMs) observed by HMI on board the Solar Dynamics Observatory. To obtain the electric current along the filament's axis, we reconstructed the magnetic fields above the photosphere by using nonlinear force-free field extrapolation based on photospheric VMs. Spatio-temporal evolutions of the vertical current on the photospheric surface and the horizontal current along the filament's axis were studied during the long-term evolution and eruption-related period, respectively. The results show that the

vertical currents of the entire active region behaved with a decreasing trend and the magnetic fields also kept decreasing during the long-term evolution. For the eruption-related evolution, the mean transverse field strengths decreased before two eruptions and increased sharply after two eruptions in the vicinity of the polarity inversion lines underneath the filament. The related vertical current showed different behaviors in two of the eruptions. On the other hand, a very interesting feature was found: opposite horizontal currents with respect to the current of the filament's axis appeared and increased under the filament before the eruptions and disappeared after the eruptions. We suggest that these opposite currents were carried by the new flux emerging from the photosphere bottom and might be the trigger mechanism for these filament eruptions.

Three-dimensional MHD modeling of propagating disturbances in fan-like coronal loops

Tongjiang **Wang**, Leon Ofman, and Joseph M. Davila

E-print, Aug **2013**; ApJL

Quasi-periodic propagating intensity disturbances (PDs) have been observed in large coronal loops in EUV images over a decade, and are widely accepted to be slow magnetosonic waves. However, spectroscopic observations from Hinode/EIS revealed their association with persistent coronal upflows, making this interpretation debatable. Motivated by the scenario that the coronal upflows could be cumulative result of numerous individual flow pulses generated by sporadic heating events (nanoflares) at the loop base, we construct a velocity driver with repetitive tiny pulses, whose energy frequency distribution follows the flare power-law scaling. We then perform 3D MHD modeling of an idealized bipolar active region by applying this broadband velocity driver at the footpoints of large coronal loops which appear open in the computational domain. Our model successfully reproduces the PDs with similar features as the observed, and shows that any upflow pulses inevitably excite slow magnetosonic wave disturbances propagating along the loop. We find that the generated PDs are dominated by the wave signature as their propagation speeds are consistent with the wave speed in the presence of flows, and the injected flows rapidly decelerate with height. Our simulation results suggest that the observed PDs and associated persistent upflows may be produced by small-scale impulsive heating events (nanoflares) at the loop base, and that the flows and waves may both contribute to the PDs at lower heights. **2010 September 16**

Pseudostreamers as the source of a separate class of solar coronal mass ejections,

Wang, Y-M.

(**2015**), Astrophys. J. Lett., 803. L12.

http://iopscience.iop.org/article/10.1088/2041-8205/803/1/L12/pdf

Using white-light and extreme-ultraviolet imaging observations, we confirm that pseudostreamers (streamers that separate coronal holes of the same polarity) give rise to a different type of coronal mass ejection (CME) from that associated with helmet streamers (defined as separating coronal holes of opposite polarity). Whereas helmet streamers are the source of the familiar bubble-shaped CMEs characterized by gradual acceleration and a three-part structure, pseudostreamers produce narrower, fanlike ejections with roughly constant speeds. These ejections, which are typically triggered by underlying filament eruptions or small, flaring active regions, are confined laterally and channeled outward by the like-polarity open flux that converges onto the pseudostreamer plasma sheet from both sides. In contrast, helmet streamer CMEs are centered on the relatively weak field around the heliospheric current sheet and thus undergo greater lateral expansion. Pseudostreamer ejections have a morphological resemblance to white-light jets from coronal holes; however, unlike the latter, they are not primarily driven by interchange reconnection, and tend to have larger widths (~20°–30°), lower speeds (~250–700 km s^{-1}), and more complex internal structure. **2007 June 23, 2007 December 15, 2008 January 27, 2008 November 29, 2009 February 6, 2010 May 8, 2010 October 10, 2010 October 26, 2010 November 24**

TRANSIENT BRIGHTENINGS ASSOCIATED WITH FLUX CANCELLATION ALONG A FILAMENT CHANNEL

Y.-M. **Wang**1 and K. Muglach

2013 ApJ 763 97

Filament channels coincide with large-scale polarity inversion lines of the photospheric magnetic field, where flux cancellation continually takes place. High-cadence Solar Dynamics Observatory (SDO) images recorded in He II 30.4 nm and Fe IX 17.1 nm during **2010 August 22** reveal numerous transient brightenings occurring along the edge of a filament channel within a decaying active region, where SDO line-of-sight magnetograms show strong opposite-polarity flux in close contact. The brightenings are elongated along the direction of the filament channel, with linear extents of several arcseconds, and typically last a few minutes; they sometimes have the form of multiple two-sided ejections with speeds on the order of 100 km s^{-1}. Remarkably, some of the brightenings rapidly develop into larger scale events, forming sheetlike structures that are eventually torn apart by the diverging flows in the filament channel and ejected in opposite directions. We interpret the brightenings as resulting from reconnections among filament-channel field lines having one footpoint located in the region of canceling flux. In some cases, the flow patterns that develop in the channel may bring successive horizontal loops together and cause a cascade to larger scales.

GROWING TRANSVERSE OSCILLATIONS OF A MULTISTRANDED LOOP OBSERVED BY SDO/AIA

Tongjiang **Wang**1,2, Leon Ofman1,2,4, Joseph M. Davila2, and Yang Su

2012 ApJ 751 L27

The first evidence of transverse oscillations of a multistranded loop with growing amplitudes and internal coupling observed by the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory is presented. The loop oscillation event occurred on **2011 March 8**, triggered by a coronal mass ejection (CME). The multiwavelength analysis reveals the presence of multithermal strands in the oscillating loop, whose dynamic behaviors are temperature-dependent, showing differences in their oscillation amplitudes, phases, and emission evolution. The physical parameters of growing oscillations of two strands in 171 Å are measured and the three-dimensional loop geometry is determined using STEREO-A/EUVI data. These strands have very similar frequencies, and between two 193 Å strands a quarter-period phase delay sets up. These features suggest the coupling between kink oscillations of neighboring strands and the interpretation by the collective kink mode as predicted by some models. However, the temperature dependence of the multistranded loop oscillations was not studied previously and needs further investigation. The transverse loop oscillations are associated with intensity and loop width variations. We suggest that the amplitude-growing kink oscillations may be a result of continuous non-periodic driving by magnetic deformation of the CME, which deposits energy into the loop system at a rate faster than its loss.

Spectroscopic Diagnosis of Propagating disturbances in coronal loops: Waves or flows?

Tongjiang **Wang**, Leon Ofman, Joseph M. Davila

Hinode 5 Science Meeting (Oct. 10-14, 2011, Boston), ASP Conference Series, *L. Golub, I. D. Moortel, and T. Shimizu, eds.* Vol. 456, **2012**

http://arxiv.org/pdf/1501.04082v1.pdf

The analysis of multiwavelength properties of propagating disturbances (PDs) using Hinode/EIS observations is presented. Quasi-periodic PDs were mostly interpreted as slow magnetoacoustic waves in early studies, but recently suggested to be intermittent upflows of the order of 50-150 km/s based on the Red-Blue (RB) asymmetry analysis of spectral line profiles. Using the forward models, velocities of the secondary component derived from the RB analysis are found significantly overestimated due to the saturation effect when its offset velocities are smaller than the Gaussian width. We developed a different method to examine spectral features of the PDs. This method is assuming that the excessive emission of the PD profile against the background (taken as that prior to the PD) is caused by a hypothetic upflow. The derived LOS velocities of the flow are on the order of 10-30 km/s from the warm (1-1.5 MK) coronal lines, much smaller than those inferred from the RB analysis. This result does not support the flow interpretation but favors of the early wave interpretation. 2007 February 1,

Propagating Intensity Disturbances in Fan-like Coronal Loops: Flows orWaves?

Tongjiang **Wang** [1,2], Leon Ofman[1,2,3], and Joseph M. Davila[2]

E-print, Feb **2011**; Hinode 4 meeting (2010), submitted (ASP Conference Series)

Quasi-periodic intensity disturbances propagating upward along the coronal structure have been extensively studied using EUV imaging observations from SOHO/EIT and TRACE. They were interpreted as either slow mode magnetoacoustic waves or intermittent upflows. In this study we aim at demonstrating that time series of spectroscopic observations are critical to solve this puzzle. Propagating intensity and Doppler shift disturbances in fanlike coronal loops are analyzed in multiple wavelengths using the sit-and-stare observations from Hinode/EIS. We find that the disturbances did not cause the blue-wing asymmetry of spectral profiles in the warm (~1.5 MK) coronal lines. The estimated small line-of-sight velocities also did not support the intermittent upflow interpretation. In the hot (~2 MK) coronal lines the disturbances did cause the blue-wing asymmetry, but the double fits revealed that a high-velocity minor component is steady and persistent, while the propagating intensity and Doppler shift disturbances are mainly due to variations of the core component, therefore, supporting the slow wave interpretation. However, the cause for blueward line asymmetries remains unclear.

2007 February 1 in AR 10940.

ENDPOINT BRIGHTENINGS IN ERUPTING FILAMENTS

Y.-M. **Wang**1, K. Muglach1,2, and B. Kliem

Astrophysical Journal, 699:133–142, **2009, File**

http://www.iop.org:80/EJ/toc/-alert=43190/0004-637X/699/1
Two well known phenomena associated with erupting filaments are the transient coronal holes that form on each side of the filament channel and the bright post-event arcade with its expanding double row of footpoints. Here we focus on a frequently overlooked signature of filament eruptions: the spike- or fan-shaped brightenings that appear to mark the far endpoints of the filament. From a sample of non-active-region filament events observed with the Extreme-Ultraviolet Imaging Telescope on the *Solar and Heliospheric Observatory*, we find that these brightenings usually occur near the outer edges of the transient holes, in contrast to the post-event arcades, which define their inner edges. The endpoints are often multiple and are rooted in and around strong network flux well outside the filament channel, a result that is consistent with the axial field of the filament being much stronger than the photospheric field inside the channel. The extreme ultraviolet brightenings, which are most intense at the time of maximum outward acceleration of the filament, can be used to determine unambiguously the direction of the axial field component from longitudinal magnetograms. Their location near the outer boundary of the transient holes suggests that we are observing the footprints of the current sheet formed at the leading edge of the erupting filament, as distinct from the vertical current sheet behind the filament which is the source of the post-event arcade.

SUCCESSIVE FLARING DURING THE 2005 SEPTEMBER 13 ERUPTION

Haimin **Wang**, Chang Liu, Ju Jing, and Vasyl Yurchyshyn

The Astrophysical Journal, 671:973Y977, **2007** December 10; File

We report a detailed analysis of successive flaring during the X1.5 event in theNOAAAR 0808 on 2005 September 13.We identify a filament lying at the southeast boundary of the active region as the physical linkage between the two flares in close succession. It is noticeable that the filament erupted_13 minutes after the initial flare onset at_19:22UT near the central magnetic polarity inversion line (PIL). During this time period, the filament only showed a slow rising; meanwhile, a spatially associated large magnetic loop with one leg connecting to the initial flaring site began to brighten in the TRACE 195 8 channel. After _19:35 UT, the filament abruptly erupted together with the bright TRACE loop. Besides the moving ribbons at the first flaring site, the filament eruption caused a secondary flare identified with another set of moving ribbons. This event thus provides a clear evidence for the successive flaring where the initial flare destabilizes the nearby flux loop system, leading to the filament eruption with the second flare. We also identify the initial flare core by finding rapid, irreversible enhancements of the photospheric transverse magnetic fields at a section of the PIL.

ON THE FORMATION OF FILAMENT CHANNELS

Y.-M. **Wang** and K. Muglach1

The Astrophysical Journal, 666:1284 Y1295, **2007**

In all of our examples, filaments form within a day or so after the fibrils become aligned with the PIL, while barbs appear at a later stage, as flux elements continue to diffuse across the PIL and cancel with the majority-polarity flux on the other side.

Transequatorial Filament Eruption and Its Link to a Coronal Mass Ejection

Wang J.-X., et al.

Chin. J. Astron. Astrophys. Vol. 6 (**2006**), No. 2, 247–259 (**file**)

We revisit the Bastille Day flare/CME Event of 2000 July 14, and demonstrate that this flare/CME event is not related to only one single active region (AR). Activation and eruption of a huge transequatorial filament are seen to precede the simultaneous filament eruption and flare in the source active region, NOAA AR9077, and the full halo-CME in the high corona.

The analysis of the Bastille Day event suggests that although the triggering of a global CME might take place in an AR, a much larger scale magnetic composition seems to be the source of the ejected magnetic flux, helicity and plasma.

In this paper, the term *CME parent magnetic structure* is used to describe a large-scale magnetic composition, whose magnetic flux and frozen-in plasma becomes a CME when erupted. The CME parent magnetic structure characterizes the pre-CME magnetic configuration.

Filament Eruption after the Onset of the X1.5 Flare on 2005 September 13

Haimin **Wang**, Chang Liu, Ju Jing and Vasyl Yurchyshyn

BBSO Number: 1332

a rare case that during the X1.5 flare on 2005 September 13, a filament at the boundary of the NOAA AR 0808 erupted ~13 minutes **after the flare** onset at ~19:22UT near the central AR neutral line.

Coronal Pseudostreamers
Y.-M. **Wang** , N. R. Sheeley, Jr. , and N. B. Rich
The Astrophysical Journal, 658:1340-1348, **2007**
https://iopscience.iop.org/article/10.1086/511416/pdf

The dynamic nature of coronal streamers
J.-M.**Wang**, N.R. Sheeley Jr., D.G. Socker, R.A. Howard, and N.B. Rich
JGR, V. 105, No. A11, P. 25,133-25,142**, 2000**
Recent high-sensitivity imaging of the Sun's white-light corona from space has revealed a variety of unexpected small-scale phenomena, including plasma blobs that are ejected continually from the cusplike bases of streamers, fine raylike structures pervading the outer streamer belt, and inflows that occur mainly during times of high solar activity. These phenomena can be interpreted as different manifestations of magnetic field line reconnection, in which plasma and magnetic flux are exchanged between closed and open field regions of the corona. The observations provide new insights into a number of long-standing questions, including the origin of the streamer material in the outer corona, the sources of the slow solar wind, and the mechanisms that regulate the interplanetary magnetic field strength.

STUDY OF RIBBON SEPARATION OF A FLARE ASSOCIATED WITH A QUIESCENT FILAMENT ERUPTION
Haimin**Wang**,1,2,3 Jiong Qiu,3 Ju Jing,2,3 and Hongqi Zhang1
Astrophysical Journal, 593:564–570, **2003; File**
http://www.journals.uchicago.edu/doi/pdf/10.1086/376360
In this paper, we present a detailed study of a two-ribbon flare in the plage region observed by Kanzelhohe Solar Observatory (KSO), which is one of the stations in our global H_ network. We select this event due to its very clear filament eruption, two-ribbon separation, and association with a fast coronal mass ejection (CME). We study the separation between the two ribbons seen in H_ as a function of time and find that the **separation motion consisted of a fast stage of rapid motion at a speed of about 15 km s_1 in the first 20 minutes and a slow stage with a separation speed of about 1 km s_1 lasting for 2 hr.** We then estimate the rate of the magnetic reconnection in the corona, as represented by the electric fields Ec in the reconnecting current sheet, by measuring the ribbon motion speed and the magnetic fields obtained from MDI. We find that there were two stages as well in evolution of the electric fields: Ec j 1 V cm_1 averaged over 20 minutes in the early stage, followed by Ec j 0:1 V cm_1 in the subsequent 2 hr. The two stages of the ribbon motion and electric fields coincide with the impulsive and decaying phases of the flare, respectively, yielding clear evidence that the impulsive flare energy release is governed by the fast magnetic reconnection in the corona. We also measure the projected heights of the erupting filament from KSO H_ and SOHO/EIT images. The filament started to rise 20 minutes before the flare. After the flare onset, it was accelerated quickly at a rate of 300 m s_2, and in 20 minutes, reached a speed of at least 540 km s_1, when it disappeared beyond the limb in the EIT observations. The acceleration rate of theCME is estimated to be 58ms_2 during the decay phase of the flare. The comparison of the height and velocity profiles between the filament and CME suggests that fast acceleration of mass ejections occurred during the impulsive phase of the flare, when the magnetic reconnection rate was also large, with Ec j 1 V cm_1.

Current systems of coronal loops in 3D MHD simulations
J. **Warnecke**1, F. Chen2,1, S. Bingert3 and H. Peter
A&A 607, A53 (**2017**)
Aims. We study the magnetic field and current structure associated with a coronal loop. Through this we investigate to what extent the assumptions of a force-free magnetic field break down and where they might be justified. Methods. We analyze a three-dimensional (3D) magnetohydrodynamic (MHD) model of the solar corona in an emerging active region with the focus on the structure of the forming coronal loops. The lower boundary of this simulation is taken from a model of an emerging active region. As a consequence of the emerging magnetic flux and the horizontal motions at the surface a coronal loop forms self-consistently. We investigate the current density along magnetic field lines inside (and outside) this loop and study the magnetic and plasma properties in and around this loop. The loop is defined as the bundle of field lines that coincides with enhanced emission in extreme UV. Results. We find that the total current along the emerging loop changes its sign from being antiparallel to parallel to the magnetic field. This is caused by the inclination of the loop together with the footpoint motion. Around the loop, the currents form a complex non-force-free helical structure. This is directly related to a bipolar current structure at the loop footpoints at the base of the corona and a local reduction of the background magnetic field (i.e., outside the loop) caused by the plasma flow into and along the loop. Furthermore, the locally reduced magnetic pressure in the

loop allows the loop to sustain a higher density, which is crucial for the emission in extreme UV. The action of the flow on the magnetic field hosting the loop turns out to also be responsible for the observed squashing of the loop. Conclusions. The complex magnetic field and current system surrounding it can only be modeled in 3D MHD models where the magnetic field has to balance the plasma pressure. A one-dimensional coronal loop model or a force-free extrapolation cannot capture the current system and the complex interaction of the plasma and the magnetic field in the coronal loop, despite the fact that the loop is under low-β conditions.

Current systems of coronal loops in 3D MHD simulations

Jörn **Warnecke** (1), Feng Chen (2,1), Sven Bingert (3), Hardi Peter (1)
A&A **2016**
https://arxiv.org/pdf/1611.06170v1.pdf
We study the magnetic field and current structure associated with a coronal loop. Through this we investigate to what extent the assumptions of a force-free magnetic field break down. We analyse a three-dimensional MHD model of the solar corona in an emerging active region with the focus on the structure of the forming coronal loops. The lower boundary of this simulation is taken from a model of an emerging active region. As a consequence of the emerging magnetic flux a coronal loop formes self-consistently. We investigate the current density along magnetic field lines inside (and outside) this loop and study the magnetic and plasma properties in and around this loop. The loop is defined as the bundle of field lines that coincides with enhanced emission in extreme UV. We find that the total current along the emerging loop changes its sign from being antiparallel to parallel to the magnetic field. Around the loop the currents form a complex non-force-free helical structure. This is directly related to a bipolar currents at the loop footpoints at the base of the corona and a local reduction of the background magnetic field (i.e. outside the loop) caused by the plasma flow into and along the loop. Furthermore, the locally reduced magnetic pressure in the loop allows to sustain a higher density, which is crucial for the emission in extreme UV. The acting of the flow on the magnetic field hosting the loop turns out to be also responsible for the observed squashing of the loop. The complex magnetic field and current system surrounding it can be modeled only in three-dimensional MHD models where the magnetic field has to balance the plasma pressure. A one-dimensional coronal loop model or a force-free extrapolation can not capture the current system and the complex interaction of the plasma and the magnetic field in the loop, despite the fact that the loop is under low-β conditions.

Influence of a coronal envelope as a free boundary to global convective dynamo simulations

Jörn **Warnecke** (1,2), Petri J. Käpylä (3,2), Maarit J. Käpylä (2), Axel Brandenburg
A&A **2015**
http://arxiv.org/pdf/1503.05251v1.pdf
We explore the effects of an outer stably stratified coronal envelope on rotating turbulent convection, differential rotation, and large-scale dynamo action in spherical wedge models of the Sun. We solve the compressible magnetohydrodynamic equations in a two-layer model with unstable stratification below the surface, representing the convection zone, and a stably stratified outer layer, the coronal envelope. The interface emulates essentially a free surface. We compare with models that have no coronal envelope. The presence of a coronal envelope is found to modify the Reynolds stress and the Λ-effect resulting in a weaker and non-cylindrical differential rotation. This is related to the reduced latitudinal temperature variations, which are caused by and dependent on the Coriolis force. Some simulations develop a rudimentary near-surface shear layer, which we can relate to a sign change of the meridional Reynolds stress term in the thermal wind balance equation. Furthermore, the presence of a free surface changes the magnetic field evolution since the field is generated closer to the surface. In all simulations, however, the migration direction of the mean magnetic field can be explained by the Parker--Yoshimura rule, which is consistent with earlier findings.

CONSTRAINTS ON THE HEATING OF HIGH-TEMPERATURE ACTIVE REGION LOOPS: OBSERVATIONS FROM HINODE AND THE SOLAR DYNAMICS OBSERVATORY

Harry P. **Warren**1, David H. Brooks2 and Amy R. Winebarger
2011 ApJ 734 90
We present observations of high-temperature emission in the core of a solar active region using instruments on Hinode and the Solar Dynamics Observatory (SDO). These multi-instrument observations allow us to determine the distribution of plasma temperatures and follow the evolution of emission at different temperatures. We find that at the apex of the high-temperature loops the emission measure distribution is strongly peaked near 4 MK and falls off sharply at both higher and lower temperatures. Perhaps most significantly, the emission measure at 0.5 MK is

reduced by more than two orders of magnitude from the peak at 4 MK. We also find that the temporal evolution in broadband soft X-ray images is relatively constant over about 6 hr of observing. Observations in the cooler SDO/Atmospheric Imaging Assembly (AIA) bandpasses generally do not show cooling loops in the core of the active region, consistent with the steady emission observed at high temperatures. These observations suggest that the high-temperature loops observed in the core of an active region are close to equilibrium. We find that it is possible to reproduce the relative intensities of high-temperature emission lines with a simple, high-frequency heating scenario where heating events occur on timescales much less than a characteristic cooling time. In contrast, low-frequency heating scenarios, which are commonly invoked to describe nanoflare models of coronal heating, do not reproduce the relative intensities of high-temperature emission lines and predict low-temperature emission that is approximately an order of magnitude too large. We also present an initial look at images from the SDO/AIA 94 Å channel, which is sensitive to Fe XVIII.

Modeling Evolving Coronal Loops with Observations from Stereo, Hinode, and Trace

Harry P. **Warren**, David M. Kim, Amanda M. DeGiorgi, and Ignacio Ugarte-Urra

ApJ **713** 1095, **2010**

The high densities, long lifetimes, and narrow emission measure distributions observed in coronal loops with apex temperatures near 1 MK are difficult to reconcile with physical models of the solar atmosphere. It has been proposed that the observed loops are actually composed of sub-resolution "threads" that have been heated impulsively and are cooling. We apply this heating scenario to nearly simultaneous observations of an evolving post-flare loop arcade observed with EUVI/*STEREO*, EIS/*Hinode*, XRT/*Hinode*, and *TRACE*. We find that it is possible to reproduce the extended loop lifetime, high electron density, and the narrow differential emission measure with a multi-thread hydrodynamic model provided that the timescale for the energy release is sufficiently short. The model, however, does not reproduce the evolution of the very high temperature emission observed with XRT. In XRT the emission appears diffuse and it may be that this discrepancy is simply due to the difficulty of isolating individual loops at these temperatures. This discrepancy may also reflect fundamental problems with our understanding of post-reconnection dynamics during the conductive cooling phase of loop evolution

Eruptive Prominences and Their Association with Coronal Mass Ejections

David F. **Webb**

Solar Prominences

Astrophysics and Space Science Library Volume 415, **2015**, pp 411-432

http://link.springer.com/chapter/10.1007/978-3-319-10416-4_16

We discuss the origins and characteristics of solar eruptive phenomena focusing on coronal mass ejections (CMEs) and their associated phenomena, particularly erupting prominences (EPs). Statistically, CMEs are most frequently associated with EPs and X-ray long-duration events. In a few large events the masses of the EP and CME have been separately measured, with the EP mass comprising a large fraction of the total CME mass. EP and CME near-surface precursors include the development of sigmoids, the darkening and broadening of filaments, and their slow rise and Doppler shifts, and the cancellation of magnetic flux near filament channels. Prominences exist within coronal cavities which themselves are embedded in helmet streamers extending to high heights. This entire structure can erupt bodily to become a CME; indeed the most massive and energetic CMEs appear to be of this type. CMEs carry into the heliosphere large quantities of coronal magnetic fields and plasma which are detected by remote sensing and measured in-situ at spacecraft. The most important in-situ CME signature is a magnetic cloud, considered to be the flux rope embedded in most if not all CMEs. Although most CMEs are frequently associated with EPs near the Sun, it is still not known why the prominence material is only rarely identified in-situ. In the last decade, however, we have had heliospheric imaging observations that are helping to distinguish prominence material from the rest of a CME.

Internal activities in a solar filament and heating to its threads

Hengyuan **Wei**, Zhenghua Huang, Chuan Li, Zhenyong Hou, Ye Qiu, Hui Fu, Xianyong Bai, Lidong Xia

ApJ **958** 116 **2023**

https://arxiv.org/pdf/2308.15747.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/acf569/pdf

Filaments are one of the most common features in the solar atmosphere, and are of significance in solar, stellar and laboratory plasma physics. Using data from the Chinese Hα Solar Explorer, the Solar Upper Transition Region Imager and the Solar Dynamics Observatory, we report on multiwavelength imaging and spectral observations of the activation of a small filament. The filament activation produces several localized dynamic brightenings, which are probably produced by internal reconnections of the braided magnetic fields in the filament. The filament expands during the activation and its threads reconnect with the ambient magnetic fields, which leads to the formation of hot arcades or loops overlying the filament. The thermal energy of each of these localized brightenings is estimated in the order of 1025−1027erg and the total energy is estimated to be ∼1.77×1028erg. Our observations demonstrate that the internal magnetic reconnections in the filament can lead to localized heating to the filament threads and prompt external reconnections with ambient corona structures, and thus could contribute to the energy and mass transferring into the corona. **2022 November 1**

Acoustic response in the transition region to transverse oscillations in a solar coronal loop

S. J. **White** and E. Verwichte

A&A 670, A1 (**2023**)

https://www.aanda.org/articles/aa/pdf/2023/02/aa44873-22.pdf

Context. Magnetohydrodynamic (MHD) waves play an important role in the dynamics and heating of the solar corona. Transverse (Alfvénic) oscillations of loops commonly occur in response to solar eruptions and are mostly studied in isolation. However, acoustic coupling has been shown to be readily observable in the form of propagating intensity variations at the loop footpoints.

Aims. We extend the modelling of wave coupling between a transverse loop oscillation and slow magnetoacoustic waves in a structured loop to include a lower atmosphere.

Methods. We achieve this with combined analytical modelling and fully non-linear MHD simulations.

Results. Transverse loop oscillations result in the excitation of propagating slow waves from the top of the transition region and the lower boundary. The rate of excitation for the upward propagating waves at the lower boundary is smaller than for waves at the top of the transition region due to the reduced local sound speed. Additionally, slow waves are found to propagate downwards from the transition region, which reflect at the lower boundary and interfere with the upward propagating waves. Resonances are present in the normal mode analysis but these do not appear in the simulations. Due to the presence of the transition region, additional longitudinal harmonics lead to a narrower slow wave profile. The slow wave field is anti-symmetric in the direction of wave polarisation, which highlights the importance that the loop orientation has on the observability of these waves. The ponderomotive effect must be accounted for when interpreting intensity oscillations. Evidence is found for an additional short-period oscillation, which is likely a hybrid mode.

Acoustic response to transverse oscillations in a solar coronal loop

S. J. **White** and E. Verwichte

A&A 654, A33 (**2021**)

https://www.aanda.org/articles/aa/pdf/2021/10/aa41515-21.pdf

https://doi.org/10.1051/0004-6361/202141515

Context. Magnetohydrodynamic (MHD) waves play an important role in the dynamics and heating of the solar corona. Their investigation also reveals information about the local conditions. Transverse (Alfvénic) oscillations of loops commonly occur in response to solar eruptions. It has been shown that these oscillations elicit an acoustic response through wave coupling at the footpoint and the pondermotive force.

Aims. We extend the modelling of wave coupling between a transverse loop oscillation and slow magnetoacoustic waves through line-tied footpoint boundary conditions by considering the effect of transverse loop structuring and non-linearity.

Methods. We combine analytical wave modelling with fully non-linear MHD simulations to study the wave field of propagating slow waves in a two-dimensional slab loop (arcade) model.

Results. We demonstrate that transverse loop oscillations generate propagating slow waves from the footpoints with the same periodicity but shorter wavelength determined by the local sound speed. The degree of wave coupling is proportional to the square root of the plasma-β. The slow wave field is anti-symmetric in the direction of transverse wave polarisation. We show through synthetic diagnostics that this has important consequences for their observability in terms of the orientation of the loop with respect to the observer. We also show that for the interpretation of intensity oscillations associated with typical loop oscillations the ponderomotive response also needs to be taken into account. The modelling presented here allows for the successful identification of the slow waves and pondermotive response in a previous observational study.

First observation of a transverse vertical oscillation during the formation of a hot post-flare loop

R. S. **White**, E. Verwichte and C. Foullon

A&A 545, A129 (**2012**)

Aims. We report and analyse the first observation of a transverse oscillation in a hot coronal loop with the Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory (SDO), following a linked coronal-flare mass-ejection event on the **3 November 2010**. The oscillating coronal loop is observed off the east solar limb and exclusively in the 131 Å and 94 Å bandpasses, indicating a loop plasma of temperature in the range of 9–11 MK.

Furthermore, the loop is not observed to cool into the other AIA channels, but just disappears from all bandpasses at the end of the oscillation.
Methods. A time series analysis of the loop oscillation is conducted by taking several cuts at different positions along the loop, estimating the transverse displacements over time for two strands in the loop and fitting those with a damped cosine curve. Intensity time variations, both along the loop and for a series of cut cross-sections, are investigated. Using a three-dimensional loop geometry obtained from a comparison of STEREO-B/EUVI and AIA images, we model different modes of transverse oscillations in the uniformly filled loop.
Results. Our time series analysis reveals a period of 302 ± 14 s (291 ± 9 s) and a damping time of 306 ± 43 s (487 ± 125 s) for the first (second) loop strand. A spatial phase shift along the loop of approximately 180° suggests that we observe a higher order harmonic. Intensity oscillations are consistent with an interpretation in terms of a vertically polarised mode. Our forward modelling suggests that the loop oscillates as either a second or third order harmonic of this mode.
Conclusions. This is the first observation of a transverse loop oscillation observed exclusively in the hot coronal lines. The loop oscillation is vertically polarised and is dominated by a higher order harmonic mode. We conclude that the excitation mechanism of this 5 min period oscillation is directly connected with the reconnection processes that form the post flare loop, which differs from the blast wave excitation mechanism often proposed as the cause of cooler transverse loop oscillations.

Transverse coronal loop oscillations seen in unprecedented detail by AIA/SDO

R. S. **White** and E. Verwichte

A&A 537, A49 (**2012**)

Aims. Detailed analysis of 11 transverse coronal loop oscillations in three events observed with the Atmospheric Imaging Assembly (AIA) instrument on board the Solar Dynamics Observatory (SDO) spacecraft. Detailed analysis includes analysis of the displacement time series, intensity variations and comparing EUVI and AIA data to estimate the 3D loop geometry.
Methods. Time distance images extracted from cuts made perpendicular to the oscillations are obtained. A Gaussian plus background fitting technique is used to extract the time series which is then fitted with a damped cosine curve. Intensity variations are extracted along the time series points. EUVI/STEREO data is compared to AIA/SDO data to obtain three-dimensional models of the loop geometry.
Results. Time series analysis revealed periods between 1.7 and 10 min and damping times between 2.9 and 13 min. Intensity variations are reliably observed for six of the loops and a comparison between EUVI/STEREO and AIA/SDO data is performed to simulate the polarisation of the kink mode. We conclude that the intensity variations are due to variations in the line of sight column depth of a horizontally polarised transverse loop oscillation. Coronal seismology of the kink mode was applied to determine the range of the internal Alfvén speed and the magnetic field strength for each loop.

Transverse coronal loop oscillations seen by AIA/SDO

Rebecca **White** and Erwin Verwichte

UKSP Nugget **-** 17. **2011**, http://www.uksolphys.org/?p=3398

Probing the coronal plasma with the diagnostic power of kink waves.
The corona is a low plasma-β plasma that is highly structured into coronal loops. These are thin, density enhanced magnetic flux tubes which can be violently perturbed by dynamic events such as CMEs and solar flares. This nugget focuses on transverse coronal loop oscillations (TLOs) which are interpreted, in terms of magneto-hydrodynamic theory, as the fast kink mode [3,4]. Kink modes are characterised by an almost constant transverse displacement of the loop axis from its equilibrium position. **13-Jun-2010**,

Velocity difference of ions and neutrals in solar prominences

Eberhard **Wiehr**, Goetz Stellmacher, Horst Balthasar, Michele Bianda

2021 *ApJ* **920** 47

https://arxiv.org/pdf/2108.13103.pdf

https://doi.org/10.3847/1538-4357/ac1791

Marked velocity excesses of ions relative to neutrals are obtained from two time series of the neighboring emission lines He I 5015 and Fe II 5018 in a quiescent prominence. Their Doppler shifts show time variations of quasi-periodic character where the ions are faster than the neutrals 1.0 < V_macro(Fe II)/V_macro(He I) < 1.35 in series-A and, respectively, <1.25 in series-B. This 'ratio excess' confirms our earlier findings of a 1.22 ion velocity excess, but the present study shows a restriction in space and time of typically 5 Mm and 5 min.

The ratio excess is superposed by a time and velocity independent 'difference excess' -0.3 < V_macro(Fe II)-V_macro(He I) < +0.7 km/s in series-A (also indicated in series-B). The high repetition rate of 3.9 sec enables the detection of high frequency oscillations with several damped 22 sec periods in series-A. These show a ratio excess with a maximum of 1.7. We confirm the absence of a significant phase delay of He neutrals with respect to the Fe ions. **June 28, 2019**

Evidence for the Two-fluid Scenario in Solar Prominences

E. **Wiehr**1, G. Stellmacher2, and M. Bianda3

2019 ApJ 873 125

https://arxiv.org/pdf/1904.01536.pdf

sci-hub.se/10.3847/1538-4357/ab04a4

This paper presents observational evidence of the different dynamical behavior of neutral and ionized species in solar prominences. The analysis of a time-series of Sr ii 4078 Å and Na D spectra in a quiescent prominence yields systematically larger Doppler shifts (line-of-sight velocities) for the ions V LOS(Sr ii) = 1.22 × V LOS(Na D). Both lines show a 30 minute oscillation of good coherence. Sixteen hours later the same prominence underwent marked morphological changes (with a rising dome), and the Sr ii velocity excess dropped to V LOS(Sr ii) = 1.11 ×V LOS(Na D). The same excess is found for the line pair Fe ii 5018 Å and He i 5015 Å. The widths of the ionic lines, mainly non-thermally broadened, are not related to the macro-velocities. The emission ratio of Na D and Sr ii, a measure of the electron density, yields n e = 4 × 1010 cm−3, shows no relation with the V LOS variation or with height above the limb, and seems to be reduced 16 hr later during the active phase. We apply a new wavelength reference from aureola spectra, which is independent of photospheric velocity fields. **2017 June 24-26**

The cross-sectional shape and height expansion of coronal loops: High-resolution Coronal Imager (Hi-C) analysis of AR 12712

Thomas **Williams**, Robert W. Walsh, Huw Morgan

2021 *ApJ* **919** 47

https://arxiv.org/pdf/2106.14579.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/ac0f76/pdf

https://doi.org/10.3847/1538-4357/ac0f76

Coronal loop observations have existed for many decades yet the precise shape of these fundamental coronal structures is still widely debated since the discovery that they appear to undergo negligible expansion between their footpoints and apex. In this work a selection of eight EUV loops and their twenty-two sub-element strands are studied from the second successful flight of NASA's High resolution Coronal Imager (Hi-C 2.1). Four of the loops correspond to open fan structures with the other four considered to be magnetically closed loops. Width analysis is performed on the loops and their sub-resolution strands using our method of fitting multiple Gaussian profiles to cross-sectional intensity slices. It is found that whilst the magnetically closed loops and their sub-element strands do not expand along their observable length, open fan structures may expand an additional 150% of their initial width. Following recent work, the Pearson correlation coefficient between peak intensity and loop/strand width are found to be predominantly positively correlated for the loops (~88%) and their sub-element strands (~80%). These results align with the hypothesis of Klimchuk & DeForest that loops and - for the first time - their sub-element strands have approximately circular cross-sectional profiles.

Multi-Stranded Coronal Loops: Quantifying Strand Number and Heating Frequency from Simulated Solar Dynamics Observatory (SDO) Atmospheric Imaging Assembly (AIA) Observations

Thomas **Williams**, Robert W. Walsh, Stephane Regnier, Craig D. Johnston

Solar Phys. **2021**

https://arxiv.org/pdf/2105.12499.pdf

Coronal loops form the basic building blocks of the magnetically closed solar corona yet much is still to be determined concerning their possible fine-scale structuring and the rate of heat deposition within them. Using an improved multi-stranded loop model to better approximate the numerically challenging transition region, this paper examines synthetic NASA Solar Dynamics Observatory's (SDO) Atmospheric Imaging Assembly (AIA) emission simulated in response to a series of prescribed spatially and temporally random, impulsive and localised heating events across numerous sub-loop elements with a strong weighting towards the base of the structure; the nanoflare heating scenario. The total number of strands and nanoflare repetition times are varied systematically in such a way that the total energy content remains approximately constant across all the cases analysed. Repeated time lag detection during an emission time series provides a good approximation for the nanoflare repetition time for low-frequency heating. Furthermore, using a combination of AIA 171/193 and 193/211 channel ratios in combination with spectroscopic determination of the standard deviation of the loop apex temperature over several hours alongside simulations from the outlined multi-stranded loop model, it is demonstrated that both the imposed heating rate and number of strands can be realised.

MASS ESTIMATES OF RAPIDLY MOVING PROMINENCE MATERIAL FROM HIGH-CADENCE EUV IMAGES

David R. **Williams**, Deborah Baker, and Lidia van Driel-Gesztelyi

2013 ApJ 764 165

We present a new method for determining the column density of erupting filament material using state-of-the-art multi-wavelength imaging data. Much of the prior work on filament/prominence structure can be divided between studies that use a polychromatic approach with targeted campaign observations and those that use synoptic observations, frequently in only one or two wavelengths. The superior time resolution, sensitivity, and near-synchronicity of data from the Solar Dynamics Observatory's Advanced Imaging Assembly allow us to combine these two techniques using photoionization continuum opacity to determine the spatial distribution of hydrogen in filament material. We apply the combined techniques to SDO/AIA observations of a filament that erupted during the spectacular coronal mass ejection on **2011 June 7**. The resulting "polychromatic opacity imaging" method offers a powerful way to track partially ionized gas as it erupts through the solar atmosphere on a regular basis, without the need for coordinated observations, thereby readily offering regular, realistic mass-distribution estimates for models of these erupting structures.

Weighing a filament by its photoionisation shadow

Dave **Williams**, Deb Baker and Lidia van Driel-Gesztelyi

UKSP nugget: 27. Sept **2012**

http://www.uksolphys.org/?p=5342

Filaments, or prominences — depending on your geometric perspective — are strange structures. They're denser than the surrounding corona by an order of magnitude. They have much lower temperatures than the surrounding corona, too. One of the trickiest things to get right is how the mass is distributed in a filament, and the mass is important for a number of reasons. The role of cold material in absorbing and redistributing radiation needs to be understood to model this environment. Additionally, we want to know how much mass is weighing down this sheared/twisted magnetic structure so that we can understand its dynamics. When a magnetic instability occurs, the erupting magnetic field will take the filament and millions of tonnes of particles with it, like a typhoon through the solar wind. **7th June 2011**

Evidence from EIS for axial filament rotation before a large flare

Williams, D. R., Harra, L. K., Brooks, D. H., Imada, S., Hansteen, V. H.

E-print, Feb. 2009; PASJ (Vol. 61, No. 3, June **2009**

http://www.mssl.ucl.ac.uk/~drw/papers/antisymvel/v4_erupfil.pdf

In this article, we present observations made with the Extreme-ultraviolet Imaging Spectrometer (EIS) on-board the Hinode solar satellite, of an active region filament in the He II emission line at 256.32 ?. The host active region (AR 10930) produces an X-class flare during these observations. We measure Doppler shifts with apparent velocities of up to 20 km/s, which are antisymmetric about the filament length and occur several minutes before the flare?s impulsive phase. This is indicative of a rotation of the filament, which is in turn consistent with expansion of a twisted flux rope due to the MHD helical kink instability. This is the first time that such an observation has been possible in this transition-region line, and we note that the signature observed occurs before the first indications of pre-flare activity in the GOES solar soft X-ray flux, suggesting that the filament begins to destabilise in tandem with a reorganistation of the local magnetic field. We suggest that this expansion is triggered by the decrease of magnetic tension around, and/or total pressure above, the filament. **13 Dec 2006**

Resonant Damping of Propagating Kink Waves in Time-Dependent Magnetic Flux Tube

A. **Williamson**, R. Erdélyi

Solar Physics, July **2014**

We explore the notion of resonant absorption in a dynamic time-dependent magnetised plasma background. Very many works have investigated resonance in the Alfvén and slow MHD continua under both ideal and dissipative MHD regimes. Jump conditions in static and steady systems have been found in previous works, connecting solutions at both sides of the resonant layer. Here, we derive the jump conditions in a temporally dependent, magnetised, inhomogeneous plasma background to leading order in the Wentzel–Kramers–Billouin (WKB) approximation. Next, we exploit the results found in Williamson and Erdélyi (Solar Phys. 289, 899, 2014) to describe the evolution of the jump condition in the dynamic model considered. The jump across the resonant point is shown to increase exponentially in time. We determined the damping as a result of the resonance over the same time period and investigated the temporal evolution of the damping itself. We found that the damping coefficient, as a result of the evolution of the resonance, decreases as the density gradient across the transitional layer decreases. This has the consequence that in such time-dependent systems resonant absorption may not be as efficient as time progresses.

Linear MHD Wave Propagation in Time-Dependent Flux Tube

A. **Williamson**, R. Erdélyi

Solar Physics, April **2014**, Volume 289, Issue 4, pp 1193-1202

The propagation of magnetohydrodynamic (MHD) waves is an area that has been thoroughly studied for idealised static and steady state magnetised plasma systems applied to numerous solar structures. By applying the generalisation of a temporally varying background density to an open magnetic flux tube, mimicking the observed slow evolution of such waveguides in the solar atmosphere, further investigations into the propagation of both fast and slow MHD waves can take place. The assumption of a zero-beta plasma (no gas pressure) was applied in Williamson and Erdélyi (Solar Phys. 2013, doi: 10.1007/s11207-013-0366-9 , Paper I) is now relaxed for further analysis here. Firstly, the introduction of a finite thermal pressure to the magnetic flux tube equilibrium modifies the existence of fast MHD waves which are directly comparable to their counterparts found in Paper I. Further, as a direct consequence of the non-zero kinetic plasma pressure, a slow MHD wave now exists, and is investigated. Analysis of the slow wave shows that, similar to the fast MHD wave, wave amplitude amplification takes place in time and height. The evolution of the wave amplitude is determined here analytically. We conclude that for a temporally slowly decreasing background density both propagating magnetosonic wave modes are amplified for over-dense magnetic flux tubes. This information can be very practical and useful for future solar magneto-seismology applications in the study of the amplitude and frequency properties of MHD waveguides, e.g. for diagnostic purposes, present in the solar atmosphere.

Linear MHD Wave Propagation in Time-Dependent Flux Tube

A. **Williamson**, R. Erdélyi

Solar Physics, March **2014**, Volume 289, Issue 3, pp 899-909

MHD waves and oscillations in sharply structured magnetic plasmas have been studied for static and steady systems in the thin tube approximation over many years. This work will generalize these studies by introducing a slowly varying background density in time, in order to determine the changes to the wave parameters introduced by this temporally varying equilibrium, i.e. to investigate the amplitude, frequency, and wavenumber for the kink and higher order propagating fast magnetohydrodynamic wave in the leading order approximation to the WKB approach in a zero-β plasma representing the upper solar atmosphere. To progress, the thin tube and over-dense loop approximations are used, restricting the results found here to the duration of a number of multiples of the characteristic density change timescale. Using such approximations it is shown that the amplitude of the kink wave is enhanced in a manner proportional to the square of the Alfvén speed, Va^2 . The frequency of the wave solution tends to the driving frequency of the system as time progresses; however, the wavenumber approaches zero after a large multiple of the characteristic density change timescale, indicating an ever increasing wavelength. For the higher order fluting modes the changes in amplitude are dependent upon the wave mode; for the m=2 mode the wave is amplified to a constant level; however, for all m≥3 the fast MHD wave is damped within a relatively small multiple of the characteristic density change timescale. Understanding MHD wave behavior in time-dependent plasmas is an important step towards a more complete model of the solar atmosphere and has a key role to play in solar magneto-seismological applications.

Identifying Observables That Can Differentiate Between Impulsive and Footpoint Heating: Time Lags and Intensity Ratios

Amy R. **Winebarger**1, Roberto Lionello2, Cooper Downs2, Zoran Mikić2, and Jon Linker2

2018 ApJ 865 111 DOi [10.3847/1538-4357/aad9fb](10.3847/1538-4357/aad9fb)

Observations of solar coronal loops have identified several common loop characteristics, including that loops appear to cool and have higher than expected densities. Two potential heating scenarios have been suggested to explain these observations. One scenario is that the loops are formed by many strands, each heated independently by a series of small-scale impulsive heating events, or nanoflares. Another hypothesis is that the heating is quasi-steady and highly stratified, i.e., "footpoint heating"; such heating can drive thermal nonequilibrium in some structures depending on the scale height and magnitude of the energy deposition, and the geometry of the structure. Studies of both types of heating have found that they can qualitatively reproduce the observed loop properties. The goal of this paper is to identify observables that can be used to differentiate between these two heating scenarios. To do this, we use a single loop geometry. For footpoint heating, we vary the heating magnitude and stratification, for impulsive heating, we vary the heating magnitude. We use one-dimensional hydrodynamic codes to calculate the resulting temperature and density evolution. We convolve the temperature and density with the response functions of four EUV channels of the Atmospheric Imaging Assembly and one filter channel of Hinode's X-ray Telescope. We consider two principal diagnostics: the time lag between the appearance of the loop in two different channels, and the ratio of the peak intensities of the loop in the two channels. Based on this limited data set, we find (1) that footpoint heating can predict longer time lags than impulsive heating in some channel pairs, (2) that footpoint heating can predict zero or negative time lags in some channel pairs, (3) that the intensity ratio expected from impulsive heating is confined to a narrow range, while footpoint heating predicts a wider range of intensity ratios, and (4) that the range of temperatures expected in impulsive heating is broader than the range of temperatures expected in footpoint heating. This preliminary study identifies observables that may be useful in discriminating between heating models in future work.

Verification of Coronal Loop Diagnostics Using Realistic Three-dimensional Hydrodynamic Models

Amy R. **Winebarger**1, Roberto Lionello2, Yung Mok3, Jon A. Linker2, and Zoran Miki

2014 ApJ 795 138

Many different techniques have been used to characterize the plasma in the solar corona: density-sensitive spectral line ratios are used to infer the density, the evolution of coronal structures in different passbands is used to infer the temperature evolution, and the simultaneous intensities measured in multiple passbands are used to determine the emission measure distributions. All these analysis techniques assume that the intensity of the structures can be isolated through background subtraction. In this paper, we use simulated observations from a three-dimensional hydrodynamic simulation of a coronal active region to verify these diagnostics. The density and temperature from the simulation are used to generate images in several passbands and spectral lines. We identify loop structures in the simulated images and calculate the background. We then determine the density, temperature, and emission measure distribution as a function of time from the observations and compare these with the true temperature and density of the loop. We find that the overall characteristics of the temperature, density, and emission measure are recovered by the analysis methods, but the details are not. For instance, the emission measure curves calculated from the simulated observations are much broader than the true emission measure distribution, though the average temperature evolution is similar. These differences are due, in part, to a limitation of the analysis methods, but also to inadequate background subtraction.

Formation and plasma circulation of solar prominences

Chun **Xia**, Rony Keppens

ApJ **2016**

http://arxiv.org/pdf/1603.05397v1.pdf

Solar prominences are long-lived cool and dense plasma curtains in the hot and rarefied outer solar atmosphere or corona. The physical mechanism responsible for their formation and especially for their internal plasma circulation has been uncertain for decades. The observed ubiquitous down flows in quiescent prominences are difficult to interpret as plasma with high conductivity seems to move across horizontal magnetic field lines. Here we present three-dimensional numerical simulations of prominence formation and evolution in an elongated magnetic flux rope as a result of in-situ plasma condensations fueled by continuous plasma evaporation from the solar chromosphere. The prominence is born and maintained in a fragmented, highly dynamic state with continuous reappearance of multiple blobs and thread structures that move mainly downward dragging along mass-loaded field lines. The prominence plasma circulation is characterized by the dynamic balance between the drainage of prominence plasma back to the chromosphere and the formation of prominence plasma via continuous condensation. Plasma evaporates from the chromosphere, condenses into the prominence in the corona, and drains back to the chromosphere, establishing a stable chromosphere-corona plasma cycle. Synthetic images of the modeled prominence with the Solar Dynamics Observatory Atmospheric Imaging Assembly closely resemble actual observations, with many dynamical threads underlying an elliptical coronal cavity. **August 10, 2011**

INTERNAL DYNAMICS OF A TWIN-LAYER SOLAR PROMINENCE

C. **Xia**1 and R. Keppens1

2016 ApJ 825 L29

Modern observations revealed rich dynamics within solar prominences. The globally stable quiescent prominences, characterized by the presence of thin vertical threads and falling knobs, are frequently invaded by small rising dark plumes. These dynamic phenomena are related to magnetic Rayleigh–Taylor instability, since prominence matter, 100 times denser than surrounding coronal plasma, is lifted against gravity by weak magnetic field. To get a deeper understanding of the physics behind these phenomena, we use three-dimensional magnetohydrodynamic simulations to investigate the nonlinear magnetoconvective motions in a twin-layer prominence in a macroscopic model from chromospheric layers up to 30 Mm height. The properties of simulated falling "fingers" and uprising bubbles are consistent with those in observed vertical threads and rising plumes in quiescent prominences. Both sheets of the twin-layer prominence show a strongly coherent evolution due to their magnetic connectivity, and demonstrate collective kink deformation. Our model suggests that the vertical threads of the prominence as seen in an edge-on view, and the apparent horizontal threads of the filament when seen top-down are different appearances of the same structures. Synthetic images of the modeled twin-layer prominence reflect the strong degree of mixing established over the entire prominence structure, in agreement with the observations.

Simulating the in situ condensation process of solar prominences

Chun **Xia**, Rony Keppens, Patrick Antolin, Oliver Porth

ApJ 792 L38 **2014**

http://arxiv.org/pdf/1408.4249v1.pdf

Prominences in the solar corona are hundredfold cooler and denser than their surroundings, with a total mass of 1.e13 up to 1.e15 g. Here we report on the first comprehensive simulations of three-dimensional, thermally and gravitationally stratified magnetic flux ropes, where in situ condensation to a prominence happens due to radiative losses. After a gradual thermodynamic adjustment, we witness a phase where runaway cooling happens while counter-streaming shearing flows drain off mass along helical field lines. After this drainage, a prominence-like condensation resides in concave upward field regions, and this prominence retains its overall characteristics for more than two hours. While condensing, the prominence establishes a prominence-corona transition region, where magnetic field-aligned thermal conduction is operative during the runaway cooling. The prominence structure represents a force-balanced state in a helical flux rope. The simulated condensation demonstrates a right-bearing barb, as a remnant of the drainage. Synthetic images at extreme ultraviolet wavelengths follow the onset of the condensation, and confirm the appearance of horns and a three-part structure for the stable prominence state, as often seen in erupting prominences. This naturally explains recent Solar Dynamics Observatory views with the Atmospheric Imaging Assembly on prominences in coronal cavities demonstrating horns.

3D Prominence-hosting Magnetic Configurations: Creating a Helical Magnetic Flux Rope

Chun **Xia**, Rony Keppens, Yang Guo

E-print, Nov **2013**; ApJ

The magnetic configuration hosting prominences and their surrounding coro- nal structure is a key research topic in solar physics. Recent theoretical and observational studies strongly suggest that a helical magnetic flux rope is an es- sential ingredient to fulfill most of the theoretical and observational requirements for hosting prominences. To understand flux rope formation details and obtain magnetic configurations suitable for future prominence formation studies, we here report on three-dimensional isothermal magnetohydrodynamic simulations including finite gas pressure and gravity. Starting from a magnetohydrostatic corona with a linear force-free bipolar magnetic field, we follow its evolution when introducing vortex flows around the main polarities and converging flows towards the polarity inversion line near the bottom of the corona. The con- verging flows bring feet of different loops together at the polarity inversion line and magnetic reconnection and flux cancellation happens. Inflow and outflow signatures of the magnetic reconnection process are identified, and the thereby newly formed helical loops wind around pre-existing ones so that a complete flux rope grows and ascends. When a macroscopic flux rope is formed, we switch off the driving flows and find that the system relaxes to a stable state containing a helical magnetic flux rope embedded in an overlying arcade structure. A major part of the formed flux rope is threaded by dipped field lines which can stably support prominence matter, while the total mass of the flux rope is in the order of 4-5.e14 g.

SIMULATIONS OF PROMINENCE FORMATION IN THE MAGNETIZED SOLAR CORONA BY CHROMOSPHERIC HEATING

C. **Xia**1, P. F. Chen1 and R. Keppens

2012 ApJ 748 L26

Starting from a realistically sheared magnetic arcade connecting the chromospheric, transition region to coronal plasma, we simulate the in situ formation and sustained growth of a quiescent prominence in the solar corona. Contrary to previous works, our model captures all phases of the prominence formation, including the loss of thermal equilibrium, its successive growth in height and width to macroscopic dimensions, and the gradual bending of the arched loops into dipped loops, as a result of the mass accumulation. Our 2.5 dimensional, fully thermodynamically and magnetohydrodynamically consistent model mimics the magnetic topology of normal-polarity prominences above a photospheric neutral line, and results in a curtain-like prominence above the neutral line through which the ultimately dipped magnetic field lines protrude at a finite angle. The formation results from concentrated heating in the chromosphere, followed by plasma evaporation and later rapid condensation in the corona due to thermal instability, as verified by linear instability criteria. Concentrated heating in the lower atmosphere evaporates plasma from below to accumulate at the top of coronal loops and supply mass to the later prominence constantly. This is the first evaporation-condensation model study where we can demonstrate how the formed prominence stays in a force balanced state, which can be compared to the Kippenhahn-Schlüter type magnetohydrostatic model, all in a finite low-beta corona.

FORMATION OF SOLAR FILAMENTS BY STEADY AND NONSTEADY CHROMOSPHERIC HEATING

C. **Xia**1, P. F. Chen1, R. Keppens2,3 and A. J. van Marle

2011 ApJ 737 27

It has been established that cold plasma condensations can form in a magnetic loop subject to localized heating of its footpoints. In this paper, we use grid-adaptive numerical simulations of the radiative hydrodynamic equations to investigate the filament formation process in a pre-shaped loop with both steady and finite-time chromospheric heating. Compared to previous works, we consider low-lying loops with shallow dips and use a more realistic description for radiative losses. We demonstrate for the first time that the onset of thermal instability satisfies the linear instability criterion. The onset time of the condensation is roughly ~2 hr or more after the localized heating at the footpoint is effective, and the growth rate of the thread length varies from 800 km hr–1 to 4000 km hr–1, depending on the amplitude and the decay length scale characterizing this localized chromospheric heating. We show how single or multiple condensation segments may form in the coronal portion. In the asymmetric heating case, when two segments form, they approach and coalesce, and the coalesced condensation later drains down into the chromosphere. With steady heating, this process repeats with a periodicity of several hours. While our parametric survey confirms and augments earlier findings, we also point out that steady heating is not necessary to sustain the condensation. Once the condensation is formed, it keeps growing even after the localized heating ceases. In such a finite-heating case, the condensation instability is maintained by chromospheric plasma that gets continuously siphoned into the filament thread due to the reduced gas pressure in the corona. Finally, we show that the condensation can survive the continuous buffeting of perturbations from photospheric p-mode waves.

Plasma parameters and geometry of cool and warm active region loops

Haixia **Xie**, Maria S. Madjarska, Bo Li, Zhenghua Huang, Lidong Xia, Thomas Wiegelmann, Hui Fu, Chaozhou Mou

ApJ 842 38 **2017**

https://arxiv.org/pdf/1705.02564.pdf

How the solar corona is heated to high temperatures remains an unsolved mystery in solar physics. In the present study we analyse observations of 50 whole active-region loops taken with the Extreme-ultraviolet Imaging Spectrometer (EIS) on board the Hinode satellite. Eleven loops were classified as cool (<1 MK) and 39 as warm (1-2 MK) loops. We study their plasma parameters such as densities, temperatures, filling factors, non-thermal velocities and Doppler velocities. We combine spectroscopic analysis with linear force-free magnetic-field extrapolation to derive the three-dimensional structure and positioning of the loops, their lengths and heights as well as the magnetic field strength along the loops. We use density-sensitive line pairs from Fe XII, Fe XIII, Si X and Mg VII ions to obtain electron densities by taking special care of intensity background-subtraction. The emission-measure loci method is used to obtain the loop temperatures. We find that the loops are nearly isothermal along the line-of-sight. Their filling factors are between 8% and 89%. We also compare the observed parameters with the theoretical RTV scaling law. We find that most of the loops are in an overpressure state relative to the RTV predictions. In a followup study, we will report a heating model of a parallel-cascade-based mechanism and will compare the model parameters with the loop plasma and structural parameters derived here.

Two Types of Long-duration Quasi-static Evolution of Solar Filaments

Chen **Xing**, Haochuan Li, Bei Jiang, Xin Cheng, M. D. Ding

ApJL 857:L14 (6pp), **2018**

https://arxiv.org/pdf/1804.01232.pdf

http://iopscience.iop.org/article/10.3847/2041-8213/aabbb1/pdf

In this Letter, we investigate the long-duration quasi-static evolution of 12 pre-eruptive filaments (4 active region and 8 quiescent filaments), mainly focusing on the evolution of the filament height in three dimension (3D) and the decay index of the background magnetic field. The filament height in 3D is derived through two-perspective observations of \textit{Solar Dynamics Observatory} and \textit{Solar TErrestrial RElations Observatory}. The coronal magnetic field is reconstructed using the potential field source surface model. A new finding is that the filaments we studied show two types of long-duration evolution: one type is comprised of a long-duration static phase and a short slow rise phase with a duration of less than 12 hours and a speed of 0.1--0.7 km s−1, while the other one only presents a slow rise phase but with an extremely long duration of more than 60 hours and a smaller speed of 0.01--0.2 km s−1. At the moment approaching the eruption, the decay index of the background magnetic field at the filament height is similar for both active region and quiescent filaments. The average value and upper limit are ∼0.9 and ∼1.4, close to the critical index of torus instability. Moreover, the filament height and background

magnetic field strength are also found to be linearly and exponentially related with the filament length, respectively.
14 Aug 2010, 3 Sept 2010, 19 Dec 2010, 7 Jun 2011
TABLE 1 Parameters of filaments at the near-eruption stage (2010-2011)

Three-dimensional Reconstruction of Filament Axes and Their Writhe Numbers

Yu **Xu**, Jiahao Zhu, and Yang Guo
2020 ApJ 892 54
https://doi.org/10.3847/1538-4357/ab791b
To reveal the correlation between the morphology of filaments and their writhe, we reconstruct the three-dimensional (3D) paths of the filament axes based on the data set of Atmospheric Imaging Assembly and Extreme Ultraviolet Imager on board the Solar Dynamics Observatory and the Solar Terrestrial Relations Observatory, respectively. Then, we calculate the writhe of the reconstructed filament axes with the polar writhe theory. All the cases obey that a projected forward (reverse) S-shaped filament possesses positive (negative) writhe. We conduct a further analysis by constructing theoretical 3D curves with non-centrosymmetric shape and only one maximum in height. It is demonstrated that (1) writhe depends on the relative height (the ratio of the height of the curve and the distance between its two footprints), the position of the highest point, and the position of the crossing point (the intersection of a projected axis curve and the line connecting two footprints); (2) for a filament with absolute value of the crossing angle less than $\pi/3$ and relative height less than 0.2, forward (reverse) S-shaped projection results in positive (negative) writhe; and (3) when the highest point and the crossing point are significantly separated, the sign of writhe can be conserved without changing the S shape orientation (forward or reverse) during the eruption.

MAGNETIC FIELDS OF AN ACTIVE REGION FILAMENT FROM FULL STOKES ANALYSIS OF Si I 1082.7 nm AND He I 1083.0 nm

Z. **Xu**1, A. Lagg2, S. Solanki2,3 and Y. Liu
2012 ApJ 749 138
Vector magnetic fields of an active region filament in the photosphere and upper chromosphere are obtained from spectro-polarimetric observations recorded with the Tenerife Infrared Polarimeter (TIP II) at the German Vacuum Tower Telescope. We apply Milne-Eddington inversions on full Stokes vectors of the photospheric Si I 1082.7 nm and the upper chromospheric He I triplet at 1083.0 nm to obtain the magnetic field vector and velocity maps in two atmosphere layers. We find that (1) a complete filament was already present in Hα at the beginning of the TIP II data acquisition. Only a partially formed one, composed of multiple small threads, was present in He I. (2) The AR filament comprises two sections. One shows strong magnetic field intensities, about 600-800 G in the upper chromosphere and 800-1000 G in the photosphere. The other exhibits only comparatively weak magnetic field strengths in both layers. (3) The Stokes V signal is indicative of a dip in the magnetic field strength close to the chromospheric PIL. (4) In the chromosphere, consistent upflows are found along the PIL flanked by downflows. (5) The transversal magnetic field is nearly parallel to the PIL in the photosphere and inclined by 20°-30° in the chromosphere. (6) The chromospheric magnetic field around the filament is found to be in normal configuration, while the photospheric field presents a concave magnetic topology. The observations are consistent with the emergence of a flux rope with a subsequent formation of a filament**.**

Measurements of Filament Height in Hα and EUV 304 Å

Yan **Xu** · Ju Jing · Haimin Wang
Solar Phys (**2010**) 264: 81–91, **File**
In this study, we present the three-dimensional (3D) configuration of a filament observed by STEREO and the Global High Resolution H-alpha Network (GHN) in EUV 304 Å and Hα line center, respectively. This was the largest filament located close to the active region NOAA 10956 that produced a small B9.6 flare and two CoronalMass Ejections (CMEs) on **19 May 2007**. The 3D coordinates of multiple points traced along this filament were reconstructed by triangulation from two different aspect angles. The two STEREO (A and B) spacecraft had a separation angle α of 8.6 degree on 19 May 2007. The "true" heights of the filament were estimated using STEREO images in EUV 304 and Hα images, respectively. Our results show that EUV emission of the filament originates from higher locations than the Hα emission. We also compare the measured reconstructed heights of the filaments in EUV with those reported in previous studies.

High-Resolution Observations of Prominence Plume Formation with the New Vacuum Solar Telescope

Jian-Chao **Xue**, Jean-Claude Vial, Yang Su, Hui Li, Zhi Xu, Ying-Na Su, Tuan-Hui Zhou, Zhen-Tong Li
Research in Astron. Astrophys. **2021**
https://arxiv.org/pdf/2105.01293.pdf

Prominence plumes are evacuated upflows that emerge from bubbles below prominences, whose formation mechanism is still unclear. Here we present a detailed study of plumes in a quiescent prominence using the high-resolution H-alpha filtergrams at the line center as well as line wing at +/-0.4 angstrom from the New Vacuum Solar Telescope. Enhancements of brightening, blue shifts, and turbulence at the fronts of plumes are found during their formation. Some large plumes split at their heads and finger-shaped structures are formed between them. Blue-shifted flows along the bubble-prominence interface are found before and during the plume formation. Our observations are consistent with the hypothesis that prominence plumes are related to coupled Kelvin-Helmholtz and Rayleigh-Taylor (KH/RT) instabilities. Plume splittings and fingers are evidence of RT instability, and the flows may increase the growth rate of KH/RT instabilities. However, the significant turbulence at plume fronts may suggest that the RT instability is triggered by the plumes penetrating into the prominence. In this scenario, extra mechanisms are necessary to drive the plumes. **2018 November 6**

A solar filament disconnected by magnetic reconnection⋆

Zhike **Xue**1,2,3, Xiaoli Yan1,2, Liheng Yang1,2, Jincheng Wang1,2, Qiaoling Li1,2,4 and Li Zhao1,2
A&A 633, A121 (**2020**)
https://doi.org/10.1051/0004-6361/201936969

Aims. We aim to study a high-resolution observation of an asymmetric inflow magnetic reconnection between a filament and its surrounding magnetic loops in active region NOAA 12436 on **2015 October 23**.
Methods. We analyzed the multiband observations of the magnetic reconnection obtained by the New Vacuum Solar Telescope (NVST) and the Solar Dynamic Observatory. We calculated the NVST Hα Dopplergrams to determine the Doppler properties of the magnetic reconnection region and the rotation of a jet.
Results. The filament firstly becomes active and then approaches its southwestern surrounding magnetic loops (L1) with a velocity of 9.0 km s^{-1}. During this period, the threads of the filament become loose in the reconnection region and then reconnect with L1 in turn. L1 is pressed backward by the filament with a velocity of 5.5 km s^{-1}, and then the magnetic reconnection occurs between them. A set of newly formed loops are separated from the reconnection site with a mean velocity of 127.3 km s^{-1}. In the middle stage, some threads of the filament return back first with a velocity of 20.1 km s^{-1}, and others return with a velocity of 4.1 km s^{-1} after about 07:46 UT. Then, L1 also begins to return with a velocity of 3.5 km s^{-1} at about 07:47 UT. At the same time, magnetic reconnection continues to occur between them until 07:51 UT. During the reconnection, a linear typical current sheet forms with a length of 5.5 Mm and a width of 1.0 Mm, and a lot of hot plasma blobs are observed propagating from the typical current sheet. During the reconnection, the plasma in the reconnection region and the typical current sheet always shows redshifted feature. Furthermore, the material and twist of the filament are injected into the newly longer-formed magnetic loops by the magnetic reconnection, which leads to the formation of a jet, and its rotation.
Conclusions. The observational evidence for the asymmetric inflow magnetic reconnection is investigated. We conclude that the magnetic reconnection does occur in this event and results in the disconnection of the filament. The looseness of the filament may be due to the pressure imbalance between the inside and outside of the filament. The redshifted feature in the reconnection site can be explained by the expansion of the right flank of the filament to the lower atmosphere because of the complex magnetic configuration in this active region.

Splitting and Reconstruction of a Solar Filament Caused by Magnetic Emergence and Reconnection

Zhike **Xue**1,2, Xiaoli Yan1,2, Jincheng Wang1,2, Liheng Yang1,2, Zhe Xu1,2, Yang Peng1,3, and Qiaoling Li4
2023 ApJ 945 5
https://iopscience.iop.org/article/10.3847/1538-4357/acb8ad/pdf

We present observations and interpretation of a nonerupting filament in NOAA active region (AR) 12827 that undergoes splitting and restructuring on 2021 June 4, using the high-resolution data obtained by the New Vacuum Solar Telescope, the Solar Dynamics Observatory, and the Interface Region Imaging Spectrograph. At the beginning, the right footpoint of the filament is rooted in the AR positive polarity, and its right leg has a spread-out structure, which is confirmed by the extrapolated 3D magnetic structure. Many small positive and negative magnetic polarities connected by EUV-emitting loops gradually appear between two extensions of the right footpoint polarity as the extensions separate. The right leg of the filament is then observed to split into two parts, which continue to separate, while the left part of the filament still maintains a whole structure. As the newly emerged magnetic loops rise between the two parts of the right leg, magnetic reconnection occurs between the newly emerged magnetic loops and the magnetic fields supporting the southeastern splitting part. The longer magnetic loops resulting from this reconnection merge with the magnetic fields of the other part of the split filament leg, thus reforming an entire filament with a displaced right footpoint. We conclude that magnetic emergence is responsible for the splitting of the filament leg, while magnetic reconnection leads to the reconstruction of the filament.

The hidden magnetic structures of a solar intermediate filament revealed by the injected flare material

X.L. **Yan**, Z.K. Xue, J.C. Wang, L.H. Yang, K.F. Ji, D.F. Kong, Z. Xu, Q.L. Li, L.P. Yang, X.S. Zhang
ApJ **2024**
https://arxiv.org/pdf/2412.02055
Solar filaments are spectacular objects in the solar atmosphere, consisting of accumulations of cool, dense, and partially ionized plasma suspended in the hot solar corona against gravity. The magnetic structures that support the filament material remain elusive, partly due to the lack of high resolution magnetic field measurements in the chromosphere and corona. In this study, we reconstruct the magnetic structures of a solar intermediate filament using EUV observations and two different methods, to follow the injection of hot material from a B-class solar flare. Our analysis reveals the fine-scale magnetic structures of the filament, including a compact set of mutually wrapped magnetic fields encasing the cool filament material, two groups of helical magnetic structures intertwining with the main filament, and a series of arched magnetic loops positioned along the filament. Additionally, we also find that the northern footpoints of the helical structures are rooted in the same location, while their southern footpoints are rooted in different areas. The results obtained in this study offer new insights into the formation and eruption mechanisms of solar filaments. **2018 April 3**

Mass and energy supply of a cool coronal loop near its apex★

Limei **Yan**1, Hardi Peter2, Jiansen He1, Lidong Xia4 and Linghua Wang1
A&A 611, A49 (**2018**)
http://sci-hub.tw/https://www.aanda.org/articles/aa/abs/2018/03/aa28436-16/aa28436-16.html
Context. Different models for the heating of solar corona assume or predict different locations of the energy input: concentrated at the footpoints, at the apex, or uniformly distributed. The brightening of a loop could be due to the increase in electron densityne, the temperature T, or a mixture of both.
Aim. We investigate possible reasons for the brightening of a cool loop at transition region temperatures through imaging and spectral observation.
Methods. We observed a loop with the Interface Region Imaging Spectrograph (IRIS) and used the slit-jaw images together with spectra taken at a fixed slit position to study the evolution of plasma properties in and below the loop. We used spectra of Si iv,which forms at around 80 000 K in equilibrium, to identify plasma motions and derive electron densities from the ratio of inter-combination lines of O IV. Additional observations from the Solar Dynamics Observatory (SDO) were employed to study the response at coronal temperatures (Atmospheric Imaging Assembly, AIA) and to investigate the surface magnetic field below the loop (Helioseismic and Magnetic Imager, HMI).
Results. The loop first appears at transition region temperatures and later also at coronal temperatures, indicating a heating of the plasma in the loop. The appearance of hot plasma in the loop coincides with a possible accelerating upflow seen in Si IV, with the Doppler velocity shifting continuously from ∼−70 km s−1 to ∼−265 km s−1. The 3D magnetic field lines extrapolated from the HMI magnetogram indicate possible magnetic reconnection between small-scale magnetic flux tubes below or near the loop apex. At the same time, an additional intensity enhancement near the loop apex is visible in the IRIS slit-jaw images at 1400 Å. These observations suggest that the loop is probably heated by the interaction between the loop and the upflows, which are accelerated by the magnetic reconnection between small-scale magnetic flux tubes at lower altitudes. Before and after the possible heating phase, the intensity changes in the optically thin (Si IV) and optical thick line (C II) are mainly contributed by the density variation without significant heating.
Conclusions. We therefore provide evidence for the heating of an envelope loop that is affected by accelerating upflows, which are probably launched by magnetic reconnection between small-scale magnetic flux tubes underneath the envelope loop. This study emphasizes that in the complex upper atmosphere of the Sun, the dynamics of the 3D coupled magnetic field and flow field plays a key role in thermalizing 1D structures such as coronal loops. **December 06, 2013**

The Formation and Magnetic Structures of Active-region Filaments Observed by NVST, SDO, and Hinode

X.L. **Yan**, Z.K. Xue, G.M. Pan, J.C. Wang, Y.Y. Xiang, D.F. Kong, and L.H. Yang
Astrophysical Journal Supplement Series (*ApJS*) **219** 17 **2015**
To better understand the properties of solar active-region filaments, we present a detailed study on the formation and magnetic structures of two active-region filaments in active region NOAA 11884 during a period of four days. It is found that the shearing motion of the opposite magnetic polarities and the rotation of the small sunspots with negative polarity play an important role in the formation of two active-region filaments. During the formation of these two active-region filaments, one foot of the filaments was rooted in a small sunspot with negative polarity. The

small sunspot rotated not only around another small sunspot with negative polarity, but also around the center of its umbra. By analyzing the nonlinear force-free field extrapolation using the vector magnetic fields in the photosphere, twisted structures were found in the two active-region filaments prior to their eruptions. These results imply that the magnetic fields were dragged by the shearing motion between opposite magnetic polarities and became more horizontal. The sunspot rotation twisted the horizontal magnetic fields and finally formed the twisted active-region filaments. **1-4 Nov 2013**

Fine-scale structures and material flows of quiescent filaments observed by New Vacuum Solar Telescope

X.L. **Yan**, Z.K. Xue, Y.Y. Xiang, L.H. Yang

Research in Astronomy and Astrophysics **2015**

http://arxiv.org/pdf/1502.03546v1.pdf

Study on the small-scale structures and material flows of solar quiescent filaments is very important for understanding the formation and equilibrium of solar filaments. Using the high resolution H{\alpha} data observed by the New Vacuum Solar Telescope (NVST), we present the structures of the barbs and the material flows along the threads across the spine in two quiescent filaments on **2013 September 29 and on 2012 November 2**, respectively. During the evolution of the filament barb, several parallel tube-shaped structures formed and the width of the structures ranges from about 2.3 Mm to 3.3 Mm. The parallel tube-shaped structures merged together accompanied with the material flows from the spine to the barb. Moreover, the boundary between the barb and surrounding atmosphere is very neat. The counter-streaming flows were not found to appear alternately in the adjacent threads of the filament. However, the large-scale patchy counter-streaming flows are detected in the filament. The flows in one patch of the filament have the same direction and the flows in the adjacent patch have opposite directions. The patches of two opposite flows with a size of about ten arcseconds exhibited alternately along the spine of the filament. The velocity of these material flows ranges from 5.6 km/s to 15.0 km/s. The material flows along the threads of the filament did not change their direction for about two hours and fourteen minutes during the evolution of the filament. Our results confirm that the large-scale counter-streaming flows with the certain width along the threads of solar filaments exist and are well coaligned with the threads.

Unwinding motion of a twisted active-region filament

X.L. **Yan**, Z.K. Xue, J.H. Liu, D.F. Kong, C.L. Xu

ApJ, 797, Issue 1, article id. 52, **2014**

http://arxiv.org/pdf/1410.1984v1.pdf

https://iopscience.iop.org/article/10.1088/0004-637X/797/1/52/pdf

To better understand the structures of active-region filaments and the eruption process, we study an active-region filament eruption in active region NOAA 11082 in detail on **June 22, 2010**. Before the filament eruption, the opposite unidirectional material flows appeared in succession along the spine of the filament. The rising of the filament triggered two B-class flares at the upper part of the filament. As the bright material was injected into the filament from the sites of the flares, the filament exhibited a rapid uplift accompanying the counterclockwise rotation of the filament body. From the expansion of the filament, we can see that the filament is consisted of twisted magnetic field lines. The total twist of the filament is at least 5π obtained by using time slice method. According to the morphology change during the filament eruption, it is found that the active-region filament was a twisted flux rope and its unwinding motion was like a solar tornado. We also find that there was a continuous magnetic helicity injection before and during the filament eruption. It is confirmed that magnetic helicity can be transferred from the photosphere to the filament. Using the extrapolated potential fields, the average decay index of the background magnetic fields over the filament is 0.91. Consequently, these findings imply that the mechanism of solar filament eruption could be due to the kink instability and magnetic helicity accumulation.

Kink Instability Evidenced by Analyzing the Leg Rotation of a Filament

X. L. **Yan**1,2, Z. K. Xue1, J. H. Liu3, L. Ma1, D. F. Kong1, Z. Q. Qu1, and Z. Li

2014 ApJ 782 67

Kink instability is a possible mechanism for solar filament eruption. However, it is very difficult to directly measure the twist of the solar filament from observation. In this paper, we measured the twist of a solar filament by analyzing its leg rotation. An inverse S-shaped filament in the active region NOAA 11485 was observed by the Atmospheric Imaging Assembly of the Solar Dynamics Observatory on **2012 May 22**. During its eruption, the leg of the filament exhibited a significant rotation motion. The 304 Å images were used to uncurl the circles, the centers of which are the axis of the filament's leg. The result shows that the leg of the filament rotated up to about 510° (about 2.83π) around the axis of the filament within 23 minutes. The maximal rotation speed reached 100 degrees/minute (about 379.9 km s–1 at radius 18"), which is the fastest rotation speed reported. We also calculated the decay index along the polarity inversion line in this active region and found that the decline of the overlying field with height is not fast enough to trigger the torus instability. According to the kink instability condition, this indicates that the kink instability is the trigger mechanism for the solar filament eruption.

SUNSPOT ROTATION, SIGMOIDAL FILAMENT, FLARE, AND CORONAL MASS EJECTION: THE EVENT ON 2000 FEBRUARY 10

X. L. **Yan**1,2, Z. Q. Qu1, D. F. Kong1,2, and C. L. Xu

2012 ApJ 754 16

We find that a sunspot with positive polarity had an obvious counterclockwise rotation and resulted in the formation and eruption of an inverse S-shaped filament in NOAA Active Region 08858 from **2000 February 9 to 10**. The sunspot had two umbrae which rotated around each other by 195° within about 24 hr. The average rotation rate was nearly 8° hr–1. The fastest rotation in the photosphere took place during 14:00 UT to 22:01 UT on February 9, with a rotation rate of nearly 16° hr–1. The fastest rotation in the chromosphere and the corona took place during 15:28 UT to 19:00 UT on February 9, with a rotation rate of nearly 20° hr–1. Interestingly, the rapid increase of the positive magnetic flux occurred only during the fastest rotation of the rotating sunspot, the bright loop-shaped structure, and the filament. During the sunspot rotation, the inverse S-shaped filament gradually formed in the EUV filament channel. The filament experienced two eruptions. In the first eruption, the filament rose quickly and then the filament loops carrying the cool and the hot material were seen to spiral counterclockwise into the sunspot. About 10 minutes later, the filament became active and finally erupted. The filament eruption was accompanied with a C-class flare and a halo coronal mass ejection. These results provide evidence that sunspot rotation plays an important role in the formation and eruption of the sigmoidal active-region filament.

Observations of the Formation and Disappearance of a Funnel Prominence

Bo **Yang**, Jiayan Yang, Yi Bi, Junchao Hong

ApJLet **2024**

https://arxiv.org/pdf/2406.18136

We present an observational study of the formation and disappearance of a funnel prominence. Before the funnel prominence formed, cool materials from the top of a preexisting polar crown prominence flowed along saddle-shaped coronal loops to their base, forming a smaller prominence. Meanwhile, the saddle-shaped coronal loops gradually rose, and U-shaped coronal loops, termed prominence horns, began to appear along with a coronal cavity. Afterwards, a cool column emerged from the chromosphere, rose vertically into the corona, and then moved laterally to be transported into the U-shaped coronal loops. The formed prominence slid into the chromosphere, while the U-shaped coronal loops and the coronal cavity became more pronounced. As cool materials accumulated at the base of the U-shaped coronal loops, these loops underwent a significant descent and a V-shaped structure appeared at the base of the cool materials, indicating that the U-shaped coronal loops may be dragged down to sag. Subsequently, cool materials from the V-shaped structure continued to flow almost vertically toward the chromosphere, forming the funnel prominence. The vertical downflows might be produced by magnetic reconnection within or between the sagging field lines. Due to persistent vertical downflows, the U-shaped coronal loops were lifted up and prominence materials followed along inclined coronal loops towards the chromosphere, causing the funnel prominence to disappear. Our observations suggest that chromospheric plasma transported into a coronal cavity and then drained out via vertical downflows can form a funnel prominence.

The Formation of a U-shaped Filament Due to the Successive Magnetic Reconnection between a Filament and Its Nearby Chromospheric Fibrils

Liping **Yang**1,2, Xiaoli Yan1,3, Zhike Xue1,3, Jincheng Wang1,3, Liheng Yang1,3, Zhe Xu1,3, Qiaoling Li4,5, Yian Zhou1,3, Yang Peng1,2, and Xinsheng Zhang1,2

2023 ApJ 952 43

https://iopscience.iop.org/article/10.3847/1538-4357/acd16e/pdf

Although magnetic reconnection plays a key role in the formation of a solar filament, the detailed formation process is still ambiguous. Combining the observational data from the New Vacuum Solar Telescope and the Solar Dynamics Observatory, we analyzed the formation of a U-shaped filament via successive magnetic reconnection in the AR NOAA 11598 on **2012 October 25**. The successive reconnection occurred between a filament (F) and its nearby chromospheric fibrils (CF). The associated brightening and magnetic cancellation were observed. The changes in appearance of the CF at the reconnection site were accompanied by the formation and accumulation of some new magnetic loops, as well as plasmas propagated along the formed magnetic loops from the reconnection site, indicating the changes in the topology of the F and CF. These can provide comprehensive observational evidence for successive reconnection. After the reconnection, a longer U-shaped filament was formed. During the formation of the U-shaped filament, two major magnetic energy releases took place. While in the two energy release processes, the injected plasma from the reconnection site can provide part of the material for the formation of the U-shaped filament. Therefore, we conclude that the successive reconnection results in both the dynamical evolution and the subsequent formation associated with the U-shaped filament. And the results of nonlinear force-free field extrapolation demonstrated that the magnetic topology of the F was changed significantly; this is consistent with the observational results and further confirms the formation of the U-shaped filament.

Transfer of Twists from a Mini-filament to Large-scale Loops by Magnetic Reconnection

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2019 ApJ 887 239
https://doi.org/10.3847/1538-4357/ab55d7

With high spatial and temporal resolution, Hα data from the New Vacuum Solar Telescope, X-ray images from the X-ray telescope on board Hinode and simultaneous observations from the Solar Dynamics Observatory, we present multiwavelength observations of the interaction between a mini-filament (MF) and its overlying large-scale active-region loops (ARLs) that occurred in AR 12497 on **2016 February 13**. The MF was activated by the convergence and cancellation of the magnetic flux under it. Brightenings first appeared at the junction of the MF and its overlying large-scale ARLs. A blowout jet with some plasma blobs was observed to move along the newly formed large-scale ARLs, and caused the oscillations of these loops. The blowout jet exhibited a counterclockwise rotation due to the untwisting motion of the MF, suggesting that the twist is transferred from the MF to the ARLs. The transferred twist was measured to be about 0.34–0.52 turn. During the interaction progress, a group of hot loops formed in the high-temperature wavelength (94 Å). These hot loops connected the west footpoints of the original ARLs and the east footpoints of the MF. The differential emission measure analysis demonstrated that these hot loops contained a high-temperature component (~8 MK). Meanwhile the footpoints of the ARLs were finally shifted to the west footpoint of the MF. These observations suggest that magnetic reconnection takes place between the MF and its overlying large-scale ARLs and results in a confined untwisting blowout jet.

High-resolution Spectroscopic Imaging of Counter-streaming Motions in Solar Active Region Magnetic Loops

Xu **Yang**[1], Wenda Cao[1,2], Haisheng Ji[3,4], Parida Hashim[5,6], and Jinhua Shen[5]

High-resolution Spectroscopic Imaging of Counter-streaming Motions in Solar Active Region Magnetic Loops

Xu **Yang**1, Wenda Cao1,2, Haisheng Ji3,4, Parida Hashim5,6, and Jinhua Shen5
2019 ApJL 881 L25
sci-hub.se/10.3847/2041-8213/ab365b

We carried out high-resolution spectroscopic imaging in He i 10830 Å and H α for a set of active region (NOAA 12569) magnetic loops of different sizes (classified into short and long loops) with the Goode Solar Telescope at the Big Bear Solar Observatory on **2016 July 18**. The long loops take the form of an chromospheric arch filament system, yet their extreme ultraviolet (EUV) counterparts are observed by the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory. Animations of blue- and red-wing images give counter-streaming motions; i.e., chromospheric absorption features in blue- and red-wing images move in opposite directions at different strands. The moving pattern is detected with the local correlation tracking method and confirmed by Doppler shifts. We speculate that, combined with the results of wavelet analysis that gives obvious 4 minute oscillation along trailing polarity, counter-streaming motions for short loops could be powered by p-mode leakage. However, for counter-streaming motions in long loops, we show that unidirectional mass flows in two opposite directions are accompanied with simultaneous weak EUV brightenings. Heating processes, probably by magnetic reconnection at footpoints, may have occurred. In addition, plasma flows along the magnetic loops, tracked with absorption features in He i 10830 Å, are found to be ejected from and drained out into inter-granule lane areas at different ends of the loop system.

Solar Tornadoes Observed with the Interface Region Imaging Spectrograph: Rotating Motion of Prominence Materials

Zihao **Yang**, Hui Tian, Hardi Peter, Yang Su, Tanmoy Samanta, Jingwen Zhang, Yajie Chen
ApJ 852, Issue 2, article id. 79, **2017**
https://arxiv.org/pdf/1711.08968.pdf
https://ui.adsabs.harvard.edu/link_gateway/2018ApJ...852...79Y/PUB_PDF

The barbs or legs of some prominences show an apparent motion of rotation, which are often termed solar tornadoes. It is under debate whether the apparent motion is a real rotating motion, or caused by oscillations or counter-streaming flows. We present analysis results from spectroscopic observations of two tornadoes by the Interface Region Imaging Spectrograph. Each tornado was observed for more than 2.5 hours. Doppler velocities are derived through a single Gaussian fit to the Mg~{\sc{ii}}~k~2796\AA{}~and Si~{\sc{iv}}~1393\AA{}~line profiles. We find coherent and stable red and blue shifts adjacent to each other across the tornado axes, favoring the interpretation of these tornadoes as rotating cool plasmas with temperatures of 10^4 K-10^5 K. This interpretation is further supported by simultaneous observations of the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory, which reveal periodic motions of dark structures in the tornadoes. Our results demonstrate that spectroscopic observations can provide key information to disentangle different physical processes in solar prominences. **2014 April 9, 2017 March 12.**

Interaction of Two Active Region Filaments Observed by NVST and SDO

Liheng **Yang**, Xiaoli Yan, Ting Li, Zhike Xue, Yongyuan Xiang

ApJ 838 131 **2017**

https://arxiv.org/pdf/1703.01712.pdf

Using high spatial and temporal resolution Hα data from the New Vacuum Solar Telescope (NVST) and simultaneous observations from the Solar Dynamics Observatory (SDO), we present a rare event on the interaction between two filaments (F1 and F2) in AR 11967 on **2014 January 31**. The adjacent two filaments were almost perpendicular to each other. Their interaction was driven by the movement of F1 and started when the two filaments collided with each other. During the interaction, the threads of F1 continuously slipped from the northeast to the southwest, accompanied by the brightenings at the junction of two filaments and the northeast footpoint of F2. Part of F1 and the main body of F2 became invisible in Hα wavelength due to the heating and the motion of F2. At the same time, bright material initiated from the junction of two filaments were observed to move along F1. The magnetic connectivities of F1 were found to be changed after their interaction. These observations suggest that magnetic reconnection was involved in the interaction of two filaments and resulted in the eruption of one filament.

OBSERVATIONS OF THE GROWTH OF AN ACTIVE REGION FILAMENT

Bo **Yang**1,2, Yunchun Jiang1, Jiayan Yang1, Yi Bi1,2, and Haidong Li

2016 ApJ 830 16

We present observations of the growth of an active region filament caused by magnetic interactions among the filament and its adjacent superpenumbral filament (SF) and dark thread-like structures (T). Multistep reconnections are identified during the whole growing process. Magnetic flux convergence and cancellation occurring at the positive footpoint region of the filament is the first step reconnection, which resulted in the filament bifurcating into two sets of intertwined threads. One set anchored in situ, while the other set moved toward and interacted with the SF and part of T. This indicates the second step reconnection, which gave rise to the disappearance of the SF and the formation of a long thread-like structure that connects the far ends of the filament and T. The long thread-like structure further interacted with the T and then separated into two parts, representing the third step reconnection. Finally, another similar long thread-like structure, which intertwined with the fixed filament threads, appeared. H α observations show that this twisted structure is a longer sinistral filament. Based on the observed photospheric vector magnetograms, we performed a non-linear force-free field extrapolation to reconstruct the magnetic fields above the photosphere and found that the coronal magnetic field lines associated with the filament consists of two twisted flux ropes winding around each other. These results suggest that magnetic interactions among filaments and their adjacent SFs and T could lead to the growth of the filaments, and the filament is probably supported in a flux rope.

Oscillation of Newly Formed Loops After Magnetic Reconnection in the Solar Chromosphere

Shuhong **Yang**, Yongyuan Xiang

ApJL **819** L24 **2016**

http://arxiv.org/pdf/1602.06370v1.pdf

With the high spatial and temporal resolution Hα images from the New Vacuum Solar Telescope, we focus on two groups of loops with a X-shaped configuration in the dynamic chromosphere. We find that the anti-directed loops approach each other and reconnect continually. The connectivity of the loops is changed and new loops are formed and stack together. The stacked loops are sharply bent, implying that they are greatly impacted by the magnetic tension force. When another more reconnection process takes place, one new loop is formed and stacks with the previously formed ones. Meanwhile, the stacked loops retract suddenly and move toward the balance position, performing an overshoot movement, which led to an oscillation with an average period of about 45 s. The oscillation of newly formed loops after magnetic reconnection in the chromosphere is observed for the first time. We suggest that the stability of the stacked loops is destroyed due to the join of the last new loop and then suddenly retract under the effect of magnetic tension. Because of the retraction, another lower loop is pushed outward and performs an oscillation with the period of about 25 s. The different oscillation periods may be due to their difference in three parameters, i.e., loop length, plasma density, and magnetic field strength. **2013 September 14**

THE RAPID FORMATION OF A FILAMENT CAUSED BY MAGNETIC RECONNECTION BETWEEN TWO SETS OF DARK THREADLIKE STRUCTURES

Bo **Yang**1,2, Yunchun Jiang1, Jiayan Yang1, Shunping Yu1,2, and Zhe Xu

2016 ApJ 816 41

Taking advantage of the high spatiotemporal resolution observations from the Atmospheric Imaging Assembly (AIA) and the Helioseismic and Magnetic Imager on board the Solar Dynamics Observatory, we present rare observations of the rapid formation of a filament caused by magnetic reconnection between two sets of dark threadlike structures. The two sets of dark threadlike structures belong to distinct flux systems with their adjacent ends anchored in an opposite-polarity magnetic field region, where the calculated photospheric velocity field shows that converging flows dominate there. Due to the converging flows, opposite-polarity magnetic flux converged and then canceled, leading to the formation of extreme ultraviolet (EUV) brightening that spread in opposite directions along the spine of the dark threadlike structures. Meanwhile, very weak remote brightening in the other terminals of the dark threadlike structures, as well as EUV loops, which rooted in the opposite-polarity magnetic field region, appeared. In addition, all of the AIA Fe line observations reveal that a flux rope was formed and underwent a rolling motion during the fadeaway of the EUV brightening. Soon after, as the EUV brightening disappeared, a filament that is very likely composed of two sets of intertwined dark threadlike structures was formed. Via differential emission measure (EM) analysis, it is found that both the EM and temperature of the plasma around the flux-canceling site increased during the brightening, implying that there, magnetic reconnection may occur to heat the plasma. These observations provide evidence that the filament is formed by magnetic reconnection associated with flux convergence and cancellation, and the magnetic structure of the filament is most likely a flux rope.

New Vacuum Solar Telescope observations of a flux rope tracked by a filament activation

Shuhong **Yang**, Jun Zhang, Zhong Liu, Yongyuan Xiang
E-print, March **2014**; ApJL, **2014**
http://arxiv.org/pdf/1403.0714v1.pdf

One main goal of the New Vacuum Solar Telescope (NVST) which is located at the \emph{Fuxian Solar Observatory} is to image the Sun at high resolution. Based on the high spatial and temporal resolution NVST Hα data and combined with the simultaneous observations from the \emph{Solar Dynamics Observatory} for the first time, we investigate a flux rope tracked by a filament activation. The filament material is initially located at one end of the flux rope and fills in a section of the rope, and then the filament is activated due to magnetic field cancellation. The activated filament rises and flows along helical threads, tracking out the twisted flux rope structure. The length of the flux rope is about 75 Mm, the average width of its individual threads is 1.11 Mm, and the estimated twist is 1π. The flux rope appears as a dark structure in H α images, a partial dark and partial bright structure in 304 {\AA}, while as bright structures in 171 {\AA} and 131 {\AA} images. During this process, the overlying coronal loops are quite steady since the filament is confined within the flux rope and does not erupt successfully. It seems that, for the event in this study, the filament is located and confined within the flux rope threads, instead of being suspended in the dips of twisted magnetic flux.
2013 February 1

The Asymmetrical Eruption of a Quiescent Filament and Associated Halo CME

J. **Yang**, Y. Jiang, B. Yang, R. Zheng, D. Yang, J. Hong, H. Li and Y. Bi
Solar Physics, Volume 279, Number 1 (**2012**), 115-126, **File**

We will present detailed observations of the asymmetrical eruption of a large quiescent filament on **24 November 2002**, which was followed by a two-ribbon flare, three coronal dimmings, endpoint brightenings, and a very fast halo-type coronal mass ejection (CME). Before the eruption, the filament lay along the main neutral line (MNL) underneath a single-arcade helmet streamer with a simple bipolar configuration. However, photospheric magnetic fields on both sides of the filament showed an asymmetrical distribution, and the filament and MNL were not located just at the center of the streamer base but were closer to the eastern leg of the streamer arcade. Therefore, instead of erupting along the streamer's symmetrical axis, the filament showed a nonradial and asymmetrical eruption. It lifted from the eastern flank of the streamer arcade to impact the western leg directly, leading to an asymmetrical CME that expanded westward; eventually the streamer was disrupted significantly. Accordingly, the opposite-polarity coronal dimmings at both sides of the filament forming in the eruption also showed an asymmetrical area distribution. We thus assume that the streamer arcade could guide the filament at the early eruption phase but failed to restrain it later. Consistent with previous results, these observations suggest that the global background magnetic field can impose additional action on the initial eruption of the filament and CME, as well as the dimming configuration.

AN OVER-AND-OUT HALO CORONAL MASS EJECTION DRIVEN BY THE FULL ERUPTION OF A KINKED FILAMENT

Jiayan **Yang**1,2, Yunchun Jiang1, Yi Bi1, Haidong Li1, Junchao Hong1,3, Dan Yang1,3, Ruisheng Zheng1,3 and Bo Yang
2012 ApJ 749 12, **File**

Over-and-out coronal mass ejections (CMEs) represent a broad class of CMEs that come from flare-producing magnetic explosions of various sizes but are laterally far offset from the flare, and their productions can be depicted by the magnetic-arch-blowout scenario. In this paper, we present observations of an over-and-out halo CME from the full eruption of a small kinking filament in an emerging active region (AR). In combination with the results of a derived coronal magnetic configuration, our observations showed that the CME was associated with a coronal helmet streamer, and the filament was located in the northern outskirts of the streamer base. Formed along a neutral line where flux cancellation was forced by the emerging AR with the surrounding opposite-polarity magnetic field, the filament underwent a full, non-radial eruption along the northern leg of the streamer arcade, accompanied by a clockwise deflection of the eruption direction. As a characteristic property of kink instability, the eruption displayed a clear inverse γ shape, indicative of a writhing motion of the filament apex. Coronal dimmings, including a remote one, formed in opposite-polarity footprint regions of the streamer arcade during the eruption, and the consequent CME was laterally offset from the AR. These observations suggest that the kink instability is likely to be the driver in the eruption. The event can be well explained by putting this driver into the magnetic-arch-blowout model, in which the eruption-direction deflection and the full-eruption nature of the kinking filament are caused by the guiding action of the streamer arcade and the external reconnection between them.

SYMPATHETIC FILAMENT ERUPTIONS FROM A BIPOLAR HELMET STREAMER IN THE SUN

Jiayan **Yang**1,2, Yunchun Jiang1, Ruisheng Zheng1, Yi Bi1, Junchao Hong1 and Bo Yang

2012 ApJ 745 9

On **2005 August 5**, two solar filaments erupted successively from different confined arcades underlying a common overarching multiple-arcade bipolar helmet streamer. We present detailed observations of these two events and identify them as sympathetic filament eruptions. The first (F1) is a small active-region filament located near the outskirts of the streamer arcade. It underwent a nonradial eruption, initially moving in the interior of the streamer arcade and resulting in an over-and-out coronal mass ejection. The second filament (F2), a larger quiescent one far away from F1, was clearly disturbed during the F1 eruption. It then underwent a very slow eruption and finally disappeared completely and permanently. Because two belt-shaped diffuse dimmings formed along the footprints of the streamer arcade in the first eruption and persisted throughout the complete disappearance of F2, the eruption series are interpreted as sympathetic: the simple expansion of the common streamer arcade forced by the F1 eruption weakened magnetic flux overlying F2 and thus led to its slow eruption, with the dimming formation indicating their physical connection. Our observations suggest that multiple-arcade bipolar helmet-streamer configurations are appropriate to producing sympathetic eruptions. Combined with the recent observations of unipolar-streamer sympathetic events, it appears that a multiple-arcade unipolar or bipolar helmet streamer can serve as a common magnetic configuration for sympathetic eruptions.

Multi-Stranded Coronal Loops: Quantifying Strand Number and Heating Frequency from Simulated Solar Dynamics Observatory (SDO) Atmospheric Imaging Assembly (AIA) Observations

Thomas **Williams**, Robert W. Walsh, Stephane Regnier & Craig D. Johnston

Solar Physics volume 296, Article number: 102 (**2021**)

https://link.springer.com/content/pdf/10.1007/s11207-021-01848-8.pdf

https://doi.org/10.1007/s11207-021-01848-8

Coronal loops form the basic building blocks of the magnetically closed solar corona yet much is still to be determined concerning their possible fine-scale structuring and the rate of heat deposition within them. Using an improved multi-stranded loop model to better approximate the numerically challenging transition region, this article examines synthetic NASA Solar Dynamics Observatory's (SDO) Atmospheric Imaging Assembly (AIA) emission simulated in response to a series of prescribed spatially and temporally random, impulsive and localised heating events across numerous sub-loop elements with a strong weighting towards the base of the structure: the nanoflare heating scenario. The total number of strands and nanoflare repetition times is varied systematically in such a way that the total energy content remains approximately constant across all the cases analysed. Repeated time-lag detection during an emission time series provides a good approximation for the nanoflare repetition time for low-frequency heating. Furthermore, using a combination of AIA 171/193 and 193/211 channel ratios in combination with spectroscopic determination of the standard deviation of the loop-apex temperature over several hours alongside simulations from the outlined multi-stranded loop model, it is demonstrated that both the imposed heating rate and number of strands can be realised.

Magnetic Field of Solar Dark Filaments Obtained from He I 10830 Angstrom Spectro-polarimetric Observation

Daiki **Yamasaki**, Yu Wei Huang, Yuki Hashimoto, Denis P. Cabezas, Tomoko Kawate, Satoru UeNo, Kiyoshi Ichimoto

Publications of the Astronomical Society of Japan **2023**
https://arxiv.org/pdf/2304.00422.pdf
Solar filaments are dense and cool plasma clouds in the solar corona. They are supposed to be supported in a dip of coronal magnetic field. However, the models are still under argument between two types of the field configuration; one is the normal polarity model proposed by Kippenhahn & Schlueter (1957), and the other is the reverse polarity model proposed by Kuperus & Raadu (1974). To understand the mechanism that the filaments become unstable before the eruption, it is critical to know the magnetic structure of solar filaments. In this study, we performed the spectro-polarimetric observation in the He I (10830 angstrom) line to investigate the magnetic field configuration of dark filaments. The observation was carried out with the Domeless Solar Telescope at Hida Observatory with a polarization sensitivity of 3.0x10^-4. We obtained 8 samples of filaments in quiet region. As a result of the analysis of full Stokes profiles of filaments, we found that the field strengths were estimated as 8 - 35 Gauss. By comparing the direction of the magnetic field in filaments and the global distribution of the photospheric magnetic field, we determined the magnetic field configuration of the filaments, and we concluded that 1 out of 8 samples have normal polarity configuration, and 7 out of 8 have reverse polarity configuration. **2022 Apr 9, 2022 Jun 4, 2022 Aug 11, and 2022 Aug 24**

Understanding the plasma and magnetic field evolution of a filament using observations and Nonlinear force-free field modelling

Stephanie L. **Yardley**, Antonia Savcheva, Lucie M. Green, Lidia van Driel-Gesztelyi, David Long, David R. Williams, Duncan H. Mackay
ApJ **887** 240 **2019**
https://arxiv.org/pdf/1911.01314.pdf
https://doi.org/10.3847/1538-4357/ab54d2
We present observations and magnetic field models of an intermediate filament present on the Sun in August 2012, associated with a polarity inversion line that extends from AR 11541 in the east into the quiet sun at its western end. A combination of SDO/AIA, SDO/HMI, and GONG H alpha data allow us to analyse the structure and evolution of the filament from 2012 August 4 23:00 UT to 2012 August 6 08:00 UT when the filament was in equilibrium. By applying the flux rope insertion method, nonlinear force-free field models of the filament are constructed using SDO/HMI line-of-sight magnetograms as the boundary condition at the two times given above. Guided by observed filament barbs, both modelled flux ropes are split into three sections each with a different value of axial flux to represent the non-uniform photospheric field distribution. The flux in the eastern section of the rope increases by 4×1020 Mx between the two models, which is in good agreement with the amount of flux cancelled along the internal PIL of AR 11541, calculated to be 3.2×1020 Mx. This suggests that flux cancellation builds flux into the filament's magnetic structure. Additionally, the number of field line dips increases between the two models in the locations where flux cancellation, the formation of new filament threads and growth of the filament is observed. This suggests that flux cancellation associated with magnetic reconnection forms concave-up magnetic field that lifts plasma into the filament. During this time, the free magnetic energy in the models increases by 0.2×1031 ergs.
4-6 Aug 2012

A Catalog of Prominence Eruptions Detected Automatically in the SDO/AIA 304 Å Images

S. **Yashiro** (1 and 2), N. Gopalswamy (2), S. Akiyama (1 and 2), P.A. Mäkelä
2020
See https://cdaw.gsfc.nasa.gov/CME_list/autope/
https://arxiv.org/ftp/arxiv/papers/2005/2005.11363.pdf
We report on a statistical study of prominence eruptions (PEs) using a catalog of these events routinely imaged by the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO) in the 304 Å pass band. Using an algorithm developed as part of an LWS project, we have detected PEs in 304 Å synoptic images with 2-min cadence since May 2010. **A catalog of these PEs is made available online (this https URL).** The 304 Å images are polar-transformed and divided by a background map (pixels with minimum intensity during one day) to get the ratio maps above the limb. The prominence regions are defined as pixels with a ratio ≥2. Two prominence regions with more than 50% of pixels overlapping are considered the same prominence. If the height of a prominence increases monotonically in 5 successive images, it is considered eruptive. All the PEs seen above the limb are detected by the routine, but only PEs with width ≥15° are included in the catalog to eliminate polar jets and other small-scale mass motions. The identifications are also cross-checked with the PEs identified in Nobeyama Radioheliograph images (this http URL). The catalog gives the date, time, central position angle, latitude, and width of the eruptive prominence. The catalog also provides links to JavaScript movies that combine SDO/AIA images with GOES soft X-ray data to identify the associated flares, and with SOHO/LASCO C2 images to identify the associated coronal mass ejections. We examined the statistical properties of the PEs and found that the high-latitude PE speed decreased with the decreasing of the average polar magnetic field strength of the previous cycle. **2011.05.30**

Automatic Detection of Prominence Eruptions from SDO/AIA Images at 304 Ã…

Yashiro, S., Gopalswamy, N., and Akiyama, S.
(**2017**), JASTP, to be submitted.
See **A Catalog of Prominence Eruptions Detected Automatically in the SDO/AIA 304 Å Images***
https://cdaw.gsfc.nasa.gov/CME_list/autope/

CHIRALITY OF HIGH-LATITUDE FILAMENTS OVER SOLAR CYCLE 23

A. R. **Yeates**1 and D. H. Mackay
2012 ApJ 753 L34
A non-potential quasi-static evolution model coupling the Sun's photospheric and coronal magnetic fields is applied to the problem of filament chirality at high latitudes. For the first time, we run a continuous 15 year simulation, using bipolar active regions determined from US National Solar Observatory, Kitt Peak magnetograms between 1996 and 2011. Using this simulation, we are able to address the outstanding question of whether magnetic helicity transport from active latitudes can overcome the effect of differential rotation at higher latitudes. Acting alone, differential rotation would produce high-latitude filaments with opposite chirality to the majority type in each hemisphere. We find that differential rotation can indeed lead to opposite chirality at high latitudes, but only for around 5 years of the solar cycle following the polar field reversal. At other times, including the rising phase, transport of magnetic helicity from lower latitudes overcomes the effect of in situ differential rotation, producing the majority chirality even on the polar crowns at polar field reversal. These simulation predictions will allow for future testing of the non-potential coronal model. The results indicate the importance of long-term memory and helicity transport from active latitudes when modeling the structure and topology of the coronal magnetic field at higher latitudes.

Modelling the Global Solar Corona III: Origin of the Hemispheric Pattern of Filaments

Yeates, A. R. and Mackay, D. H.
E-print, Oct 2008; Solar Phys., (**2009**) 254: 77–88
We consider the physical origin of the hemispheric pattern of filament chirality on the Sun. Our 3D simulations of the coronal field evolution over a period of 6 months, based on photospheric magnetic measurements, were previously shown to be highly successful at reproducing observed filament chiralities. In this paper we identify and describe the physical mechanisms responsible for this success. The key mechanisms are found to be (1) differential rotation of north-south polarity inversion lines, (2) the shape of bipolar active regions, and (3) evolution of skew over a period of many days. As on the real Sun, the hemispheric pattern in our simulations holds in a statistical sense. Exceptions arise naturally for filaments in certain locations relative to bipolar active regions, or from interactions between a number of active regions.

Modelling the Global Solar Corona II: Coronal Evolution and Filament Chirality Comparison

A.R. **Yeates** · D.H. Mackay · A.A. van Ballegooijen
Solar Phys (**2008**) 247: 103–121
http://www.springerlink.com/content/66h3876790633575/fulltext.pdf
14 Sept 1999
This paper considers the hemispheric pattern of solar filaments using newly developed simulations of the real photospheric and 3D coronal magnetic fields over a six-month period, on a global scale. The magnetic field direction in the simulation is compared directly with the chirality of observed filaments, at their observed locations. In our model the coronal field evolves through a continuous sequence of nonlinear force-free equilibria, in response to the changing photospheric boundary conditions and the emergence of new magnetic flux. In total 119 magnetic bipoles with properties matching observed active regions are inserted. These bipoles emerge twisted and inject magnetic helicity into the solar atmosphere. When we choose the sign of this active-region helicity to match that observed in each hemisphere, the model produces the correct chirality for up to 96% of filaments, including exceptions to the hemispheric pattern. If the emerging bipoles have zero helicity, or helicity of the opposite sign, then this percentage is much reduced. In addition, the simulation produces a higher proportion of filaments with the correct chirality after longer times. This indicates that a key element in the evolution of the coronal field is its long-term memory, and the build-up and transport of helicity from low to high latitudes over many months. It highlights the importance of continuous evolution of the coronal field, rather than independent extrapolations at different times. This has significant consequences for future modelling such as that related to the origin and development of coronal mass ejections.

Observations of Photospheric Magnetic Structure below a Dark Filament using the Hinode Spectro-Polarimeter

Takaaki **Yokoyama**, Yukio Katsukawa, Masumi Shimojo

PASJ 2019

https://arxiv.org/pdf/1901.10695.pdf

The structure of the photospheric vector magnetic field below a dark filament on the Sun is studied using the observations of the Spectro-Polarimeter attached to the Solar Optical Telescope onboard Hinode. Special attention is paid to discriminate the two suggested models, a flux rope or a bent arcade. "Inverse-polarity" orientation is possible below the filament in a flux rope, whereas "normal-polarity" can appear in both models. We study a filament in active region NOAA 10930, which appeared on the solar disk during 2006 December. The transverse field perpendicular to the line of sight has a direction almost parallel to the filament spine with a shear angle of 30 deg, whose orientation includes the 180-degree ambiguity. To know whether it is in the normal orientation or in the inverse one, the center-to-limb variation is used for the solution under the assumption that the filament does not drastically change its magnetic structure during the passage. When the filament is near the east limb, we found that the line-of-site magnetic component below is positive, while it is negative near the west limb. This change of sign indicates that the horizontal photospheric field perpendicular to the polarity inversion line beneath the filament has an "inverse-polarity", which indicates a flux-rope structure of the filament supporting field. **2006 December 8-16**

Conditions for Solar Prominence Formation Triggered by Single Localized Heating

Takero **Yoshihisa**, Takaaki Yokoyama, Takafumi Kaneko

ApJ **2024**

https://arxiv.org/pdf/2411.18193

We performed numerical simulations to study mechanisms of solar prominence formation triggered by a single heating event. In the widely accepted ``chromospheric-evaporation condensation" model, localized heating at footpoints of a coronal loop drives plasma evaporation and eventually triggers condensation. The occurrence of condensation is strongly influenced by the characteristics of the this http URL theoretical studies have been conducted along one-dimensional field lines with quasi-steady localized heating. The quasi-steady heating is regarded as the collection of multiple heating events among multiple strands constituting a coronal loop. However, it is reasonable to consider a single heating event along a single field line as an elemental this http URL investigated the condensation phenomenon triggered by a single heating event using 1.5-dimensional magnetohydrodynamic simulations. By varying the magnitude of the localized heating rate, we explored the conditions necessary for condensation. We found that when a heating rate approximately ∼104 times greater than that of steady heating was applied, condensation occurred. Condensation was observed when the thermal conduction efficiency in the loop became lower than the cooling efficiency, with the cooling rate significantly exceeding the heating rate. Using the loop length L and the Field length λF, the condition for condensation is expressed as λF≲L/2 under conditions where cooling exceeds heating. We extended the analytically derived condition for thermal non-equilibrium to a formulation based on heating amount.

VELOCITY MEASUREMENTS FOR A SOLAR ACTIVE REGION FAN LOOP FROM HINODE/EIS OBSERVATIONS

P. R. **Young**1, B. O'Dwyer2 and H. E. Mason

2012 ApJ 744 14

The velocity pattern of a fan loop structure within a solar active region over the temperature range 0.15-1.5 MK is derived using data from the EUV Imaging Spectrometer (EIS) on board the Hinode satellite. The loop is aligned toward the observer's line of sight and shows downflows (redshifts) of around 15 km s–1 up to a temperature of 0.8 MK, but for temperatures of 1.0 MK and above the measured velocity shifts are consistent with no net flow. This velocity result applies over a projected spatial distance of 9 Mm and demonstrates that the cooler, redshifted plasma is physically disconnected from the hotter, stationary plasma. A scenario in which the fan loops consist of at least two groups of "strands"—one cooler and downflowing, the other hotter and stationary—is suggested. The cooler strands may represent a later evolutionary stage of the hotter strands. A density diagnostic of Mg VII was used to show that the electron density at around 0.8 MK falls from 3.2 × 109 cm–3 at the loop base, to 5.0 × 108 cm–3 at a projected height of 15 Mm. A filling factor of 0.2 is found at temperatures close to the formation temperature of Mg VII (0.8 MK), confirming that the cooler, downflowing plasma occupies only a fraction of the apparent loop volume. The fan loop is rooted within a so-called outflow region that displays low intensity and blueshifts of up to 25 km s–1 in Fe XII λ195.12 (formed at 1.5 MK), in contrast to the loop's redshifts of 15 km s–1 at 0.8 MK. A new technique for obtaining an absolute wavelength calibration for the EIS instrument is presented and an instrumental effect, possibly related to a distorted point-spread function, that affects velocity measurements is identified.

Effects of Background Periodic Flow on MHD Fast-wave Propagation to a Coronal Loop

D. J. **Yu**1

2022 ApJ 940 154

https://arxiv.org/pdf/2212.01061

https://iopscience.iop.org/article/10.3847/1538-4357/ac9e4f/pdf

This paper investigates the propagation of MHD fast waves into a cylindrical coronal loop through an inhomogeneous stationary flow region. The background flow is assumed to have a small, spatially periodic structure in addition to a constant speed. This study focuses on the absorption of the wave energy in Alfvén resonance, comparing it with the constant flow case. A new flow (absorption) regime is induced by the periodic flow structure, which enhances the absorption for the antiparallel flow and inverse absorption (overreflection) for the parallel flow with respect to the axial wavevector, depending on the transitional layer and flow profiles. A giant overreflection and anomalous absorption behavior arises for some flow configurations. In the other flow regimes, its effect on the absorption is shown to be weak.

A STUDY ON THE EXCITATION AND RESONANT ABSORPTION OF CORONAL LOOP KINK OSCILLATIONS

Dae Jung **Yu** and Tom Van Doorsselaere

2016 ApJ 831 30

We study theoretically the issue of externally driven excitations of standing kink waves and their resonant absorption into torsionally polarized m = 1 waves in the coronal loops in pressureless plasmas. We use the ideal MHD equations, for which we develop an invariant imbedding method available in cylindrical geometry. We assume a sinusoidal density profile at the loop boundary where the density inside the loop is lower than the outside and vice versa. We present field distributions for these two cases and find that they have similar behaviors. We compare the results for the overdense loops, which describe the usual coronal loops, with the analytical solutions of Soler et al. obtained using the Frobenius method. Our results show some similarity for thin nonuniform layers but deviate a lot for thick nonuniform layers. For the first case, which describes the wave train propagation in funnels, we find that resonant absorption depends crucially on the thickness of the nonuniform boundary, loop length, and density contrast. The resonant absorption of the kink mode is dominant when the loop length is sufficiently larger compared with its radius (thin loop). The behavior of the far-field pattern of the scattered wave by the coronal loop is closely related to that of the resonant absorption. For the mode conversion phenomena in inhomogeneous plasmas, a certain universal behavior of the resonant absorption is found for the first time. We expect that the main feature may also apply to the overdense loops and discuss its relation to the damping rate.

Random bursty perturbations leading to wave-like characteristics in the corona

Ding **Yuan** and Robert W. Walsh

UKSP Nuggets of **2016** #68

http://www.uksolphys.org/uksp-nugget/68-random-bursty-perturbations-leading-to-wave-like-characteristics-in-the-corona/

Forward Modelling of Standing Kink Modes in Coronal Loops II. Applications

Ding **Yuan**, Tom Van Doorsselaere

ApJS **2016**

http://arxiv.org/pdf/1602.07598v1.pdf

Magnetohydrodynamic waves are believed to play a significant role in coronal heating, and could be used for remote diagnostics of solar plasma. Both the heating and diagnostic applications rely on a correct inversion (or backward modelling) of the observables into the thermal and magnetic structures of the plasma. However, owing to the limited availability of observables, this is an ill-posed issue. Forward Modelling is to establish a plausible mapping of plasma structuring into observables. In this study, we set up forward models of standing kink modes in coronal loops and simulate optically thin emissions in the extreme ultraviolet bandpasses, and then adjust plasma parameters and viewing angles to match three events of transverse loop oscillations observed by the Solar Dynamics Observatory/Atmospheric Imaging Assembly. We demonstrate that forward models could be effectively used to identify the oscillation overtone and polarization, to reproduce the general profile of oscillation amplitude and phase, and to predict multiple harmonic periodicities in the associated emission intensity and loop width variation.

16 Oct 2010, 03 Nov 2010, 6 Sept 2011

Forward Modelling of Standing Kink Modes in Coronal Loops I. Synthetic Views

Ding **Yuan**, Tom Van Doorsselaere

ApJS **2016**

http://arxiv.org/pdf/1603.01632v1.pdf

Kink magnetohydrodynamic (MHD) waves are frequently observed in various magnetic structures of the solar atmosphere. They may contribute significantly to coronal heating and could be used as a tool to diagnose the solar plasma. In this study, we synthesise the \ion{Fe}{9} λ171.073 emission of a coronal loop supporting a standing kink MHD mode. The kink MHD wave solution of a plasma cylinder is mapped into a semi-torus structure to simulate a curved coronal loop. We decompose the solution into a quasi-rigid kink motion and a quadrupole term, which dominate the plasma inside and outside the flux tube, respectively. At the loop edges, the line-of-sight integrates relatively more ambient plasma, and the background emission becomes significant. The plasma motion associated with the quadrupole term causes spectral line broadening and emission suppression. The periodic intensity suppression will modulate the integrated intensity and the effective loop width, which both exhibit oscillatory variations at half of the kink period. The quadrupole term can be directly observed as a pendular motion at front view.

Automatic Solar Filament Segmentation and Characterization

Y. **Yuan**, F. Y. Shih, J. Jing, H. Wang and J. Chae

Solar Physics, Volume 272, Number 1, 101-117, **2011**

This paper presents a generic method to automatically segment and characterize solar filaments from various Hα full-disk solar images, obtained by different solar observatories, with different dynamic ranges and statistical properties. First, a cascading Hough circle detector is designed to find the center location and radius of the solar disks. Second, polynomial surface fitting is adopted to correct unbalanced luminance. Third, an adaptive thresholding method is put forward to segment solar filaments. Finally, for each piece of a solar filament, its centroid location, area, and length are characterized, in which morphological thinning and graph theory are used for identifying the main skeletons of filaments. To test the performance of the proposed methods, a dataset composed of 125 Hα images is considered. These images were obtained by four solar observatories from January 2000 to May 2010, one image per month. Experimental results show that the accuracy rate is above 95% as measured by filament number and above 99% as measured by filament area, indicating that only a few tiny filaments are not detected.
http://filament.njit.edu/dataset/

DYNAMICS OF CHROMOSPHERIC UPFLOWS AND UNDERLYING MAGNETIC FIELDS

V. **Yurchyshyn**, V. Abramenko, and P. Goode

2013 ApJ 767 17

We used Hα-0.1 nm and magnetic field (at 1.56μ) data obtained with the New Solar Telescope to study the origin of the disk counterparts to type II spicules, so-called rapid blueshifted excursions (RBEs). The high time cadence of our chromospheric (10 s) and magnetic field (45 s) data allowed us to generate x-t plots using slits parallel to the spines of the RBEs. These plots, along with potential field extrapolation, led us to suggest that the occurrence of RBEs is generally correlated with the appearance of new, mixed, or unipolar fields in close proximity to network fields. RBEs show a tendency to occur at the interface between large-scale fields and small-scale dynamic magnetic loops and thus are likely to be associated with the existence of a magnetic canopy. Detection of kinked and/or inverse "Y"-shaped RBEs further confirm this conclusion.

Particle Acceleration and Plasma Heating in the Chromosphere

V. V. **Zaitsev**, A. V. Stepanov

Solar Phys. **2015**

We propose m−3 a new mechanism of electron acceleration and plasma heating in the solar chromosphere, based on the magnetic Rayleigh–Taylor instability. The instability develops at the chromospheric footpoints of a flare loop and deforms the local magnetic field. As a result, the electric current in the loop varies, and a resulting inductive electric field appears. A pulse of the induced electric field, together with the pulse of the electric current, propagates along the loop with the Alfvén velocity and begins to accelerate electrons up to an energy of about 1 MeV. Accelerated particles are thermalized in the dense layers of the chromosphere with the plasma density n≈1014--1015 cm−3, heating them to a temperature of about several million degrees. Joule dissipation of the electric current pulse heats the chromosphere at heights that correspond to densities n≤1011--1013 c. Observations with the New Solar Telescope at Big Bear Solar Observatory indicate that chromospheric footpoints of coronal loops might be heated to coronal temperatures and that hot plasma might be injected upwards, which brightens ultra-fine loops from the photosphere to the base of the corona. Thereby, recent observations of the Sun and the model we propose stimulate a déjà vu – they are reminiscent of the concept of the chromospheric flare.

Doppler-velocity Drifts Detected in a Solar Prominence

Maciej **Zapiór**1, Petr Heinzel1,2, and Elena Khomenko3,4

2022 ApJ 934 16

https://iopscience.iop.org/article/10.3847/1538-4357/ac778a/pdf

We analyzed multiline observations of a quiescent prominence from the slit spectrograph located at the Ondřejov Observatory. Dopplergrams and integrated intensity maps of the whole prominence were obtained from observations in six spectral lines: Ca ii H, Hϵ, Hβ, He i D3, Hα, and Ca ii IR. By combining integrated intensity maps with non-LTE radiative-transfer modeling, we carefully identified areas in an optically thin regime. The comparison of the Doppler-velocity maps and scatterplots from different lines shows the existence of differences in the velocity of ions and neutrals called velocity drift. The drift is of a local nature, present mostly at prominence edges in the area with a large velocity gradient, as can be tentatively expected based on multifluid MHD models. We could not explore the time evolution of the drift, since our data set consists of a single scan only. Our paper brings another contribution to a rather controversial problem of the detection of multifluid effects in solar prominences. **2011 August 26**

Exploration of long-period oscillations in an Hα prominence

M. **Zapiór**, B. Schmieder, P. Mein, N. Mein, N. Labrosse, M. Luna

A&A 623, A144 **2019**

https://arxiv.org/pdf/1903.00230.pdf

https://www.aanda.org/articles/aa/pdf/2019/03/aa33614-18.pdf

Context. In previous work, we studied a prominence which appeared like a tornado in a movie made from 193 {\AA} filtergrams obtained with the Atmospheric Imaging Assembly (AIA) imager aboard the Solar Dynamics Observatory (SDO). The observations in Hα obtained simultaneously during two consecutive sequences of one hour with the Multi-channel Subtractive Double Pass Spectrograph (MSDP) operating at the solar tower in Meudon showed that the cool plasma inside the tornado was not rotating around its vertical axis. Furthermore, the evolution of the Dopplershift pattern suggested the existence of oscillations of periods close to the time-span of each sequence. Aims. The aim of the present work is to assemble the two sequences of Hα observations as a full data set lasting two hours to confirm the existence of oscillations, and determine their nature. Methods. After having coaligned the Doppler maps of the two sequences, we use a Scargle periodogram analysis and cosine fitting to compute the periods and the phase of the oscillations in the full data set. Results. Our analysis confirms the existence of oscillations with periods between 40 and 80 minutes. In the Dopplershift maps, we identify large areas with strong spectral power. In two of them, the oscillations of individual pixels are in phase. However, in the top area of the prominence, the phase is varying slowly, suggesting wave propagation. Conclusions. We conclude that the prominence does not oscillate as a whole structure but exhibits different areas with their own oscillation periods and characteristics: standing or propagating waves. We discuss the nature of the standing oscillations and the propagating waves. These can be interpreted in terms of gravito-acoustic modes and magnetosonic waves, respectively. **September 24, 2013**

SYNTHETIC HYDROGEN SPECTRA OF OSCILLATING PROMINENCE SLABS IMMERSED IN THE SOLAR CORONA

M. **Zapiór**1,2, R. Oliver2,3, J. L. Ballester2,3, and P. Heinzel

2016 *ApJ* **827** 131

We study the behavior of Hα and Hβ spectral lines and their spectral indicators in an oscillating solar prominence slab surrounded by the solar corona, using an MHD model combined with a 1D radiative transfer code taken in the line of sight perpendicular to the slab. We calculate the time variation of the Doppler shift, half-width, and maximum intensity of the Hα and Hβspectral lines for different modes of oscillation. We find a non-sinusoidal time dependence of some spectral parameters with time. Because Hα and Hβ spectral indicators have different behavior for different modes, caused by differing optical depths of formation and different plasma parameter variations in time and along the slab, they may be used for prominence seismology, especially to derive the internal velocity field in prominences.

Simultaneous Observations of Solar Prominence Oscillations Using Two Remote Telescopes

Maciej **Zapiór**, Pavel Kotrč, Paweł Rudawy, Ramon Oliver

Solar Phys. Volume 290, Issue 6, pp 1647-1659 **2015**

We present the first results of the joint Polish–Czech observational campaign devoted to simultaneous observations of prominence oscillations. As was shown earlier by other authors, not all of the observed periodicities in the Doppler signal come from solar sources (seeing and slight changes in the position of the spectrograph slit may have a significant influence). To exclude false signals, we performed simultaneous observations of the same object on the Sun using two independent telescopes. On **23 September 2010**, a quiescent prominence on the north-eastern part of the solar limb was observed with two distant solar telescopes: the Large Coronagraph installed at the Białków Observatory, Poland, and the Horizontal Telescope at the Ondřejov Observatory, Czech Republic. Of the many detected periods, the periods of 26, 31, and 55 min unquestionably originate in the prominence, but other periodicities are spurious. Proper detection of periodicities in prominences is crucial for modelling wave propagation and movements in the solar plasma, as well as for seismologically inverting prominence structures and physical parameters.

Estimation of Solar Prominence Magnetic Fields Based on the Reconstructed 3D Trajectories of Prominence Knots

Maciej **Zapiór**, Paweł Rudawy

Solar Physics, October **2012**, Volume 280, Issue 2, pp 445-456, We present an estimation of the lower limits of local magnetic field strengths in quiescent, activated, and active (surges) prominences, based on reconstructed three-dimensional (3D) trajectories of individual prominence knots. The 3D trajectories, velocities, tangential and centripetal accelerations of the knots were reconstructed using observational data collected with a single ground-based telescope equipped with a Multi-channel Subtractive Double Pass imaging spectrograph. Lower limits of magnetic fields channeling observed plasma flows were estimated under assumption of the equipartition principle. Assuming approximate electron densities of the plasma n e=5×1011 cm−3 in surges and n e=5×1010 cm−3 in quiescent/activated prominences, we found that the magnetic fields channeling two observed surges range from 16 to 40 Gauss, while in quiescent and activated prominences they were less than 10 Gauss. Our results are consistent with previous detections of weak local magnetic fields in the solar prominences.

Exact solution to the problem of slow oscillations in coronal loops and its diagnostic applications

Dmitrii I. **Zavershinskii**, Nonna E. Molevich, Dmitrii S. Riashchikov, Sergey A. Belov

Front. Astron. Space Sci. 10: 1167781 **2023**
https://arxiv.org/pdf/2304.03632.pdf
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https://www.frontiersin.org/articles/10.3389/fspas.2023.1167781/pdf

Magnetoacoustic oscillations are nowadays routinely observed in various regions of the solar corona. This allows them to be used as means of diagnosing plasma parameters and processes occurring in it. Plasma diagnostics, in turn, requires a sufficiently reliable MHD model to describe the wave evolution. In our paper, we focus on obtaining the exact analytical solution to the problem of the linear evolution of standing slow magnetoacoustic (MA) waves in coronal loops. Our consideration of the properties of slow waves is conducted using the infinite magnetic field assumption. The main contribution to the wave dynamics in this assumption comes from such processes as thermal conduction, unspecified coronal heating, and optically thin radiation cooling. In our consideration, the wave periods are assumed to be short enough so that the thermal misbalance has a weak effect on them. Thus, the main non-adiabatic process affecting the wave dynamics remains thermal conduction. The exact solution of the evolutionary equation is obtained using the Fourier method. This means that it is possible to trace the evolution of any harmonic of the initial perturbation, regardless of whether it belongs to entropy or slow mode. We show that the fraction of energy between entropy and slow mode is defined by the thermal conduction and coronal loop parameters. It is shown for which parameters of coronal loops it is reasonable to associate the full solution with a slow wave, and when it is necessary to take into account the entropy wave. Furthermore, we obtain the relationships for the phase shifts of various plasma parameters applicable to any values of harmonic number and thermal condition coefficient. In particular, it is shown that the phase shifts between density and temperature perturbations for the second harmonic of the slow wave vary between π/2 to 0, but are larger than for the fundamental harmonic.

Multiwavelength Observations for a Double-decker Filament Channel in AR 13102

Yin **Zhang**1,2, Baolin Tan1,2,3, Quan Wang1,2,3, Jing Huang1,2,3, Zhe Xu4, Kanfan Ji4, Xiao Yang1,2, Jie Chen1,2, Xianyong Bai1,2,3, Zhenyong Hou5Show full author list

2024 ApJ 973 9
https://iopscience.iop.org/article/10.3847/1538-4357/ad5d70/pdf

We present the observational evidence of the existence of a double-decker filament channel (FC) by using observations in extreme ultraviolet and Hα wavelengths. For both FCs, the east foot-point roots in the active region (AR), while the west one roots in the remote quiet region. The bottom FC (FC1) appears as intermittent filaments. Within the AR, the FC1 appears as an S-shaped filament (F1), which consisted of two J-shaped filaments (F1S/F1N for the south/north one). For the upper one (FC2), only the east part is filled with dark plasma and visible as a small filament (F2). Its east foot-point roots around the junction of F1S and F1N. Initially, due to the recurrent reconnections, F1N and F1S link to each other and form a new filament (F3) thread by thread. Meanwhile, the heated plasma, which appears as brightening features, flows from the east foot-point of F2 to the west, and becomes invisible about 1.1 × 105 km away. The failed eruption of F1S is triggered by the reconnection, which appears as the brightening threads changing their configuration from crossed to quasiparallel in between the F1S and F3, and is confined by the upper magnetic field. Associated with the eruption, the distant invisible plasma becomes visible as a brightening feature. It continuously flows to the remote foot-point, and becomes invisible before reaching it. The brightening plasma flow outlines the skeleton of FC2 gradually. The observations show the existence of a double-decker FC, as a magnetic structure, before they appear as a brightening/dark feature when fully filled with hot/cool plasma. **15-19 Sep 2022**

Unraveling the untwisting process and upward mass transfer of a twisted prominence driven by vortex motion

X. F. **Zhang**, G. P. Zhou, C. L. Jin, Y. Z. Zhang, G. W. Li, Z. H. Shang, L. P. Li, S. B. Yang, S. H. Yang, J. X. Wang

A&A 690, A134 **2024**

https://arxiv.org/pdf/2408.09732
https://www.aanda.org/articles/aa/pdf/2024/10/aa48070-23.pdf
Solar filaments/prominences are common features in the Sun's atmosphere that contain cool chromospheric material suspended within the hot corona. However, the intricate topology of these structures and the mechanisms driving their instability and upward material transfer are not well understood. This study is to analyze a specific twisted prominence on **February 10, 2021**, and to explore its dynamics, including stability, motion, and material transfer. The study utilizes high-resolution Hα observations from the 1-m New Vacuum Solar Telescope and space-borne observations from the Solar Dynamics Observatory. We analyzed the data to investigate the characteristics and behavior of the twisted prominence. We also detected and measured the outflow speed surrounding the prominence. The study reveals that the observed prominence exhibited a stretched and twisted structure at its apex, distinguishing it from familiar cloudy prominences. Following more than 30 hours of equilibrium, the prominence destabilized, leading to a series of dynamic phenomena, such as vortex motion, oscillations, resonations, untwisting, and the upward transfer of mass. Consequently, material from the top of the prominence was carried upward and deposited into the overlying magnetic arcades. Noteworthy, outflows surrounding the prominence were characterized by speeds exceeding 40 km s−1. We propose, for the first time, a mechanism rooted in the Kármán Vortex Street instability to explain the destabilization of the prominence. The estimated typical Strouhal Number of 0.23±0.06, which is related to vortex shedding, falls within the expected range for the Kármán Vortex Street effect, as predicted by simulations. These discoveries provide new insights into the dynamics and fundamental topology of solar prominences and reveal a previously unknown mechanism for mass loading into the upper atmosphere.

Transverse Oscillation of Prominence and Filament Induced by an Extreme-ultraviolet Wave from the Far Side of the Sun

Yanjie **Zhang**1, Qingmin Zhang1,2, De-chao Song1, and Haisheng Ji1
2024 ApJ 963 140
https://iopscience.iop.org/article/10.3847/1538-4357/ad206d/pdf
https://arxiv.org/pdf/2401.15858.pdf
In this paper, we report our multi-angle observations of the transverse oscillation of a prominence and a filament induced by an EUV wave originating from the far side of the Sun on **2014 September 1**. The prominence oscillation was simultaneously observed by both the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory spacecraft and the Extreme-UltraViolet Imager on board the Behind Solar Terrestrial Relations Observatory spacecraft. The speed of the shock traveling in interplanetary space exceeds that of the EUV wave, and the coronal dimming area experiences minimal growth. ***This indicates that the shock wave is driven by the CME, while the EUV wave freely propagates after the lateral motion of the CME flanks has stopped***. The observed oscillation direction of the prominence, determined through three-dimensional reconstruction, further supports this point. Moreover, detailed investigation of the oscillations in the prominence and filament induced by the EUV wave reveals initial amplitudes of 16.08 and 2.15 Mm, periods of 1769 and 1863 s, damping timescales of 2640 and 1259 s, and damping ratios of 1.49 and 0.68, respectively. The radial component of the magnetic field, as derived from the prominence and filament oscillation measurements, was estimated to be 5.4 and 4.1 G, respectively. In turn, utilizing the onset times of both the prominence and filament oscillation, the average speeds of the EUV wave are determined to be 498 and 451 km s−1, respectively.

Statistical Analyses of Solar Prominences and Active Region Features in 304 Å Filtergrams detected via Deep Learning

T. **Zhang**, Q. Hao, P. F. Chen
ApJS **2024**
https://arxiv.org/pdf/2402.13502.pdf
Solar active regions (ARs) are areas on the Sun with very strong magnetic fields where various activities take place. Prominences are one of the typical solar features in the solar atmosphere, whose eruptions often lead to solar flares and coronal mass ejections (CMEs). Therefore, studying their morphological features and their relationship with solar activity is useful in predicting eruptive events and in understanding the long-term evolution of solar activities. A huge amount of data have been collected from various ground-based telescopes and satellites. The massive data make human inspection difficult. For this purpose, we developed an automated detection method for prominences and ARs above the solar limb based on deep learning techniques. We applied it to process the 304 Ådata obtained by SDO/AIA from 2010 May 13 to 2020 December 31. Besides the butterfly diagrams and latitudinal migrations of the prominences and ARs during solar cycle 24, the variations of their morphological features (such as the locations, areas, heights, and widths) with the calendar years and the latitude bands were analyzed. Most of these statistical results based on our new method are in agreement with previous studies, which also guarantees the validity of our method. The N-S asymmetry indices of the prominences and ARs show that the northern hemisphere dominates in solar cycle 24, except for 2012--2015, and 2020 for ARs. The high-latitude prominences show much stronger N-S asymmetry that the northern hemisphere is dominant in ∼2011 and ∼2015 and the southern hemisphere is dominant during 2016--2019.

Transverse vertical oscillations during the contraction and expansion of coronal loops

Qingmin **Zhang**, Yuhao Zhou, Chuan Li, Qiao Li, Fanxiaoyu Xia, Ye Qiu, Jun Dai, Yanjie Zhang

ApJ **951** 126 **2023**

https://arxiv.org/pdf/2305.08338.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/acd5cf/pdf

In this paper, we carry out a detailed analysis of the M1.6 class eruptive flare occurring in NOAA active region 13078 on **2022 August 19**. The flare is associated with a fast coronal mass ejection (CME) propagating in the southwest direction with an apparent speed of ∼926 km s−1. Meanwhile, a shock wave is driven by the CME at the flank. The eruption of CME generates an extreme-ultraviolet (EUV) wave expanding outward from the flare site with an apparent speed of ≥200 km s−1. As the EUV wave propagates eastward, it encounters and interacts with the low-lying adjacent coronal loops (ACLs), which are composed of two loops. The compression of EUV wave results in contraction, expansion, and transverse vertical oscillations of ACLs. The commencements of contraction are sequential from western to eastern footpoints and the contraction lasts for ∼15 minutes. The speeds of contraction lie in the range of 13−40 km s−1 in 171 Å and 8−54 km s−1 in 193 Å. A long, gradual expansion follows the contraction at lower speeds. Concurrent vertical oscillations are superposed on contraction and expansion of ACLs. The oscillations last for 2−9 cycles and the amplitudes are ≤4 Mm. The periods are between 3 to 12 minutes with an average value of 6.7 minutes. The results show rich dynamics of coronal loops.

First detection of transverse vertical oscillation during the expansion of coronal loops

Qingmin **Zhang**, Chuan Li, Dong Li, Ye Qiu, Yanjie Zhang, Yiwei Ni

ApJL **937** L21 **2022**

https://arxiv.org/pdf/2209.00194.pdf

https://iopscience.iop.org/article/10.3847/2041-8213/ac8e01/pdf

In this Letter, we perform a detailed analysis of the M5.5-class eruptive flare occurring in active region 12929 on **2022 January 20**. The eruption of a hot channel generates a fast coronal mass ejection (CME) and a dome-shaped extreme-ultraviolet (EUV) wave at speeds of 740−860 km s−1. The CME is associated with a type II radio burst, implying that the EUV wave is a fast-mode shock wave. During the impulsive phase, the flare shows quasi-periodic pulsations (QPPs) in EUV, hard X-ray, and radio wavelengths. The periods of QPPs range from 18 s to 113 s, indicating that flare energy is released and nonthermal electrons are accelerated intermittently with multiple time scales. The interaction between the EUV wave and low-lying adjacent coronal loops (ACLs) results in contraction, expansion, and transverse vertical oscillation of ACLs. The speed of contraction in 171, 193, and 211 Å is higher than that in 304 Å. The periods of oscillation are 253 s and 275 s in 304 Å and 171 Å, respectively. A new scenario is proposed to explain the interaction. The equation that interprets the contraction and oscillation of the overlying coronal loops above a flare core can also interpret the expansion and oscillation of ACLs, suggesting that the two phenomena are the same in essence.

A Double-decker Filament Formation Driven by Sunspot Rotation and Magnetic Reconnection

Yan **Zhang**1,2, Xiaoli Yan1,3, Jincheng Wang1,3, Qiaoling Li4, Liheng Yang1,3, and Zhike Xue1,3

2022 ApJ 933 200

https://iopscience.iop.org/article/10.3847/1538-4357/ac7391/pdf

In this paper, through analyzing data from the Solar Dynamics Observatory (SDO) and the Global Oscillation Network Group (GONG), we present a study on the formation of a double-decker filament in NOAA Active Region 12665 from **2017 July 8 to 14**. We find that magnetic reconnection occurs between two smaller filaments to form a longer filament. According to the evolution of the leading sunspot, it is obvious that the sunspot experiences a continuous rotation around its umbra. During the period from 03:00 UT on July 11 to 10:00 UT on July 14, the average speed of sunspot rotation is about 3°.7 hr–1. The continuous rotation of sunspot stretches the filament and results in the formation of a reversed S-shaped filament. Due to the motion of the magnetic field and internal magnetic reconnection, the filament splits into two branches and forms a double-decker filament structure. In the process of filament separation, internal magnetic reconnection can also accelerate the filament separation. Nonlinear force-free field extrapolation indicates that there are two magnetic flux ropes, which are consistent with the observed results. Eventually, the upper filament erupts and produces an M-class flare and a halo coronal mass ejection.

Formation and Immediate Deformation of a Small Filament Through Intermittent Magnetic Interactions

Liang **Zhang**, Ruisheng Zheng, Changhui Rao, Bing Wang, Huadong Chen, Libo Zhong, Yao Chen

Solar Phys. **297**, Article number: 56 **2022**

https://arxiv.org/pdf/2202.09633.pdf

https://doi.org/10.1007/s11207-022-01969-8

It is generally believed that filament formation involves a process of the accumulation of magnetic energy. However, in this paper we discuss the idea that filaments will not erupt and will only deform when the stored magnetic energy is released gradually. Combining high-quality observations from Solar Dynamics Observatory and other instruments, we present the formation and immediate deformation of a small filament (F1) in the active region (AR) 12760 on **28-30 April 2020**. Before the filament formation, three successive dipoles quickly emerged with separation motions in the center of AR 12760. Due to the magnetic interaction between magnetic dipoles and pre-existing positive polarities, coronal brightenings consequently appeared in the overlying atmosphere. Subsequently, because of the continuous cancellation of magnetic flux that happened around the adjacent ends of F1 and another nearby filament (F2), the magnetic reconections occurred intermittently occurred between F1 and F2. Finally, F1 lessened in the shear, and F2 became shorter. All the results show that the formation of F1 was closely associated with intermittent interactions between the sequence of emerging dipoles and pre-existing magnetic polarities, and the immediate deformation of F1 was intimately related to intermittent interactions between F1 and F2. We also suggest that the intermittent magnetic interactions driven by the continuous magnetic activities (magnetic-flux emergence, cancellation, and convergence) play an important role in the formation and deformation of filaments.
Correction: ***Solar Physics*** volume 297**,** Article number: 68 **(2022)**
https://link.springer.com/content/pdf/10.1007/s11207-022-02012-6.pdf

Transverse Coronal-Loop Oscillations Induced by the Non-radial Eruption of a Magnetic Flux Rope

Q. M. **Zhang**, J. L. Chen, S. T. Li, L. Lu, D. Li
Solar Phys. **2022**
https://arxiv.org/pdf/2201.07389.pdf
We investigate the transverse coronal-loop oscillations induced by the eruption of a prominence-carrying flux rope on **7 December 2012**. The flux rope originating from NOAA Active Region (AR) 11621 was observed in EUV wavelengths by the SDO/AIA and in Hα line center by the ground-based telescope at the BBSO. The early evolution of the flux rope is divided into two steps: a slow rise phase at a speed of ≈230\,km\,s−1 and a fast rise phase at a speed of ≈706\,km\,s−1. The eruption generates a C5.8 flare and the onset of the fast rise is consistent with the HXR peak time of the flare. The embedded prominence has a lower speed of ≈452\,km\,s−1. During the early eruption of the flux rope, the nearby coronal loops are disturbed and experience independent kink-mode oscillations in the horizontal and vertical directions. The oscillation in the horizontal direction has an initial amplitude of ≈3.1\,Mm, a period of ≈294\,seconds, and a damping time of ≈645\,seconds. It is most striking in 171\,Å and lasts for three to four cycles. The oscillations in the vertical directions are observed mainly in 171, 193, and 211\,Å. The initial amplitudes lie in the range of 3.4\,--\,5.2\,Mm, with an average value of 4.5\,Mm. The periods are between 407\,seconds and 441\,seconds, with an average value of 423\,seconds. The oscillations are damping and last for nearly four cycles. The damping times lie in the range of 570\,--\,1012\,seconds, with an average value of 741\,seconds. Assuming a semi-circular shape of the vertically oscillating loops, we calculate the loop lengths according to their heights. Using the observed periods, we carry out coronal seismology and estimate the internal Alfvén speeds (988\,--\,1145\,km\,s−1) and the magnetic-field strengths (12\,--\,43\,G) of the oscillating loops.

Magnetic Rayleigh–Taylor Instability in an Experiment Simulating a Solar Loop

Yang **Zhang**, Pakorn Wongwaitayakornkul, and Paul M. Bellan
2020 ApJL 889 L32
https://doi.org/10.3847/2041-8213/ab6b2d
A hoop force driven magnetic Rayleigh–Taylor instability (MRTI) is observed in a laboratory experiment that simulates a solar coronal loop. Increase of the axial wavelength λ is observed when the axial magnetic field increases. This scaling is consistent with the theoretical MRTI growth rate , which implies that if is parallel to (i.e., undular mode), the fastest-growing mode has .

Longitudinal filament oscillations enhanced by two C-class flares

Q. M. **Zhang**, J. H. Guo, K. V. Tam, A. A. Xu
A&A **2020**
https://arxiv.org/pdf/2001.01250.pdf
In this paper, we report the multiwavelength observations of a very long filament in active region (AR) 11112 on **2010 October 18**. The filament was composed of two parts, the eastern part (EP) and western part (WP). We focus on longitudinal oscillations of the EP, which were enhanced by two homologous C-class flares in the same AR. The C1.3 flare was confined without a CME. Both EP and WP of the filament were slightly disturbed and survived the flare. After 5 hrs, eruption of the WP generated a C2.6 flare and a narrow, jet-like CME. Three oscillating threads (thda, thdb, thdc) are obviously identified in the EP and their oscillations are naturally divided into three phases by the two flares. The initial amplitude ranges from 1.6 to 30 Mm with a mean value of ∼14 Mm. The period ranges from 34 to 73 minutes with a mean value of ∼53 minutes. The curvature radii of the magnetic dips are estimated to be 29 to 133 Mm with a mean value of ∼74 Mm. The damping times ranges from ∼62 to ∼96 minutes with a mean

value of ~82 minutes. The value of τ/P is between 1.2 and 1.8. For thda in the EP, the amplitudes were enhanced by the two flares from 6.1 Mm to 6.8 Mm after the C1.3 flare and further to 21.4 Mm after the C2.6 flare. The period variation as a result of perturbation from the flares was within 20\%. The attenuation became faster after the C2.6 flare. To the best of our knowledge, this is the first report of large-amplitude, longitudinal filament oscillations enhanced by flares. Numerical simulations reproduce the oscillations of thda very well. The simulated amplitudes and periods are close to the observed values, while the damping time in the last phase is longer, implying additional mechanisms should be taken into account apart from radiative loss.

Damping Mechanisms of the Solar Filament Longitudinal Oscillations in Weak Magnetic Field

L. Y. **Zhang**, C. Fang, P. F. Chen

ApJ **884** 74 **2019**

https://arxiv.org/pdf/1908.07148.pdf

https://doi.org/10.3847/1538-4357/ab3d3a

Longitudinal oscillations of solar filament have been investigated via numerical simulations continuously, but mainly in one dimension (1D), where the magnetic field line is treated as a rigid flux tube. Whereas those one-dimensional simulations can roughly reproduce the observed oscillation periods, implying that gravity is the main restoring force for filament longitudinal oscillations, the decay time in one-dimensional simulations is generally longer than in observations. In this paper, we perform a two-dimensional (2D) non-adiabatic magnetohydrodynamic simulation of filament longitudinal oscillations, and compare it with the 2D adiabatic case and 1D adiabatic and non-adiabatic cases. It is found that, whereas both non-adiabatic processes (radiation and heat conduction) can significantly reduce the decay time, wave leakage is another important mechanism to dissipate the kinetic energy of the oscillating filament when the magnetic field is weak so that gravity is comparable to Lorentz force. In this case, our simulations indicate that the pendulum model might lead to an error of ~100% in determining the curvature radius of the dipped magnetic field using the longitudinal oscillation period when the gravity to Lorentz force ratio is close to unity.

Propagating wave in active region-loops, located over the solar disk observed by the Interface Region Imaging Spectrograph★

B. **Zhang**1,2, Y. J. Hou1,2 and J. Zhang

A&A 611, A47 (**2018**)

https://arxiv.org/pdf/1801.02880.pdf

Aims. We aim to ascertain the physical parameters of a propagating wave over the solar disk detected by the Interface Region Imaging Spectrograph (IRIS).
Methods. Using imaging data from the IRIS and the Solar Dynamic Observatory (SDO), we tracked bright spots to determine the parameters of a propagating transverse wave in active region (AR) loops triggered by activation of a filament. Deriving the Doppler velocity of Si IV line from spectral observations of IRIS, we have determined the rotating directions of active region loops which are relevant to the wave.
Results. On **2015 December 19**, a filament was located on the polarity inversion line of the NOAA AR 12470. The filament was activated and then caused a C1.1 two-ribbon flare. Between the flare ribbons, two rotation motions of a set of bright loops were observed to appear in turn with opposite directions. Following the end of the second rotation, a propagating wave and an associated transverse oscillation were detected in these bright loops. In 1400 Å channel, there was bright material flowing along the loops in a wave-like manner, with a period of ~128 s and a mean amplitude of ~880 km. For the transverse oscillation, we tracked a given loop and determine the transverse positions of the tracking loop in a limited longitudinal range. In both of 1400 Å and 171 Å channels, approximately four periods are distinguished during the transverse oscillation. The mean period of the oscillation is estimated as ~143 s and the displacement amplitude as between ~1370 km and ~690 km. We interpret these oscillations as a propagating kink wave and obtain its speed of ~1400 km s^{-1}.
Conclusions. Our observations reveal that a flare associated with filament activation could trigger a kink propagating wave in active region loops over the solar disk.

Simultaneous transverse and longitudinal oscillations in a quiescent prominence triggered by a coronal jet

Qingmin **Zhang**, Dong Li, Zongjun Ning

ApJ **851** 47 **2017**

https://arxiv.org/pdf/1711.00670.pdf

In this paper, we report our multiwavelength observations of the simultaneous transverse and longitudinal oscillations in a quiescent prominence on **2015 June 29**. A C2.4 flare took place in active region 12373, which was associated with a pair of short ribbons and a remote ribbon. During the impulsive phase of the flare, a coronal jet spurted out of the primary flare site and propagated in the northwest direction at an apparent speed of ∼224 km s−1. Part of the jet stopped near the remote ribbon. The remaining part continued moving forward before stopping to the east of prominence. Once the jet encountered the prominence, it pushed the prominence to oscillate periodically. The transverse oscillation of the eastern part (EP) of prominence can be divided into two phases. In phase I, the initial amplitude, velocity, period, and damping timescale are ∼4.5 Mm, ∼20 km s−1, ∼25 minutes, and ∼7.5 hr, respectively. In phase II, the initial amplitude increases to ∼11.3 Mm while the initial velocity halves to ∼10 km s−1. The period increases by a factor of ∼3.5. The western part (WP) of prominence also experienced transverse oscillation. The initial amplitude is only ∼2 Mm and the velocity is less than 10 km s−1. The period (∼27 minutes) is slightly longer than that of EP in phase I. To the east of prominence, a handful of horizontal threads experienced longitudinal oscillation. The initial amplitude, velocity, period, and damping timescale are ∼52 Mm, ∼50 km s−1, ∼99 minutes, and 2.5 hr, respectively. To our knowledge, this is the first report of simultaneous transverse and longitudinal prominence oscillations triggered by a coronal jet.

Large-amplitude longitudinal oscillations in a solar filament

Q. M. **Zhang**, T. Li, R. S. Zheng, Y. N. Su, H. S. Ji
ApJ 842 27 **2017**
https://arxiv.org/pdf/1705.04820.pdf
http://sci-hub.cc/10.3847/1538-4357/aa73d2

In this paper, we report our multiwavelength observations of the large-amplitude longitudinal oscillations of a filament on **2015 May 3**. Located next to active region 12335, the sigmoidal filament was observed by the ground-based Hα telescopes from GONG and by AIA aboard SDO. The filament oscillations were most probably triggered by the magnetic reconnection in the filament channel. The directions of oscillations have angles of 4∘-36∘ with respect to the filament axis. The whole filament did not oscillate in phase as a rigid body. Meanwhile, the periods (3100−4400 s) of oscillations have a spatial dependence. The values of R are estimated to be 69.4 −133.9 Mm, and the minimum transverse magnetic field of the dips is estimated to be 15 G. The amplitudes of S5-S8 grew with time, while the amplitudes of S9-S14 damped with time. The amplitudes of oscillations range from a few to ten Mm, and the maximal velocity can reach 30 km s−1. Interestingly, the filament experienced mass drainage southwards at a speed of ∼27 km s−1. The oscillations continued after the mass drainage and lasted for more than 11 hr. After the mass drainage, the phases of oscillations did not change a lot. The periods of S5-S8 decreased, while the periods of S9-S14 increased. The amplitudes of S5−S8 damped with time, while the amplitudes of S9-S14 grew. Most of the damping (growing) ratios are between -9 and 14. We propose a schematic cartoon to explain the complex behaviors of oscillations by introducing thread-thread interaction.

Damped large amplitude oscillations in a solar prominence and a bundle of coronal loops

Quanhao **Zhang**, Yuming Wang, Rui Liu, Chenglong Shen, Min Zhang, Tingyu Gou, Jiajia Liu, Kai Liu, Zhenjun Zhou, Shui Wang
Research in Astronomy and Astrophysics **2016**
http://arxiv.org/pdf/1606.09020v1.pdf

We investigate the evolutions of two prominences (P1,P2) and two bundles of coronal loops (L1,L2), observed with SDO/AIA near the east solar limb on 2012 September 22. It is found that there were large-amplitude oscillations in P1 and L1, but no detectable motions in P2 and L2. These transverse oscillations were triggered by a large-scale coronal wave, originating from a large flare in a remote active region behind the solar limb. By carefully comparing the locations and heights of these oscillating and non-oscillating structures, we conclude that the propagating height of the wave is between 50 Mm and 130 Mm. The wave energy deposited in the oscillating prominence and coronal loops is at least of the order of 1028 erg. Furthermore, local magnetic field strength and Alfv\'{e}n speeds are derived from the oscillating periods and damping time scales, which are extracted from the time series of the oscillations. It is demonstrated that oscillations can be used in not only coronal seismology, but also revealing the properties of the wave.

The Role of the Inner Coronal Null Point in the Formation and Evolution of Solar Quiescent Prominences

Y. Z. **Zhang**
2015 ApJ 800 43
Using a 2.5-dimensional MHD simulation, we investigate the role played by the inner coronal null point in the formation and evolution of solar quiescent prominences. The flux rope is characterized by its magnetic fluxes, the toroidal magnetic flux Φ p and the poloidal flux Φ^{φ}. It is found that for a given Φ p , the catastrophe does not occur in the flux rope system until Φ^{φ} increases to a critical point. Moreover, the magnetic flux of the null point is the maximum value of the magnetic flux in the quadrupole background magnetic field, and represented by ψ N . The

results show that the bigger ψ N usually corresponds to the smaller catastrophic point, the lower magnetic energy of the flux rope system, and the lesser magnetic energy inside the flux rope. Our results confirm that catastrophic disruption of the prominence occurs more easily when there is a bigger ψ N . However, ψ N has little influence on the maximum speed of the coronal mass ejections (CMEs) with an erupted prominence. Thus we argue that a topological configuration with the inner coronal null point is a necessary structure for the formation and evolution of solar quiescent prominences. In conclusion, it is easier for the prominences to form and to erupt as a core part of the CMEs in the magnetic structure with a greater ψN .

The Formation and Eruption of Solar Quiescent Prominences

Y. Z. **Zhang**

2013 ApJ 777 52

Following the two-stage catastrophic flux rope model presented by Zhang et al., we investigate how magnetic flux emergence affects the formation and evolution of solar quiescent prominences. The magnetic properties of the flux rope are described with its toroidal magnetic flux per radian Φ p and poloidal flux Φ, and Φ p is defined as the emerging strength (ES) of the magnetic flux. After the first catastrophe, the quiescent prominences are supported by the vertical current sheet and located in cavities below the curved transverse current sheet in the inner corona, for which both ES and Φ are in the certain ranges. We calculate the strength range as 0.25 < ES < 0.50 for the quadrupolar field, and obtain the equation Φ p Φ = const., that is, the relationship between Φ p and Φ of the emerging flux for which the quiescent prominences are formed in the inner corona. After the second catastrophe, the quiescent prominences would either fall down onto the solar surface or erupt as an important part of coronal mass ejections. During the eruption of the quiescent prominences, most of the magnetic energy in the flux rope is lost, and less than half of the energy loss of the rope is released in the form of Alfvèn waves. We argue that there would be two important conditions required for the formation and eruption of solar quiescent prominences, a complicated source region and emerging toroidal magnetic flux that exceeds a critical strength.

Parametric survey of longitudinal prominence oscillation simulations

Q. M. **Zhang**1,2, P. F. Chen1,3, C. Xia4, R. Keppens4 and H. S. Ji

A&A 554, A124 (**2013**)

Context. Longitudinal filament oscillations recently attracted increasing attention, while the restoring force and the damping mechanisms are still elusive.
Aims. We intend to investigate the underlying physics for coherent longitudinal oscillations of the entire filament body, including their triggering mechanism, dominant restoring force, and damping mechanisms.
Methods. With the MPI-AMRVAC code, we carried out radiative hydrodynamic numerical simulations of the longitudinal prominence oscillations. We modeled two types of perturbations of the prominence, impulsive heating at one leg of the loop and an impulsive momentum deposition, which cause the prominence to oscillate. We studied the resulting oscillations for a large parameter scan, including the chromospheric heating duration, initial velocity of the prominence, and field line geometry.
Results. We found that both microflare-sized impulsive heating at one leg of the loop and a suddenly imposed velocity perturbation can propel the prominence to oscillate along the magnetic dip. Our extensive parameter survey resulted in a scaling law that shows that the period of the oscillation, which weakly depends on the length and height of the prominence and on the amplitude of the perturbations, scales with √R/g⊙, where R represents the curvature radius of the dip, and g⊙ is the gravitational acceleration of the Sun. This is consistent with the linear theory of a pendulum, which implies that the field-aligned component of gravity is the main restoring force for the prominence longitudinal oscillations, as confirmed by the force analysis. However, the gas pressure gradient becomes significant for short prominences. The oscillation damps with time in the presence of non-adiabatic processes. Radiative cooling is the dominant factor leading to damping. A scaling law for the damping timescale is derived, i.e., τ~ l1.63 D0.66w-1.21v0-0.30, showing strong dependence on the prominence length l, the geometry of the magnetic dip (characterized by the depth D and the width w), and the velocity perturbation amplitude v0. The larger the amplitude, the faster the oscillation damps. We also found that mass drainage significantly reduces the damping timescale when the perturbation is too strong.

Observation and Simulation of Longitudinal Oscillations of an Active Region Prominence

Qingmin **Zhang**, Pengfei Chen, Chun Xia, Rony Keppens

E-print, April **2012**

Filament longitudinal oscillations have been observed on the solar disk in Hα . We intend to find an example of the longitudinal oscillations of a prominence, where the magnetic dip can be seen directly, and examine what is the restoring force of such kind of oscillations. We carry out a multiwavelength data analysis of the active region prominence oscillations above the western limb on **2007 February 8**. Besides, we perform a one-dimensional hydrodynamic simulation of the longitudinal oscillations. The high-resolution observations by Hinode/SOT indicate that the prominence, seen as a concave-inward shape in lower-resolution Extreme Ultraviolet (EUV) images, actually consists of many concave-outward threads, which is indicative of the existence of magnetic dips. After being injected into the dip region, a bulk of prominence material started to oscillate for more than 3.5 hours, with the period being 52 min. The oscillation decayed with time, with the decay timescale being 133 min. Our hydrodynamic simulation can well reproduce the oscillation period, but the damping timescale in the simulation is 1.5 times as long as the observations. The results clearly show the prominence longitudinal oscillations around the dip of the prominence and our study suggests that the restoring force of the longitudinal oscillations might be the gravity. Radiation and heat conduction are insufficient to explain the decay of the oscillations. Other mechanisms, such as wave leakage and mass accretion, have to be considered. The possible relation between the longitudinal oscillations and the later eruption of a prominence thread, as well as a coronal mass ejection (CME), is also discussed.

REVISION OF SOLAR SPICULE CLASSIFICATION

Y. Z. **Zhang**1,2, K. Shibata2, J. X. Wang1, X. J. Mao1,3, T. Matsumoto4, Y. Liu5, and J. T. Su

2012 ApJ 750 16

Solar spicules are the fundamental magnetic structures in the chromosphere and may play a key role in channeling the chromosphere and corona. Recently, it was suggested by De Pontieu et al. that there were two types of spicules with very different dynamic properties, which were detected by the space-time plot technique in the Ca II H line (3968 Å) wavelength from Hinode/Solar Optical Telescope observations. A "Type I" spicule with a 3-7-minute lifetime undergoes a cycle of upward and downward motions; by contrast, a "Type II" spicule fades away within dozens of seconds without a descending phase. We are motivated by the fact that for a spicule with complicated three-dimensional motion the space-time plot, which is made through a slit on a fixed position, could not match the spicule behavior all the time and might lose its real life story. By revisiting the same data sets, we identify and trace 105 and 102 spicules in the quiet Sun (QS) and coronal hole (CH), respectively, and obtain their statistical dynamic properties. First, we have not found a single convincing example of "Type II" spicules. Second, more than 60% of the identified spicules in each region show a complete cycle, i.e., the majority are "Type I" spicules. Third, the lifetimes of the spicules in the QS and CH are 148 s and 112 s, respectively, but there is no fundamental lifetime difference between the spicules in the QS and CH reported earlier. Therefore, the suggestion of coronal heating by "Type II" spicules should be taken with caution.

Numerical Simulations of Helicity Condensation in the Solar Corona

L. **Zhao**1, C. R. DeVore2, S. K. Antiochos2, and T. H. Zurbuchen

2015 ApJ 805 61

The helicity condensation model has been proposed by Antiochos to explain the observed smoothness of coronal loops and the observed buildup of magnetic shear at filament channels. The basic hypothesis of the model is that magnetic reconnection in the corona causes the magnetic stress injected by photospheric motions to collect only at those special locations where prominences are observed to form. In this work we present the first detailed quantitative MHD simulations of the reconnection evolution proposed by the helicity condensation model. We use the well-known ansatz of modeling the closed corona as an initially uniform field between two horizontal photospheric plates. The system is driven by applying photospheric rotational flows that inject magnetic helicity into the corona. The flows are confined to a finite region on the photosphere so as to mimic the finite flux system of a bipolar active region, for example. The calculations demonstrate that, contrary to common belief, opposite helicity twists do not lead to significant reconnection in such a coronal system, whereas twists with the same sense of helicity do produce substantial reconnection. Furthermore, we find that for a given amount of helicity injected into the corona, the evolution of the magnetic shear is insensitive to whether the pattern of driving photospheric motions is fixed or quasi-random. In all cases, the shear propagates via reconnection to the boundary of the flow region while the total magnetic helicity is conserved, as predicted by the model. We discuss the implications of our results for solar observations and for future, more realistic simulations of the helicity condensation process.

Developing an Automated Detection, Tracking and Analysis Method for Solar Filaments Observed by CHASE via Machine Learning

Z. **Zheng**, Q. Hao, Y. Qiu, J. Hong, C. Li, M.D. Ding

ApJ **2024**

https://arxiv.org/pdf/2402.14209.pdf

Studies on the dynamics of solar filaments have significant implications for understanding their formation, evolution, and eruption, which are of great importance for space weather warning and forecasting. The Hα Imaging Spectrograph (HIS) onboard the recently launched Chinese Hα Solar Explorer (CHASE) can provide full-disk solar

Hα spectroscopic observations, which bring us an opportunity to systematically explore and analyze the plasma dynamics of filaments. The dramatically increased observation data require automate processing and analysis which are impossible if dealt with manually. In this paper, we utilize the U-Net model to identify filaments and implement the Channel and Spatial Reliability Tracking (CSRT) algorithm for automated filament tracking. In addition, we use the cloud model to invert the line-of-sight velocity of filaments and employ the graph theory algorithm to extract the filament spine, which can advance our understanding of the dynamics of filaments. The favorable test performance confirms the validity of our method, which will be implemented in the following statistical analyses of filament features and dynamics of CHASE/HIS observations. 2023 January 19, 2023 April 25, 16 Sep 2023

Comparison of damping models for kink oscillations of coronal loops

Yu **Zhong**,1 Dmitrii Y. Kolotkov , 1,2 Sihui Zhong 1 and Valery M. Nakariakov
Monthly Notices of the Royal Astronomical Society, Volume 525, Issue 4, 2023, Pages 5033–5040,
https://doi.org/10.1093/mnras/stad2598
https://watermark.silverchair.com/stad2598.pdf
https://warwick.ac.uk/fac/sci/physics/research/cfsa/people/valery/zhong_y_23.pdf
Kink oscillations of solar coronal loops are of intense interest due to their potential for diagnosing plasma parameters in the corona. The accurate measurement of the kink oscillation damping time is crucial for precise seismological diagnostics, such as the transverse density profile, and for the determination of the damping mechanism. Previous studies of large-amplitude rapidly decaying kink oscillations have shown that both an exponential damping model and a generalized model (consisting of Gaussian and exponential damping patterns) fit observed damping profiles sufficiently well. However, it has recently been shown theoretically that the transition from the decaying regime to the decayless regime could be characterized by a superexponential damping model. In this work, we reanalyse a sample of decaying kink oscillation events, and utilize the Markov chain Monte Carlo Bayesian approach to compare the exponential, Gaussian–exponential, and superexponential damping models. It is found that in 7 out of 10 analysed oscillations, the preferential damping model isthe superexponential one. In two events, the preferential damping is exponential, and in one it is Gaussian–exponential. This finding indicates the plausibility of the superexponential damping model. The possibility of a non-exponential damping pattern needs to be taken into account in the analysis of a larger number of events, especially in the estimation of the damping time and its associated empirical scalings with the oscillation period and amplitude, and in seismological inversions.
2012-05-30, 2015-04-23, 2015-10-02, 2017-09-07
Table 1. Kink oscillation events under study, 2012-2017

Polarisation of decayless kink oscillations of solar coronal loops

Sihui **Zhong**, Valery M. Nakariakov, Dmitrii Y. Kolotkov, Lakshmi Pradeep Chitta, Patrick Antolin, Cis Verbeeck, David Berghmans
Nature Communications **2023**
https://arxiv.org/pdf/2308.10573.pdf
Decayless kink oscillations of plasma loops in the solar corona may contain an answer to the enigmatic problem of solar and stellar coronal heating. The polarisation of the oscillations gives us a unique information about their excitation mechanisms and energy supply. However, unambiguous determination of the polarisation has remained elusive. Here, we show simultaneous detection of a 4-min decayless kink oscillation from two non-parallel lines-of-sights, separated by about 104\textdegree, provided by unique combination of the High Resolution Imager on Solar Orbiter and the Atmospheric Imaging Assembly on Solar Dynamics Observatory. The observations reveal a horizontal or weakly oblique linear polarisation of the oscillation. This conclusion is based on the comparison of observational results with forward modelling of the observational manifestation of various kinds of polarisation of kink oscillations. The revealed polarisation favours the sustainability of these oscillations by quasi-steady flows which may hence supply the energy for coronal heating. **1 Apr 2022**

First Detection of Kink Oscillations with Solar Orbiter

Sihui **ZHONG** et al.
RHESSI Science Nuggets №436 **2022**
https://sprg.ssl.berkeley.edu/~tohban/wiki/index.php/First_Detection_of_Kink_Oscillations_with_Solar_Orbiter
5-6 Nov 2021

Comparison of damping models for kink oscillations of coronal loops

Yu **Zhong**,1 Dmitrii Y. Kolotkov,1,2 Sihui Zhong1 and Valery M. Nakariakov1,3
MNRAS **2023**
https://warwick.ac.uk/fac/sci/physics/research/cfsa/people/valery/zhong_y_23.pdf
Kink oscillations of solar coronal loops are of intense interest due to their potential for diagnosing plasma parameters in the corona. The accurate measurement of the kink oscillation damping time is crucial for precise seismological diagnostics, such as the transverse density profile, and for the determination of the damping

mechanism. Previous studies of large-amplitude rapidly-decaying kink oscillations have shown that both an exponential damping model and a generalised model (consisting of Gaussian and exponential damping patterns) fit observed damping profiles sufficiently well. However, it has recently been shown theoretically that the transition from the decaying regime to the decayless regime could be characterised by a super-exponential damping model. In this work, we re-analyse a sample of decaying kink oscillation events, and utilise the Markov Chain Monte Carlo Bayesian approach to compare the exponential, Gaussian–exponential and super-exponential damping models. It is found that in seven out of **ten analysed oscillations**, the preferential damping model is the super-exponential one. In two events, the preferential damping is exponential, and in one it is Gaussian–exponential. This finding indicates the plausibility of the superexponential damping model. The possibility of a non-exponential damping pattern needs to be taken into account in the analysis of a larger number of events, especially in the estimation of the damping time and its associated empirical scalings with the oscillation period and amplitude, and in seismological inversions.
2012 May 30, 2015 Apr 23, 2015 Oct 02, 2017 Sep 07
Table 1. Kink oscillation events under study, randomly selected from the catalogue (Nechaeva et al. 2019).

Two-Spacecraft Detection of Short-period Decayless Kink Oscillations of Solar Coronal Loops

Sihui **Zhong**, Valery M. Nakariakov, Dmitrii Y. Kolotkov, Cis Verbeeck, David Berghmans
MNRAS Volume 516, Issue 4 Pages 5989–5996 **2022**
https://arxiv.org/pdf/2209.01917.pdf
https://doi.org/10.1093/mnras/stac2545
Decayless kink oscillations of an ensemble of loops are captured simultaneously by the High Resolution Imager (HRI) of the Extreme Ultraviolet Imager (EUI) and the Atmospheric Imaging Assembly (AIA) from 22:58 UT on 5 November to 00:27 UT on 6 November 2021. Oscillations are analysed by processing image sequences taken by the two instruments with a motion magnification technique. The analysed loops are around 51 Mm in length, and oscillate with short periods of 1-3 min (1.6 min in average) and displacement amplitudes of 27-83 km. The signals recorded by AIA are delayed by 66 s as compared to HRI, which coincides with the light travel time difference from the Sun to each instrument. After correction of this time difference, the cross-correlation coefficient between the signals from the two data varies from 0.82 to 0.97, indicating that they are well consistent. This work confirms that HRI sees the same oscillations as AIA, which is the necessary first step before proceeding to the detection of shorter time scales by EUI. In addition, our results indicate the robustness of the de-jittering procedure in the study of kink oscillations with HRI. **5-6 Nov 2021**

Long-term evolution of decayless kink oscillations of solar coronal loops

Sihui **Zhong**, Valery M Nakariakov, Dmitrii Y Kolotkov, Sergey A Anfinogentov
Monthly Notices of the Royal Astronomical Society, Volume 513, Issue 2, June **2022**, Pages 1834–1841,
https://doi.org/10.1093/mnras/stac1014
Long-term evolution of instantaneous parameters of decayless kink oscillations of six solar coronal loops observed for longer than 2 h each is studied. The oscillations are analysed by processing sequences of 171 Å images obtained with the Solar Dynamics Observatory (SDO)/Atmospheric Imaging Assembly (AIA) in the time interval from 2020 December till 2021 June, with the motion magnification technique. It is established that decayless kink oscillations could exist for more than 30 or 40 oscillation cycles. Neither the loop brightness nor instantaneous parameters of the oscillations show a monotonic increase or decrease during the oscillation. The observed instantaneous oscillation periods and amplitudes are found to vary randomly in time, with distributions around the mean values that resemble Gaussian profiles. Mean values of the oscillation periods and amplitudes are consistent with previous observations of this phenomenon. A power-law dependence of the oscillation period on the displacement amplitude is found, with the power-law index of 0.41 and with the 95 per cent confidence interval of [0.39, 0.71]. In general, we established the lack of correlation between instantaneous oscillation parameters and loop brightness. One exception is an event with relatively strong anticorrelation of the amplitude and the loop's brightness, with the cross-correlation coefficient of about −0.81, but this effect requires a further study. Fourier power spectra of the envelopes of the time-evolving instantaneous amplitudes and periods are white noise, indicating that consecutive values of the instantaneous parameters are independent of each other. The results obtained provide an empirical ground for validating and comparing existing and future theoretical models of decayless kink oscillations of coronal loops.

Motion Magnification in Solar Imaging Data Sequences in the Sub-pixel Regime

Sihui **Zhong**, Timothy J. Duckenfield, Valery M. Nakariakov & Sergey A. Anfinogentov
Solar Physics volume 296, Article number: 135 (**2021**)
https://link.springer.com/content/pdf/10.1007/s11207-021-01870-w.pdf
https://doi.org/10.1007/s11207-021-01870-w
The capability of the motion-magnification technique for the detection of transverse oscillations, such as kink oscillations of solar coronal loops observed with an imaging telescope, in the sub-pixel regime is investigated. The technique is applied to artificial-image sequences imitating harmonic transverse displacements of the loop, observed

in the optically thin regime. Motion magnification is found to work well on the analysis of sub-pixel, ≥0.01≥0.01 pixel oscillations, and it is characterised by linear scaling between the magnified amplitude and input amplitude. Oscillations of loops with transverse density profiles of different steepness are considered. After magnification, the original transverse profiles are preserved sufficiently well. The motion-magnification performance is found to be robust in noisy data, for coloured noise with spectral indices ranging from 0 to 3, and additional Poisson noise with a signal-to-background-noise ratio down to unity. Our findings confirm the reliability of the motion-magnification technique for applications in magnetohydrodynamic seismology of the solar corona.

Winking filaments due to cyclic evaporation-condensation

Yuhao **Zhou**, Xiaohong Li, Jie Hong, Rony Keppens
A&A 675, A31 **2023**
https://arxiv.org/pdf/2305.13237.pdf
https://www.aanda.org/articles/aa/pdf/2023/07/aa46004-23.pdf

Observations have shown that some filaments appear and disappear in the Hα line wing images periodically. There have been no attempts to model these "winking filaments" thus far. The evaporation--condensation mechanism is widely used to explain the formation of solar filaments. Here, we demonstrate, for the first time, how multi-dimensional evaporation--condensation in an arcade setup invariably causes a stretching of the magnetic topology. We aim to check whether this magnetic stretching during cyclic evaporation--condensation could reproduce a winking filament. We used our open-source code MPI-AMRVAC to carry out 2D magnetohydrodynamic simulations based on a quadrupolar configuration. A periodic localized heating, which modulates the evaporation--condensation process, was imposed before, during, and after the formation of the filament. Synthetic Hα and 304 Å, images were produced to compare the results with observations. For the first time, we noticed the winking filament phenomenon in a simulation of the formation of on-disk solar filaments, which was in good agreement with observations. Typically, the period of the winking is different from the period of the impulsive heating. A forced oscillator model explains this difference and fits the results well. A parameter survey is also done to look into details of the magnetic stretching phenomenon. We found that the stronger the heating or the higher the layer where the heating occurs, the more significant the winking effect appears.

Measuring three-dimensional shapes of stable solar prominences using stereoscopic observations from SDO and STEREO

Chengrui **Zhou**, Chun Xia, Yuandeng Shen
A&A 647, A112 **2021**
https://arxiv.org/pdf/2103.07111.pdf
https://doi.org/10.1051/0004-6361/202039558
https://www.aanda.org/articles/aa/pdf/2021/03/aa39558-20.pdf

Although the real shapes and trajectories of erupting solar prominences in three dimensions have been intensively studied, the three-dimensional (3D) shapes of stable prominences before eruptions have not been measured accurately so far. We intend to make such a measurement to constrain 3D prominence models and to extend our knowledge of prominences. Using multiperspective observations from the Atmospheric Imaging Assembly on board SDO and the Extreme Ultraviolet Imager on board STEREO, we reconstructed 3D coordinates of three stable prominences: a quiescent, an intermediate, and a mixed type. Based on the 3D coordinates, we measured the height, length, and inclination angle of the legs of these prominences. To study the spatial relationship between the footpoints of prominences and photospheric magnetic structures, we also used the Global Oscillation Network Group H alpha images and magnetograms from the HMI on board the SDO. In three stable prominences, we find that the axes of the prominence legs are inclined by 68 degrees on average to the solar surface. Legs at different locations along a prominence axis have different heights with a two- to threefold difference. Our investigation suggests that over 96% of prominence footpoints in a sample of 70 footpoints are located at supergranular boundaries. The widths of two legs have similar values measured in two orthogonal lines of sight. We also find that a prominence leg above the solar limb showed horizontal oscillations with larger amplitudes at higher locations. With a limited image resolution and number of cases, our measurement suggests that the legs of prominences may have various orientations and do not always stand vertically on the surface of the sun. Moreover, the locations of prominence legs are closely related to supergranules. **November 15-19, 2011 , February 9, 2012 , May 25, 2012**

Simulations of solar filament fine structures and their counterstreaming flows

Y. H. **Zhou**, P. F. Chen, J. Hong, C. Fang
2020, Nature Astronomy, 4, 994
https://arxiv.org/pdf/2104.13564.pdf
https://www.nature.com/articles/s41550-020-1094-3

Solar filaments, also called solar prominences when appearing above the solar limb, are cold, dense materials suspended in the hot tenuous solar corona, consisting of numerous long, fibril-like threads. These threads are the key to disclosing the physics of solar filaments. Similar structures also exist in galaxy clusters. Besides their mysterious formation, filament threads are observed to move with alternating directions, which are called counterstreaming flows. However, the origin of these flows has not been clarified yet. Here we report that turbulent heating at the solar surface is the key, which randomly evaporates materials from the solar surface to the corona, naturally reproducing the formation and counterstreamings of the sparse threads in the solar corona. We further suggest that while the cold Hα counterstreamings are mainly due to longitudinal oscillations of the filament threads, there are million-kelvin counterstreamings in the corona between threads, which are alternating unidirectional flows.

Three-dimensional MHD Simulations of Solar Prominence Oscillations in a Magnetic Flux Rope

Yu-Hao **Zhou**, C. Xia, R. Keppens, C. Fang, P. F. Chen

ApJ **856** 179 **2018**

https://arxiv.org/pdf/1803.03385.pdf

http://sci-hub.tw/http://iopscience.iop.org/0004-637X/856/2/179/

Solar prominences are subject to all kinds of perturbations during their lifetime, and frequently demonstrate oscillations. The study of prominence oscillations provides an alternative way to investigate their internal magnetic and thermal structures as the oscillation characteristics depend on their interplay with the solar corona. Prominence oscillations can be classified into longitudinal and transverse types. We perform three-dimensional ideal magnetohydrodynamic simulations of prominence oscillations along a magnetic flux rope, with the aim to compare the oscillation periods with those predicted by various simplified models and to examine the restoring force. We find that the longitudinal oscillation has a period of about 49 minutes, which is in accordance with the pendulum model where the field-ligned component of gravity serves as the restoring force. In contrast, the horizontal transverse oscillation has a period of about 10 minutes and the vertical transverse oscillation has a period of about 14 minutes, and both of them can be nicely fitted with a two-dimensional slab model. We also find that the magnetic tension force dominates most of the time in transverse oscillations, except for the first minute when magnetic pressure overwhelms.

Solar Filament Longitudinal Oscillations along a Magnetic Field Tube with Two Dips

Yu-Hao **Zhou**, Li-Yue Zhang, Y. Ouyang, P. F. Chen, C. Fang

ApJ **839** 9 **2017**

https://arxiv.org/pdf/1703.06560.pdf

The large-amplitude longitudinal oscillations of solar filaments have been observed and explored for more than ten years. Previous studies are mainly based on the one-dimensional rigid flux tube model with a single magnetic dip. However, it is noticed that there might be two magnetic dips, and hence two threads, along one magnetic field line. Following the previous work, we intend to investigate the kinematics of the filament longitudinal oscillations when two threads are magnetically connected, which is done by solving one-dimensional radiative hydrodynamic equations with the numerical code MPI-AMRVAC. Two different types of perturbations are considered, and the difference from previous works resulting from the filament thread-thread interaction is investigated. We find that even with the inclusion of the thread-thread interaction, the oscillation period is modified weakly, by at most 20% compared to the traditional pendulum model with one thread. However, the damping timescale is significantly affected by the thread-thread interaction. Hence, we should take it into account when applying the consistent seismology to the filaments where two threads are magnetically connected.

An Observational Study of the Recurring Formation and Dissipation of a Dynamic Filament

Guiping **Zhou**, Jingxiu Wang, Jie Zhang

Solar Phys. Volume 291, Issue 8, pp 2373–2390 **2016**

Based on observations at the \(\mbox{H}\upalpha\) wavelength from the Hinode spacecraft, we report here the detailed process of a dynamical filament that showed repeated appearance and dissipation in a filament channel. First, \(\mbox{H}\upalpha\) short fibrils spreading in the pre-formed filament channel joined into longer threads. The joining process was found to be accompanied by small-scale brightening activity, indicating the possible involvement of magnetic reconnection. The forming filament was thickened by merging the neighboring dark threads that were nearly parallel to the axis and also those adjacent to its main endpoints. The formed filament as a single coherent structure only existed for tens of minutes, immediately followed by the dissipation. The dissipation appeared to start with expansion of the filament body, ascending and stripping away of the filament threads, and mass drainage along the legs of the filament. The formation–dissipation process of the filament was repeated three times within the four-hour observational window of Hinode. These observations indicate that the filament structure is highly dynamic. This study provides the observational evidence to confirm the hypothesis of Martin et al. (Ann. Geophys.26, 3061, 2008) on the irreversible build-up of magnetic fields in the corona by discrete threads or groups of threads ascending bodily into the corona. **2 December 2007**

Quasi-Simultaneous Flux Emergence in the Events of October – November 2003
Guiping **Zhou** · Jingxiu Wang · Yuming Wang · Yuzong Zhang
Solar Phys (**2007**) 244: 13–24; **File**
From late October to the beginning of November 2003, a series of intense solar eruptive events took place on the Sun. More than six active regions (ARs), including three large ARs (NOAA numbers AR 10484, AR 10486, and AR 10488), were involved in the activity. Among the six ARs, four of them bear obviously quasi-simultaneous emergence of magnetic flux. Based on the global H*α* and SOHO/EIT EUV observations, we found that a very long filament channel went through the six ARs. This implies that there is a magnetic connection among these ARs. The idea of large-scale magnetic connectivity among the Ars is supported by the consistency of the same chirality in the three major ARs and in their associated magnetic clouds. Although the detailed mechanisms for the quasi-simultaneous flux emergence and the large-scale flux system formation need to be extensively investigated, the observations provide new clues in studying the global solar activity.

Two Successive Coronal Mass Ejections Driven by the Kink and Drainage Instabilities of an Eruptive Prominence
G. P. **Zhou**, J. X. Wang, J. Zhang, P. F. Chen, H. S. Ji, and K. Dere
The Astrophysical Journal, 651:1238-1244, **2006**

Solar Filament Recognition Based on Deep Learning
Gaofei **Zhu**, Ganghua Lin, Dongguang Wang, Suo Liu, Xiao Yang
Solar Physics September **2019**, 294:117
https://link.springer.com/content/pdf/10.1007%2Fs11207-019-1517-4.pdf
https://arxiv.org/pdf/1909.06580.pdf
The paper presents a reliable method using deep learning to recognize solar filaments in Hαα full-disk solar images automatically. This method cannot only identify filaments accurately but also minimize the effects of noise points of the solar images. Firstly, a raw filament dataset is set up, consisting of tens of thousands of images required for deep learning. Secondly, an automated method for solar filament identification is developed using the U-Net deep convolutional network. To test the performance of the method, a dataset with 60 pairs of manually corrected Hαα images is employed. These images are obtained from the Big Bear Solar Observatory/Full-Disk H-alpha Patrol Telescope (BBSO/FDHA) in 2013. Cross-validation indicates that the method can efficiently identify filaments in full-disk Hαα images.

THE ORIGIN OF POLAR STREAMERS IN THE SOLAR CORONA
A. N. **Zhukov**,1, 2 F. Saez,3 P. Lamy,3 A. Llebaria,3 and G. Stenborg
The Astrophysical Journal, 680:1532-1541, 2008
http://www.journals.uchicago.edu/doi/pdf/10.1086/587924
We investigate the large-scale three-dimensional (3D) structure of the solar corona near the maximum of the 23rd solar cycle in an attempt to determine the origin of polar streamers. We use a model that allows us to simulate the quasi-stationary configuration of the large-scale coronal density distribution. The coronal neutral line, as given by the potential field source surface (PFSS) model, serves as a proxy for mid- and low-latitude current sheets.We investigate the contribution of possible polar coronal current sheets associated with large-scale photospheric magnetic neutral lines around the poles of the Sun (polar crown neutral lines). Positions of polar neutral lines are radially extrapolated outward to obtain the configuration of polar current sheets. Coronal plasma sheets are centered around introduced current sheets. Streamer positions during Carrington rotation 1965, near the activity maximum, are calculated. Simulated synoptic maps of the coronal brightness are compared with those obtained from observations by the LASCO C2 coronagraph on board the SOHO spacecraft. We demonstrate that polar streamers are ‘‘classical’’ streamers situated above low-lying loops (observed by SOHO EIT) connecting the regions of opposite magnetic polarity on two sides of polar crown neutral lines. Polar streamer configurations obtained from our model are close to those observed by LASCO. Our results suggest that the PFSS model cannot adequately describe the configuration of streamers during the epoch of high solar activity. The representation of the streamer belt as a single tilted and warped current sheet becomes questionable. Multiple coronal current sheets may better correspond to the observed streamer configurations.

Can Injection Model Replenish the Filaments in Weak Magnetic Environment?
Peng **Zou**, Chaowei Jiang, Fengsi Wei, Wenda Cao
Research in Astronomy and Astrophysics **2019**
https://arxiv.org/pdf/1901.00659.pdf

We observed an Hα surge occurred in the active region NOAA 12401 on **2015 August 17**, and discuss its trigger mechanism, kinematic and thermal properties. It is suggested that this surge is caused by a chromospheric reconnection which ejects cool and dense material with the transverse velocity about 21-28 km s−1 and the initial doppler velocity of 12 km s−1. This surge is similar to the injection of newly formed filament materials from their footpoints, except that the surge here occurred in a relatively weak magnetic environment of ~100 G. Thus we discuss the possibility of filament material replenishment via the erupting mass in such a weak magnetic field, which is often associated with quiescent filaments. It is found that the local plasma can be heated up to about 1.3 times of original temperature, which results in an acceleration about -0.017 km s−2. It can lift the dense material up to 10 Mm and higher with a inclination angle smaller than 50∘, namely typical height of active region filaments. But it can hardly inject the material up to those filaments higher than 25 Mm, namely some quiescent filaments. Thus we think injection model does not work well in the formation of quiescent filaments.

Magnetic separatrix as the source region of the plasma supply for an active-region filament

P. **Zou**, C. Fang, P. F. Chen, K. Yang, Wenda Cao

ApJ **836** 122 **2017**

https://arxiv.org/pdf/1701.01526v1.pdf

Solar filaments can be formed via chromospheric evaporation followed by condensation in the corona or by the direct injection of cool plasma from the chromosphere to the corona. In this paper, with high-resolution Hα data observed by the 1.6 m New Solar Telescope of the Big Bear Solar Observatory on **2015 August 21**, we confirmed that an active-region filament is maintained by the continuous injection of cold chromospheric plasma. We find that the filament is rooted along a bright ridge in Hα, which corresponds to the intersection of a magnetic quasi-separatrix layer with the solar surface. This bright ridge consists of many small patches and the sizes of these patches are comparable to the width of the filament threads. It is found that upflows originate from the brighter patches of the ridge, whereas the downflows move toward the weaker patches of the ridge. The whole filament is composed of two opposite directional streams, implying that longitudinal oscillations are not the only cause of the counterstreamings, and unidirectional siphon flows with alternative directions are another possibility.

MATERIAL SUPPLY AND MAGNETIC CONFIGURATION OF AN ACTIVE REGION FILAMENT

P. **Zou**1,2,3, C. Fang1,2,3, P. F. Chen1,2,3, K. Yang1,2,3, Q. Hao1,2,3, and Wenda Cao4

2016 ApJ 831 123

https://arxiv.org/pdf/1701.02407v1.pdf

It is important to study the fine structures of solar filaments with high-resolution observations, since it can help us understand the magnetic and thermal structures of the filaments and their dynamics. In this paper, we study a newly formed filament located inside the active region NOAA 11762, which was observed by the 1.6 m New Solar Telescope at Big Bear Solar Observatory from 16:40:19 UT to 17:07:58 UT on **2013 June 5**. As revealed by the Hα filtergrams, cool material is seen to be injected into the filament spine with a speed of 5–10 km s−1. At the source of the injection, brightenings are identified in the chromosphere, which are accompanied by magnetic cancellation in the photosphere, implying the importance of magnetic reconnection in replenishing the filament with plasmas from the lower atmosphere. Counter-streamings are detected near one endpoint of the filament, with the plane-of-the-sky speed being 7–9 km s−1 in the Hα red-wing filtergrams and 9–25 km s−1 in the blue-wing filtergrams. The observations are indicative that this active region filament is supported by a sheared arcade without magnetic dips, and the counter-streamings are due to unidirectional flows with alternative directions, rather than due to the longitudinal oscillations of filament threads as in many other filaments.

Mid-term periods of solar filaments†

Peng **Zou**1,2 andQixiu Li

JGR, **2014**

http://onlinelibrary.wiley.com/doi/10.1002/2014JA020304/pdf

On the basis of the Carte Synoptique catalogue of solar filaments from March 1919 to December 1989, we measure power spectra of detrended full-disk (FSFNs, latitudinal bands: 0°–90°), low-latitude (LSFNs, latitudinal bands: <50°) and high-latitude (HSFNs, latitudinal bands: ≥50°) solar filament numbers by Maximum Entropy Method (MEM) and Continuous wavelet transform (CWT) to detect mid-term periods. It is found as following: 1. FSFNs and LSFNs have same mid-term periodicity, while HSFNs show a different mid-range periodicity. Some periods frequently mentioned in other solar indices are also detected from the solar filament numbers, such as 2-3 years period (quasi-biennial oscillation - QBO), ~1.7-yr, ~1.3-yr, ~1-yr, 150-157 days period (Rieger period) and 6.0-6.4 months (Rieger type period). These periods are intermittent during considered time span. Some of them are missing in some Solar cycles. 2. QBO is detected from total data and most Solar cycles of FSFNs, LSFNs and HSFNs. It maybe relates to oscillation of magnetic field of Solar surface. 3. ~1.3-yr period occasionally appears, but ~1.7-yr period is hardly seen. These two periods probably are seasonal effects. 4. ~1-yr period is detected from both total data and every Solar cycle of FSFNs and LSFNs, but hardly detected from HSFNs. It is perhaps connected with sunspot activity. 5. Rieger period of 5.0-5.2 months is detected in total data and even Solar cycles of HSFNs. Rieger type period of 6.0-6.4 months is found in total data and most Solar cycles except cycle 18 of LSFNs and FSFNs. These periods seem to be subharmonics of ~11-yr period.

An MHD Study of Large-Amplitude Oscillations in Solar Filaments

Ernesto **Zurbriggen**, Mariana Cécere, María Valeria Sieyra, Gustavo Krause, Andrea Costa & C. Guillermo Giménez de Castro

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https://link.springer.com/content/pdf/10.1007/s11207-021-01908-z.pdf
https://doi.org/10.1007/s11207-021-01908-z

Quiescent filaments are usually affected by internal and/or external perturbations triggering oscillations of different kinds. In particular, external large-scale coronal waves can perturb remote quiescent filaments leading to large-amplitude oscillations. Observational reports have indicated that the activation time of oscillations coincides with the passage of a large-scale coronal wavefront through the filament, although the disturbing wave is not always easily detected. Aiming to contribute to understanding how –and to what extent– coronal waves are able to excite filament oscillations, here we modelled with 2.5D magnetohydrodynamic simulations a filament floating in a gravitationally stratified corona disturbed by a coronal shock wave. This simplified scenario results in a two-coupled-oscillation pattern of the filament, which is damped in a few cycles, enabling a detailed analysis. A parametric study was carried out varying parameters of the scenario such as height, size, and mass of the filament. An oscillatory analysis reveals a general tendency for periods of oscillations, amplitudes, and damping times to increase with height, whereas filaments of larger radius exhibit shorter periods and smaller amplitudes. The calculation of forces exerted on the filament shows that the main restoring force is the magnetic tension.

The role of photospheric shearing motions in a filament eruption related to the 2010 April 3 coronal mass ejection A28

F. P. **Zuccarello**, P. Romano, F. Zuccarello and S. Poedts

A&A 537, A28 (**2012**)

Context. Coronal mass ejections (CMEs) are huge expulsion of solar plasma and magnetic field in the interplanetary medium. Understanding the physics that lies beyond the CME initiation is one of the most fascinating research questions. Several models have been proposed to explain the initiation of CMEs. However, which model better explains the different aspects of the initiation process and the early evolution of the CMEs is a subject of ongoing discussion.
Aims. We investigate the magnetic field evolution of NOAA 11059 in order to provide a further contribution to our understanding of the possible causes and mechanisms that lead to the initiation of the geoeffective CME that occurred on **2010 April 3**.
Methods. Using KSO Hα images we determine the chirality of the active region and some properties of the filament that eventually erupted. Using SOHO/MDI line-of-sight magnetograms we investigate the magnetic configuration of NOAA 11059 by means of both linear force free and potential field extrapolations. We also determine the photospheric velocity maps using the Differential Affine Velocity Estimator (DAVE).
Results. We find that the magnetic configuration of the active region is unstable to the torus instability. Moreover, we find that persistent shearing motions characterized the negative polarity, resulting in a southward, almost parallel to the meridians, drift motion of the negative magnetic field concentrations.
Conclusions. We conclude that persistent and coherent shearing motions played a significant role in facilitating the eruption. These shearing motions increased the axial field of the filament eventually bringing the fluxrope axis to a height where the onset condition for the torus instability was satisfied. Our observations show that both the magnetic configuration of the system and the photopsheric dynamics that preceded the event, were favourable for the eruption to occur.

Filament destabilization and CME release during a long duration flare

F. **Zuccarello**1, L. Contarino1, F. Farnik2, M. Karlicky2, P. Romano3 and I. Ugarte-Urra

A&A 533, A100 (**2011**)

Context. During complex and long duration solar flares, several filament destabilizations or eruptions can occur that are often related to coronal mass ejections (CMEs).
Aims. We describe the study of an X3.8 long duration event (LDE) that occurred in NOAA 10720 on 17 January 2005 and was characterized by three filament destabilizations and two CMEs.
Methods. Using multi-wavelength data provided by both ground-based instruments and satellites, in addition to MDI magnetograms, we investigated the morphological and magnetic evolution of the active region before and during the LDE.
Results. Our analysis of Hα and 1600 Å images showed that initially a two-ribbon structure developed in the central part of the active region, where a filament was previously observed. At a later time, two bright ribbons (in the most eastern side) and a strong brightness increase (at the western outskirt of the active region) were simultaneously

observed. In a subsequent time interval, a new pair of ribbons was observed in the western side of the active region. Moreover, a linear force-free field extrapolation helped identify a null point in the central part of the active region.
Conclusions. The initial filament destabilization that occurred in the central part of NOAA 10720 was probably due to magnetic flux emergence and photospheric shearing motions, which caused a slow tether-cutting process beneath the filament. The rearrangement of the magnetic field configuration, occurring in the same area as the location of the null point, changed the magnetic field connectivity in the active region, triggering two filament eruptions in the eastern and western part of the active region and two halo CMEs, in a kind of domino effect.

Magnetic helicity balance during a filament eruption that occurred in active region NOAA 9682

F. P. **Zuccarello**1,2, P. Romano2, F. Zuccarello3 and S. Poedts

A&A 530, A36 (**2011**), **File**

Context. Photospheric shear plasma flows in active regions may be responsible for the magnetic helicity injection in the solar corona not only during the energy storage process before a solar eruption, but also during and after the release of the free magnetic energy caused by the eruption. Indeed, after a filament eruption or expansion the magnetic torque imbalance can induce shear flows that can be responsible for yet another injection of magnetic helicity into the corona.
Aims. We investigated the magnetic helicity balance in an active region where a confined solar eruption occurred. This was done to verify a possible relationship between the filament expansion and the helicity transport at its footpoints. We aimed to verify if this variation in the helicity transport rate could be interpreted as a consequence of the magnetic torque imbalance caused by the tube expansion, as proposed by Chae et al. (2003, J. Kor. Astron. Soc., 36, 33).
Methods. We used 171ÅTRACE data to measure some geometrical parameters of the new magnetic system produced by a filament eruption that occurred on **2001 November 1** in active region NOAA 9682. We used MDI full disk line-of-sight magnetogram data to measure the accumulation of magnetic helicity in the corona before and after the event.
Results. From the measured expansion factor in the magnetic arcade, visible at 171 Åduring the eruption, we estimated that the resulting torque imbalance at the photosphere ought to lead to the injection of negative helicity following the eruption. We compared this with measurements of the helicity injection using photospheric velocity and magnetogram data.
Conclusions. In contradiction to the expectations from the Chae et al. model, the helicity injection after the eruption was positive. We offer the alternative interpretation that the helicity injection resulted from torque of the opposite sign, generated as the filament lost its negative helicity through magnetic reconnection with its surroundings.

The X17.2 flare occurred in NOAA 10486: an example of filament destabilization caused by a domino effect:

F. **Zuccarello**, P. Romano, F. Farnik, M. Karlicky, L. Contarino, V. Battiato, S.═L. Guglielmino, M. Comparato and I. Ugarte-Urra

A&A 493 (**2009**) 629-637

Context. It is now possible to distinguish between two main models describing the mechanisms responsible for eruptive flares : the standard model, which assumes that most of the energy is released, by magnetic reconnection, in the region hosting the core of a sheared magnetic field, and the breakout model, which assumes reconnection occurs at first in a magnetic arcade overlaying the eruptive features.
Aims. We analyze the phenomena observed in NOAA 10486 before and during an X17.2 flare that occurred on **2003 October 28**, to study the relationship between the pre-flare and flare phases and determine which model is the most suitable for interpreting this event.
Methods. We performed an analysis of multiwavelength data set available for the event using radio data (0.8–4.5 GHz), images in the visible range (WL and H α), EUV images (1600 and 195 Å), and X-ray data, as well as MDI longitudinal magnetograms. We determined the temporal sequence of events occurring before and during the X17.2 flare and the magnetic field configuration in the linear force-free field approximation.
Results. The active region was characterized by a multiple arcade configuration and the X17.2 flare was preceded, by ~2 h, by the partial eruption of one filament. This eruption caused reconnection at null points located in the low atmosphere and a decrease in magnetic tension in the coronal field lines overlaying other filaments present in the active region. As a consequence, these filaments were destabilized and the X17.2 flare occurred.
Conclusions. The phenomena observed in NOAA 10486 before and during the X17.2 flare cannot be explained by a simple scenario such as the standard or breakout model, but instead in terms of a so-called domino effect, involving a sequence of destabilizing processes that triggered the flare.

ВОЛОКНА И ПОДСТИЛАЮЩИЕ ИХ ПОВЕРХНОСТИ ПО НАБЛЮДЕНИЯМ В ЛИНИЯХ НЕ I И Н

БАРАНОВСКИЙ Э.А.1, СТЕПАНЯН Н.Н.1, ТАРАЩУК В.П.1, ШТЕРЦЕР Н.И.

АЖ Том: 94Номер: 1 Год: **2017** Страницы: 80

Вдоль волокон в линии He I 1083 нм наблюдаются яркие полоски. Для волокон в H 656.3 нм они бывают как яркими, так и темными. Диапазон изменения яркости около волокон в линии He I составляет 1.005 □1.10 при среднем значении , а в линии H , соответственно, 0.91 □1.5 от яр
физическое состояние вещества в таких полосках. Для объяснения наблюдаемых особенностей проведены вычисления яркости полосок для различных моделей хромосферы. Рассматривались два типа моделей: во-первых, модели с изменениями температуры или плотности в верхней хромосфере, во-вторых, модели с изменениями температуры в средней и нижней хромосфере. Модели первого типа изменяют яркость в линии He I, не меняя при этом яркость в линии H . Модели второго типа изменяют только яркость H . Используя изменения параметров хромосферы и модели первого и второго типа, мы получили различные комбинации яркостей полосок в линиях He I и H . Для оценки яркости областей рассчитывались профили линий He I и H по соответствующим моделям с использованием не-ЛТР приближения. Сравнение наблюдаемых и вычисленных величин позволяет заключить, что увеличение яркости в линии He I вызвано уменьшением температуры или плотности в верхней хромосфере (в области температур около 10000 □24000 К). Увеличение яркости и потемнения в линии H вызваны увеличением или уменьшением температуры на 800 □1000 К в
яркости полосок от расстояния до центра диска Солнца. Яркость в линии He I увеличивается от центра к краю на 2 □4 . Расчеты измен

СОЛНЕЧНЫЕ ВСПЫШЕЧНЫЕ ЭРУПЦИИ С ДЛИТЕЛЬНОЙ ЭКРАНИРОВКОЙ ИЗЛУЧЕНИЯ В ЛИНИИ HeII 304 ˚А И В МИКРОВОЛНОВОМ ДИАПАЗОНЕ

В. В. **Гречнев**1, И.В.Кузьменко2, И.М.Черток3, А. М. Уралов1

АСТРОНОМИЧЕСКИЙЖУРНАЛ, ***2011****, том 88,№7, с. 692–703*

Извергнутая при солнечных эрупциях плазма с температурами, близкими к хромосферным, может экранировать часть излучения как компактных источников в активных областях, так и областей спокойного Солнца. Явления поглощения могут наблюдаться в микроволновом диапазоне в виде так называемых “отрицательных всплесков”, а также в линии HeII 304 ˚ А. Рассмотрены три эруптивных события, связанных с довольно мощными вспышками. По записям потока “отрицательного всплеска” на нескольких радиочастотах для одного из рассмотренных событий оценены параметры поглощавшего излучение вещества выброса. В единичных событиях обнаружено “разрушение” эруптивного волокна и его распыление в виде облака по огромной поверхности, наблюдаемое в виде грандиозных депрессий излучения в линии HeII 304 ˚ А. Одно из трех известных нам таких событий рассматривается в данной статье, еще одно из рассмотренных – возможный кандидат.

Изгибные колебания несимметричных корональных арок

Н. С. **Петрухин**

Письма в Астрономический журнал, **2014**, С. 416-425

Исследуются собственные колебания корональных арок с постоянной плотностью и переменными магнитными полями, изменяющимися по параболическим законам. С помощью разработанного авторами метода получены волновые уравнения с постоянными коэффициентами, описывающие изгибные колебания симметричных и несимметричных магнитных трубок. Для таких моделей получены аналитические выражения для спектров и амплитуд колебаний, а также величины и направления смещений экстремумов основной и первой мод относительно их значений для однородных трубок. Для первой моды несимметричной петли определена зависимость смещения координаты внутреннего узла от соотношений величин магнитного поля в несимметричных частях, а также отношение значений амплитуды в точках экстремумов.

ПЕРЕСОЕДИНЕНИЕ КОРОНАЛЬНЫХ ПЕТЕЛЬ В НУЛЕВОЙ ТОЧКЕ НАД ЛИМБОМ СОЛНЦА

Филиппов Б.П.

Астрономия-**2018** Том 2 Солнечно-земная физика – современное состояние и перспективы С.246

http://www.izmiran.ru/library/eaas2018/eaas-2018-2.pdf

Observations of the coronal loop dynamics near a saddle-like structure in the corona above the western limb of the Sun on **18 July 2017** are analysed. The structure was clearly outlined by coronal loops with typical coronal temperature no more than 1 MK. Coronal loops converged toward the center of the saddle in the vertical (radial) direction and diverged in the horizontal direction. Velocities of their movement are in the range of 2 – 6 km/s. Potential magnetic field calculations, which use as the boundary condition the SDO/HMI magnetogram taken on July 14, confirmed the presence of the null point at the height of about 120" above the photosphere just at the centre of the saddle structure. The event is a clear example of smooth coronal magnetic field reconnection. No heating manifestations in the reconnection region or magnetically connected areas were observed.

О МОРФОЛОГИЧЕСКИХ ПРИЗНАКАХ КИРАЛЬНОСТИ СОЛНЕЧНЫХ ВОЛОКОН

ФИЛИППОВ Б.П.1

АЖ Том: 94Номер: 10 Год: **2017** Страницы: 883

Детали структуры волокон несомненно отражают такие свойства их магнитного поля, как киральность и спиральность. Однако некоторые морфологические признаки при ограниченном времени наблюдения и недостаточно высоком пространственном разрешении могут интерпретироваться как свидетельства, ведущие к неверным заключениям. Волокна, несмотря на определенное постоянство формы, являются динамическими образованиями с движущимися неоднородностями вдоль составляющих их нитей, поэтому можно наблюдать вещество, сосредоточенное не только в магнитных ямках-ловушках, но и в выпуклых арках. Часто возникают трудности в определении киральности волокон, у которых имеются “аномальные” зубчики, т.е. зубчики, отклоняющиеся в другую сторону от оси, нежели основная масса “нормальных”. На примере простой модели показано, что аномальные зубчики могут существовать в обыкновенном магнитном жгуте, причем отрезки нитей их тонкой структуры ориентированы практически поперек их длины. Тщательный анализ изображений с максимально возможным пространственным разрешением, с динамикой во времени и сопоставлением с наблюдениями в различных спектральных линиях позволяет правильно определить киральность волокон.

НЕЙТРАЛЬНЫЕ ПОВЕРХНОСТИ КОРОНАЛЬНОГО МАГНИТНОГО ПОЛЯ И СОЛНЕЧНЫЕ ВОЛОКНА

ФИЛИППОВ Б.П.

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Проводится сравнение формы солнечных волокон с проекцией участков нейтральной поверхности магнитного поля короны в определенном интервале высот при различных ракурсах наблюдения за счет вращения Солнца. Нейтральные поверхности рассчитываются в потенциальном приближении по фотосферным данным. Сопоставление показывает, что вещество волокон концентрируется в основном вблизи нейтральной поверхности потенциального поля. Сечения нейтральной поверхности горизонтальной плоскостью служат линиями раздела полярностей (ЛРП) вертикального поля на данной высоте. В проекции на диск, нижний край волокна с выступающими по бокам промежуточными “ножками” (barbs) обрисовывается ЛРП на малой высоте, а верхний край касается высокой ЛРП. Все вещество волокна заключено в пространстве между этими двумя линиями. Хотя в действительности структура магнитного поля вблизи волокон очень сильно отличается от структуры потенциального поля, их нейтральные поверхности могут быть подобны и близки, особенно на низких высотах. Этот факт, вероятно, является причиной наблюдаемой корреляции. Ее можно использовать для определения высоты верхнего края волокон над фотосферой при наблюдениях только на диске.

СПОСОБ ОПРЕДЕЛЕНИЯ ВЫСОТЫ ВОЛОКОН НА ДИСКЕ СОЛНЦА

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Сравнение действительной высоты волокна над фотосферой Солнца с его рассчитанной по магнитным данным предельной высотой дает информацию о запасе устойчивости волокна, готовности его к эрупции. Предлагается способ измерения высоты волокон на диске Солнца по сопоставлению положения верхнего края волокна (хребта) с положением линии раздела полярностей потенциального магнитного поля, рассчитанных для различных высот. Та линия, которая ближе всего к хребту волокна, соответствует его высоте. Для проверки предлагаемого метода используются наблюдения в период времени, когда космические аппараты STEREO (Solar Terrestrial Relations Observatory) находились на угловом расстоянии 90° от Земли, обеспечивая “вид сбоку” волокон вблизи центрального меридиана при наблюдениях с поверхности Земли и околоземных орбит. Предлагаемая методика может быть полезной для оценки возможной геоэффективности волокон на диске Солнца.

ВЫСОТА СОЛНЕЧНОГО ВОЛОКНА ПЕРЕД ЭРУПЦИЕЙ

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АЖ, **2013, текст**

Анализируется соотношение высоты солнечного волокна над фотосферой перед эрупцией **21 октября 2010** г.
с критической высотой устойчивого равновесия магнитного жгута в корональном магнитном поле. Наблюдения космических обсерваторий SDO (Solar Dynamic Observatory), SOHO (Solar and Heliospheric Observatory) и STEREO (Solar Terrestrial Relations Observatory) с различных точек зрения в пространстве дают возможность измерить эти параметры с высокой точностью. Показано, что высота волокна медленно возрастала в течение нескольких дней и эрупция наступила, когда она достигла критического значения 80 Мм.

КРУПНОМАСШТАБНЫЕ ЯВЛЕНИЯ НА СОЛНЦЕ, СВЯЗАННЫЕ С ЭРУПЦИЕЙ ВОЛОКОН ВНЕ АКТИВНЫХ ОБЛАСТЕЙ: СОБЫТИЕ 12.09.1999

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*АСТРОНОМИЧЕСКИЙЖУРНАЛ, **2009**, том 86,№4, с. 392–405*

На примере события **12.09.1999** проанализированы крупномасштабные возмущения, связанные с корональными выбросами массы при эрупции волокон вне активных областей. Анализ основан на H*α*-фильтрограммах, изображениях крайнего УФ- и мягкого рентгеновского диапазонов, и данных коронографов. Эрупция волокна происходила в относительно слабых магнитных полях, но сопровождалась более масштабными явлениями, чем вспышечные события. После эрупции в течение нескольких часов развивалась крупномасштабная аркада, основаниями которой были расходящиеся ленты, подобные вспышечным. Объем события был ограничен “волной EIT”, квазистационарной на солнечной поверхности и расширяющейся над лимбом. Событие не имело импульсной компоненты, поэтому “волна EIT” над лимбом — магнитная структура, идентифицированная как фронтальная структура коронального выброса массы, в силу их совпадения по форме, структурным деталям и кинематике. В ареале события наблюдалось три типа диммингов, обусловленных (а) эвакуацией плазмы, (б) нагревом плазмы и ее последующей эвакуацией, (в) поглощением излучения в системе волокон, активизированных эрупцией. Факт возникновения димминга из-за нагрева плазмы был выявлен по данным мягкого рентгеновского диапазона, но он не обнаруживается по четырем каналам EIT. Это ставит вопрос о корректности некоторых выводов, сделанных ранее только по данным EIT. Обусловленные эрупцией трансформации магнитных полей имели место также в стационарной корональной дыре, примыкавшей к ареалу события. Расширение коронального выброса массы является автомодельным и характеризуется быстро уменьшающимся ускорением, что не учитывается широко используемой полиномиальной аппроксимацией.