Coronal holes and bright points

Space Weather Live

https://www.spaceweatherlive.com/en.html

See **https://www.spaceweatherlive.com/en/solar-activity/coronal-holes.html**

- Real-time CH monitor: https://sun.njit.edu/#/monitor
- recorded talks can be found on the HERMES website

https://hermes.epss.ucla.edu/resources.html

- Some synoptic CH maps are available at: https://sun.njit.edu/#/coronal_holes

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HEliospheRic Magnetic Energy Storage and conversion (HERMES) DRIVE Science Center: monthly seminar series

Next seminar in the series: **18 August**, 2021, 11 am Pacific, 2 pm Eastern. = **21 по Москве**

K. Muglach, ***Solar Coronal Hole Boundaries***

Join Zoom Meeting

https://ucla.zoom.us/j/97995095734?pwd=ZlIrSkUvamYzbVJaeUJ3R1Uwb3g0Zz09

Meeting ID: 979 9509 5734

Passcode: 038994

Presentations from the 1st ISWAT Coronal Hole Boundary Working Team Meeting
https://iswat-cospar.org/virtual-meeting-series_S2-01

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*A **poorly defined** trans equatorial coronal hole (CH943) was Earth facing on November 6-8.*

Catalogue of SDO/AIA 193 Å synoptic maps and **coronal holes**
Authors: Illarionov E., Kosovichev A., Tlatov A.
https://sun.njit.edu/#/coronal_holes

CATCH Catalog of Coronal Holes
Collection of Analysis Tools for Coronal Holes
https://github.com/sgheinemann/CATCH

Earth-affecting Solar Transients: A Review of Progresses in Solar Cycle 24

Jie **Zhang**, Manuela Temmer, Nat Gopalswamy, +

https://arxiv.org/ftp/arxiv/papers/2012/2012.06116.pdf **File 2021**

2020 **https://arxiv.org/abs/2012.06116**

Coronal Holes	--	Coronal holes during SDO era list https://cdsarc.unistra.fr/viz-bin/cat/J/other/SoPh/294.144	(Stephan G. Heinemann,
			Temmer, Heinemann, et al. 2019)

Machine-learning approach to identification of coronal holes in solar disk images and synoptic maps

Egor **Illarionov**, Alexander Kosovichev, Andrey Tlatov

ApJ **2020**

https://arxiv.org/pdf/2006.08529.pdf

To make this approach more readily available, we open-sourced the code for synoptic map construction and CHs segmentation in the repository https://github.com/observethesun/synoptic maps and opened free access to ***CHs synoptic maps in the catalog*** https://sun.njit.edu/coronal holes/ available in FITS and JPEG formats.

Recurrent Magnetic Storms: Corotating Solar Wind Streams

Editor(s): Bruce Tsurutani, Robert McPherron, Gang Lu, José H. A. Sobral, Natchimuthukonar Gopalswamy

AGU Monograph, Vol. 167, **2006** (?), 2013

http://onlinelibrary.wiley.com/book/10.1029/GM167

Magnetic Field of Coronal Holes During the Polarity Reversal

V. I. **Abramenko** & R. A. Biktimirova

Geomagnetism and Aeronomy volume 62, pages 869–872 (**2022**)

https://doi.org/10.1134/S0016793222070039

Polar coronal holes are large-scale configurations with open magnetic fields on the surface of the Sun. They are most active during the period of minimum solar activity and almost disappear during the period of maximum solar activity. We present the evolution of two coronal holes that were observed during the polarity reversal of cycle 23. Data were taken from SOHO/MDI/fd and SOHO/EIT/284 Å. These coronal holes had the polarity of the next, 24th, cycle. Instead of localization at the pole, in both cases, the propagation of coronal holes to the opposite hemisphere was observed. Thus, the open magnetic fields actively interacted with the toroidal magnetic field of the active regions during the polarity reversal period.

CHARACTERISTIC LENGTH OF ENERGY-CONTAINING STRUCTURES AT THE BASE OF A CORONAL HOLE

V. I. **Abramenko**1, G. P. Zank2, A. Dosch2, V. B. Yurchyshyn1, P. R. Goode1, K. Ahn1, and W. Cao

2013 ApJ 773 167

An essential parameter for models of coronal heating and fast solar wind acceleration that rely on the dissipation of MHD turbulence is the characteristic energy-containing length λ⊥ of the squared velocity and magnetic field fluctuations (u 2 and b 2) transverse to the mean magnetic field inside a coronal hole (CH) at the base of the corona. The characteristic length scale directly defines the heating rate. We use a time series analysis of solar granulation and magnetic field measurements inside two CHs obtained with the New Solar Telescope at Big Bear Solar Observatory. A data set for transverse magnetic fields obtained with the Solar Optical Telescope/Spectro-Polarimeter on board the Hinode spacecraft was utilized to analyze the squared transverse magnetic field fluctuations . Local correlation tracking was applied to derive the squared transverse velocity fluctuations u 2. We find that for u 2 structures, the Batchelor integral scale λ varies in a range of 1800-2100 km, whereas the correlation length and the e-folding length L vary between 660 and 1460 km. Structures for yield λ 1600 km, 640 km, and L 620 km. An averaged (over λ, , and L) value of the characteristic length of u 2 fluctuations is 1260 ± 500 km, and that of is 950 ± 560 km. The characteristic length scale in the photosphere is approximately 1.5-50 times smaller than that adopted in previous models (3-30 × 103 km). Our results provide a critical input parameter for current models of coronal heating and should yield an improved understanding of fast solar wind acceleration.

TURBULENT DIFFUSION IN THE PHOTOSPHERE AS DERIVED FROM PHOTOSPHERIC BRIGHT POINT MOTION

V. I. **Abramenko**1, V. Carbone2, V. Yurchyshyn1, P. R. Goode1, R. F. Stein3, F. Lepreti2, V. Capparelli2 and A. Vecchio

2011 ApJ 743 133

On the basis of observations of solar granulation obtained with the New Solar Telescope of Big Bear Solar Observatory, we explored proper motion of bright points (BPs) in a quiet-sun area, a coronal hole, and an active region plage. We automatically detected and traced BPs and derived their mean-squared displacements as a function of time (starting from the appearance of each BP) for all available time intervals. In all three magnetic environments, we found the presence of a super-diffusion regime, which is the most pronounced inside the time interval of 10-300 s. Super-diffusion, measured via the spectral index, γ, which is the slope of the mean-squared displacement spectrum, increases from the plage area (γ = 1.48) to the quiet-sun area (γ = 1.53) to the coronal hole (γ = 1.67). We also found that the coefficient of turbulent diffusion changes in direct proportion to both temporal and spatial scales. For the minimum spatial scale (22 km) and minimum time scale (10 s), it is 22 and 19 km2 s–1 for the coronal hole and the quiet-sun area, respectively, whereas for the plage area it is about 12 km2 s–1 for the minimum time scale of 15 s. We applied our BP tracking code to three-dimensional MHD model data of solar convection and found the super-diffusion with γ = 1.45. An expression for the turbulent diffusion coefficient as a function of scales and γ is obtained.

STATISTICAL DISTRIBUTION OF SIZE AND LIFETIME OF BRIGHT POINTS OBSERVED WITH THE NEW SOLAR TELESCOPE

Valentyna **Abramenko**, Vasyl Yurchyshyn, Philip Goode, and Ali Kilcik

Astrophysical Journal Letters, 725:L101–L105, **2010**

We present results of 2 hr non-interrupted observations of solar granulation obtained under excellent seeing conditions
with the largest aperture ground-based solar telescope—the New Solar Telescope (NST)—of Big Bear Solar Observatory. Observations were performed with adaptive optics correction using a broadband TiO filter in the 705.7 nm spectral line with a time cadence of 10 s and a pixel size of 0._0375. Photospheric bright points (BPs) were
detected and tracked. We find that the BPs detected in NST images are cospatial with those visible in *Hinode/*SOT *G*-band images. In cases where *Hinode/*SOT detects one large BP, NST detects several separated BPs. Extended filigree features are clearly fragmented into separate BPs in NST images. The distribution function of BP sizes extends to the diffraction limit of NST (77 km) without saturation and corresponds to a log-normal distribution. The lifetime distribution function follows a log-normal approximation for all BPs with lifetime exceeding 100 s. A majority of BPs are transient events reflecting the strong dynamics of the quiet Sun: 98.6% of BPs live less than 120 s. The longest registered lifetime was 44 minutes. The size and maximum intensity of BPs were found to be proportional to their lifetimes.

Low-Latitude Coronal Holes at the Minimum of the 23rd Solar Cycle

Valentyna **Abramenko**, Vasyl Yurchyshyn, Jon Linker, Zoran Mikić, Janet Luhmann, and Christina O. Lee

ApJ **712** 813-818, **2010**

Low- and mid-latitude coronal holes (CHs) observed on the Sun during the current solar activity minimum (from 2006 September 21, Carrington rotation (CR) 2048, to 2009 June 26, CR 2084) were analyzed using *Solar and Heliospheric Observatory*/Extreme ultraviolet Imaging Telescope and *STEREO-A* SECCHI EUVI data. From both the observations and Potential Field Source Surface modeling, we find that the area occupied by CHs inside a belt of ±40° around the solar equator is larger in the current 2007 solar minimum relative to the similar phase of the previous 1996 solar minimum. The enhanced CH area is related to a recurrent appearance of five persistent CHs, which survived during 7-27 solar rotations. Three of the CHs are of positive magnetic polarity and two are negative. The most long-lived CH was being formed during 2 days and existed for 27 rotations. This CH was associated with fast solar wind at 1 AU of approximately 620 ± 40 km s^{-1}. The three-dimensional magnetohydrodynamic modeling for this time period shows an open field structure above this CH. We conclude that the global magnetic field of the Sun possessed a multi-pole structure during this time period. Calculation of the harmonic power spectrum of the solar magnetic field demonstrates a greater prevalence of multi-pole components over the dipole component in the 2007 solar minimum compared to the 1996 solar minimum. The unusual large separation between the dipole and multi-pole components is due to the very low magnitude of the dipole component, which is three times lower than that in the previous 1996 solar minimum.

Parameters of the Magnetic Flux inside Coronal Holes

Valentyna **Abramenko** · Vasyl Yurchyshyn · Hiroko Watanabe

Solar Phys (**2009**) 260: 43–57

The parameters of the magnetic flux distribution inside low-latitude coronal holes (CHs) were analyzed. A statistical study of 44 CHs based on Solar and Heliospheric Observatory (SOHO)/MDI full disk magnetograms and SOHO/EIT 284Å images showed that the density of the net magnetic flux, *B*net, does not correlate with the associated solar wind speeds, *Vx* . Both the area and net flux of CHs correlate with the solar wind speed and the corresponding spatial Pearson correlation coefficients are 0.75 and 0.71, respectively. A possible explanation for the low correlation between *B*net and *Vx* is proposed. The observed non-correlation might be rooted in the structural complexity of the magnetic field. As a measure of the complexity of the magnetic field, the filling factor, *f (r)*, was calculated as a function of spatial scales. In CHs, *f (r)* was found to be nearly constant at scales above 2 Mm, which indicates a monofractal structural organization and smooth temporal evolution. The magnitude of the filling factor is 0.04 from the *Hinode* SOT/SP data and 0.07 from the MDI/HR data. The *Hinode* data show that at scales smaller than 2 Mm, the filling factor decreases rapidly, which means a multifractal structure and highly intermittent, burst-like energy release regime. The absence of the necessary complexity in CH magnetic fields at scales above 2 Mm seems to be the most plausible reason why the net magnetic flux density does not seem to be related to the solar wind speed: the energy release dynamics, needed for solar wind acceleration, appears to occur at small scales below 1 Mm.

Table, 2001-2006

The Rate of Emergence of Magnetic Dipoles in Coronal Holes and Adjacent Quiet-Sun Regions –

Abramenko, V. I.; Fisk, L. A.; Yurchyshyn, V. B. E-print, Oct 2006

PROPERTIES OF MAGNETIC FIELDS IN CORONAL HOLES AND GEOEFFECTIVE DISTURBANCES IN SOLAR CYCLE 24

Maria **Abunina**, Artem Abunin, Anatoly Belov, Sergey Gaidash, Yordan Tassev* , Peter I.Y. Velinov*, Lachezar Mateev*, Peter Tonev*

Comptes rendus de l'Academie bulgare des Sciences Tome 67, No 5, **2014**

http://spaceweather.izmiran.ru/papers/abunina2014.pdf

The coronal holes (CH) are sources of high-speed flows of solar wind, and, in its turn, are one of the main sources of geomagnetic disturbances. The coronal holes differ very much one from another and their geoeffectivity varies in a wide range. In this paper we implement a study to answer the question how the coronal holes characterized by different location on the Sun and by their polarity influence the geomagnetic activity. We considered 53 coronal holes observed in the period 2011-2012 of solar cycle 24, and separated them into groups by the heliolatitude and their polarity. A conclusion is made that the trans-equatorial group is the most effective one. Less, but yet sufficiently effective, are the holes of negative polarity at north latitudes and those of positive polarity at south latitudes. The much smaller number of coronal holes of opposite polarity (CH of negative polarity in south hemisphere and CH of positive one in north hemisphere) are less effective

A Small-scale Eruption Leading to a Blowout Macrospicule Jet in an On-disk Coronal Hole

Mitzi **Adams**, Alphonse C. Sterling, Ronald L. Moore, and G. Allen Gary

2014 ApJ 783 11

We examine the three-dimensional magnetic structure and dynamics of a solar EUV-macrospicule jet that occurred on **2011 February 27** in an on-disk coronal hole. The observations are from the Solar Dynamics Observatory (SDO) Atmospheric Imaging Assembly (AIA) and the SDO Helioseismic and Magnetic Imager (HMI). The observations reveal that in this event, closed-field-carrying cool absorbing plasma, as in an erupting mini-filament, erupted and opened, forming a blowout jet. Contrary to some jet models, there was no substantial recently emerged, closed, bipolar-magnetic field in the base of the jet. Instead, over several hours, flux convergence and cancellation at the polarity inversion line inside an evolved arcade in the base apparently destabilized the entire arcade, including its cool-plasma-carrying core field, to undergo a blowout eruption in the manner of many standard-sized, arcade-blowout eruptions that produce a flare and coronal mass ejection. Internal reconnection made bright "flare" loops over the polarity inversion line inside the blowing-out arcade field, and external reconnection of the blowing-out arcade field with an ambient open field made longer and dimmer EUV loops on the outside of the blowing-out arcade. That the loops made by the external reconnection were much larger than the loops made by the internal reconnection makes this event a new variety of blowout jet, a variety not recognized in previous observations and models of blowout jets.

Using a Chandra Source-Finding Algorithm to Automatically Identify Solar X-ray Bright Points

M. **Adams**, Allyn F. Tennant and J. W. Cirtain

Solar Phys. 262(2), 315-320, **2010**

We describe adapting a method that is used to find point sources in *Chandra* X-ray telescope data for use in finding solar X-ray bright points. The algorithm allows selected pixels to be excluded from the source-finding, thus excluding saturated pixels (from flares and/or active regions). For *Chandra* data the noise is determined by photon-counting statistics, whereas solar telescopes typically integrate a flux. Thus, the calculated signal-to-noise ratio is incorrect, but we find that we can scale the number to get reasonable results. We compare our source-finding to previous *Yohkoh* results and find a similar number of bright points. Finally, we analyze three sets of data from *Hinode*, representing different parts of the decline to minimum of the solar cycle. Although these preliminary results are based on a small sample, we see no dependence on the solar cycle.

On the role of current dissipation in the energization of coronal bright points

E. **Adamson**[1⋆], J. Büchner[1] and A. Otto

A&A 557, A118 (**2013**)

Aims. In the context of the contributions by DC dissipation to the energization of solar coronal X-ray and EUV bright points, we analyze the role of Joule heating in the formation of X-ray and EUV coronal bright points through current dissipation due to anomalous resistivity.

Methods. We utilized the improved resistive MHD simulation code MPSCORONA3D, which allows for investigating resistive effects within the corona over a wide range of Reynolds numbers, starting from the nearly ideal Spitzer value of resistivity and including various models of current-carrier velocity dependent resistivity, arising from the consideration of turbulence in microscopic theory.

Results. DC current dissipation contributes to the thermal energy increase in coronal bright point regions only under the assumption of an unrealistically low critical current-carrier velocity at which turbulent resistivity is switched on. For more realistic resistivity models, the corona is energized by plasma compression rather than by Joule heating due to the dissipation of direct currents.

Conclusions. Joule heating within the solar corona depends critically on the magnitude of the resistivity.

A Solar Coronal Hole and Fast Solar Wind Turbulence Model and First-orbit Parker Solar Probe (PSP) Observations

L. **Adhikari**[1], G. P. Zank[1,2], and L.-L. Zhao[1]

2020 ApJ 901 102

https://doi.org/10.3847/1538-4357/abb132

We propose a turbulence-driven solar wind model for a fast solar wind flow in an open coronal hole where the solar wind flow and the magnetic field are highly aligned. We compare the numerical results of our model with Parker Solar Probe measurements of the fast solar wind flow and find good agreement between them. We find that (1) the majority quasi-2D turbulence is mainly responsible for coronal heating, raising the temperature to about $\sim 10^6$ K within a few solar radii, which leads in turn to the acceleration of the solar wind; (2) the heating rate due to quasi-2D turbulence near the coronal base is larger than that due to nearly incompressible/slab turbulence; (3) the quasi-2D energy in forward-propagating modes decreases with increasing distance, while the nearly incompressible/slab energy in forward-propagating modes increases, reaching a peak value at ~11.7 $R_\odot$ before decreasing with increasing heliocentric distance; (4) the correlation length increases with increasing distance from the coronal base; and (5) the variance of the density fluctuations decreases as a function of heliocentric distance.

A Study of Coronal Holes Observed by SoHO/EIT and the Nobeyama Radioheliograph

S. **Akiyama**, N. Gopalswamy, S. Yashiro, and P. Mäkelä

Publi. Astron. Soc. Japan 65, No SP1, S15 [10 pages] (**2013**) **File**
http://pasj.asj.or.jp/v65/sp1/65S015/65S015.pdf
DOI 10.1093/pasj/65.sp1.S15

Coronal holes (CHs) are areas of reduced emission in EUV and X-ray images that show bright patches of microwave enhancements (MEs) related to magnetic network junctions inside the CHs. A clear correlation between the CH size and the solar wind (SW) speed is well known, but we have less information about the relationship between MEs and other CH and SW properties. We studied the characteristics of 21 equatorial CHs associated with corotating interaction regions (CIRs) during 1996 to 2005. Our CHs were divided into two groups according to the intensity of the associated geomagnetic storms: *Dst* __100 nT (10 events) and > _100 nT (11 events). Using EUV 284 ˚A images obtained by SOHO/EIT and 17 GHz microwave images obtained by the Nobeyama Radioheliograph (NoRH), we found a linear correlation not only between the maximum SW speed and the area of EUV CH (r = 0.62), but also between the maximum SW speed and the area of the ME (r = 0.79). We also compared the EUVCH areas with and without an overlapping ME. The area of the CHs with an ME is better correlated with the SW speed (r = 0.71) than the area of those without an ME (r = 0.36). Therefore, the radio ME may play an important role in understanding the origin of SW. **Tables**

Hinode observations and 3D magnetic structure of an X-ray bright point

C. E. **Alexander**, Del Zanna, R. C. Maclean

EIS Science Nugget for May **2011**, http://msslxr.mssl.ucl.ac.uk:8080/SolarB/eisnuggets.jsp
See Alexander, C. E., Del Zanna, G., & Maclean, R. C. 2011, A&A, 526, 134

The Hinode satellite is especially suited to study small features like XBPs as it can utilise all three instruments to work together and follow the entire evolution of a bright point from emergence to decay. Such a complete study is not possible for active regions as they tend to last much longer often, out of view over the solar limb. The EUV Imaging Spectrometer (EIS), in particular, is great for studying XBPs as they can easily be captured by the 1" or 2" slit with minimal exposures being needed to cover their area. This means less 'temporal smearing' due to the rastering process, making more accurate analysis possible.

Hinode observations and 3D magnetic structure of an X-ray bright point

C. E. **Alexander**1, G. Del Zanna2 and R. C. Maclean

A&A 526, A134 (**2011**)

Aims. We present complete Hinode Solar Optical Telescope (SOT), X-Ray Telescope (XRT)and EUV Imaging Spectrometer (EIS) observations of an X-ray bright point (XBP) observed on the 10, 11 of October 2007 over its entire lifetime (~12 h). We aim to show how the measured plasma parameters of the XBP change over time and also what kind of similarities the X-ray emission has to a potential magnetic field model.
Methods. Information from all three instruments on-board Hinode was used to study its entire evolution. XRT data was used to investigate the structure of the bright point and to measure the X-ray emission. The EIS instrument was used to measure various plasma parameters over the entire lifetime of the XBP. Lastly, the SOT was used to measure the magnetic field strength and provide a basis for potential field extrapolations of the photospheric fields to be made. These were performed and then compared to the observed coronal features.
Results. The XBP measured ~15´´ in size and was found to be formed directly above an area of merging and cancelling magnetic flux on the photosphere. A good correlation between the rate of X-ray emission and decrease in total magnetic flux was found.

The magnetic fragments of the XBP were found to vary on very short timescales (minutes), however the global quasi-bipolar structure remained throughout the lifetime of the XBP. The potential field extrapolations were a good visual fit to the observed coronal loops in most cases, meaning that the magnetic field was not too far from a potential state. Electron density measurements were obtained using a line ratio of and the average density was found to be 4.95 × 109 cm-3 with the volumetric plasma filling factor calculated to have an average value of 0.04. Emission measure loci plots were then used to infer a steady temperature of log Te [K] ~ 6.1. The calculated Doppler shifts show velocity changes in and around the bright point of ±15 km s-1 which are observed to change on a timescale of less than 30 min

Statistical Properties of Solar Coronal Bright Points

N. **Alipour** and H. Safari

2015 ApJ 807 175

Here, we aim to study the statistical properties (i.e., spatial, temporal, and magnetic structures) of extreme ultraviolet coronal bright points (CBPs) observed by SDO during a 4.4 yr period (2010 June 1 to 2014 October 31). We developed the automatic detection method for CBPs based on the machine-learning technique and Zernike image moments. The average number and the mean density of CBPs are estimated to be about 572 (per full disk image taken at 193 Å) and 1.9×10^{-4} Mm−2, respectively. There is a negative correlation (−0.7) between the number of CBPs and the number of sunspots. The size and lifetime frequency distribution of CBPs show the lognormal and power-law (exponent equal to −1.6) behaviors, respectively. The relationship between the lifetime and size of CBPs is clearly treated by a power-law function with an exponent equal to 0.13. Around 1.3% of the solar surface is covered by the bright cores of CBPs and 2.6% of that is covered by their total area. About 52% of CBPs have lifetimes of less than 20 minutes and the remaining 48% have mean lifetimes of 6 hr. More than 95% of CBPs with lifetimes of less than 20 hr and nine CBPs with lifetimes of more than 72 hr are detected. The average number of the new CBPs emerging every 45 s in the whole of the Sun is about 27 ± 3. The temporal self-affinity of the time series of CBPs that emerged, indexed by the Hurst exponent determined using both detrended fluctuation analysis and R/S analysis, is 0.78. This long-temporal correlation suggests that CBPs form a system of self-organized criticality.

MAGNETIC BRIGHT POINTS IN THE QUIET SUN

J. S´anchez **Almeida**[1,2], J. A. Bonet[1,2], B. Viticchi´e[3,4], and D. Del Moro[4]

Astrophysical Journal Letters, 715:L26–L29, **2010** May

We present a visual determination of the number of bright points (BPs) existing in the quiet Sun, which are structures though to trace intense kG magnetic concentrations. The measurement is based on a 0.__1 angular resolution G-band movie obtained with the Swedish Solar Telescope at the solar disk center.We find 0.97 BPsMm−2, which is a factor 3 larger than any previous estimate. It corresponds to 1.2 BPs per solar granule. Depending on the details of the segmentation, the BPs cover between 0.9% and 2.2% of the solar surface. Assuming their field strength to be 1.5 kG, the detected BPs contribute to the solar magnetic flux with an unsigned flux density between 13 G and 33 G. If network and inter-network regions are counted separately, they contain 2.2 BPs Mm−2 and 0.85 BPs Mm−2, respectively.

Observations of coronal holes with the Siberian Radioheliograph

Altyntsev, Alexander , Globa, Mariia Meshalkina, Nataliya ; Sych, Robert

Solar-Terrestrial Physics, vol. 10, issue 3, pp. 3-10, **2024**

https://naukaru.ru/en/storage/download/169702

Multi-wavelength observations of a coronal hole (CH) with two-dimensional spatial resolution have been made for the first time in the frequency range from 2.8 to 12 GHz. At frequencies below 6 GHz, the average brightness of the hole is 1.5 times lower than the brightness level of the quiet Sun. The distribution of radio brightness over the hole is inhomogeneous: the ratio of maximum to minimum brightness temperatures falls from several times at low frequencies to tenths of fractions at the upper received frequencies. At frequencies above 6 GHz, the temperature contrast between the CH and regions of the quiet Sun is small. Within the CH, there are compact sources that are bright relative to the quiet Sun. In general, observations of CHs with SRH are promising both for the research into the nature of CHs and for the applied problems of forecasting solar wind characteristics. **April 25, 2023**

CESRA #3879   2024   https://www.astro.gla.ac.uk/users/eduard/cesra/?p=3879

RESPONSE OF GRANULATION TO SMALL-SCALE BRIGHT FEATURES IN THE QUIET SUN

A. Anđić, J. Chae, P. R. Goode, W. Cao, K. Ahn, V. Yurchyshyn and V. Abramenko

2011 ApJ 731 29

We detected 2.8 bright points (BPs) per Mm2 in the quiet Sun with the New Solar Telescope at Big Bear Solar Observatory, using the TiO 705.68 nm spectral line at an angular resolution ~01 to obtain a 30 minute data sequence. Some BPs formed knots that were stable in time and influenced the properties of the granulation pattern around them. The observed granulation pattern within ~3" of knots presents smaller granules than those observed in a normal granulation pattern, i.e., around the knots a suppressed convection is detected. Observed BPs covered ~5% of the solar surface and were not homogeneously distributed. BPs had an average size of 022, they were detectable for 4.28 minutes on average, and had an averaged contrast of 0.1% in the deep red TiO spectral line.

Signature of Collision of Magnetic Flux Tubes in the Quiet Solar Photosphere

Aleksandra **Andic**

Preprint BBSO#1467, **2010**; *Physics of Sun and Star Spots Proceedings IAU Symposium No. 273, 2010*

Collision of the magnetic flux tubes in the Quiet Sun was proposed as one of the possible sources for the heating of the solar atmosphere (Furusawa and Sakai, 2000). The solar photosphere was observed using the New Solar Telescope ad Big Bear Solar Observatory. In TiO spectral line at 705.68 nm we approached resolution of 0.1". The horizontal plasma wave was observed spreading from the larger bright point. Shorty after this wave an increase in the oscillatory power appeared at the same location as the observed bright point. This behavior matches some of the results from the simulation of the collision of the two flux tubes with a weak current.

Substructure of Quiet Sun Bright Points

Aleksandra **Andić**, Jongchul Chae and Philip R. Goode

Preprint BBSO#1466, **2010**; *Physics of Sun and Star Spots Proceedings IAU Symposium No. 273, 2010*

Since photospheric bright points (BPs) were first observed, there has been a question as to how are they structured. Are they just single flux tubes or a bundle of the flux-tubes? Surface photometry of the quiet Sun (QS) has achieved resolution close to 0.1″ with the New Solar Telescope at Big Bear Solar Observatory. This resolution allowed us to detect a richer spectrum of BPs in the QS. The smallest BPs we observed with TiO 705.68 nm were 0.13″ , and we were able to resolve individual components in some of the BPs clusters and ribbons observed in the QS, showing that they are composed of the individual BPs. Average size of observed BPs was 0.22″.

Evolutionary features of polar and non-polar coronal holes during solar cycle 24 and the rising phase of cycle 25

Olga **Andreeva**

Advances in Space Research Volume 71, Issue 4, 15 February **2023**, Pages 1915-1921

https://doi.org/10.1016/j.asr.2022.07.043

This paper presents the results of the analysis of the evolution of coronal holes (CHs) on the Sun during the period May 13, 2010 – March 20, 2022, covering Solar Cycle 24. Our study uses images in the extreme-ultraviolet iron line (Fe XII 193 Å) obtained with the Atmospheric Imager Assembly of the Solar Dynamics Observatory (AIA/SDO). ***To localize CHs and determine their areas, we used the Heliophysics Event Knowledgebase (HEK).*** We separate the CHs into polar and non-polar and study the evolutionary features of each group. During this period, an asymmetry between the Northern (N) and Southern (S) Hemispheres (N-S or hemispheric asymmetry) is detected both in the solar activity (SA) indices and in the localization of the maximum areas of the polar and non-polar CHs. It is shown that the hemispheric asymmetry of the areas of polar and non-polar CHs varies significantly over time and that the nature of these changes is clearly related to the SA cycle. We find that for most of the period, the polar CHs were predominated generated in the S- hemisphere while the non-polar CHs were dominant in the N-hemisphere. It is found that the maximum and minimum of the hemispheric imbalance in the areas of non-polar CHs are close in time to the maximum and minimum of the asymmetry of the SA indices (the number and areas of sunspots). The maximum hemispheric imbalance of the polar CH areas is observed at the maximum of Cycle 24, and the minimum imbalance is found at the cycle minimum. These results confirm our assumption that these two types of CHs are of a different nature and that the non-polar CHs, like sunspots, are elements of the general magnetic activity.

A MODEL FOR THE SOURCES OF THE SLOW SOLAR WIND

S. K. **Antiochos**1, Z. Mikić2, V. S. Titov2, R. Lionello2 and J. A. Linker

2011 ApJ 731 112

Models for the origin of the slow solar wind must account for two seemingly contradictory observations: the slow wind has the composition of the closed-field corona, implying that it originates from the continuous opening and closing of flux at the boundary between open and closed field. On the other hand, the slow wind also has large angular width, up to ~60°, suggesting that its source extends far from the open-closed boundary. We propose a model that can explain both observations. The key idea is that the source of the slow wind at the Sun is a network of narrow (possibly singular) open-field corridors that map to a web of separatrices and quasi-separatrix layers in the heliosphere. We compute analytically the topology of an open-field corridor and show that it produces a quasi-separatrix layer in the heliosphere that extends to angles far from the heliospheric current sheet. We then use an

MHD code and MDI/SOHO observations of the photospheric magnetic field to calculate numerically, with high spatial resolution, the quasi-steady solar wind, and magnetic field for a time period preceding the 2008 August 1 total solar eclipse. Our numerical results imply that, at least for this time period, a web of separatrices (which we term an S-web) forms with sufficient density and extent in the heliosphere to account for the observed properties of the slow wind. We discuss the implications of our S-web model for the structure and dynamics of the corona and heliosphere and propose further tests of the model.

STRUCTURE AND DYNAMICS OF THE SUN'S OPEN MAGNETIC FIELD

S. K. **Antiochos**, C. R. DeVore, J. T. Karpen, and Z. Mikic

The Astrophysical Journal, 671:936Y946, **2007** December 10

http://www.journals.uchicago.edu/doi/pdf/10.1086/522489

The solar magnetic field is the primary agent that drives solar activity and couples the Sun to the heliosphere. Although the details of this coupling depend on the quantitative properties of the field, many important aspects of the corona-solar wind connection can be understood by considering only the general topological properties of those regions on the Sun where the field extends from the photosphere out to interplanetary space, the so-called open field regions that are usually observed as coronal holes. From the simple assumptions that underlie the standard quasisteady corona-wind theoretical models, and that are likely to hold for the Sun as well, we derive two conjectures as to the possible structure and dynamics of coronal holes: (1) coronal holes are unique in that every unipolar region on the photosphere can contain at most one coronal hole, and (2) coronal holes of nested polarity regions must themselves be nested. Magnetic reconnection plays the central role in enforcing these constraints on the field topology. From these conjectures we derive additional properties for the topology of open field regions, and propose several observational predictions for both the slowly varying and transient corona/solar wind.

UVCS Observations of Temperature and Velocity Profiles in Coronal Holes

Ester **Antonucci**, Lucia Abbo, Daniele Telloni

Space Science Reviews, November **2012**, Volume 172, Issue 1-4, pp 5-22

The spectroscopic observations of the Ultraviolet Coronagraph Spectrometer (UVCS), on board the SOHO observatory, allow the study and the full characterization of the expansion of the solar atmosphere by means of measurements of the outflow speeds and the physical properties of the wind, directly in the region where the solar plasma is heated and accelerated: the extended corona. During solar minimum, when the magnetic configuration of the corona is rather simple, the open magnetic fields emerging from the wide polar coronal holes channel toward the heliosphere both the fast and the slow wind. The fast wind flows along flux tubes with lower areal divergence than the slow wind which is guided by flux tubes characterized by non-monotonic areal expansion functions. Differences in the physical properties, such as kinetic temperature, electron density, composition and density fluctuations, of the fast and slow wind in the corona are discussed.

Extraction of Active Regions and Coronal Holes from EUV Images Using the Unsupervised Segmentation Method in the Bayesian Framework

S. **Arish**, M. Javaherian , H. Safari, A. Amiri

Solar Physics April **2016**, Volume 291, Issue 4, pp 1209-1224

The solar corona is the origin of very dynamic events that are mostly produced in active regions (AR) and coronal holes (CH). The exact location of these large-scale features can be determined by applying image-processing approaches to extreme-ultraviolet (EUV) data.

We here investigate the problem of segmentation of solar EUV images into ARs, CHs, and quiet-Sun (QS) images in a firm Bayesian way. On the basis of Bayes' rule, we need to obtain both prior and likelihood models. To find the prior model of an image, we used a Potts model in non-local mode. To construct the likelihood model, we combined a mixture of a Markov–Gauss model and non-local means. After estimating labels and hyperparameters with the Gibbs estimator, cellular learning automata were employed to determine the label of each pixel.

We applied the proposed method to a Solar Dynamics Observatory/Atmospheric Imaging Assembly (SDO/AIA) dataset recorded during 2011 and found that the mean value of the filling factor of ARs is 0.032 and 0.057 for CHs. The power-law exponents of the size distribution of ARs and CHs were obtained to be −1.597 and −1.508, respectively, with the maximum likelihood estimator method. When we compare the filling factors of our method with a manual selection approach and the SPoCA algorithm, they are highly compatible.

CHARACTERISTICS OF ANEMONE ACTIVE REGIONS APPEARING IN CORONAL HOLES OBSERVED WITH THE YOHKOH SOFT X-RAY TELESCOPE

Ayumi **Asai**,1,2,3 Kazunari Shibata,4 Hirohisa Hara,2,3 and Nariaki V. Nitta5

The Astrophysical Journal, 673:1188–1193, **2008**; File

Coronal structure of active regions appearing in coronal holes is studied, using data that were obtained with the Soft

X-Ray Telescope (SXT) aboard Yohkoh between 1991 November and 1993 March. The following characteristics are found.Many of the active regions (ARs) appearing in coronal holes show a structure that looks like a sea anemone. Such active regions are called anemone ARs. About one-fourth of all active regions that were observed with SXT from their births showed the anemone structure. For almost all the anemone ARs, the order of the magnetic polarities is consistent with the Hale-Nicholson polarity law. These anemone ARs also showed, to a greater or lesser extent, an east-west asymmetry in the X-ray intensity distribution, such that the following (eastern) part of the AR was brighter than its preceding (western) part. This, as well as the anemone shape itself, is consistent with the magnetic polarity distribution around the anemoneARs. These observations also suggest that an active region appearing in coronal holes has a simpler (less sheared) and more preceding-spot–dominant magnetic structure than those appearing in other regions.

Effects of Density Fluctuations on Alfvén Wave Turbulence in a Coronal Hole

M. **Asgari-Targhi**1, A. Asgari-Targhi1,2, M. Hahn3, and D. W. Savin3

2021 ApJ 911 63

https://doi.org/10.3847/1538-4357/abe9b4

We present a study of density fluctuations in coronal holes. We used a reduced magnetohydrodynamic (RMHD) model that incorporated observationally constrained density fluctuations to determine whether density fluctuations in coronal holes can enhance Alfvén wave reflection and dissipation, thereby heating coronal holes and driving the fast solar wind. We show results for two models of the background atmosphere. Each model is a solution of the momentum equation and includes the effects of wave pressure on the solar wind outflow. In the first model, the plasma density and Alfvén speed vary smoothly with height. Wave reflection is relatively weak in the smooth model, resulting in a low energy dissipation rate. In the second model, we include additional density fluctuations along the flux tube based on the observations. We find that density ρ fluctuations on the order of $\delta\rho/\rho \sim 0.24$ increase the Alfvén wave turbulence to levels sufficient to heat the open field regions in coronal holes.

The Dynamic Structure of Coronal Hole Boundaries

V. **Aslanyan**1, D. I. Pontin2, R. B. Scott3, A. K. Higginson4, P. F. Wyper5, and S. K. Antiochos6

2022 ApJ 931 96

https://iopscience.iop.org/article/10.3847/1538-4357/ac69ed/pdf

The boundaries of solar coronal holes are difficult to uniquely define observationally but are sites of interest in part because the slow solar wind appears to originate there. The aim of this article is to explore the dynamics of interchange magnetic reconnection at different types of coronal hole boundaries—namely streamers and pseudostreamers—and their implications for the coronal structure. We describe synthetic observables derived from three-dimensional magnetohydrodynamic simulations of the atmosphere of the Sun in which coronal hole boundaries are disturbed by flows that mimic the solar supergranulation. Our analysis shows that interchange reconnection takes place much more readily at the pseudostreamer boundary of the coronal hole. As a result, the portion of the coronal hole boundary formed by the pseudostreamer remains much smoother, in contrast to the highly distorted helmet-streamer portion of the coronal hole boundary. Our results yield important new insights on coronal hole boundary regions, which are critical in coupling the corona to the heliosphere as the formation regions of the slow solar wind.

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.

Coronal Models and Detection of the Open Magnetic Field

Eleanna **Asvestari**1, Manuela Temmer2, Ronald M. Caplan3, Jon A. Linker3, Stephan G. Heinemann2,4, Rui F. Pinto5,6, Carl J. Henney7, Charles N. Arge8, Mathew J. Owens9, Maria S. Madjarska4,10Show full author list
2024 ApJ 971 45
https://iopscience.iop.org/article/10.3847/1538-4357/ad5155/pdf
A plethora of coronal models, from empirical to more complex magnetohydrodynamic (MHD) ones, are being used for reconstructing the coronal magnetic field topology and estimating the open magnetic flux. However, no individual solution fully agrees with coronal hole observations and in situ measurements of open flux at 1 au, as there is a strong deficit between the model and observations contributing to the known problem of the missing open flux. In this paper, we investigate the possible origin of the discrepancy between modeled and observed magnetic field topology by assessing the effect on the simulation output by the choice of the input boundary conditions and the simulation setup, including the choice of numerical schemes and the parameter initialization. In the frame of this work, we considered four potential field source surface-based models and one fully MHD model, different types of global magnetic field maps, and model initiation parameters. After assessing the model outputs using a variety of metrics, we conclude that they are highly comparable regardless of the differences set at initiation. When comparing all models to coronal hole boundaries extracted by extreme-ultraviolet filtergrams, we find that they do not compare well. This mismatch between observed and modeled regions of the open field is a candidate contributing to the open flux problem. **2010-09-18-19**

Reconstructing coronal hole areas with EUHFORIA and adapted WSA model: optimising the model parameters

Eleanna **Asvestari**, Stephan G. Heinemann, Mannuela Temmer, Jens Pomoell, Emilia Kilpua, Jasmina Magdalenic, Stefaan Poedts
JGR **Volume124, Issue11** Pages 8280-8297 **2019**
https://arxiv.org/pdf/1907.03337.pdf
https://doi.org/10.1029/2019JA027173
The adopted WSA model embedded in EUHFORIA (EUropean Heliospheric FORecasting Information Asset) is compared to EUV observations. According to the standard paradigm coronal holes are sources of open flux thus we use remote sensing EUV observations and \textsc{catch} (Collection of Analysis Tools for Coronal Holes) to extract CH areas and compare them to the open flux areas modelled by EUHFORIA. From the adopted WSA model we employ only the Potential Field Source Surface (PFSS) model for the inner corona and the Schatten Current Sheet (SCS) model for the outer (PFSS+SCS). The height, Rss, of the outer boundary of the PFSS, known as the source surface, and the height, Ri, of the inner boundary of the SCS are important parameters affecting the modelled CH areas. We investigate the impact the two model parameters can have in the modelled results. We vary Rss within the interval [1.4, 3.2]R⊙ with a step of 0.1R⊙, and Ri within the interval [1.3, 2.8]R⊙with the same step, and the condition that Ri<Rss. This way we have a set of 184 initial parameters to the model and we assess the model results for all these possible height pairs. We conclude that the default heights used so far fail in modelling accurately CH areas and lower heights need to be considered.
Table 1. CH characteristics based on remote sensing observations and catch extractions, where CoM is Centre of Mass (2012-2017)

Critical magnetic field strengths for solar coronal plumes in quiet regions and coronal holes?

Ellis A. **Avallone**, Sanjiv K. Tiwari, Navdeep K. Tiwari, Ronald L. Moore, Amy Winebarger
ApJ **2018**
https://arxiv.org/pdf/1805.11188.pdf
Coronal plumes are bright magnetic funnels found in quiet regions (QRs) and coronal holes (CHs). They extend high into the solar corona and last from hours to days. The heating processes of plumes involve dynamics of the magnetic field at their base, but the processes themselves remain mysterious. Recent observations suggest that plume heating is a consequence of magnetic flux cancellation and/or convergence at the plume base. These studies suggest that the base flux in plumes is of mixed polarity, either obvious or hidden in SDO HMI data, but do not quantify it. To investigate the magnetic origins of plume heating, we select ten unipolar network flux concentrations, four in CHs, four in QRs, and two that do not form a plume, and track plume luminosity in SDO AIA 171 A images along with the base flux in SDO HMI magnetograms, over each flux concentrations lifetime. We find that plume heating is triggered when convergence of the base flux surpasses a field strength of 200 to 600 G. The luminosity of both QR and CH plumes respond similarly to the field in the plume base, suggesting that the two have a common formation mechanism. Our examples of non-plume-forming flux concentrations, reaching field strengths of 200 G for a similar number of pixels as for a couple of our plumes, suggest that a critical field might be necessary to form a plume but is not sufficient for it, thus, advocating for other mechanisms, e.g. flux cancellation due to hidden opposite-polarity field, at play. **July 5, 2011, September 8-9, 2011, October 5, 2013, February 1, 2015, August 5, 2015, December 4, 2015, May 12-13, 2016, December 23, 2016, May 12, 2017**

Constraining Global Coronal Models with Multiple Independent Observables

Samuel T. **Badman**, David H. Brooks, Nicolas Poirier, Harry P. Warren, Gordon Petrie, Alexis P. Rouillard, C. Nick Arge, Stuart D. Bale, Diego de Pablos Aguero, Louise Harra, Shaela I. Jones, Athanasios Kouloumvakos, Pete Riley, Olga Panasenco, Marco Velli, Samantha Wallace

ApJ **932** 135 **2022**

https://arxiv.org/pdf/2201.11818.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/ac6610/pdf

Global coronal models seek to produce an accurate physical representation of the Sun's atmosphere which can be used, for example, to drive space weather models. Assessing their accuracy is a complex task and there are multiple observational pathways to provide constraints and tune model parameters. Here, we combine several such independent constraints, defining a model-agnostic framework for standardized comparison. We require models to predict the distribution of coronal holes at the photosphere, and neutral line topology at the model outer boundary. We compare these predictions to extreme ultraviolet (EUV) observations of coronal hole locations, white-light Carrington maps of the streamer belt and the magnetic sector structure measured \textit{in situ} by Parker Solar Probe and 1AU spacecraft. We study these metrics for Potential Field Source Surface (PFSS) models as a function of source surface height and magnetogram choice, as well as comparing to the more physical Wang-Sheeley-Arge (WSA) and the Magnetohydrodynamics Algorithm outside a Sphere (MAS) models. We find that simultaneous optimization of PFSS models to all three metrics is not currently possible, implying a trade-off between the quality of representation of coronal holes and streamer belt topology. WSA and MAS results show the additional physics they include addresses this by flattening the streamer belt while maintaining coronal hole sizes, with MAS also improving coronal hole representation relative to WSA. We conclude that this framework is highly useful for inter- and intra-model comparisons. Integral to the framework is the standardization of observables required of each model, evaluating different model aspects.

Solar Event Detection Using Deep-Learning-Based Object Detection Methods

Ji-Hye **Baek**, Sujin Kim, Seonghwan Choi, Jongyeob Park, Jihun Kim, Wonkeun Jo & Dongil Kim

Solar Physics volume 296, Article number: 160 (**2021**)

https://link.springer.com/content/pdf/10.1007/s11207-021-01902-5.pdf

Research on the detection of solar events has been conducted over many years. Recently, deep learning and data-driven approaches have been applied to solar event recognition. In this study, we present solar event detection using deep-learning-based object detection methods for real-time space weather monitoring. First, we construct a new object detection dataset using imaging data obtained by the Solar Dynamics Observatory with bounding boxes as labels for three representative features: coronal holes, sunspots, and prominences. Second, we train two representative object detection models: the Single Shot MultiBox Detector (SSD) and the Faster Region-based Convolutional Neural Network (R-CNN) using the new dataset. The results show that both models perform similarly well for coronal hole and sunspot detection. For prominence detection, the SSD and Faster R-CNN exhibited relatively low performance. This study demonstrates that deep-learning-based object detection can successfully detect multiple types of solar events, and it may be extended to detect other solar events. In addition, we provide the dataset for further achievements of object detection studies in solar physics.

Evidence for precursors of the coronal hole jets in solar bright points

Salome R. **Bagashvili**, Bidzina M. Shergelashvili, Darejan R. Japaridze, Vasil Kukhianidze, Stefaan Poedts, Teimuraz V. Zaqarashvili, Maxim L. Khodachenko, Patrick De Causmaecker

ApJL **855** L21 **2018**

https://arxiv.org/pdf/1803.00551.pdf

http://sci-hub.tw/http://iopscience.iop.org/2041-8205/855/2/L21/

A set of 23 observations of coronal jet events that occurred in coronal bright points has been analyzed. The focus was on the temporal evolution of the mean brightness before and during coronal jet events. In the absolute majority of the cases either single or recurrent coronal jets were preceded by slight precursor disturbances observed in the mean intensity curves. The key conclusion is that we were able to detect quasi-periodical oscillations with characteristic periods from sub-minute up to 3-4 min values in the bright point brightness which precede the jets. Our basic claim is that along with the conventionally accepted scenario of bright point evolution through new magnetic flux emergence and its reconnection with the initial structure of the bright point and the coronal hole, certain MHD oscillatory and wave-like motions can be excited and these can take an important place in the observed dynamics. These quasi-oscillatory phenomena might play the role of links between different epochs of the coronal jet ignition and evolution. They can be an indication of the MHD wave excitation processes due to the system entropy variations, density variations or shear flows. It is very likely a sharp outflow velocity transverse gradients at the edges between the open and closed field line regions. We suppose that magnetic reconnections can be the source of MHD waves due to impulsive generation or rapid temperature variations, and shear flow driven nonmodel MHD wave evolution (self-heating and/or overreflection mechanisms). **9 Dec 2015** **Table** 23 events (2015-2016)

Statistical properties of coronal hole rotation rates: Are they linked to the solar interior?

Salome R. **Bagashvili**, Bidzina M. Shergelashvili, Darejan R. Japaridze, Bidzina B. Chargeishvili, Alexander G. Kosovichev, Vasil Kukhianidze, George Ramishvili, Teimuraz V. Zaqarashvili, Stefaan Poedts, Maxim L. Khodachenko, Patrick De Causmaecker

A&A 603, A134 **2017**

https://arxiv.org/pdf/1706.04464.pdf

The present paper discusses results of a statistical study of the characteristics of coronal hole (CH) rotation in order to find connections to the internal rotation of the Sun. The goal is to measure CH rotation rates and study their distribution over latitude and their area sizes. In addition, the CH rotation rates are compared with the solar photospheric and inner layer rotational profiles. We study coronal holes observed within ±60 latitude and longitude degrees from the solar disc centre during the time span from the 1 January 2013 to 20 April 2015, which includes the extended peak of solar cycle 24.We used data created by the Spatial Possibilistic Clustering Algorithm (SPoCA), which provides the exact location and characterisation of solar coronal holes using SDO=AIA 193 {\AA} channel images. The CH rotation rates are measured with four-hour cadence data to track variable positions of the CH geometric centre. North-south asymmetry was found in the distribution of coronal holes: about 60 percent were observed in the northern hemisphere and 40 percent were observed in the southern hemisphere. The smallest and largest CHs were present only at high latitudes. The average sidereal rotation rate for 540 examined CHs is 13:86(±0:05)degrees/d. Conclusions. The latitudinal characteristics of CH rotation do not match any known photospheric rotation profile. The CH angular velocities exceed the photospheric angular velocities at latitudes higher than 35-40 degrees. According to our results, the CH rotation profile perfectly coincides with tachocline and the lower layers of convection zone at around 0.71 R⊙; this indicates that CHs may be linked to the solar global magnetic field, which originates in the tachocline region.

Research on the quantity and brightness evolution characteristics of Photospheric Bright Points groups

HaiCheng **Bai**

A&A **2022**

https://arxiv.org/pdf/2210.02635.pdf

Context. Photospheric bright points (BPs), as the smallest magnetic element of the photosphere and the footpoint tracer of the magnetic flux tube, are of great significance to the study of BPs. Compared with the study of the characteristics and evolution of a few specific BPs, the study of BPs groups can provide us with a better understanding of the characteristics and overall activities of BPs groups. Aims. We aim to find out the evolution characteristics of the brightness and number of BPs groups at different brightness levels, and how these characteristics differ between quiet and active regions. Methods. We propose a hybrid BPs detection model (HBD Model) combining traditional technology and neural network. The Model is used to detect and calculate the BPs brightness characteristics of each frame of continuous high resolution image sequences of active and quiet regions in TiO-band of a pair of BBSO. Using machine learning clustering method, the PBs of each frame was divided into four levels groups (level1-level4) according to the brightness from low to high. Finally, Fourier transform and inverse Fourier transform are used to analyze the evolution of BPs brightness and quantity in these four levels groups. Results. The activities of BPs groups are not random and disorderly. In different levels of brightness, their quantity and brightness evolution show complex changes. Among the four levels of brightness, BPs in the active region were more active and intense than those in the quiet region. However, the quantity and brightness evolution of BPs groups in the quiet region showed the characteristics of large periodic changes and small periodic changes in the medium and high brightness levels (level3 and level4). The brightness evolution of PBs group in the quiet region has obvious periodic changes, but the active region is in a completely random and violent fluctuation state. **22 June, 2016, 30 July, 2020**

Improving ambient solar wind model predictions with machine learning

R.L. **Bailey**, M.A. Reiss, C.N. Arge, C. Möstl, M.J. Owens, U.V. Amerstorfer, C.J. Henney, T. Amerstorfer, A.J. Weiss, J. Hinterreiter

2020

https://arxiv.org/pdf/2006.12835.pdf

The study of ambient solar wind, a continuous pressure-driven plasma flow emanating from our Sun, is an important component of space weather research. The ambient solar wind flows in interplanetary space determine how solar storms evolve through the heliosphere before reaching Earth, and especially during solar minimum are themselves a driver of activity in the Earth's magnetic field. Accurately forecasting the ambient solar wind flow is therefore imperative to space weather awareness. Here we present a novel machine learning approach in which solutions from magnetic models of the solar corona are used to output the solar wind conditions near the Earth. The results are compared to observations and existing models in a comprehensive validation analysis, and the new model outperforms existing models in almost all measures. The final model discussed here represents an extremely fast, well-validated and open-source approach to the forecasting of ambient solar wind at Earth.

Plasma composition of a sigmoidal anemone active region

D. **Baker**, D. H. Brooks, P. Demoulin, L. Gesztelyi, L. M. Green, J. Carlyle

E-print, Oct **2013**; ApJ

Using spectra obtained by the EIS instrument onboard Hinode, we present a detailed spatially resolved abundance map of an active region (AR) - coronal hole (CH) complex that covers an area of 359 arcsec x □ 485 arcsec. The abundance map provides fi rst ionization potential (FIP) bias levels in various coronal structures within the large EIS fi eld of view. Overall, FIP bias in the small, relatively young AR is 2-3. This modest FIP bias is a consequence of the AR age, its weak heating, and its partial reconnection with the surrounding CH. Plasma with a coronal composition is concentrated at AR loop footpoints, close to where fractionation is believed to take place in the chromosphere. In the AR, we found a moderate positive correlation of FIP bias with nonthermal velocity and magnetic flux density, both of which are also strongest at the AR loop footpoints. Pathways of slightly enhanced FIP bias are traced along some of the loops connecting opposite polarities within the AR. We interpret the traces of enhanced FIP bias along these loops to be the beginning of fractionated plasma mixing in the loops. Low FIP bias in a sigmoidal channel above the AR's main polarity inversion line where ongoing flux cancellation is taking place, provides new evidence of a bald patch magnetic topology of a sigmoid/flux rope configuration. **2007 October 17**.

Signatures of Interchange Reconnection: STEREO, ACE and Hinode Observations Combined

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E-print, Sept **2009;** Ann. Geophys., 27, 3883–3897, **2009, File**

Combining STEREO, ACE and Hinode observations has presented an opportunity to follow a filament eruption and coronal mass ejection (CME) on the **17th of October 2007** from an active region (AR) inside a coronal hole (CH) into the heliosphere. This particular combination of `open' and closed magnetic topologies provides an ideal scenario for interchange reconnection to take place. With Hinode and STEREO data we were able to identify the emergence time and type of structure seen in the in-situ data four days later. On the 21st, ACE observed in-situ the passage of an ICME with `open' magnetic topology. The magnetic field configuration of the source, a mature AR located inside an equatorial CH, has important implications for the solar and interplanetary signatures of the eruption. We interpret the formation of an `anemone' structure of the erupting AR and the passage in-situ of the ICME being disconnected at one leg, as manifested by uni-directional suprathermal electron flux in the ICME, to be a direct result of interchange reconnection between closed loops of the CME originating from the AR and `open' field lines of the surrounding CH.

Interchange reconnection within coronal holes powers the fast solar wind

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2022

https://arxiv.org/ftp/arxiv/papers/2208/2208.07932.pdf

The fast solar wind that fills the heliosphere originates from deep within regions of open magnetic field on the Sun called coronal holes. However the energy source responsible for accelerating the outflowing plasma to such high speeds is still widely debated, although there is broad evidence that it is ultimately magnetic in nature with candidate mechanisms including Alfven wave heating and interchange reconnection. The magnetic field near the solar surface within coronal holes is structured on spatial scales associated with the boundaries of meso-scale supergranulation convection cells, where descending flows create intense bundles of magnetic field. The energy density in these network magnetic field bundles is a likely candidate as an energy source of the wind. Here we report measurements of two fast solar wind streams from the Parker Solar Probe (PSP) spacecraft near its 10th perihelion which provides strong evidence for the interchange reconnection mechanism. Specifically, we show that supergranulation structure at the coronal hole base remains imprinted in the near-Sun solar wind resulting in asymmetric patches of magnetic 'switchbacks' and bursty solar wind streams with corresponding energetic ions with power law-like distributions extending to beyond 100 keV. Particle-in-cell simulations of interchange reconnection between open and closed magnetic structures support key features of the observations, including the energetic ion spectra. Important characteristics of interchange reconnection in the low corona are inferred from the PSP data including that the reconnection is collisionless and that the rate of energy release is sufficient to heat the ambient plasma and drive the fast wind.   20-22 Nov 2021

A Quantum Fuzzy-based Approach for Real-Time Detection of Solar Coronal Holes

Sanmoy **Bandyopadhyay**, Suman Kundu
2024
https://arxiv.org/pdf/2403.18347.pdf
The detection and analysis of the solar coronal holes (CHs) is an important field of study in the domain of solar physics. Mainly, it is required for the proper prediction of the geomagnetic storms which directly or indirectly affect various space and ground-based systems. For the detection of CHs till date, the solar scientist depends on manual hand-drawn approaches. However, with the advancement of image processing technologies, some automated image segmentation methods have been used for the detection of CHs. In-spite of this, fast and accurate detection of CHs are till a major issues. Here in this work, a novel quantum computing-based fast fuzzy c-mean technique has been developed for fast detection of the CHs region. The task has been carried out in two stages, in first stage the solar image has been segmented using a quantum computing based fast fuzzy c-mean (QCFFCM) and in the later stage the CHs has been extracted out from the segmented image based on image morphological operation. In the work, quantum computing has been used to optimize the cost function of the fast fuzzy c-mean (FFCM) algorithm, where quantum approximate optimization algorithm (QAOA) has been used to optimize the quadratic part of the cost function. The proposed method has been tested for 193 Å SDO/AIA full-disk solar image datasets and has been compared with the existing techniques. The outcome shows the comparable performance of the proposed method with the existing one within a very lesser time.

Comparative Study and Development of Two Contour-Based Image Segmentation Techniques for Coronal Hole Detection in Solar Images

Sanmoy **Bandyopadhyay**, Saurabh Das & Abhirup Datta
Solar Physics volume 295, Article number: 110 (**2020**)
https://link.springer.com/content/pdf/10.1007/s11207-020-01674-4.pdf
The study of solar coronal holes (CHs) is important in the understanding of solar physics and the prediction of space weather events, which have significant impact on space-based instruments, communication and navigation systems. With the availability of the multi-wavelength Atmospheric Imaging Assembly (AIA) instrument on board Solar Dynamics Observatory (SDO) satellite, a large volume of high-resolution solar images are produced continuously. Proper detection of CHs from AIA images is an important issue and recently, a few contour and machine learning-based techniques are found to be promising for such purpose. However, accuracy, time complexity and the requirement of human intervention are some of the critical issues with such methods. In this paper, to address these challenging issues, two contour-based approaches are developed, namely i) the Hough transformed simulated parameterized online region-based active contour method (POR-ACM) and ii) fast fuzzy c-means clustering followed by Hough transformed simulated static contour method (FFCM-SCM). The major issues that are addressed here are automated initialization of contour, reducing time complexity and avoidance of non-coronal hole inside a coronal hole region during contour evolution. The proposed techniques have been tested on three benchmark solar disk images and compared with the existing active contour without edge- (ACWE) based method and fuzzy energy-based dual contour method (FEDCM) of CHs segmentation. The results indicate the capability of the proposed techniques in detection and extraction of CHs in solar disk image with higher accuracy and reduced time complexity. **2017-01-30, 2017-03-14, 2017-09-14**

MHD Waves in the coronal holes **Review**

D. **Banerjee**, S. Krishna Prasad
Chapter in AGU Monograph **2015**
http://arxiv.org/pdf/1505.04475v1.pdf
Coronal holes are the dark patches in the solar corona associated with relatively cool, less dense plasma and unipolar fields. The fast component of the solar wind emanates from these regions. Several observations reveal the presence of magnetohydrodynamic (MHD) waves in coronal holes which are believed to play a key role in the acceleration of fast solar wind. The recent advent of high-resolution instruments had brought us many new insights on the properties of MHD waves in coronal holes which are reviewed in this article. The advances made in the identification of compressive slow MHD waves in both polar and equatorial coronal holes, their possible connection with the recently discovered high- speed quasi-periodic upflows, their dissipation, and the detection of damping in Alfven waves from the spectral line width variation are discussed in particular. **20-07-2010**

Propagating MHD Waves in Coronal Holes

D. **Banerjee**, G. R. Gupta & L. Teriaca
Space Science Reviews, Volume 158, Numbers 2-4, 267-288, **2011**
Coronal holes are the coolest and darkest regions of the upper solar atmosphere, as observed both on the solar disk and above the solar limb. Coronal holes are associated with rapidly expanding open magnetic fields and the acceleration of the high-speed solar wind. During the years of the solar minima, coronal holes are generally confined

to the Sun's polar regions, while at solar maxima they can also be found at lower latitudes. Waves, observed via remote sensing and detected in-situ in the wind streams, are most likely responsible for the wind and several theoretical models describe the role of MHD waves in the acceleration of the fast solar wind. This paper reviews the observational evidences of detection of propagating waves in these regions. The characteristics of the waves, like periodicities, amplitude, speed provide input parameters and also act as constraints on theoretical models of coronal heating and solar wind acceleration.

Signatures of Alfv?en waves in the polar coronal holes as seen by EIS/Hinode

D. **Banerjee**, D. P?erez-Su?arez, and J.G. Doyle

E-print, June **2009**; A&A

We diagnose the properties of the plume and interplume regions in a polar coronal hole and the role of waves in the acceleration of the solar wind.

Aims. We attempt to detect whether Alfven waves are present in the polar coronal holes through variations in EUV line widths.

Methods. Using spectral observations performed over a polar coronal hole region with the EIS spectrometer on Hinode, we study the variation in the line width and electron density as a function of height. We use the density sensitive line pairs of Fe xii 186.88 A & 195.119 A and Fe xiii 203.82 A & 202.04 A .

Results. For the polar region, the line width data show that the nonthermal line-of-sight velocity increases from 26 km/s at 1000 above the limb to 42 km/s some 15000 (i.e. 110,000 km) above the limb. The electron density shows a decrease from 3.3 10^9 cm^-3 to 1.9 10^8 cm^-3 over the same distance. Conclusions. These results imply that the nonthermal velocity is inversely proportional to the quadratic root of the electron density, in excellent agreement with what is predicted for undamped radially propagating linear Alfven waves. Our data provide signatures of Alfven waves in the polar coronal hole regions, which could be important for the acceleration of the solar wind.

A Statistical Comparison of EUV Brightenings Observed by SO/EUI with Simulated Brightenings in Nonpotential Simulations

Krzysztof **Barczynski**, Karen A. Meyer, Louise K. Harra, Duncan H. Mackay, Frédéric Auchère & David Berghmans

Solar Physics volume 297, Article number: 141 (**2022**)

https://link.springer.com/content/pdf/10.1007/s11207-022-02074-6.pdf

The High Resolution Imager (HRIEUV) 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 nonpotential 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 HRIEUV telescope. We applied the same detection method to the simulated energy dissipation maps from the nonpotential simulation to detect simulated brightenings. We detected EUV brightenings with a density of 1.41×10−3 brightenings/Mm2 in the EUI observations and simulated brightenings between 2.76×10−2 – 4.14×10−2 brightenings/Mm2 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 nonpotential 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.

A search for mode coupling in magnetic bright points

Arthur **Berberyan**, Peter H. Keys, David B. Jess, Damian J. Christian

A&A **2024**

https://arxiv.org/pdf/2409.11553

Context. Magnetic bright points (MBPs) are one of the smallest manifestations of the magnetic field in the solar atmosphere and are observed to extend from the photosphere up to the chromosphere. As such, they represent an excellent feature to use in searches for types of magnetohydrodynamic (MHD) waves and mode coupling in the solar atmosphere. Aims. In this work, we aim to study wave propagation in the lower solar atmosphere by comparing intensity oscillations in the photosphere with the chromosphere via a search for possible mode coupling, in order to establish the importance of these types of waves in the solar atmosphere, and their contribution to heating the chromosphere. Methods. Observations were conducted in July 2011 with the ROSA and the HARDCam instruments at the Dunn Solar Telescope. We used wavelet analysis to identify traveling MHD waves and derive frequencies in the G-band and Hαwave bands. We isolated a large sample of MBPs using an automated tracking algorithm throughout our observations. Two dozen of the brightest MBPs were selected from the sample for further study. Results. We find oscillations in the G-band MBPs, with frequencies between 1.5 and 3.6 mHz. Corresponding MBPs in the lower solar chromosphere observed in Hα show a frequency range of 1.4 to 4.3 mHz. In about 38\% of the MBPs, the ratio of Hα to G-band frequencies was near two. Thus, these oscillations show a form of mode coupling where the transverse waves in the photosphere are converted into longitudinal waves in the chromosphere. Conclusions. From simple estimates we find an energy flux of ≈45 ×103 W m−2 and show that the energy flowing through MBPs is enough to heat the chromosphere, and mode coupling is important in helping us understand the types of MHD waves in the lower solar atmosphere and the overall energy budget. **2011 July 11**

Observational evidence for two-component distributions describing solar magnetic bright points

G. **Berrios** Saavedra, D. Utz, S. Vargas Dominguez, J. I. Campos Rozo, S. J. González Manrique, P. Gömöry, C. Kuckein, H. Balthasar, P. Zelina

A&A **2021**

https://arxiv.org/pdf/2110.12404.pdf

Context. High-resolution observations of the solar photosphere reveal the presence of fine structures, in particular the so-called magnetic bright points (MBPs), which are small-scale features associated with strong magnetic field regions of the order of kilogauss (kG). It is especially relevant to study these magnetic elements, which are extensively detected at all moments of the solar cycle, in order to establish their contribution to the behaviour of the solar atmosphere, and ultimately a plausible role within the coronal heating problem. Aims. We aim to characterise the size and velocity distributions of MBPs in the solar photosphere in two different datasets of quiet Sun images acquired with the Solar Optical Telescope SOT/Hinode and the High-resolution Fast Imager HiFI/GREGOR, in the G-band (4308 angstroms). Methods. In order to detect the MBPs, an automatic segmentation and identification algorithm was used. Next, the identified features were tracked to measure their proper motions. Finally, a statistical analysis of hundreds of MBPs was carried out, generating histograms for areas, diameters, and horizontal velocities. Results. This work establishes that areas and diameters of MBPs display log-normal distributions that are well fitted by two different components, whereas the velocity vector components follow Gaussians, and the vector magnitude follows a Rayleigh distribution again revealing a two-component composition for all vector elements. Conclusions. The results can be interpreted as due to the presence of two different populations of MBPs in the solar photosphere, one likely related to stronger network magnetic flux elements and the other one to weaker intranetwork flux elemens. In particular, this work concludes on the effect of the different spatial resolutions of the GREGOR and Hinode telescopes, affecting detections and average values. **March 10, 2007**

Formation and evolution of coronal holes during the rising phase of cycle 23

Irina A. **Bilenko**, Kseniya S. Tavastsherna

2019

https://arxiv.org/ftp/arxiv/papers/1907/1907.03126.pdf

Regularities of formation of coronal holes (CH) at the rising phase of cycle 23 are investigated. The period from 01.01.1997 to 01.03.2000 (Carrington rotations (CRs) 1918-2059) is considered in detail. The evolution of the global magnetic field (GMF) of the Sun from the zonal to the sectorial structure is analyzed. It is shown that the zonal structure is quasi-stable. The sum of zonal harmonics dominated up to CR 1941, although a stable four-sector structure of GMF was formed in 1932. In CRs 1941-1950 the contribution of the zonal and sectorial components becomes approximately equal and from CR 1950 the sectorial structure of GMF was dominated. Sectorial structure of GMF undergoing sharp changes from four-sector, at the beginning of growth of the sectorial harmonics (CR 1926), to the two-sector structure, then back to four-sector and then again to the two-sector structure. CHs clearly trace all evolutionary changes in the GMF. The structure of the polarity of the GMF uniquely determines the zones of photospheric magnetic fields where the CHs are formed.

Coronal Hole and Solar Global Magnetic Field Evolution in 1976 – 2012

Irina A. **Bilenko**, Ksenia S. Tavastsherna

Solar Phys. Volume 291, Issue 8, pp 2329–2352 **2016**

We study the spatial-temporal evolution of a coronal hole and compare it with that of the solar global magnetic field in Cycles 21 – 23 (1976 – 2012). We also analyze the latitude-longitude distribution dynamics of coronal holes and the regularities in the global magnetic field associated with the solar polar field reversal. Polar and non-polar coronal hole populations are considered. The investigation reveals some temporal and spatial regularities in coronal hole distributions that match the global magnetic-field cycle evolution well. The results show that the non-polar coronal hole longitudinal distribution follows all configuration changes in the global magnetic-field structure. Reorganizations of the global magnetic field and coronal hole distributions occur simultaneously during a time interval of a few solar rotations. The cycle evolution of the non-polar coronal holes reflects the transition of the solar global magnetic field from the zonal structure to sectorial and *vice versa*. Two different types of waves of non-polar coronal holes are revealed from their latitudinal distribution. The first are short poleward waves. They trace the poleward motion of the unipolar photospheric magnetic fields from approximately 35∘ to the associated pole in each hemisphere and the redevelopment of a new-polarity polar CH. Although they start the poleward movement before the change of the polar magnetic field in the associated hemisphere, they reach the pole after the polar reversal. The other type of non-polar CH wave forms two sinusoidal branches associated with the positive- and negative-polarity magnetic fields. The complete period of the wave is equal to ≈268 CRs (22 years). These wave CHs arrive at high latitudes during declining phases when the new-polarity polar CHs are already completely formed.

SPECTROSCOPIC SIGNATURE OF ALFVÉN WAVES DAMPING IN A POLAR CORONAL HOLE UP TO 0.4 SOLAR RADII

A. **Bemporad** and L. Abbo

2012 ApJ 751 110

Between **2009 February 24 and 25**, the EUV Imaging Spectrometer (EIS) spectrometer on board the Hinode spacecraft performed special "sit and stare" observations above the south polar coronal hole continuously over more than 22 hr. Spectra were acquired with the 1" slit placed off-limb covering altitudes up to 0.48 R ⊙ (3.34 × 102 Mm) above the Sun surface, in order to study with EIS the non-thermal spectral line broadenings. Spectral lines such as Fe XII λ186.88, Fe XII λ193.51, Fe XII λ195.12, and Fe XIII λ202.04 are observed with good statistics up to high altitudes and they have been analyzed in this study. Results show that the FWHM of the Fe XII λ195.12 line increases up to 0.14 R ⊙, then decreases higher up. EIS stray light has been estimated and removed. Derived electron density and non-thermal velocity profiles have been used to estimate the total energy flux transported by Alfvén waves off-limb in the polar coronal hole up to 0.4 R ⊙. The computed Alfvén wave energy flux density fw progressively decays with altitude from fw 1.2 × 106 erg cm–2 s–1 at 0.03 R ⊙ down to fw 8.5 × 103 erg cm–2 s–1 at 0.4 R ⊙, with an average energy decay rate of Δfw /Δh –4.5 × 10–5 erg cm–1. Hence, this result suggests energy deposition by Alfvén waves in a polar coronal hole, thus providing a significant source for coronal heating.

Data-Driven Classification of Coronal Hole and Streamer Belt Solar Wind

Téo **Bloch**, Clare Watt, Mathew Owens, Leland McInnes & Allan R. Macneil

Solar Physics volume 295, Article number: 41 (**2020**)

https://link.springer.com/content/pdf/10.1007/s11207-020-01609-z.pdf

https://doi.org/10.1007/s11207-020-01609-z

We present two new solar wind origin classification schemes developed independently using unsupervised machine learning. The first scheme aims to classify solar wind into three types: coronal-hole wind, streamer-belt wind, and ‘unclassified’ which does not fit into either of the previous two categories. The second scheme independently derives three clusters from the data; the coronal-hole and streamer-belt winds, and a differing unclassified cluster. The classification schemes are created using non-evolving solar wind parameters, such as ion charge states and composition, measured during the three Ulysses fast latitude scans. The schemes are subsequently applied to the Ulysses and the Advanced Compositional Explorer (ACE) datasets. The first scheme is based on oxygen charge state ratio and proton specific entropy. The second uses these data, as well as the carbon charge state ratio, the alpha-to-proton ratio, the iron-to-oxygen ratio, and the mean iron charge state. Thus, the classification schemes are grounded in the properties of the solar source regions. Furthermore, the techniques used are selected specifically to reduce the introduction of subjective biases into the schemes. We demonstrate significant best case disparities (minimum ≈8%, maximum ≈22%) with the traditional fast and slow solar wind determined using speed thresholds. By comparing the results between the in- (ACE) and out-of-ecliptic (Ulysses) data, we find morphological differences in the structure of coronal-hole wind. Our results show how a data-driven approach to the classification of solar wind origins can yield results which differ from those obtained using other methods. As such, the results form an important part of the information required to validate how well current understanding of solar origins and the solar wind match with the data we have.

Coronal Hole and Solar Global Magnetic Field Evolution in 1976 – 2012

Irina A. **Bilenko**, Ksenia S. Tavastsherna

Solar Phys. Volume 291, Issue 8, pp 2329–2352 **2016**

https://arxiv.org/pdf/1805.09543.pdf

We study the spatial-temporal evolution of a coronal hole and compare it with that of the solar global magnetic field in Cycles 21 – 23 (1976 – 2012). We also analyze the latitude-longitude distribution dynamics of coronal holes and the regularities in the global magnetic field associated with the solar polar field reversal. Polar and non-polar coronal hole populations are considered. The investigation reveals some temporal and spatial regularities in coronal hole distributions that match the global magnetic-field cycle evolution well. The results show that the non-polar coronal hole longitudinal distribution follows all configuration changes in the global magnetic-field structure. Reorganizations of the global magnetic field and coronal hole distributions occur simultaneously during a time interval of a few solar rotations. The cycle evolution of the non-polar coronal holes reflects the transition of the solar global magnetic field from the zonal structure to sectorial and *vice versa*. Two different types of waves of non-polar coronal holes are revealed from their latitudinal distribution. The first are short poleward waves. They trace the poleward motion of the unipolar photospheric magnetic fields from approximately 35∘ to the associated pole in each hemisphere and the redevelopment of a new-polarity polar CH. Although they start the poleward movement before the change of the polar magnetic field in the associated hemisphere, they reach the pole after the polar reversal. The other type of non-polar CH wave forms two sinusoidal branches associated with the positive- and negative-polarity magnetic fields. The complete period of the wave is equal to ≈268 CRs (22 years). These wave CHs arrive at high latitudes during declining phases when the new-polarity polar CHs are already completely formed.

On Dynamics of G-Band Bright Points

M. **Bodnárová**, D. Utz, J. Rybák

Solar Physics, May **2014**, Volume 289, Issue 5, pp 1543-1556

Various parameters describing the dynamics of G-band bright points (GBPs) were derived from G-band images, acquired by the Dutch Open Telescope (DOT), of a quiet region close to the disk center. Our study is based on four commonly used diagnostics (effective velocity, change in the effective velocity, change in the direction angle, and centrifugal acceleration) and two new ones (rate of motion and time lag between recurrence of GBPs). The results concerning the commonly used parameters are in agreement with previous studies for a comparable spatial and temporal resolution of the used data. The most probable value of the effective velocity is ∼ 0.9 km s−1, whereas we found a deviation of the effective velocity distribution from the expected Rayleigh function for velocities in the range from 2 to 4 km s−1. The change in the effective velocity distribution is consistent with a Gaussian one with FWHM=0.079 km s−2. The distribution of the centrifugal acceleration exhibits a highly exponential nature (a symmetric Gaussian centered at the zero value). To broaden our understanding of the dynamics of GBPs, two new parameters were defined: the real displacement between their appearance and disappearance (rate of motion) and the frequency of their recurrence at the same locations (time lag). For ∼ 45 % of the tracked GBPs, their displacement was found to be small compared to their size (the rate of motion smaller than one). The locations of the tracked GBPs mainly cover the boundaries of supergranules representing the network, and there is no significant difference in the locations of GBPs with small (m<1) and large (m>2) values of the rate of motion. We observed a difference in the overall trend of the obtained distribution for the values of the time lag smaller (slope of the trend line being −0.14) and greater (−0.03) than ∼ 7 min. The time lags mostly lie within the interval of ∼ 2 – 3 min, with those up to ∼ 4 min being more abundant than longer ones. Results for both new parameters indicate that the locations of different dynamical types of GBPs (stable/farther traveling or with short/long lifetimes) are bound to the locations of more stable and long-living magnetic field concentrations. Thus, the disappearance/reappearance of the tracked GBPs cannot be perceived as the disappearance/reappearance of their corresponding magnetic field concentrations.

Center-to-limb variation of the area covered by magnetic bright points in the quiet Sun

J. A. **Bonet**1,2, I. Cabello3 and J. Sánchez Almeida

A&A 539, A6 (**2012**)

Context. The quiet Sun magnetic fields produce ubiquitous bright points (BPs) that cover a significant fraction of the solar surface. Their contribution to the total solar irradiance (TSI) is so-far unknown.
Aims. We aim at measuring the center-to-limb variation (CLV) of the fraction of solar surface covered by quiet Sun magnetic bright points. The fraction is referred to as the fraction of covered surface (FCS).
Methods. We count the area covered by BPs in G-band images obtained at various heliocentric angles with the 1-m Swedish Solar Telescope on La Palma. We restore the images to bring them close to the diffraction limit of the instrument (~0'.1).

Results. The FCS is largest at the disk center (≃1%), and then drops down to become ≃0.2% at μ ≃ 0.3 (where μ is the cosine of the heliocentric angle). The relationship has a large scatter, which we evaluate by comparing different subfields within our FOVs. We develop a toy-model to describe the observed CLV, which considers the BPs as depressions in the mean solar photosphere characterized by a depth, a width, and a spread in the inclinations.

Although the model is poorly constrained by observations, it shows the BPs to be shallow structures (depth < width) with a large range of inclinations. We also estimate how different parts of the solar disk may contribute to the TSI variations, finding that 90% is contributed by BPs with μ > 0.5, and half of it is due to BPs with μ > 0.8.

The Trailing Edges of High-Speed Streams at 1 AU

Joseph E. **Borovsky**, Michael H. Denton

JGR **2016**

The trailing-edge rarefactions of **54 high-speed streams at 1 AU** are analyzed. The temporal durations of the trailing-edge rarefactions agree with ballistic calculations based on the observed speeds of the fast and slow wind bounding the rarefactions. A methodology is developed to measure solar-wind compression and rarefaction using the orientations of solar-wind current sheets. One focus is to determine the signature that best describes the location of the trailing-edge stream interface between coronal-hole-origin plasma and streamer-belt-origin plasma; based on the current-sheet orientations, on the magnetic-field strength, on the intensity of the electron strahl, and on the intensity of the negative vorticity, an inflection point in the temporal profile of the solar-wind velocity is taken as the best indicator of the trailing-edge stream interface. Computer simulations support this choice. Using superposed-epoch analysis, the plasma properties and turbulence properties of trailing-edge rarefactions are surveyed. Whereas the signatures of the coronal-hole/streamer-belt (slow-wind/fast-wind) boundary in the leading edge (CIR) stream interface are simultaneous, they are not simultaneous in the trailing edge, with ion-charge-state signatures occurring on average 13.7 hours prior to the proton-entropy signature. It is suggested that differences in the leading and trailing edges of coronal holes on the Sun might account for the differences in the leading and trailing edges of high-speed streams at 1 AU: the formation timescales, heating timescales, and charge-state-equilibration timescales of closed flux loops in the corona might be involved.

The Plasma Structure of Coronal-Hole Solar Wind: Origins and Evolution

Joseph E. **Borovsky**

JGR Volume 121, Issue 6 June 2016 Pages 5055–5087 **2016**

Whereas slow solar wind is known to be highly structured, the fast (coronal-hole-origin) wind is usually considered to be homogeneous. Using measurements from Helios 1 + 2, ACE, Wind, and Ulysses, structure in the coronal-hole-origin solar wind is examined from 0.3 AU to 2.3 AU. Care is taken to collect and analyze intervals of “unperturbed coronal-hole plasma”. In these intervals, solar-wind structure is seen in the proton number density, proton temperature, proton specific entropy, magnetic-field strength, magnetic field to density ratio, electron heat flux, helium abundance, heavy-ion charge-state ratios, and Alfvenicity. Typical structure amplitudes are factors of two, far from homogeneous. Variations are also seen in the solar wind radial velocity. Using estimates of the motion of the solar-wind-origin footpoint on the Sun for the various spacecraft, the satellite time-series measurements are converted to distance along the photosphere. Typical variation scale lengths for the solar-wind structure are several variations per supergranule. The structure amplitude and structure scale sizes do not evolve with distance from the Sun from 0.3 to 2.3 AU. An argument is quantified that these variations are the scale expected for solar-wind production in open magnetic-flux funnels in coronal holes. Additionally, a population of magnetic-field foldings (switchbacks, reversals) in the coronal-hole plasma is examined: this population evolves with distance from the Sun such that the magnetic-field is mostly Parker-spiral aligned at 0.3 AU and becomes more misaligned with distance outward.

Experimental Study of Alfvén Wave Reflection from an Alfvén-speed Gradient Relevant to the Solar Coronal Holes

Sayak **Bose**1,2, Jason M. TenBarge2, Troy Carter3, Michael Hahn4, Hantao Ji1,2, James Juno1, Daniel Wolf Savin4, Shreekrishna Tripathi3, and Stephen Vincena3

2024 ApJ 971 72

https://iopscience.iop.org/article/10.3847/1538-4357/ad528f/pdf

We report the first experimental detection of a reflected Alfvén wave from an Alfvén-speed gradient under conditions similar to those in coronal holes. The experiments were conducted in the Large Plasma Device at the University of California, Los Angeles. We present the experimentally measured dependence of the coefficient of reflection versus the wave inhomogeneity parameter, i.e., the ratio of the wavelength of the incident wave to the length scale of the gradient. Two-fluid simulations using the Gkeyll code qualitatively agree with and support the experimental findings. Our experimental results support models of wave heating that rely on wave reflection at low heights from a smooth Alfvén-speed gradient to drive turbulence.

The Chromosphere Underneath a Coronal Bright Point

Souvik **Bose**1,2,3,4, Daniel Nóbrega-Siverio3,4,5,6, Bart De Pontieu1,3,4, and Luc Rouppe van der Voort3,4

2023 ApJ 944 171

https://iopscience.iop.org/article/10.3847/1538-4357/acb544/pdf

https://arxiv.org/pdf/2301.08596

Coronal bright points (CBPs) are sets of small-scale coronal loops, connecting opposite magnetic polarities, primarily characterized by their enhanced extreme-ultraviolet (EUV) and X-ray emission. Being ubiquitous, they are thought to play an important role in heating the solar corona. We aim at characterizing the barely explored chromosphere underneath CBPs, focusing on the related spicular activity and on the effects of small-scale magnetic flux emergence on CBPs. We used high-resolution observations of a CBP in Hβ and Fe i 617.3 nm from the Swedish 1 m Solar Telescope in coordination with the Solar Dynamics Observatory. This work presents the first high-resolution observation of spicules imaged in Hβ. The spicules were automatically detected using advanced image processing techniques, which were applied to the Dopplergrams derived from Hβ. Here we report their abundant occurrence close to the CBP "footpoints" and find that the orientation of such spicules is aligned along the EUV loops, indicating that they constitute a fundamental part of the whole CBP magnetic structure. Spatiotemporal analysis across multiple channels indicates that there are coronal propagating disturbances associated with the studied spicules, producing transient EUV intensity variations of the individual CBP loops. Two small-scale flux emergence episodes appearing below the CBP were analyzed, one of them leading to quiet-Sun Ellerman bombs and enhancing the nearby spicular activity. This paper presents unique evidence of the tight coupling between the lower and upper atmosphere of a CBP, thus helping to unravel the dynamic phenomena underneath CBPs and their impact on the latter. **4 Aug 2021**

Measured reduction in Alfvén wave energy propagating through longitudinal gradients scaled to match solar coronal holes

Sayak **Bose**, Troy Carter, Michael Hahn, Shreekrishna Tripathi, Stephen Vincena, Daniel Wolf Savin

2019 *ApJ* **882** 183

https://arxiv.org/pdf/1904.12650.pdf

https://doi.org/10.3847/1538-4357/ab2fe0

We have explored the effectiveness of a longitudinal gradient in Alfvén speed in reducing the energy of propagating Alfvén waves under conditions scaled to match solar coronal holes. The experiments were conducted in the Large Plasma Device at the University of California, Los Angeles. Our results show that the energy of the transmitted Alfvén wave decreases as the inhomogeneity parameter, λ/LA, increases. Here, λ is the wavelength of the Alfvén wave and LA is the scale length of Alfvén speed gradient. For gradients similar to those in coronal holes, the waves are observed to lose a factor of ≈5 more energy than they do when propagating through a uniform plasma without a gradient. We have carried out further experiments and analyses to constrain the cause of wave energy reduction in the gradient. The loss of Alfvén wave energy from mode coupling is unlikely, as we have not detected any other modes. Contrary to theoretical expectations, the reduction in the energy of the transmitted wave is not accompanied by a detectable reflected wave. Nonlinear effects are ruled out as the amplitude of the initial wave is too small and the wave frequency well below the ion cyclotron frequency. Since the total energy must be conserved, it is possible that the lost wave energy is being deposited in the plasma. Further studies are needed to explore where the energy is going.

Segmentation of Coronal Holes Using Active Contours Without Edges

L. E. **Boucheron**, M. Valluri, R. T. J. McAteer

Solar Phys. Volume 291, Issue 8, pp 2353–2372 **2016**

https://arxiv.org/pdf/1610.01023v1.pdf

An application of active contours without edges is presented as an efficient and effective means of extracting and characterizing coronal holes. Coronal holes are regions of low-density plasma on the Sun with open magnetic field lines. The detection and characterization of these regions is important for testing theories of their formation and evolution, and also from a space weather perspective because they are the source of the fast solar wind. Coronal holes are detected in full-disk extreme ultraviolet (EUV) images of the corona obtained with the Solar Dynamics Observatory Atmospheric Imaging Assembly (SDO/AIA). The proposed method detects coronal boundaries without determining any fixed intensity value in the data. Instead, the active contour segmentation employs an energy-minimization in which coronal holes are assumed to have more homogeneous intensities than the surrounding active regions and quiet Sun. The segmented coronal holes tend to correspond to unipolar magnetic regions, are consistent with concurrent solar wind observations, and qualitatively match the coronal holes segmented by other methods. The means to identify a coronal hole without specifying a final intensity threshold may allow this algorithm to be more robust across multiple datasets, regardless of data type, resolution, and quality. **2010 Jul. 13, 2011 Jan. 20, 2013 Jan. 25, 2014 May 04**

A RECONNECTION-DRIVEN RAREFACTION WAVE MODEL FOR CORONAL OUTFLOWS

S. J. **Bradshaw**1, G. Aulanier2 and G. Del Zanna

2011 ApJ 743 66

We conduct numerical experiments to determine whether interchange reconnection at high altitude coronal null points can explain the outflows observed as blueshifts in coronal emission lines at the boundaries between open and closed magnetic field regions. In this scenario, a strong, post-reconnection pressure gradient forms in the field-aligned direction when dense and hot, active region core loops reconnect with neighboring tenuous and cool, open field lines. We find that the pressure gradient drives a supersonic outflow and a rarefaction wave develops in both the open and closed post-reconnection magnetic field regions. We forward-model the spectral line profiles for a selection of coronal emission lines to predict the spectral signatures of the rarefaction wave. We find that the properties of the rarefaction wave are consistent with the observed velocity versus temperature structure of the corona in the outflow regions, where the velocity increases with the formation temperature of the emission lines. In particular, we find excellent agreement between the predicted and observed Fe XII 195.119 Å spectral line profiles in terms of the blueshift (10 km s–1), full width at half-maximum (83 mÅ) and symmetry. Finally, we find that $T_i < T_e$ in the open field region, which indicates that the interchange reconnection scenario may provide a viable mechanism and source region for the slow solar wind.

ALMA small-scale features in the quiet Sun and active regions

R. **Brajsa**, I. Skokic, D. Sudar, A. O. Benz, S. Krucker, H.-G. Ludwig, S. H. Saar, C. L. Selhorst
A&A **2021**
https://arxiv.org/pdf/2105.03644.pdf

Aims. The main aim of the present analysis is to decipher (i) the small-scale bright features in solar images of the quiet Sun and active regions obtained with the Atacama Large Millimeter/submillimeter Array (ALMA) and (ii) the ALMA correspondence of various known chromospheric structures visible in the H-alpha images of the Sun. Methods. Small-scale ALMA bright features in the quiet Sun region were analyzed using single-dish ALMA observations (1.21 mm, 248 GHz) and in an active region using interferometric ALMA measurements (3 mm, 100 GHz). With the single-dish observations, a full-disk solar image is produced, while interferometric measurements enable the high-resolution reconstruction of part of the solar disk, including the active region. The selected quiet Sun and active regions are compared with the H-alpha (core and wing sum), EUV, and soft X-ray images and with the magnetograms. Results. In the quiet Sun region, enhanced emission seen in the ALMA is almost always associated with a strong line-of-sight (LOS) magnetic field. Four coronal bright points were identified, while other small-scale ALMA bright features are most likely associated with magnetic network elements and plages. In the active region, in 14 small-scale ALMA bright features randomly selected and compared with other images, we found five good candidates for coronal bright points, two for plages, and five for fibrils. Two unclear cases remain: a fibril or a jet, and a coronal bright point or a plage. A comparison of the H-alpha core image and the 3 mm ALMA image of the analyzed active region showed that the sunspot appears dark in both images (with a local ALMA radiation enhancement in sunspot umbra), the four plage areas are bright in both images and dark small H-alpha filaments are clearly recognized as dark structures of the same shape also in ALMA. **16 and 18 December 2015**

First analysis of solar structures in 1.21 mm full-disc ALMA image of the Sun

R. **Brajša**1, D. Sudar1, A. O. Benz2, I. Skokić1, M. Bárta3, B. De Pontieu4,10, S. Kim5, A. Kobelski6, M. Kuhar2,7, M. Shimojo8,9, S. Wedemeyer10, S. White11, P. Yagoubov12 and Y. Yan13
A&A 613, A17 (**2018**)
https://www.aanda.org/articles/aa/pdf/2018/05/aa30656-17.pdf

Context. Various solar features can be seen in emission or absorption on maps of the Sun in the millimetre and submillimetre wavelength range. The recently installed Atacama Large Millimetre/submillimetre Array (ALMA) is capable of observing the Sun in that wavelength range with an unprecedented spatial, temporal and spectral resolution. To interpret solar observations with ALMA, the first important step is to compare solar ALMA maps with simultaneous images of the Sun recorded in other spectral ranges.
Aims. The first aim of the present work is to identify different structures in the solar atmosphere seen in the optical, infrared, and EUV parts of the spectrum (quiet Sun, active regions, prominences on the disc, magnetic inversion lines, coronal holes and coronal bright points) in a full-disc solar ALMA image. The second aim is to measure the intensities (brightness temperatures) of those structures and to compare them with the corresponding quiet Sun level.
Methods. A full-disc solar image at 1.21 mm obtained on **December 18, 2015**, during a CSV-EOC campaign with ALMA is calibrated and compared with full-disc solar images from the same day in Hα line, in He I 1083 nm line core, and with various SDO images (AIA at 170 nm, 30.4 nm, 21.1 nm, 19.3 nm, and 17.1 nm and HMI magnetogram). The brightness temperatures of various structures are determined by averaging over corresponding regions of interest in the calibrated ALMA image.
Results. Positions of the quiet Sun, active regions, prominences on the disc, magnetic inversion lines, coronal holes and coronal bright points are identified in the ALMA image. At the wavelength of 1.21 mm, active regions appear as bright areas (but sunspots are dark), while prominences on the disc and coronal holes are not discernible from the quiet Sun background, despite having slightly less intensity than surrounding quiet Sun regions. Magnetic inversion lines appear as large, elongated dark structures and coronal bright points correspond to ALMA bright points.
Conclusions. These observational results are in general agreement with sparse earlier measurements at similar wavelengths. *The identification of coronal bright points represents the most important new result*. By comparing ALMA and other maps, it was found that the ALMA image was oriented properly and that the procedure of overlaying the ALMA image with other images is accurate at the 5 arcsec level. The potential of ALMA for physics of the solar chromosphere is emphasised.

An Interpretation of the Coronal Holes' Visibility in the Millimeter Wavelength Range

R. **Brajša** · A.O. Benz · M. Temmer · R. Jurdana-Šepi´c · B. Šaina · H. Wöhl
Solar Phys (**2007**) 245: 167–176

Attention-based machine vision models and techniques for solar wind speed forecasting using solar EUV images

Edward J. E. **Brown**,Filip Svoboda,Nigel P. Meredith,Nicholas Lane,Richard B. Horne

Space Weather e2021SW002976 **2022**
https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021SW002976
https://doi.org/10.1029/2021SW002976
Extreme ultraviolet images taken by the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory make it possible to use deep vision techniques to forecast solar wind speed - a difficult, high-impact, and unsolved problem. At a four day time horizon, this study uses attention-based models and a set of methodological improvements to deliver an 11.1% lower RMSE and a 17.4% higher prediction correlation compared to the previous work testing on the period from 2010 to 2018. Our analysis shows that attention-based models combined with our pipeline consistently outperform convolutional alternatives. Our study shows a large performance improvement by using a 30 minute as opposed to a daily sampling frequency. Our model has learned *relationships between coronal holes' characteristics and the speed of their associated high speed streams*, agreeing with empirical results. Our study finds a strong dependence of our best model on the phase of the solar cycle, with the best performance occurring in the declining phase. **2011-06-07**

Investigating the Chromospheric Footpoints of the Solar Wind

Paul **Bryans**1, Scott W. McIntosh1, David H. Brooks2, and Bart De Pontieu3,4,5
2020 ApJL 905 L33
https://doi.org/10.3847/2041-8213/abce69
Coronal holes present the source of the fast solar wind. However, the fast solar wind is not unimodal—there are discrete, but subtle, compositional, velocity, and density structures that differentiate different coronal holes as well as wind streams that originate within one coronal hole. In this Letter we exploit full-disk observational "mosaics" performed by the Interface Region Imaging Spectrograph (IRIS) spacecraft to demonstrate that significant spectral variation exists within the chromospheric plasma of coronal holes. The spectral differences outline the boundaries of some—but not all—coronal holes. In particular, we show that the "peak separation" of the Mg ii h line at 2803 Å illustrates changes in what appear to be open magnetic features within a coronal hole. These observations point to a chromospheric source for the inhomogeneities found in the fast solar wind. These chromospheric signatures can provide additional constraints on magnetic field extrapolations close to the source, potentially on spatial scales smaller than from traditional coronal hole detection methods based on intensity thresholding in the corona. This is of increased importance with the advent of Parker Solar Probe and Solar Orbiter and the ability to accurately establish the connectivity between their in situ measurements and remote sensing observations of the solar atmosphere.

Forecasting high-speed solar wind streams based on solar extreme-ultraviolet images

X. **Bu** , B. Luo, C. Shen , S. Liu, J. Gong, Y. Cao , H. Wang
Space Weather **2019**
sci-hub.se/10.1029/2019SW002186
High-speed solar wind streams that originate from coronal holes play an important role in space weather disturbances, especially during the declining phase of the solar cycle. Space weather forecasters attempt to find good coronal hole indices that can be used to predict high speed streams days in advance. Several indices related to the coronal hole area, brightness, or magnetic field expansion factor have been reported in the literature. Empirical solar wind forecast models have been developed and used in operational service by several organizations by constructing prediction functions that relate the coronal hole index to the solar wind speed. In this paper, we present a new empirical modeling method, and test its validity by comparing it with a previously reported method when applied to different coronal hole indices. In total, six empirical models are tested for a long period of time (2011--2018), with a 27-day persistence model as a comparison benchmark. The results show that while all these empirical models can capture the temporal patterns of the solar wind observations well, the new modeling method and utilization of a composite coronal hole index PCH as an input parameter indeed improves the forecast accuracy. The high speed streams can be predicted approximately 3 days in advance, with a probability of detection (POD) of 0.78, a positive predictive value (PPV) of 0.73, and a threat score (TS) of 0.61. The uncertainty of the high-speed stream arrival time is approximately 1 day and the uncertainty of the peak speed is approximately 80 km/s. **February 28, 2011**

OBSERVATIONS OF EUV WAVES IN 3He-RICH SOLAR ENERGETIC PARTICLE EVENTS

R. **Bučík**1,2,3, D. E. Innes1,2, L. Guo1,2, G. M. Mason4, and M. E. Wiedenbeck
2015 ApJ 812 53
Small 3He-rich solar energetic particle (SEP) events with their anomalous abundances, markedly different from the solar system, provide evidence for a unique acceleration mechanism that operates routinely near solar active regions. Although the events are sometimes accompanied by coronal mass ejections (CMEs), it is believed that mass and isotopic fractionation is produced directly in the flare sites on the Sun. We report on a large-scale extreme-ultraviolet (EUV) coronal wave observed in association with 3He-rich SEP events. In the two examples discussed, the observed waves were triggered by minor flares and appeared concurrently with EUV jets and type III radio bursts, but without CMEs. The energy spectra from one event are consistent with so-called class-1 (characterized by power laws) 3He-rich SEP events, while the other with class-2 (characterized by rounded 3He and Fe spectra),

suggesting different acceleration mechanisms in the two. The observation of EUV waves suggests that large-scale disturbances, in addition to more commonly associated jets, may be responsible for the production of 3He-rich SEP events.

THE HELIUM ABUNDANCE IN POLAR CORONAL HOLES AND THE FAST SOLAR WIND

H. S. **Byhring**

2011 ApJ 738 172

I have studied the helium abundance in polar coronal holes and the fast solar wind using a time-dependent numerical model for the hydrogen-helium solar wind that spans the mid-to-upper chromosphere, transition region, corona, and solar wind. The model calculates the particle density, flow velocity, parallel and perpendicular temperature, and heat flux for all particle species simultaneously. The focus is on (1) the coronal/solar wind helium abundance as a function of the total magnetic field expansion and (2) the coronal abundance enhancements resulting from low helium heating rates. It is shown that the magnetic field expansion factor may be important in the determination of the solar wind helium abundance and that this can be understood in terms of gravitational settling in the chromosphere. I find that a total magnetic field expansion factor of about 20 is consistent with the observed helium abundance in the solar wind. Furthermore, it is demonstrated that existing observations, both spectroscopic observations of the corona and in situ observations in the solar wind, are compatible with helium abundance enhancements in the corona. For proton-electron plasma properties in accordance with observations, the coronal helium abundance enhancements occur in the region 1.2-2 R .

Comparison of the Scaling Properties of EUV Intensity Fluctuations in Coronal Hole and Quiet-Sun Regions

Ana Cristina **Cadavid**, Mari Paz Miralles, Kristine Romich

ApJ **886** 143 **2019**

https://arxiv.org/ftp/arxiv/papers/1910/1910.09541.pdf

https://doi.org/10.3847/1538-4357/ab4d4e

Using detrended fluctuation analysis (DFA) and rescaled range (R/S) analysis, we investigate the scaling properties of EUV intensity fluctuations of low-latitude coronal holes (CHs) and neighboring quiet-Sun (QS) regions in signals obtained with the Solar Dynamics Observatory/Atmospheric Imaging Assembly (SDO/AIA) instrument. Contemporaneous line-of-sight SDO/Helioseismic and Magnetic Imager (HMI) magnetic fields provide a context for the physical environment. We find that the intensity fluctuations in the time series of EUV images present at each spatial point a scaling symmetry over the range ∼20 min to ∼ 1 hour. Thus we are able to calculate a generalized Hurst exponent and produce image maps, not of physical quantities like intensity or temperature, but of a single dynamical parameter that sums up the statistical nature of the intensity fluctuations at each pixel. In quiet-Sun (QS) regions and in coronal holes (CHs) with magnetic bipoles, the scaling exponent ($1.0<\alpha\leq1.5$) corresponds to anti-correlated turbulent-like processes. In coronal holes, and in quiet-Sun regions primarily associated with (open) magnetic field of dominant polarity, the generalized exponent ($0.5 <\alpha< 1$) corresponds to positively-correlated (persistent) processes. We identify a tendency for $\alpha \sim 1$ near coronal hole boundaries and in other regions in which open and closed magnetic fields are in proximity. This is a signature of an underlying 1/f type process that is characteristic for self-organized criticality and shot-noise models. **2017 February 27, 2017 April 16, 2017 April 21**

Non-magnetic photospheric bright points in 3D simulations of the solar atmosphere⋆

F. **Calvo**1,2, O. Steiner1,3 and B. Freytag4

A&A 596, A43 (**2016**)

https://arxiv.org/pdf/1612.04278v1.pdf

Context. Small-scale bright features in the photosphere of the Sun, such as faculae or G-band bright points, appear in connection with small-scale magnetic flux concentrations.

Aims. Here we report on a new class of photospheric bright points that are free of magnetic fields. So far, these are visible in numerical simulations only. We explore conditions required for their observational detection.

Methods. Numerical radiation (magneto-)hydrodynamic simulations of the near-surface layers of the Sun were carried out. The magnetic field-free simulations show tiny bright points, reminiscent of magnetic bright points, only smaller. A simple toy model for these non-magnetic bright points (nMBPs) was established that serves as a base for the development of an algorithm for their automatic detection. Basic physical properties of 357 detected nMBPs were extracted and statistically evaluated. We produced synthetic intensity maps that mimic observations with various solar telescopes to obtain hints on their detectability.

Results. The nMBPs of the simulations show a mean bolometric intensity contrast with respect to their intergranular surroundings of approximately 20%, a size of 60–80 km, and the isosurface of optical depth unity is at their location depressed by 80–100 km. They are caused by swirling downdrafts that provide, by means of the centripetal force, the necessary pressure gradient for the formation of a funnel of reduced mass density that reaches from the

subsurface layers into the photosphere. Similar, frequently occurring funnels that do not reach into the photosphere, do not produce bright points.
Conclusions. Non-magnetic bright points are the observable manifestation of vertically extending vortices (vortex tubes) in the photosphere. The resolving power of 4-m-class telescopes, such as the DKIST, is needed for an unambiguous detection of them.

Magnetic Imbalance at Supergranular Scale: A Driving Mechanism for Coronal Hole Formation.

Cantoresi, M., Berrilli, F.
Sol Phys 299, 101 (**2024**).
https://doi.org/10.1007/s11207-024-02342-7
https://link.springer.com/content/pdf/10.1007/s11207-024-02342-7.pdf
Unraveling the intricate interplay between the solar photosphere's magnetic field and the dynamics of the upper solar atmosphere is paramount to understanding the organization of solar magnetic fields and their influence on space weather events. This study delves into the organization of photospheric magnetic fields particularly in the context of coronal holes (CHs), as they are believed to harbor the sources of fast solar wind. We employed the signed measure technique on synthetic images that depict various arrangements of magnetic fields, encompassing imbalances in the sign of the magnetic field (inward and outward) and spatial organization.
This study provides compelling evidence that the cancellation functions of simulated regions with imbalanced magnetic fields along the boundaries of supergranular cells align with cancellation function trends of observed photospheric magnetic regions associated with CHs. Thus the analysis serves as a significant proof that CHs arise from the formation of imbalanced magnetic patterns on the edges of supergranular cells.

Improving Coronal Hole Detections and Open Flux Estimates

Ronald M. **Caplan**1, Emily I. Mason1, Cooper Downs1, and Jon A. Linker1
2023 ApJ 958 43
https://iopscience.iop.org/article/10.3847/1538-4357/ad01b6/pdf
One systematic limitation of solar coronal hole (CH) detection at extreme ultraviolet (EUV) wavelengths is the obscuration of dark regions of the corona by brighter structures along the line of sight. Another problem arises when using CHs to compute the Sun's open magnetic flux, where surface measurements of the radial magnetic field, , are situated slightly below the effective height of coronal EUV emission. In this paper, we explore these two limitations utilizing a thermodynamic magnetohydrodynamic (MHD) model of the corona for Carrington rotation (CR) 2101, where we generate CH detections from EUV 193 Å images of the corona forward-modeled from the MHD solution, and where the modeled open field is known. We demonstrate a method to combine EUV images into a full Sun map that helps alleviate CH obscuration called the minimum intensity diskmerge (MIDM). We also show the variation in measured open flux and CH area that is due to the effective height differences between EUV and measurements. We then apply the MIDM method to SDO/AIA 193 Å observations from CR 2101, and conduct an analogous analysis. In this case, the MIDM method uses time-varying images, the effects of which are discussed. We show that overall, the MIDM method and an appreciation of the effective height mismatch provide a useful new way to extract a broader view of CHs, especially near the poles. In turn, they enable improved estimates of the open magnetic flux, and help facilitate comparisons between models and observations.

Synchronic coronal hole mapping using multi-instrument EUV images: Data preparation and detection method

R.M. **Caplan**, C. Downs, J.L. Linker
ApJ **823** 53 **2015**
http://arxiv.org/pdf/1510.04718v1.pdf
A method for the automatic mapping of coronal holes (CH) using simultaneous multi-instrument EUV imaging data is described. Synchronized EUV images from STEREO/EUVI A\&B 195\AA\ and SDO/AIA 193\AA\ undergo preprocessing steps that include PSF-deconvolution and the application of data-derived intensity corrections that account for center-to-limb variations (limb-brightening) and inter-instrument intensity normalization. A systematic approach is taken to derive a robust limb-brightening correction technique that takes advantage of unbiased long-term averages of data and respects the physical nature of the problem. The new preprocessing greatly assists in CH detection, allowing for the use of a simplified variable-connectivity two-threshold region growing image segmentation algorithm to obtain consistent detection results. Some examples of the generated synchronic EUV and CH maps are shown, as well as preliminary analysis of CH evolutions.
Several data and code products are made available to the community **http://www.predsci.com/chd/** . For the period of this study (06/10/2010 to 08/18/14) we provide synchronic EUV and coronal hole map data at 6-hour cadence, data derived limb brightening corrections for STEREO/EUVI A\&B 195\AA\ and SDO/AIA 193\AA, and inter-instrument correction factors to equate their intensities. We also provide the coronal hole image segmentation code

modules ({\tt ezseg}) which are implemented in both FORTRAN OpenMP and GPU-accelerated C-CUDA. A complete implementati on of our coronal hole detection pipeline in the form of a ready-to-use MATLAB driver script {\tt euv2chm} utilizing {\tt ezseg} is also made available.

New Solar Telescope Observations of Magnetic Reconnection Occurring in the Chromosphere of the Quiet Sun

Jongchul **Chae**, P. R. Goode, K. Ahn, V. Yurchysyn, V. Abramenko, A. Andic, W. Cao, and Y. D. Park
ApJ **713** L6, **2010**

Magnetic reconnection is a process in which field-line connectivity changes in a magnetized plasma. On the solar surface, it often occurs with the cancellation of two magnetic fragments of opposite polarity. Using the 1.6 m New Solar Telescope, we observed the morphology and dynamics of plasma visible in the Hα line, which is associated with a canceling magnetic feature (CMF) in the quiet Sun. The region can be divided into four magnetic domains: two pre-reconnection and two post-reconnection. In one post-reconnection domain, a small cloud erupted, with a plane-of-sky speed of 10 km s^{-1}, while in the other one, brightening began at points and then tiny bright loops appeared and subsequently shrank. These features support the notion that magnetic reconnection taking place in the chromosphere is responsible for CMFs

Preferential energization of alpha particles in polar coronal holes at one solar radius above the photosphere

Aniruddha **Chakravarty**, M. Bose
MNRAS, **2015**
http://arxiv.org/ftp/arxiv/papers/1501/1501.03941.pdf

Heating of polar coronal holes during solar minimum and acceleration of the fast solar wind issuing therefrom lack comprehensive theoretical understanding. Wave particle interactions are considered to have crucial effects on the extreme properties of heavy ions in the collision-less region of the polar coronal holes. In this article, we have presented a novel sensitivity analysis to investigate plasma heating by radio waves at lower hybrid frequencies. We have employed a three fluid Maxwell model comprising electrons, protons, and alpha particles at around two solar radius heliocentric distance in the polar coronal holes and derived a dispersion relation as a thirteenth order polynomial for the frequency. Our model provides indications of preferential heating of alpha particles in comparison with protons by means of lower hybrid instabilities. We have employed the electron velocity and spatial charge distribution as our basic study tools so as to show the effects of alpha proton differential mass and differential perpendicular velocity on the preferential heating of alpha particles.

Energy Gain of Positive Ions in Solar Polar Coronal Holes

A. **Chakravarty**, M. Bose
Solar Physics, March **2014**, Volume 289, Issue 3, pp 911-918

We have investigated heating of solar polar coronal holes and acceleration of fast solar wind by means of lower hybrid (LH) waves. A three-fluid Maxwell model comprising electrons, protons, and α-particles is employed at around two solar radii heliocentric distance, where wave dissipation starts to be dominated by collisionless processes. We suggest specific wavenumber ranges corresponding to LH as well as stochastic instabilities and find that these instabilities may bring about a significant energy gain in positive ions.

Modeling solar coronal bright point oscillations with multiple nanoflare heated loops

K. **Chandrashekhar**, Aveek Sarkar
ApJ 810 163 **2015**
http://arxiv.org/pdf/1507.04403v1.pdf

Intensity oscillations of coronal bright points (BPs) have been studied for past several years. It has been known for a while that these BPs are closed magnetic loop like structures. However, initiation of such intensity oscillations is still an enigma. There have been many suggestions to explain these oscillations, but modeling of such BPs have not been explored so far. Using a multithreaded nanoflare heated loop model we study the behavior of such BPs in this work. We compute typical loop lengths of BPs using potential field line extrapolation of available data (Chandrashekhar et al. 2013), and set this as the length of our simulated loops. We produce intensity like observables through forward modeling and analyze the intensity time series using wavelet analysis, as was done by previous observers. The result reveals similar intensity oscillation periods reported in past observations. It is suggested these oscillations are actually shock wave propagations along the loop. We also show that if one considers different background subtractions, one can extract adiabatic standing modes from the intensity time series data as well, both from the observed and simulated data.

Characteristics of polar coronal hole jets⋆

K. **Chandrashekhar**1, A. Bemporad2, D. Banerjee1, G. R. Gupta3 and L. Teriaca
A&A 561, A104 (**2014**)
Context. High spatial- and temporal-resolution images of coronal hole regions show a dynamical environment where mass flows and jets are frequently observed. These jets are believed to be important for the coronal heating and the acceleration of the fast solar wind.
Aims. We studied the dynamics of two jets seen in a polar coronal hole with a combination of imaging from EIS and XRT onboard Hinode. We observed drift motions related to the evolution and formation of these small-scale jets, which we tried to model as well.
Methods. Stack plots were used to find the drift and flow speeds of the jets. A toymodel was developed by assuming that the observed jet is generated by a sequence of single reconnection events where single unresolved blobs of plasma are ejected along open field lines, then expand and fall back along the same path, following a simple ballistic motion.
Results. We found observational evidence that supports the idea that polar jets are very likely produced by multiple small-scale reconnections occurring at different times in different locations. These eject plasma blobs that flow up and down with a motion very similar to a simple ballistic motion. The associated drift speed of the first jet is estimated to be ≈27 km s-1. The average outward speed of the first jet is ≈171 km s-1, well below the escape speed, hence if simple ballistic motion is considered, the plasma will not escape the Sun. The second jet was observed in the south polar coronal hole with three XRT filters, namely, C−poly, Al−poly, and Al−mesh filters. Many small-scale (≈3″−5″) fast (≈200−300 km s-1) ejections of plasma were observed on the same day; they propagated outwards. We observed that the stronger jet drifted at all altitudes along the jet with the same drift speed of ≃7 km s-1. We also observed that the bright point associated with the first jet is a part of sigmoid structure. The time of appearance of the sigmoid and that of the ejection of plasma from the bright point suggest that the sigmoid is the progenitor of the jet.
Conclusions. The enhancement in the light curves of low-temperature EIS lines in the later phase of the jet lifetime and the shape of the jet's stack plots suggests that the jet material falls back, and most likely cools down. To further support this conclusion, the observed drifts were interpreted within a scenario where reconnection progressively shifts along a magnetic structure, leading to the sequential appearance of jets of about the same size and physical characteristics. On this basis, we also propose a simple qualitative model that mimics the observations.
April 15, 2007, June 22 to July 3, 2008, July 1, 2008

The dynamical behaviour of a jet in an on-disk coronal hole observed with AIA/SDO

K. **Chandrashekhar**, R. J. Morton, D. Banerjee, G. R. Gupta
E-print, Oct **2013**; A&A 562, A98 (**2014**)
http://arxiv.org/abs/1310.7853
EUV jets situated in coronal holes are thought to play an important role in supplying heated material to the corona and solar wind. The multi-wavelength capabilities and high signal-to-noise of detectors on-board SDO allows for detailed study of these jet's evolution. We aim to exploit SDO's capabilities to reveal information on the jet dynamics and obtain estimates for plasma properties associated with the jet. We study the dynamics an EUV jet with AIA/SDO at a coronal hole boundary. The details of the jet evolution are discussed and measurements of the jet's parameters, e.g. length, width, life time, outward speed, are obtained. Further, automated emission measure analysis is exploited to determine estimates for the temperature and density of the jet. A propagating transverse wave supported by the jet spire is also observed. Measurement of the wave properties are exploited for magneto-seismology and are used in conjunction with the emission measure results to estimate the magnetic field strength of the jet. We present a detailed description of the jet's evolution, with new evidence for plasma flows, prior to the jet's initiation, along the loops at the base of the jet and also find further evidence that flows along the jet spire consist of multiple, quasi-periodic small-scale plasma ejection events. In addition, DEM analysis suggests that the jet has temperatures of log5.89±0.08 K and electron densities of log8.75±0.05 cm−3. Measured properties of the transverse wave suggest the wave is heavily damped as it propagates along the jet spire with speeds of ∼110 km/s. The magneto-seismological inversion of the wave parameters provides values of B=1.21±0.2 G along the jet spire, which is in line with previous estimates for open fields in coronal holes.} **31 May 2011**

Dynamics of Coronal Bright Points as seen by Sun Watcher using Active Pixel System detector and Image Processing (SWAP), Atmospheric Imaging Assembly AIA), and Helioseismic and Magnetic Imager (HMI)

K. **Chandrashekhar**, S. Krishna Prasad, D. Banerjee, B. Ravindra, Daniel B. Seaton
E-print, 5 june **2012**, Solar Phys. (**2013**) 286:125–142
The extit{Sun Watcher using Active Pixel system detector and Image Processing}(SWAP) on board the extit{PRoject for OnBoard Autonomy odash 2} (PROBA odash 2) spacecraft provides images of the solar corona in EUV channel centered at 174 AA. These data, together with extit{Atmospheric Imaging Assembly} (AIA) and the

extit{Helioseismic and Magnetic Imager} (HMI) on board extit{Solar Dynamics Observatory} (SDO), are used to study the dynamics of coronal bright points. The evolution of the magnetic polarities and associated changes in morphology are studied using magnetograms and multi-wavelength imaging. The morphology of the bright points seen in low-resolution SWAP images and high-resolution AIA images show different structures, whereas the intensity variations with time show similar trends in both SWAP 174 and AIA 171 channels. We observe that bright points are seen in EUV channels corresponding to a magnetic-flux of the order of 1018 Mx. We find that there exists a good correlation between total emission from the bright point in several UV odash EUV channels and total unsigned photospheric magnetic flux above certain thresholds. The bright points also show periodic brightenings and we have attempted to find the oscillation periods in bright points and their connection to magnetic flux changes. The observed periods are generally long (10 odash 25 minutes) and there is an indication that the intensity oscillations may be generated by repeated magnetic reconnection.

Variation of coronal holes latitudinal distribution: Correction of limb brightening of EUV coronal images

B.B. **Chargeishvili**, D.A. Maghradze, D.R. Japaridze, N.B. Oghrapishvili, ... B.M. Shergelashvili
Advances in Space Research Volume 64, Issue 2, 15 July **2019**, Pages 491-503
sci-hub.se/10.1016/j.asr.2019.04.009
We studied the limb brightening of SOHO EIT daily images of the solar corona taken in 195 Å wavelength line from 1996 to 2018. Using special software, we studied the distribution of the background intensity of the entire disk in the direction of rotation (horizontally) and perpendicular to the direction of rotation (vertical). The study shows that the intensity distribution from the center to the limb of the solar disk is not polar-symmetric. A data-derived study showed that the coronal limb brightening has rather elliptical than circular isophotes. The pattern of the limb brightening correlates with the cycle of solar activity. The moving average patterns with the window of the year give good results for removing the limb brightening when preparing coronal images for further study.

Propagating Oscillations in the Lower Atmosphere under Coronal Holes

Andrei **Chelpanov**, Nikolai Kobanov, Maksim Chelpanov, Aleksandr Kiselev
ApJ **296**, Article number: 179 **2021**
https://arxiv.org/pdf/2110.12672.pdf
https://link.springer.com/content/pdf/10.1007/s11207-021-01909-y.pdf
https://doi.org/10.1007/s11207-021-01909-y
The subject of this study is oscillations in the lower atmosphere in coronal-hole regions, where the conditions are favorable for propagation between the atmospheric layers. Based on spectroscopic observations in photospheric and chromospheric lines, we analysed the features of the oscillations that show signs of propagation between layers of the solar atmosphere. Using the cross-spectrum wavelet algorithm, we found that both chromospheric and photospheric signals under coronal holes share a range of significant oscillations of periods around five minutes, while the signals outside of coronal holes show no mutual oscillations in the photosphere and chromosphere. The phase shift between the layers indicates a predominantly upward propagation with partial presence of standing waves. We also tested the assumption that torsional Alfvén waves propagating in the corona originate in the lower atmosphere. However, the observed line-width oscillations, although similar in period to the Alfvén waves observed earlier in the corona of open-field regions, seem to be associated with other MHD modes. If we assume that the oscillations that we observed are related to Alfvén waves, then perhaps this is only through the mechanisms of the slow MHD wave transformation. **22 September 2020**

QUIET-SUN NETWORK BRIGHT POINT PHENOMENA WITH SIGMOIDAL SIGNATURES

D. L. **Chesny**[1,2], H. M. Oluseyi[1,3], N. B. Orange[2], and P. R. Champey
2015 ApJ 814 124
Ubiquitous solar atmospheric coronal and transition region bright points (BPs) are compact features overlying strong concentrations of magnetic flux. Here, we utilize high-cadence observations from the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory to provide the first observations of extreme ultraviolet quiet-Sun (QS) network BP activity associated with sigmoidal structuring. To our knowledge, this previously unresolved fine structure has never been associated with such small-scale QS events. This QS event precedes a bi-directional jet in a compact, low-energy, and low-temperature environment, where evidence is found in support of the typical fan-spine magnetic field topology. As in active regions and micro-sigmoids, the sigmoidal arcade is likely formed via tether-cutting reconnection and precedes peak intensity enhancements and eruptive activity. Our QS BP sigmoid provides a new class of small-scale structuring exhibiting self-organized criticality that highlights a multi-scaled self-similarity between large-scale, high-temperature coronal fields and the small-scale, lower-temperature QS network. Finally, our QS BP sigmoid elevates arguments for coronal heating contributions from cooler atmospheric layers, as this class of structure may provide evidence favoring mass, energy, and helicity injections into the heliosphere.

Coronal hole picoflare jets are the progenitors of both the fast and the Alfvénic slow solar wind

L. P. **Chitta**, Z. Huang, R. D'Amicis, D. Calchetti, A. N. Zhukov, E. Kraaikamp, C. Verbeeck, R. Aznar Cuadrado, J. Hirzberger, D. Berghmans, T. S. Horbury, S. K. Solanki, C. J. Owen, L. Harra, H. Peter, U. Schühle, L. Teriaca, P. Louarn, S. Livi, A. S. Giunta, D. M. Hassler, Y.-M. Wang

A&A **2024**

https://arxiv.org/pdf/2411.16513

The solar wind, classified by its bulk speed and the Alfvénic nature of its fluctuations, generates the heliosphere. The elusive physical processes responsible for the generation of the different types of the wind are a topic of active debate. Recent observations revealed intermittent jets with kinetic energy in the picoflare range, emerging from dark areas of a polar coronal hole threaded by open magnetic field lines. These could substantially contribute to the solar wind. However, their ubiquity and direct links to the solar wind have not been established. Here we report a unique set of remote-sensing and in-situ observations from the Solar Orbiter spacecraft, that establish a unified picture of the fast and Alfvénic slow wind, connected to the similar widespread picoflare jet activity in two coronal holes. Radial expansion of coronal holes ultimately regulates the speed of the emerging wind. **13-16 October 2022, 15-17 April 2023**

Picoflare jets power the solar wind emerging from a coronal hole on the Sun

L. P. **Chitta**, A. N. Zhukov, D. Berghmans, H. Peter, S. Parenti, +++

Science 381, 867-872 (**2023**)

https://arxiv.org/ftp/arxiv/papers/2308/2308.13044.pdf

Coronal holes are areas on the Sun with open magnetic field lines. They are a source region of the solar wind, but how the wind emerges from coronal holes is not known. We observed a coronal hole using the Extreme Ultraviolet Imager on the Solar Orbiter spacecraft. We identified jets on scales of a few hundred kilometers, which last 20 to 100 seconds and reach speeds of ~100 kilometers per second. The jets are powered by magnetic reconnection and have kinetic energy in the picoflare range. They are intermittent but widespread within the observed coronal hole. We suggest that such picoflare jets could produce enough high-temperature plasma to sustain the solar wind and that the wind emerges from coronal holes as a highly intermittent outflow at small scales. **2022 March 30**

DYNAMICS OF THE SOLAR MAGNETIC BRIGHT POINTS DERIVED FROM THEIR HORIZONTAL MOTIONS

L. P. **Chitta**1,2, A. A. van Ballegooijen1, L. Rouppe van der Voort3, E. E. DeLuca1, and R. Kariyappa

2012 ApJ 752 48

The subarcsecond bright points (BPs) associated with the small-scale magnetic fields in the lower solar atmosphere are advected by the evolution of the photospheric granules. We measure various quantities related to the horizontal motions of the BPs observed in two wavelengths, including the velocity autocorrelation function. A 1 hr time sequence of wideband Hα observations conducted at the Swedish 1 m Solar Telescope (SST) and a 4 hr Hinode G-band time sequence observed with the Solar Optical Telescope are used in this work. We follow 97 SST and 212 Hinode BPs with 3800 and 1950 individual velocity measurements, respectively. For its high cadence of 5 s as compared to 30 s for Hinode data, we emphasize more the results from SST data. The BP positional uncertainty achieved by SST is as low as 3 km. The position errors contribute 0.75 km2 s–2 to the variance of the observed velocities. The raw and corrected velocity measurements in both directions, i.e., (vx , vy), have Gaussian distributions with standard deviations of (1.32, 1.22) and (1.00, 0.86) km s–1, respectively. The BP motions have correlation times of about 22-30 s. We construct the power spectrum of the horizontal motions as a function of frequency, a quantity that is useful and relevant to the studies of generation of Alfvén waves. Photospheric turbulent diffusion at timescales less than 200 s is found to satisfy a power law with an index of 1.59.

Accelerating and Supersonic Density Fluctuations in Coronal Hole Plumes: Signature of Nascent Solar Winds

Il-Hyun **Cho**, Valery M. Nakariakov, Yong-Jae Moon, Jin-Yi Lee, Dae Jung Yu, Kyung-Suk Cho, Vasyl Yurchyshyn, Harim Lee

ApJL **900** L19 **2020**

https://arxiv.org/pdf/2008.07848.pdf

https://doi.org/10.3847/2041-8213/abb020

Slow magnetoacoustic waves in a static background provide a seismological tool to probe the solar atmosphere in the analytic frame. By analyzing the spatiotemporal variation of the electron number density of plume structure in coronal holes above the limb for a given temperature, we find that the density perturbations accelerate with supersonic speeds in the distance range from 1.02 to 1.23 solar radii. We interpret them as slow magnetoacoustic waves propagating at about the sound speed with accelerating subsonic flows. The average sonic height of the subsonic flows is calculated to be 1.27 solar radii. The mass flux of the subsonic flows is estimated to be

44.1% relative to the global solar wind. Hence, the subsonic flow is likely to be the nascent solar wind. In other words, the evolution of the nascent solar wind in plumes at the low corona is quantified for the first time from imaging observations. Based on the interpretation, propagating density perturbations present in plumes could be used as a seismological probe of the gradually accelerating solar wind. **2017-Jan-03**

A New Type of Jet in a Polar Limb of the Solar Coronal Hole

Il-Hyun **Cho**1, Yong-Jae Moon1,2, Kyung-Suk Cho3,4, Valery M. Nakariakov2,5,6, Jin-Yi Lee1, and Yeon-Han Kim3

2019 ApJL 884 L38

https://doi.org/10.3847/2041-8213/ab4799

A new type of chromospheric jet in a polar limb of a coronal hole is discovered in the Ca ii filtergram of the Solar Optical Telescope on board the Hinode. We identify 30 jets in a filtered Ca ii movie with a duration of 53 minutes. The average speed at their maximum heights is found to be 132 ± 44 km s−1 ranging from 57 to 264 km s−1 along the propagation direction. The average lifetime is 20 ± 6 ranging from 11 to 36 s. The speed and lifetime of the jets are located at end-tails of those parameters determined for type II spicules, hence implying a new type of jets. To confirm whether these jets are different from conventional spicules, we construct a time–height image averaged over a horizontal region of 1", and calculate lagged cross-correlations of intensity profiles at each height with the intensity at 2 Mm. From this, we obtain a cross-correlation map as a function of lag and height. We find that the correlation curve as a function of lag time is well fitted into three different Gaussian functions whose standard deviations of the lag time are 193, 42, and 17 s. The corresponding propagation speeds are calculated to be 9 km s−1, 67 km s−1, and 121 km s−1, respectively. The kinematic properties of the former two components seem to correspond to the 3-minute oscillations and type II spicules, while the latter component to the jets is addressed in this study.

Oscillation of a Small Hα Surge in a Solar Polar Coronal Hole

Kyung-Suk **Cho**1,2, Il-Hyun Cho3, V. M. Nakariakov4,5, Vasyl B. Yurchyshyn6, Heesu Yang1, Yeon-Han Kim1, Pankaj Kumar7, and Tetsuya Magara3,4

2019 ApJL 877 L1

sci-hub.se/10.3847/2041-8213/ab1eb5

https://warwick.ac.uk/fac/sci/physics/research/cfsa/people/valery/research/eprints/Cho_2019_ApJL_877_L1.pdf

Hα surges (i.e., cool/dense collimated plasma ejections) may act as a guide for a propagation of magnetohydrodynamic waves. We report a high-resolution observation of a surge observed with 1.6 m Goode Solar Telescope (GST) on **2009 August 26**, from 18:20 UT to 18:45 UT. Characteristics of plasma motions in the surge are determined with the normalizing radial gradient filter and the Fourier motion filter. The shape of the surge is found to change from a "C" shape to an inverse "C" shape after a formation of a cusp, a signature of reconnection. There are apparent upflows seen above the cusp top and downflows below it. The upflows show rising and rotational motions in the right-hand direction, with the rotational speed decreasing with height. Near the cusp top, we find a transverse oscillation of the surge, with the period of ~2 minutes. There is no change of the oscillation phase below the cusp top, but above the top a phase change is identified, giving a vertical phase speed about 86 km s−1. As the height increases, the initial amplitude of the oscillation increases, and the oscillation damping time decreases from 5.13 to 1.18 minutes. We conclude that the oscillation is a propagating kink wave that is possibly excited by the repetitive spontaneous magnetic reconnection.

Seismological determination of the Alfvén speed and plasma-beta in solar photospheric bright points

Il-Hyun **Cho**, Yong-Jae Moon, Valery M. Nakariakov, Dae Jung Yu, Jin-Yi Lee, Su-Chan Bong, Rok-Soon Kim, Kyung-Suk Cho, Yeon-Han Kim, Jae-Ok Lee

ApJLett **871** L14 **2019**

https://arxiv.org/pdf/1901.04144.pdf

sci-hub.tw/10.3847/2041-8213/aafe0a

The Alfvén speed and plasma beta in photospheric bright points observed by the Broadband Filter Imager (BFI) of the Solar Optical Telescope (SOT) on board the \textit{Hinode} satellite, are estimated seismologically. The diagnostics is based on the theory of slow magnetoacoustic waves in a non-isothermally stratified photosphere with a uniform vertical magnetic field. We identify and track bright points in a G-band movie by using the 3D region growing method, and align them with blue continuum images to derive their brightness temperatures. From the Fourier power spectra of 118 continuum light curves made in the bright points, we find that light curves of 91 bright points have oscillations with properties which are significantly different from oscillation in quiet regions, with the periods ranging 2.2--16.2~min. We find that the model gives a moderate value of the plasma beta when γ lies at around 5/3. The calculated Alfvén speed is 9.68±2.02~km~s−1, ranging in 6.3--17.4~km~s−1. The plasma beta is estimated to be of 0.93±0.36, ranging in 0.2--1.9. **2007-Mar-01**

Statistical Analysis of the Relationships among Coronal Holes, Corotating Interaction Regions, and Geomagnetic Storms

Yunhee **Choi** · Y.-J. Moon · Seonghwan Choi · Ji-Hye Baek · Sungsoo S. Kim · K.-S. Cho · G.S. Choe
Solar Phys (**2009**) 254: 311–323; **File**

We have examined the relationships among coronal holes (CHs), corotating interaction regions (CIRs), and geomagnetic storms in the period 1996 – 2003. We have identified 123 CIRs with forward and reverse shock or wave features in ACE and *Wind* data and have linked them to coronal holes shown in National Solar Observatory/Kitt Peak (NSO/KP) daily He I 10 830 Å maps considering the Sun – Earth transit time of the solar wind with the observed wind speed. A sample of 107 CH – CIR pairs is thus identified. We have examined the magnetic polarity, location, and area of the CHs as well as their association with geomagnetic storms (Dst≤−50 nT). For all pairs, the magnetic polarity of the CHs is found to be consistent with the sunward (or earthward) direction of the interplanetary magnetic fields (IMFs), which confirms the linkage between the CHs and the CIRs in the sample. Our statistical analysis shows that (1) the mean longitude of the center of CHs is about 8°E, (2) 74% of the CHs are located between 30°S and 30°N (*i.e.*, mostly in the equatorial regions), (3) 46% of the CIRs are associated with geomagnetic storms, (4) the area of geoeffective coronal holes is found to be larger than 0.12% of the solar hemisphere area, and (5) the maximum convective electric field E_y in the solar wind is much more highly correlated with the Dst index than any other solar or interplanetary parameter. In addition, we found that there is also a semiannual variation of CIR-associated geomagnetic storms and discovered new tendencies as follows: For negative-polarity coronal holes, the percentage (59%; 16 out of 27 events) of CIRs associated with geomagnetic storms in the first half of the year is much larger than that (25%; 6 out of 24 events) in the second half of the year and the occurrence percentage (63%; 15 out of 24 events) of CIR-associated storms in the southern hemisphere is significantly larger than that (26%; 7 out of 27 events) in the northern hemisphere. Positive-polarity coronal holes exhibit an opposite tendency.

Forecasting High-Speed Solar Wind Streams from Solar Images

Daniel **Collin**, Yuri Shprits, Stefan J. Hofmeister, Stefano Bianco, Guillermo Gallego
ApJ **2024**
https://arxiv.org/pdf/2410.05068

The solar wind, a stream of charged particles originating from the Sun and transcending interplanetary space, poses risks to technology and astronauts. In this work, we present a prediction model to forecast the solar wind speed at the Earth, focusing on high-speed streams (HSSs) and their solar source regions, coronal holes. As input features, we use the coronal hole area, extracted from solar extreme ultraviolet (EUV) images and mapped on a fixed grid, as well as the solar wind speed 27 days before. We use a polynomial regression model and a distribution transformation to predict the solar wind speed with a lead time of four days. Our forecast achieves a root mean square error (RMSE) of 68.1 km/s for the solar wind speed prediction and an RMSE of 76.8 km/s for the HSS peak velocity prediction for the period 2010 to 2019. The study shows that a small number of physical features explains most of the solar wind variation, and that focusing on these features with simple but robust machine learning algorithms even outperforms current approaches based on deep neural networks. In addition, we explain why the typically used loss function, the mean squared error, systematically underestimates the HSS peak velocities and effectively aggravates the space weather forecasts in operational settings. We show how a distribution transformation can resolve this issue.

Corotating Interaction Regions as Seen by the STEREO Heliospheric Imagers 2007 – 2010

T. M. **Conlon**, S. E. Milan, J. A. Davies
Solar Phys., **2015**

NASA's Solar Terrestrial Relations Observatory (STEREO) mission has coincided with a pronounced solar minimum. This allowed for easier detection of corotating interaction regions (CIRs). CIRs are formed by the interaction between fast and slow solar-wind streams ejected from source regions on the solar surface that rotate with the Sun. High-density plasma blobs that have become entrained at the stream interface can be tracked out to large elongations in data from the Heliospheric Imager (HI) instruments onboard STEREO. These blobs act as tracers of the CIR itself such that their HI signatures can be used to estimate CIR source location and radial speed. We estimate the kinematic properties of solar-wind transients associated with 40 CIRs detected by the HI instrument onboard the STEREO-A spacecraft between 2007 and 2010. We identify in-situ signatures of these transients at L1 using the Advanced Composition Explorer (ACE) and compare the in-situ parameters with the HI results. We note that solar-wind transients associated with CIRs appear to travel at or close to the slow solar-wind speed preceding the event as measured in situ. We also highlight limitations in the commonly used analysis techniques of solar-wind transients by considering variability in the solar wind.

Table 2 Timing and propagation speed of the 40 events used in this study. The start time is the start time of the time–elongation profile that starts at $\varphi = 180^\circ$ to the nearest hour in the format dd mmm yyyy hh.

Heating Rates for Protons and Electrons in Polar Coronal Holes: Empirical Constraints from the Ultraviolet Coronagraph Spectrometer

Steven R. **Cranmer** (CU Boulder)

ApJ **900** 105 **2020**

https://arxiv.org/pdf/2007.13180.pdf

https://doi.org/10.3847/1538-4357/abab04

Ultraviolet spectroscopy of the extended solar corona is a powerful tool for measuring the properties of protons, electrons, and heavy ions in the accelerating solar wind. The large coronal holes that expand up from the north and south poles at solar minimum are low-density collisionless regions in which it is possible to detect departures from one-fluid thermal equilibrium. An accurate characterization of these departures is helpful in identifying the kinetic processes ultimately responsible for coronal heating. In this paper, Ultraviolet Coronagraph Spectrometer (UVCS) measurements of the H I Lyman alpha line are analyzed to constrain values for the solar wind speed, electron density, electron temperature, proton temperature (parallel and perpendicular to the magnetic field) and Alfven-wave amplitude. The analysis procedure involves creating a large randomized ensemble of empirical models, simulating their Lyman alpha profiles, and building posterior probability distributions for only the models that agree with the UVCS data. The resulting temperatures do not exhibit a great deal of radial variation between heliocentric distances of 1.4 and 4 solar radii. Typical values for the electron, parallel proton, and perpendicular proton temperatures are 1.2, 1.8, and 1.9 MK, respectively. Resulting values for the "nonthermal" Alfven wave amplitude show evidence for weak dissipation, with a total energy-loss rate that agrees well with an independently derived total heating rate for the protons and electrons. The moderate Alfven-wave amplitudes appear to resolve some tension in the literature between competing claims of both higher (undamped) and lower (heavily damped) values.

"Coronal Holes," Review

Cranmer, S. R.

Living **Review**s in Solar Physics, 6, lrsp-2009-3, **2009**, **File**.

[see also the online version of this paper, as well as arXiv:0909.2847]

Coronal holes are the darkest and least active regions of the Sun, as observed both on the solar disk and above the solar limb. Coronal holes are associated with rapidly expanding open magnetic fields and the acceleration of the high-speed solar wind. This paper reviews measurements of the plasma properties in coronal holes and how these measurements are used to reveal details about the physical processes that heat the solar corona and accelerate the solar wind. It is still unknown to what extent the solar wind is fed by flux tubes that remain open (and are energized by footpoint-driven wave-like fluctuations), and to what extent much of the mass and energy is input intermittently from closed loops into the open-field regions. Evidence for both paradigms is summarized in this paper. Special emphasis is also given to spectroscopic and coronagraphic measurements that allow the highly dynamic non-equilibrium evolution of the plasma to be followed as the asymptotic conditions in interplanetary space are established in the extended corona. For example, the importance of kinetic plasma physics and turbulence in coronal holes has been affirmed by surprising measurements from UVCS that heavy ions are heated to hundreds of times the temperatures of protons and electrons. These observations point to specific kinds of collisionless Alfven wave damping (i.e., ion cyclotron resonance), but complete models do not yet exist. Despite our incomplete knowledge of the complex multi-scale plasma physics, however, much progress has been made toward the goal of understanding the mechanisms responsible for producing the observed properties of coronal holes.

The statistical distribution of the magnetic-field strength in G-band bright points

S. **Criscuoli** and H. Uitenbroek

A&A 562, L1 (**2014**)

Context. G-band bright points are small-sized features characterized by high photometric contrast. Theoretical investigations indicate that these features have associated magnetic-field strengths of 1 to 2 kG. Results from observations, however, lead to contradictory results, indicating magnetic fields of only kG strength in some and including hG strengths in others.

Aims. To understand the differences between measurements reported in the literature, and to reconcile them with results from theory, we analyzed the distribution of the magnetic-field strength of G-band bright features identified in synthetic images of the solar photosphere and its sensitivity to observational and methodological effects.

Methods. We investigated the dependence of magnetic-field strength distributions of G-band bright points identified in 3D magnetohydrodynamic simulations on feature selection method, data sampling, alignment, and spatial resolution.

Results. The distribution of the magnetic-field strength of G-band bright features shows two peaks, one at about 1.5 kG and one below 1 hG. The former corresponds to magnetic features, the second mostly to bright granules. Peaks at several hG are obtained only on spatially degraded or misaligned data.

Conclusions. Simulations show that magnetic G-band bright points have typically associated field strengths of a few kG. Field strengths in the hG range can result from observational effects, which explains the discrepancies presented in the literature. Our results also indicate that results from spectro-polarimetric inversions with an imposed unit filling-factor should be employed with great caution.

THE AREA DISTRIBUTION OF SOLAR MAGNETIC BRIGHT POINTS

P. J. **Crockett**[1], M. Mathioudakis[1], D. B. Jess[1], S. Shelyag[1], F. P. Keenan[1], and D. J. Christian[2]

Astrophysical Journal Letters, 722:L188–L193, **2010**

Magnetic bright points (MBPs) are among the smallest observable objects on the solar photosphere. A combination of *G*-band observations and numerical simulations is used to determine their area distribution. An automatic detection algorithm, employing one-dimensional intensity profiling, is utilized to identify these structures in the observed and simulated data sets. Both distributions peak at an area of ≈45,000 km^2, with a sharp decrease toward smaller areas. The distributions conform with log-normal statistics, which suggests that flux fragmentation dominates over flux convergence. Radiative magneto-convection simulations indicate an independence in theMBP area distribution for differing magnetic flux densities. The most commonly occurring bright point size corresponds to the typical width of inter-granular lanes.

Interchange Reconnection: Remote Sensing of Solar Signature and Role in Heliospheric Magnetic Flux Budget **Review**

N. U. **Crooker**, M. J. Owens

Space Science Reviews, November **2012**, Volume 172, Issue 1-4, pp 201-208

Interchange reconnection at the Sun, that is, reconnection between a doubly-connected field loop and singly-connected or open field line that extends to infinity, has important implications for the heliospheric magnetic flux budget. Recent work on the topic is reviewed, with emphasis on two aspects. The first is a possible heliospheric signature of interchange reconnection at the coronal hole boundary, where open fields meet closed loops. The second aspect concerns the means by which the heliospheric magnetic field strength reached record-lows during the recent solar minimum period. A new implication of this work is that interchange reconnection may be responsible for the puzzling, occasional coincidence of the heliospheric current sheet and the interface between fast and slow flow in the solar wind.

Electron acceleration and small scale coherent structures formation by an Alfvén wave propagating in coronal interplume region

Khalil **Daiffallah**, Fabrice Mottez

Astronomische Nachrichten **2019**

https://arxiv.org/pdf/1904.12224.pdf

We use 2.5-D electromagnetic particle-in-cell simulation code to investigate the acceleration of electrons in solar coronal holes through the interaction of Alfvén waves with an interplume region. The interplume is modeled by a cavity density gradients that are perpendicular to the background magnetic field. The aim is to contribute to explain the observation of suprathermal electrons under relatively quiet sun. Simulations show that Alfvén waves in interaction with the interplume region gives rise to a strong local electric field that accelerates electrons in the direction parallel to the background magnetic field. Suprathermal electron beams and small-scale coherent structures are observed within interplume of strong density gradients. These features result from non linear evolution of the electron beam plasma instability.

The GOES-R Solar UltraViolet Imager

Jonathan M. **Darnel**, Daniel B. Seaton, Christian Bethge, Laurel Rachmeler, Alison Jarvis, Steven M. Hill, Courtney L. Peck, J. Marcus Hughes, Jason Shapiro … See all authors

Space Weather **2022**

https://doi.org/10.1029/2022SW003044

https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2022SW003044

The four Solar UltraViolet Imagers on board the GOES-16 and GOES-17 and the upcoming GOES-T and GOES-U weather satellites serve as NOAA's operational solar coronal imagers. These four identically designed solar EUV instruments are similar in design and capability to the SDO-AIA suite of solar telescopes, and are planned to operationally span two solar cycles or more, from 2017 through 2040. We present the concept of operations for the SUVI instruments, operational requirements, and constraints. The reader is also introduced to the instrument design, testing, and performance characteristics. Finally, the various data products are described along with their potential utility to the operational user or researcher. **21 Aug 2017, 10 Sep 2017, 29 Nov 2020, 29 Apr 2021**

Composition of Coronal Hole Boundary Layers at Low Heliographic Latitudes

K. **Delano**, H. A. Elliott, S. T. Lepri, S. A. Fuselier
JGR Volume126, Issue8 August **2021** e2021JA029187
https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021JA029187
https://doi.org/10.1029/2021JA029187
In some polar coronal holes, previous studies have identified a coronal hole boundary layer (CHBL), which is different in composition from the coronal hole core region. However, compositionally distinct CHBL structure at low heliographic latitudes remains underexplored. Using solar wind composition measurements from the Advanced Composition Explorer (ACE), we study two particular low-latitude coronal holes of 2003: a large polar hole extension with outward magnetic polarity and a smaller equatorial hole with inward magnetic polarity. For both of these coronal holes, we examine the distribution of two composition parameters, the O7+ to O6+ charge state density ratio (n(O7+)/n(O6+)) and the Fe to O abundance ratio (n(Fe)/n(O)), and find that each hole has an identifiable CHBL based on an anticorrelation of solar wind speed and n(O7+)/n(O6+). We also examine the FIP (first ionization potential) effect in the CHBL using n(Fe)/n(O), and find that there is no significant change from the CHBL to the core region for one of the coronal holes we study, while the other coronal hole has a noticeable decrease in n(Fe)/n(O) values in its core. Finally, we discuss our results in the context of previous work studying CHBL structure.

The SPoCA-suite: a software for extraction and tracking of active regions and coronal holes on EUV images,

Delouille, V., B. Mampaey, C. Verbeeck, and R. de Visscher
Arxive-prints, 1208.1483, **2012**.

The plasma filling factor of coronal bright points II. Combined EIS and TRACE results

K. P. **Dere**
A&A 497, 287-290 (**2009**) ; DOI: 10.1051/0004-6361/200811329
Aims. In a previous paper, the volumetric plasma filling factor of coronal bright points was determined from spectra obtained with the Extreme ultraviolet Imaging Spectrometer (EIS). The analysis of these data showed that the median plasma filling factor was 0.015. One interpretation of this result was that the small filling factor was consistent with a single coronal loop with a width of 1–2´´, somewhat below the apparent width. In this paper, higher spatial resolution observations with the Transition Region and Corona Explorer (TRACE) are used to test this interpretation.
Methods. Rastered spectra of regions of the quiet Sun were recorded by the EIS during operations with the Hinode satellite. Many of these regions were simultaneously observed with TRACE. Calibrated intensities of Fe XII lines were obtained and images of the quiet corona were constructed from the EIS measurements. Emission measures were determined from the EIS spectra and geometrical widths of coronal bright points were obtained from the TRACE images. Electron densities were determined from density-sensitive line ratios measured with EIS. A comparison of the emission measure and bright point widths with the electron densities yielded the plasma filling factor.
Results. The median electron density of coronal bright points is 3x109 cm-3 at a temperature of 1.6x106 K. The volumetric plasma filling factor of coronal bright points was found to vary from 3x10-3 to 0.3 with a median value of 0.04.
Conclusions. The current set of EIS and TRACE coronal bright-point observations indicate the median value of their plasma filling factor is 0.04. This can be interpreted as evidence of a considerable subresolution structure in coronal bright points or as the result of a single completely filled plasma loop with widths on the order of 0.2–1.5´´ that has not been spatially resolved in these measurements.

Evolution of Coronal Holes and Implications for High-Speed Solar Wind During the Minimum Between Cycles 23 and 24

G. **de Toma**
Solar Physics, Volume 274, Numbers 1-2, 195-217, **2011**
We analyze coronal holes present on the Sun during the extended minimum between Cycles 23 and 24, study their evolution, examine the consequences for the solar wind speed near the Earth, and compare it with the previous minimum in 1996. **We identify coronal holes and determine their size and location using a combination of EUV observations from SOHO/EIT and STEREO/EUVI and magnetograms.** We find that the long period of low solar activity from 2006 to 2009 was characterized by weak polar magnetic fields and polar coronal holes smaller than observed during the previous minimum. We also find that large, low-latitude coronal holes were present on the Sun until 2008 and remained important sources of recurrent high-speed solar wind streams. By the

end of 2008, these low-latitude coronal holes started to close down, and finally disappeared in 2009, while smaller, mid-latitude coronal holes formed in the remnants of Cycle 24 active regions shifting the sources of the solar wind at the Earth to higher latitudes.

Observed and Modeled Coronal Holes
de Toma, G.; **Arge, C. N.**; **Riley, P.**
Proceedings of the Solar Wind 11 / SOHO 16, "Connecting Sun and Heliosphere" Conference (ESA SP-592). 12 - 17 June 2005 Whistler, Canada. Editors: B. Fleck, T.H. Zurbuchen, H. Lacoste. Published on CDROM., p.118.1, **File**

TRANSIENT CORONAL HOLES AS SEEN IN THE He i 1083 nm MLSO OBSERVATIONS
G. **de Toma**, T. E. Holzer, J. T. Burkepile, and H. R. Gilbert
The Astrophysical Journal, 621:1109–1120, 2005, File

A new model for heating of Solar North Polar Coronal Hole
E. **Devlen**, D. Zengin Çamurdan, M. Yardımcı, E. R. Pekünlü
MNRAS **201**5
http://arxiv.org/pdf/1512.06606v1.pdf
This paper presents a new model of North Polar Coronal Hole (NPCH) to study dissipation/propagation of MHD waves. We investigate the effects of the isotropic viscosity and heat conduction on the propagation characteristics of the MHD waves in NPCH. We first model NPCH by considering the differences in radial as well as in the direction perpendicular to the line of sight (\textit{los}) in temperature, particle number density and non-thermal velocities between plumes and interplume lanes for the specific case of \ion{O}{VI} ions. This model includes parallel and perpendicular (to the magnetic field) heat conduction and viscous dissipation. Next, we derive the dispersion relations for the MHD waves in the case of absence and presence of parallel heat conduction. In the case of absence of parallel heat conduction, we find that MHD wave dissipation strongly depends on the viscosity for modified acoustic and Alfven waves. The energy flux density of acoustic waves varies between 104.7 and 107ergcm−2s−1 while the energy flux density of Alfven waves turned out to be between 106−108.6ergcm−2s−1. But, solutions of the magnetoacustic waves show that the parallel heat conduction introduce anomalous dispersion to the NPCH plasma wherein the group velocity of waves exceeds the speed of light in vacuum. Our results suggests all these waves may provide significant source for the observed preferential accelerating and heating of \ion{O}{VI} ions, in turn coronal plasma heating and an extra accelerating agent for fast solar wind in NPCH.

Evolution of Small-Scale Magnetic Elements in the Vicinity of Granular-Sized Swirl Convective Motions
S. Vargas **Domínguez**, J. Palacios, L. Balmaceda, I. Cabello, V. Domingo
Solar Phys. **201**4
Advances in solar instrumentation have led to widespread use of time series to study the dynamics of solar features, especially at small spatial scales and at very fast cadences. Physical processes at such scales are important as building blocks for many other processes occurring from the lower to the upper layers of the solar atmosphere and beyond, ultimately for understanding the larger picture of solar activity. Ground-based (*Swedish Solar Telescope*) and space-borne (*Hinode*) high-resolution solar data are analyzed in a quiet-Sun region that displays negative-polarity small-scale magnetic concentrations and a cluster of bright points observed in G-band. The region is characterized by two granular-sized convective vortex-type plasma motions, one of which appears to be affecting the dynamics of magnetic features and bright points in its vicinity and is therefore the main target of our investigations. We followed the evolution of the bright points, intensity variations at different atmospheric height, and the magnetic evolution for a set of interesting selected regions. We describe the evolution of the photospheric plasma motions in the region near the convective vortex and some plausible cases for convective collapse detected in Stokes profiles.

Automatic detection and tracking of coronal bright points in SDO/AIA images
I. **Dorotovič** 1,2, A. Coelho 2 , J. Rybák 3 , A. Mora 2 , R. Ribeiro 2 , W. Kusa 4 , R. Pires 2
Sun and Geosphere, **2018**; 13/2: 129 - 133
http://newserver.stil.bas.bg/SUNGEO//00SGArhiv/SG_v13_No2_2018-pp-129-133.pdf
The AIA instrument, on-board the SDO satellite, provides high-resolution and high-cadence solar images since 2010. To extract scientific knowledge about coronal bright points (CBPs) from those high-resolution images there is a need for efficient automatic algorithms to detect and/or track the CBPs. In the last decade other research teams

have developed algorithms to obtain more precise estimations of the solar rotation profile. However, it is a difficult task because CBPs may change shape and size over time, yielding great difficulty to track them. In this work we discuss the usage of two automatic segmentation algorithms to detect CBPs in SDO/AIA images: (1) using SunPy and OpenCV in Python and (2) using a Gradient Path Labeling (GPL) algorithm. Our preliminary tests and results, with a three-day dataset, show that these algorithms are promising tools to help refine the solar rotational profile.
9 – 11 August 2010

BRIGHT POINTS AND JETS IN POLAR CORONAL HOLES OBSERVED BY THE EXTREME-ULTRAVIOLET IMAGING SPECTROMETER ON HINODE

G. A. Doschek1, E. Landi1, H. P. Warren1 and L. K. Harra2

ApJ 710 1806-1824, **2010**

We present observations of polar coronal hole bright points (BPs) made with the Extreme-ultraviolet Imaging Spectrometer (EIS) on the Hinode spacecraft. The data consist of raster images of BPs in multiple spectral lines from mostly coronal ions, e.g., Fe X-Fe XV. The BPs are observed for short intervals and thus the data are snapshots of the BPs obtained during their evolution. The images reveal a complex unresolved temperature structure (EIS resolution is about 2"), with the highest temperature being about 2×10^6 K. Some BPs appear as small loops with temperatures that are highest near the top. But others are more point-like with surrounding structures. However, the thermal time evolution of the BPs is an important factor in their appearance. A BP may appear quite different at different times. We discuss one BP with an associated jet that is bright enough to allow statistically meaningful measurements. The jet Doppler speed along the line of sight is about 15-20 km s^{-1}. Electron densities of the BPs and the jet are typically near 10^9 cm^{-3}, which implies path lengths along the line of sight on the order of a few arcsec. We also construct differential emission measure curves for two of the best observed BPs. High spatial resolution (significantly better than 1") is required to fully resolve the BP structures.

Solar coronal plumes and the fast solar wind

B.N. **Dwivedi**, K. Wilhelm

A&A **2015**

http://arxiv.org/pdf/1506.01700v1.pdf

The spectral profiles of the coronal Ne viii line at 77 nm have different shapes in quiet-Sun regions and coronal holes (CHs). A single Gaussian fit of the line profile provides an adequate approximation in quiet-Sun areas, whereas a strong shoulder on the long-wavelength side is a systematic feature in CHs. Although this has been noticed since 1999, no physical reason for the peculiar shape could be given. In an attempt to identify the cause of this peculiarity, we address three problems that could not be conclusively resolved in a review article by a study team of the International Space Science Institute (ISSI; Wilhelm et al. 2011) : (1) The physical processes operating at the base and inside of plumes as well as their interaction with the solar wind (SW). (2) The possible contribution of plume plasma to the fast SW streams. (3) The signature of the first-ionization potential (FIP) effect between plumes and inter-plume regions (IPRs). Before the spectroscopic peculiarities in IPRs and plumes in polar coronal holes (PCHs) can be further investigated with the instrument Solar Ultraviolet Measurements of Emitted Radiation (SUMER) aboard the Solar and Heliospheric Observatory (SOHO), it is mandatory to summarize the results of the review to place the spectroscopic observations into context. Finally, a plume model is proposed that satisfactorily explains the plasma flows up and down the plume field lines and leads to the shape of the neon line in PCHs.

INTERCHANGE RECONNECTION AND CORONAL HOLE DYNAMICS

J. K. **Edmondson**1,3, S. K. Antiochos1, C. R. DeVore2, B. J. Lynch4, and T. H. Zurbuchen3

Astrophysical Journal, 714:517–531, **2010** May

We investigate the effect of magnetic reconnection between open and closed fields, often referred to as "interchange"
reconnection, on the dynamics and topology of coronal hole boundaries. The most important and most prevalent three-dimensional topology of the interchange process is that of a small-scale bipolar magnetic field interacting with a large-scale background field. We determine the evolution of such a magnetic topology by numerical solution of the fully three-dimensional MHD equations in spherical coordinates. First, we calculate the evolution of a small-scale bipole that initially is completely inside an open field region and then is driven across a coronal hole boundary by photospheric motions. Next the reverse situation is calculated in which the bipole is initially inside the closed region and driven toward the coronal hole boundary. In both cases, we find that the stress imparted by the photospheric motions results in deformation of the separatrix surface between the closed field of the bipole and the background field, leading to rapid current sheet formation and to efficient reconnection. When the bipole is inside the open field region, the reconnection is of the interchange type in that it exchanges open and closed fields. We examine, in detail, the topology of the field as the bipole moves across the coronal hole boundary and find that the field remains well connected throughout this process. Our results, therefore, provide essential support for the quasi-steady models of the open field, because in these models

the open and closed flux are assumed to remain topologically distinct as the photosphere evolves. Our results also support the uniqueness hypothesis for open field regions as postulated by Antiochos et al. On the other hand, the results argue against models in which open flux is assumed to diffusively penetrate deeply inside the closed field region under a helmet streamer. We discuss the implications of this work for coronal observations.

RECONNECTION-DRIVEN DYNAMICS OF CORONAL-HOLE BOUNDARIES

J. K. Edmondson[1,2], B. J. Lynch[3], S. K. Antiochos[1], C. R. DeVore[4] and T. H. Zurbuchen[2]

2009 ApJ 707 1427-1437

We investigate the effect of magnetic reconnection on the boundary between open and closed magnetic field in the solar corona. The magnetic topology for our numerical study consists of a global dipole that gives rise to polar coronal holes and an equatorial streamer belt, and a smaller active-region bipole embedded inside the closed-field streamer belt. The initially potential magnetic field is energized by a rotational motion at the photosphere that slowly twists the embedded-bipole flux. Due to the applied stress, the bipole field expands outward and reconnects with the surrounding closed flux, eventually tunneling through the streamer boundary and encountering the open flux of the coronal hole. The resulting interchange reconnection between closed and open field releases the magnetic twist and free energy trapped inside the bipole onto open field lines, where they freely escape into the heliosphere along with the entrained closed-field plasma. Thereafter, the bipole field relaxes and reconnects back down into the interior of the streamer belt. Our simulation shows that the detailed properties of magnetic reconnection can be crucial to the coronal magnetic topology, which implies that both potential-field source-surface and quasi-steady magnetohydrodynamic models may often be an inadequate description of the corona and solar wind. We discuss the implications of our results for understanding the dynamics of the boundary between open and closed field on the Sun and the origins of the slow wind.

Influence of Non-Potential Coronal Magnetic Topology on Solar-Wind Models

S. J. **Edwards**, A. R. Yeates , F.-X. Bocquet, D.H. Mackay

Solar Phys. Volume 290, Issue 10, pp 2791-2808 **2015**

http://arxiv.org/pdf/1511.00427v1.pdf

By comparing a magneto-frictional model of the low-coronal magnetic-field to a potential-field source-surface model, we investigate the possible impact of non-potential magnetic structure on empirical solar-wind models. These empirical models (such as Wang–Sheeley–Arge) estimate the distribution of solar-wind speed solely from the magnetic-field structure in the low corona. Our models are computed in a domain between the solar surface and 2.5 solar radii, and they are extended to 0.1 AU using a Schatten current-sheet model. The non-potential field has a more complex magnetic skeleton and quasi-separatrix structures than the potential field, leading to different sub-structure in the solar-wind speed proxies. It contains twisted magnetic structures that can perturb the separatrix surfaces traced down from the base of the heliospheric current sheet. A significant difference between the models is the greater amount of open magnetic flux in the non-potential model. Using existing empirical formulae this leads to higher predicted wind speeds for two reasons: partly because magnetic-flux tubes expand less rapidly with height, but more importantly because more open-field lines are further from coronal-hole boundaries.

Improving Multiday Solar Wind Speed Forecasts

H. A. **Elliott**, C. N. Arge,C. J. Henney,M. A. Dayeh,G. Livadiotis,J.-M. Jahn,C. E DeForest

Space Weather e2021SW002868 **Volume 20, Issue 9** **2022**

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https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021SW002868

We analyze the residual errors for the Wang-Sheeley-Arge (WSA) solar wind speed forecasts as a function of the photospheric magnetic field expansion factor (fp) and the minimum separation angle (d) in the photosphere between the footpoints of open field lines and the nearest coronal hole boundary. We find the map of residual speed errors are systematic when examined as a function of fp and d. We use these residual error maps to apply corrections to the model speeds. We test this correction approach using 3-day lead time speed forecasts for an entire year of observations and model results. Our methods can readily be applied to develop corrections for the remaining WSA forecast lead times which range from 1 to 7 days in 1-day increments. Since the solar wind density, temperature, and the interplanetary magnetic field strength all correlate well with the solar wind speed, the improved accuracy of solar wind speed forecasts enables the production of multiday forecasts of the solar wind density, temperature, pressure, and interplanetary field strength, and geophysical indices. These additional parameters would expand the usefulness of ADAPT-WSA forecasts for space weather clients.

Latitude Variations in Primary and Secondary Polar Crown Polarity Inversion Lines and Polar Coronal Hole Boundaries over Five Solar Cycles

B. A. **Emery**, D. F. Webb, S. E. Gibson, I. M. Hewins, R. H. McFadden & T. A. Kuchar

Solar Physics volume 296, Article number: 119 (**2021**)
https://link.springer.com/content/pdf/10.1007/s11207-021-01857-7.pdf
https://doi.org/10.1007/s11207-021-01857-7
We undertake a five solar-cycle (SC 19 - 23) ≈55-year (December 1954 to August 2009) study of the high latitude polarity inversion lines (PILs) using the recently digitized McIntosh Archive (McA) of solar synoptic (Carrington) maps. We looked at the evolution of the median solar latitudes of primary and secondary PILs, and of the polar coronal hole (CH) boundary for all 732 Carrington Rotations (CRs). We found hemispheric differences in the "Rush to the Poles" (RttP) where the polar CH gaps are often longer in the southern hemisphere (SH), and the secondary PIL reaches its polemost latitude at the end of its RttP later and more poleward than in the northern hemisphere (NH). The latitude oscillations found after this poleward peak are also stronger and often longer in the SH than in the NH, and exhibit a 22-year variation. The location variations in the CH boundaries and PILs appear to be at least partly associated with similar variations in the magnetic field. We also found equatorward expansions of the polar CHs by ≈50% and equatorward shifts in the PILs that were part of a disturbance that propagated ≈15°/CR from the SH to the NH in the descending phase of SC 23.

MAGNETIC FLUX DENSITY MEASURED IN FAST AND SLOW SOLAR WIND STREAMS

G. **Erdős**1 and A. Balogh

2012 ApJ 753 130

The radial component of the heliospheric magnetic field vector is used to estimate the open magnetic flux density of the Sun. This parameter has been calculated using observations from the Ulysses mission that covered heliolatitudes from 80°S to 80°N, from 1990 to 2009 and distances from 1 to 5.4 AU, the Advanced Composition Explorer mission at 1 AU from 1997 to 2010, the OMNI interplanetary database from 1971, and the Helios 1 and 2 missions that covered the distance range from 0.3 to 1 AU. The flux density was found to be much affected by fluctuations in the magnetic field which make its calculated value dependent on heliospheric location, type of solar wind (fast or slow), and the level of solar activity. However, fluctuations are distributed symmetrically perpendicular to the average Parker direction. Therefore, distributions of the field vector in the two-dimensional plane defined by the radial and azimuthal directions in heliospheric coordinates provide a way to reduce the effects of the fluctuations on the measurement of the flux density. This leads to a better defined flux density parameter; the distributions modified by removing the effects of fluctuations then allow a clearer assessment of the dependence of the flux density on heliospheric location, solar wind type, and solar activity. This assessment indicates that the flux density normalized to 1 AU is independent of location and solar wind type (fast or slow). However, there is a residual dependence on solar activity which can be studied using the modified flux density measurements.

AN INVESTIGATION OF THE SOURCES OF EARTH-DIRECTED SOLAR WIND DURING CARRINGTON ROTATION 2053

A. N. **Fazakerley**1, L. K. Harra1, and L. van Driel-Gesztelyi

2016 ApJ 823 145

In this work we analyze multiple sources of solar wind through a full Carrington Rotation (CR 2053) by analyzing the solar data through spectroscopic observations of the plasma upflow regions and the in situ data of the wind itself. Following earlier authors, we link solar and in situ observations by a combination of ballistic backmapping and potential-field source-surface modeling. We find three sources of fast solar wind that are low-latitude coronal holes. The coronal holes do not produce a steady fast wind, but rather a wind with rapid fluctuations. The coronal spectroscopic data from Hinode's Extreme Ultraviolet Imaging Spectrometer show a mixture of upflow and downflow regions highlighting the complexity of the coronal hole, with the upflows being dominant. There is a mix of open and multi-scale closed magnetic fields in this region whose (interchange) reconnections are consistent with the up- and downflows they generate being viewed through an optically thin corona, and with the strahl directions and freeze-in temperatures found in in situ data. At the boundary of slow and fast wind streams there are three short periods of enhanced-velocity solar wind, which we term intermediate based on their in situ characteristics. These are related to active regions that are located beside coronal holes. The active regions have different magnetic configurations, from bipolar through tripolar to quadrupolar, and we discuss the mechanisms to produce this intermediate wind, and the important role that the open field of coronal holes adjacent to closed-field active regions plays in the process.

THE EMISSION MEASURE OF THE SOLAR LOWER TRANSITION REGION (2 × 104-2 × 105 K)

U. **Feldman** et al

ApJ 693 1474-1483, **2009**

We analyze Solar Ultraviolet Measurements of Emitted Radiation (SUMER) spectra in the 750-790 Å wavelength range from 12 different solar regions on the disk to measure the thermal structure of the lower transition region (LTR). We considered four coronal hole (CH), four quiet Sun (QS), and four active region (AR) data sets observed by SUMER during the rising phase of the solar cycle, and we analyzed the emission of seven different ions formed between 2 × 104 and 2 × 105 K. We study the spatial variation of line radiances along the slit within each observation, as well as their relative radiances in different data sets. We also use them to determine the differential emission measure of the LTR. We find that all lines behave in the same way both along the slit within the same observation, and between different data sets from different regions of the Sun. We also find that while the absolute value of the differential emission measure of LTR plasmas changes from region to region, its distribution with temperature is fairly constant, suggesting that the thermal structure of LTR plasmas is the same in CH, QS, and AR regions, and as a function of time along the solar cycle. We discuss the implications of our results for studies of coronal heating and of the solar cycle.

Data-driven modeling of the solar wind from 1 Rs to 1 AU

Xueshang **Feng**, Xiaopeng Ma, Changqing Xiang

JGR Volume 120, Issue 12 December **2015** Pages 10,159–10,174

We present here a time-dependent three-dimensional magnetohydrodynamic (MHD) solar wind simulation from the solar surface to the Earth's orbit driven by time-varying line-of-sight solar magnetic field data. The simulation is based on the three-dimensional (3-D) solar-interplanetary (SIP) adaptive mesh refinement (AMR) space-time conservation element and solution element (CESE) MHD (SIP-AMR-CESE MHD) model. In this simulation, we first achieve the initial solar wind background with the time-relaxation method by inputting a potential field obtained from the synoptic photospheric magnetic field and then generate the time-evolving solar wind by advancing the initial 3-D solar wind background with continuously varying photospheric magnetic field. The model updates the inner boundary conditions by using the projected normal characteristic method, inputting the high-cadence photospheric magnetic field data corrected by solar differential rotation, and limiting the mass flux escaping from the solar photosphere. We investigate the solar wind evolution from 1 July to 11 August 2008 with the model driven by the consecutive synoptic maps from the Global Oscillation Network Group. We compare the numerical results with the previous studies on the solar wind, the solar coronal observations from the Extreme ultraviolet Imaging Telescope board on Solar and Heliospheric Observatory, and the measurements from OMNI at 1 astronomical unit (AU). Comparisons show that the present data-driven MHD model's results have overall good agreement with the large-scale dynamical coronal and interplanetary structures, including the sizes and distributions of the coronal holes, the positions and shapes of the streamer belts, the heliocentric distances of the Alfvénic surface, and the transitions of the solar wind speeds. However, the model fails to capture the small-sized equatorial holes, and the modeled solar wind near 1 AU has a somewhat higher density and weaker magnetic field strength than observed. Perhaps better preprocessing of high-cadence observed photospheric magnetic field (particularly 3-D global measurements), combined with plasma measurements and higher resolution grids, will enable the data-driven model to more accurately capture the time-dependent changes of the ambient solar wind for further improvements. In addition, other measures may also be needed when the model is employed in the period of high solar activity.

STEREOSCOPIC POLAR PLUME RECONSTRUCTIONS FROM *STEREO*/SECCHI IMAGES

L. **Feng**[1,2], B. Inhester[1], S. K. Solanki[1], K. Wilhelm[1], T. Wiegelmann[1], B. Podlipnik[1], R. A. Howard[3], S. P. Plunkett[3], J. P. Wuelser[4], and W. Q. Gan[2]

Astrophysical Journal, 700:292–301, **2009** July

We present stereoscopic reconstructions of the location and inclination of polar plumes of two data sets based on the two simultaneously recorded images taken by the EUVI telescopes in the SECCHI instrument package onboard the *Solar TErrestrial RElations Observatory* spacecraft. The 10 plumes investigated show a superradial expansion in the coronal hole in three dimensions (3D) which is consistent with the two-dimensional results. Their deviations from the local meridian planes are rather smallwith an average of 6.◦47. By comparing the reconstructed plumes with a dipole field with its axis along the solar rotation axis, it is found that plumes are inclined more horizontally than the dipole field. The lower the latitude is, the larger is the deviation from the dipole field. The relationship between plumes and bright points has been investigated and they are not always associated. For the first data set, based on the 3D height of plumes and the electron density derived from SUMER/*SOHO* Si viii line pair, we found that electron densities along the plumes decrease with height above the solar surface. The temperature obtained from the density scale height is 1.6–1.8 times larger than the temperature obtained from Mg ix line ratios. We attribute this discrepancy to a deviation of the electron and the ion temperatures. Finally, we have found that the outflow speeds studied in the O vi line in the plumes corrected by the angle between the line of sight and the plume orientation are quite smallwith amaximum of 10 km s^{-1}. It is unlikely that plumes are a dominant contributor to the fast solarwind.

X-Ray Jet Dynamics in a Polar Coronal Hole Region

Boris **Filippov** · Leon Golub · Serge Koutchmy

Solar Phys (**2009**) 254: 259–269, **File**

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.

Distribution and properties of open magnetic flux outside of coronal holes

Fisk, L. A.; Zurbuchen, T. H.

Journal of Geophysical Research, Volume 111, Issue A9, CiteID A09115

The open magnetic flux of the Sun, the component of the solar magnetic field that forms the heliospheric magnetic field, is known to be concentrated into coronal holes, regions of low plasma density where the solar wind escapes easily. There also is evidence for concentrations of open flux in the vicinity of active regions. In this paper we explore the possibility that there is an additional component of open flux. We argue that open magnetic flux will reconnect with closed magnetic loops and that this process will distribute a small fraction of the open flux into a uniform, radial component in regions that do not underlie the overexpansion of the magnetic field from coronal holes. This additional component of open flux will facilitate the escape of energetic particles from solar flares and also the escape of plasma to form the slow solar wind.

First observations from the SPICE EUV spectrometer on Solar Orbiter

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A&A **2021**

https://arxiv.org/pdf/2110.11252.pdf

We present first science observations taken during the commissioning activities of the Spectral Imaging of the Coronal Environment (SPICE) instrument on the ESA/NASA Solar Orbiter mission. SPICE is a high-resolution imaging spectrometer operating at extreme ultraviolet (EUV) wavelengths. In this paper we illustrate the possible types of observations to give prospective users a better understanding of the science capabilities of SPICE. The paper discusses the first observations of the Sun on different targets and presents an example of the full spectra from the quiet Sun, identifying over 40 spectral lines from neutral hydrogen and ions of carbon, oxygen, nitrogen, neon, sulphur, magnesium, and iron. These lines cover the temperature range between 20,000 K and 1 million K (10MK in flares), providing slices of the Sun's atmosphere in narrow temperature intervals. We provide a list of count rates for the 23 brightest spectral lines. We show examples of raster images of the quiet Sun in several strong transition region lines, where we have found unusually bright, compact structures in the quiet Sun network, with extreme intensities up to 25 times greater than the average intensity across the image. The lifetimes of these structures can exceed 2.5 hours. We identify them as a transition region signature of coronal ***bright points*** and compare their areas and intensity enhancements. We also show the first above-limb measurements with SPICE above the polar limb in C III, O VI, and Ne VIII lines, and far off limb measurements in the equatorial plane in Mg IX, Ne VIII, and O VI lines. We discuss the potential to use abundance diagnostics methods to study the variability of the elemental composition that can be compared with in situ measurements to help confirm the magnetic connection between the spacecraft location and the Sun's surface, and locate the sources of the solar wind. **21 April 2020, 14 May 2020, 28 May 2020, 17 June 2020, 26 March 2021**

PLASMOID RELEASES IN THE HELIOSPHERIC CURRENT SHEET AND ASSOCIATED CORONAL HOLE BOUNDARY LAYER EVOLUTION

C. **Foullon**1,2, B. Lavraud3, J. G. Luhmann4, C. J. Farrugia5, A. Retinò6, K. D. C. Simunac5, N. C. Wardle2,7, A. B. Galvin5, H. Kucharek5, C. J. Owen2, M. Popecki5, A. Opitz3 and J.-A. Sauvaud

2011 ApJ 737 16

As the heliospheric current sheet (HCS) is corotating past STEREO-B, near-Earth spacecraft ACE, Wind and Cluster, and STEREO-A over more than three days between 2008 January 10 and 14, we observe various sections of (near-pressure-balanced) flux-rope- and magnetic-island-type plasmoids in the associated heliospheric plasma sheet (HPS). The plasmoids can qualify as slow interplanetary coronal mass ejections and are relatively low proton beta

(<0.5) structures, with small length scales (an order of magnitude lower than typical magnetic cloud values) and low magnetic field strengths (2-8 nT). One of them, in particular, detected at STEREO-B, corresponds to the first reported evidence of a detached plasmoid in the HPS. The in situ signatures near Earth are associated with a long-decay X-ray flare and a slow small-scale streamer ejecta, observed remotely with white-light coronagraphs aboard STEREO-B and SOHO and tracked by triangulation. Before the arrival of the HPS, a coronal hole boundary layer (CHBL) is detected in situ. The multi-spacecraft observations indicate a CHBL stream corotating with the HCS but with a decreasing speed distribution suggestive of a localized or transient nature. While we may reasonably assume that an interaction between ejecta and CHBL provides the source of momentum for the slow ejecta's acceleration, the outstanding composition properties of the CHBL near Earth provide here circumstantial evidence that this interaction or possibly an earlier one, taking place during streamer swelling when the ejecta rises slowly, results in additional mixing processes.

Charge States and FIP Bias of the Solar Wind from Coronal Holes, Active Regions, and Quiet Sun

Hui **Fu**, Maria Madjarska, Bo Li, Zhenghua Huang, Zhipeng Wangguan

ApJ **836** 169 2017

https://arxiv.org/pdf/1701.07610v1.pdf

Connecting in-situ measured solar-wind plasma properties with typical regions on the Sun can provide an effective constraint and test to various solar wind models. We examine the statistical characteristics of the solar wind with an origin in { different types of source regions}. We find that the speed distribution of coronal hole (CH) wind is bimodal with the slow wind peaking at ~400 \velunit\ and a fast at ~600 \velunit. An anti-correlation between the solar wind speeds and the \oql\ ion ratio remains valid in all three types of solar wind as well during the three studied solar cycle activity phases, i.e. solar maximum, decline and minimum. The \feo\ range and its average values all decrease with the increasing solar wind speed in different types of solar wind. The \feo\ range (0.06--0.40, FIP bias range 1--7) for AR wind is wider than for CH wind (0.06--0.20, FIP bias range 1--3) while the minimum value of \feo\ (~ 0.06) does not change with the variation of speed, and it is similar for all source regions. The two-peak distribution of CH wind and the anti-correlation between the speed and \oql\ in all three types of solar wind can be explained qualitatively by both the wave-turbulence-driven (WTD) and reconnection-loop-opening (RLO) models, whereas the distribution features of \feo\ in different source regions of solar wind can be explained more reasonably by the RLO models. **2003-11-09, 2003-11-28, 2003-12-03, 2003-12-09**

Coronal Sources and In Situ Properties of the Solar Winds Sampled by ACE During 1999–2008

Hui **Fu**, Bo Li, Xing Li, Zhenghua Huang, Chaozhou Mou, Fangran Jiao, Lidong Xia

Solar Phys. **2015**

http://arxiv.org/pdf/1505.00407v1.pdf

We identify the coronal sources of the solar winds sampled by the ACE spacecraft during 1999 – 2008 and examine the in situ solar wind properties as a function of wind sources. The standard two-step mapping technique is adopted to establish the photospheric footpoints of the magnetic flux tubes along which the ACE winds flow. The footpoints are then placed in the context of EIT 284 Å images and photospheric magnetograms, allowing us to categorize the sources into four groups: coronal holes (CHs), active regions (ARs), the quiet Sun (QS), and "undefined". This practice also enables us to establish the response to solar activity of the fractions occupied by each type of solar wind, and of their speeds and O^{7+}/O^{6+} ratios measured in situ. We find that during the maximum phase, the majority of ACE winds originate from ARs. During the declining phase, CHs and ARs are equally important contributors to the ACE solar winds. The QS contribution increases with decreasing solar activity and maximizes in the minimum phase when the QS appears to be the primary supplier of the ACE winds. With decreasing activity, the winds from all sources tend to become cooler, as represented by the increasingly low O^{7+}/O^{6+} ratios. On the other hand, during each activity phase, the AR winds tend to be the slowest and are associated with the highest O^{7+}/O^{6+} ratios, while the CH winds correspond to the other extreme, with the QS winds lying in between. Applying the same analysis method to the slow winds alone, here defined as the winds with speeds lower than 500 km s^{-1}, we find basically the same overall behavior, as far as the contributions of individual groups of sources are concerned. This statistical study indicates that QS regions are an important source of the solar wind during the minimum phase.

LONG-TERM TREND OF SOLAR CORONAL HOLE DISTRIBUTION FROM 1975 TO 2014

K. **Fujiki**[1], M. Tokumaru[1], K. Hayashi[1], D. Satonaka[1], and K. Hakamada

2016 ApJ 827 L41

We developed an automated prediction technique for coronal holes using potential magnetic field extrapolation in the solar corona to construct a database of coronal holes appearing from 1975 February to 2015 July (Carrington rotations from 1625 to 2165). Coronal holes are labeled with the location, size, and average magnetic field of each coronal hole on the photosphere and source surface. As a result, we identified 3335 coronal holes and found that the long-term distribution of coronal holes shows a similar pattern known as the magnetic butterfly diagram, and polar/low-latitude coronal holes tend to decrease/increase in the last solar minimum relative to the previous two minima.
See http://aasnova.org/2016/08/31/monitoring-holes-in-the-suns-corona/

Relationship Between Solar Wind Speed and Coronal Magnetic Field Properties

Ken'ichi **Fujiki**, Munetoshi Tokumaru, Tomoya Iju, Kazuyuki Hakamada, Masayoshi Kojima
Solar Phys. **2015**
http://arxiv.org/pdf/1507.03301v2.pdf

We have studied the relationship between the solar-wind speed [V] and the coronal magnetic-field properties (a flux expansion factor [f] and photospheric magnetic-field strength [Bs]) at all latitudes using data of interplanetary scintillation and solar magnetic field obtained for 24 years from 1986 to 2009. Using a cross-correlation analyses, we verified that V is inversely proportional to f and found that V tends to increase with Bs if f is the same. As a consequence, we find that V has extremely good linear correlation with Bs/f. However, this linear relation of V and Bs/f cannot be used for predicting the solar-wind velocity without information on the solar-wind mass flux. We discuss why the inverse relation between V and f has been successfully used for solar-wind velocity prediction, even though it does not explicitly include the mass flux and magnetic-field strength, which are important physical parameters for solar-wind acceleration.

Relation between solar wind velocity and properties of its source region.

Fujiki, K., Hirano, M., Kojima, M., Tokumaru, M., Baba, D., Yamashita, M., Hakamada, K.,
2005. Advances in Space Research 35 (12), 2185–2188.

Recently, Fujiki et al. (2005) showed that these may not be independent parameters and that a combination of the expansion factor and the photospheric magnetic field in the coronal hole photospheres is best correlated with the solar wind speed.

Outflow Velocity Structure in the Upper Transition Region and Corona

Alan **Gabriel**, Lucia Abbo
Solar Physics, October **2012**, Volume 280, Issue 2, pp 435-443

Outflow velocity maps in the quiet Sun and coronal hole regions have been observed with the EUV Imaging Spectrometer on Hinode over a range of coronal and transition region temperatures, in order to correlate the solar wind with effects due to the underlying supergranule network and to coronal holes. The cell structure has been identified using data from the Solar Dynamics Observatory: specifically, 1600 Å images from the Advanced Imaging Assembly instrument and dopplergrams from the Helioseismic and Magnetic Imager. We find that the expansion of the velocity field with height through the upper transition region and the corona follows the same general pattern that has been long established for the emitted intensities. The outflow velocity field expands laterally with height with the magnetic funnels, eventually filling the space between the cell boundaries. Moreover, the detailed structure of the outflow morphology, combined with the decrease of velocity dispersion with increasing temperature, supports the concept of local stochastic energy release at lower heights. This is consistent with a reconnection process between emerging fields within the cell and the funnels at the cell boundaries.

THE STRUCTURE AND ORIGIN OF SOLAR PLUMES: NETWORK PLUMES

A. **Gabriel** et al
ApJ 700 551-558, **2009** doi: 10.1088/0004-637X/700/1/551

This study is based upon plumes seen close to the solar limb within coronal holes in the emission from ions formed in the temperature region of 1 MK, in particular, the band of Fe IX 171 Å from EIT on the Solar and Heliospheric Observatory. It is shown, using geometric arguments, that two distinct classes of structure contribute to apparently similar plume observations. Quasi-cylindrical structures are anchored in discrete regions of the solar surface (beam plumes), and faint extended structures require integration along the line of sight (LOS) in order to reproduce the observed brightness. This second category, sometimes called "curtains," are ubiquitous within the polar holes and are usually more abundant than the beam plumes, which depend more on the enhanced magnetic structures detected at their footpoints. It is here proposed that both phenomena are based on plasma structures in which emerging magnetic loops interact with ambient monopolar fields, involving reconnection. The important difference is in terms of physical scale. It is proposed that curtains are composed of a large number of microplumes, distributed along the LOS. The supergranule network provides the required spatial structure. It is shown by modeling that the observations can be reproduced if microplumes are concentrated within some 5 Mm of the cell boundaries. For this reason, we propose to call this second population "network plumes." The processes involved could represent a major contribution to the heating mechanism of the solar corona.

Eruptions from Quiet Sun Coronal Bright Points. II. Non-Potential Modeling

Klaus **Galsgaard**, Maria S. Madjarska, Duncan H. Mackay, Chaozhou Mou

A&A 623, A78 **2019**

https://arxiv.org/pdf/1901.09875.pdf

Our recent observational study shows that the majority of coronal bright points (CBPs) in the quiet Sun are sources of one or more eruptions during their lifetime. Here, we investigate the non-potential time dependent structure of the magnetic field of the CBP regions with special emphasis on the time evolving magnetic structure at the spatial locations where the eruptions are initiated. The magnetic structure is evolved in time using a Non-Linear Force Free Field (NLFFF) relaxation approach, based on a time series of Helioseismic and Magnetic Imager (HMI) longitudinal magnetograms. This results in a continuous time series of NLFFFs. The time series is initiated with a potential field extrapolation based on a magnetogram taken well before the time of the eruptions. This initial field is then evolved in time in response to the observed changes in the magnetic field distribution at the photosphere. The local and global magnetic field structures from the time series of NLFFF field solutions are analysed in the vicinity of the eruption sites at the approximate times of the eruptions. The analysis shows that many of the CBP eruptions reported in Mou etl. (2018) contain twisted flux tube located at the sites of eruptions. The presence of flux ropes at these locations provides in many cases a direct link between the magnetic field structure, their eruption and the observation of mini coronal mass ejections (mini-CMEs). It is found that all repetitive eruptions are homologous. The NLFFF simulations show that twisted magnetic field structures are created at the locations hosting eruptions in CBPs. These twisted structures are produced by footpoint motions imposed by changes in the photospheric magnetic field observations. The true nature of the micro-flares remains unknown. Further 3D data-driven MHD modelling is required to show how these twisted regions become unstable and erupt. **01-03 Jan 2011**

Magnetic topological analysis of coronal bright points

K. **Galsgaard**, M. S. Madjarska, F. Moreno-Insertis, Z. Huang, T. Wiegelmann

A&A 606, A46 **2017**

https://arxiv.org/pdf/1707.04174.pdf

{We report on the first of a series of studies on coronal bright points investigating the physical mechanism that generates these phenomena.} {The aim of this paper is to understand the magnetic-field structure that hosts the bright points.} {We use longitudinal magnetograms taken by the Solar Optical Telescope with the Narrowband Filter Imager. For a single case, magnetograms from the Helioseismic and Magnetic Imager were added to the analysis. The longitudinal magnetic field component is used to derive the potential magnetic fields of the large regions around the bright points. A magneto-static field extrapolation method is tested to verify the accuracy of the potential field modelling. The three dimensional magnetic fields are investigated for the presence of magnetic null points and their influence on the local magnetic domain.} {In 9 out of 10 cases the bright point resides in areas where the coronal magnetic field contains an opposite polarity intrusion defining a magnetic null point above it. It is found that X-ray bright points reside, in these 9 cases, in a limited part of the projected fan dome area, either fully inside the dome or expanding over a limited area below which typically a dominant flux concentration resides. The 10th bright point is located in a bipolar loop system without an overlying null point.} {All bright points in coronal holes and two out of tree bright points in quiet Sun regions are seen to reside in regions containing a magnetic null point. An yet unidentified process(es) generates the BPs in specific regions of the fan-dome structure. }
2007 October 10, 2007-Nov-09, 2007-Nov-12, 2007-Nov-27, 2011-June-18

Decayless oscillations in solar coronal bright points

Yuhang **Gao**, Hui Tian, Tom Van Doorsselaere, Yajie Chen

ApJ **930** 55 **2022**

https://arxiv.org/pdf/2203.17034.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/ac62cf/pdf

Decayless kink oscillations of solar coronal loops (or decayless oscillations for short) have attracted great attention since their discovery. Coronal bright points (CBPs) are mini-active regions and consist of loops with a small size. However, decayless oscillations in CBPs have not been widely reported. In this study, we identified this kind of oscillations in some CBPs using 171 Å\, images taken by the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO). After using the motion magnification algorithm to increase oscillation amplitudes, we made time-distance maps to identify the oscillatory signals. We also estimated the loop lengths and velocity amplitudes. We analysed 23 CBPs, and found 31 oscillation events in 16 of them. The oscillation periods range from 1 to 8 minutes (on average about 5 minutes), and the displacement amplitudes have an average value of 0.07 Mm. The average loop length and velocity amplitude are 23 Mm and 1.57 \kms, respectively. Relationships between different oscillation paraments are also examined. Additionally, we performed a simple forward model to illustrate how these sub-pixel oscillation amplitudes (less than 0.4 Mm) could be detected. Results of the model confirm the reliability of our data processing methods. Our study shows for the first time that decayless oscillations are common in small-scale loops of CBPs. These oscillations allow for seismological diagnostics of the Alfvén speed and magnetic field strength in the corona. **2018-01-01, 03-04, 2018-03-07, 2018-03-16, 03-25**

Possible Signature of Sausage Waves in Photospheric Bright Points

Yuhang **Gao**, Fuyu Li, Bo Li, Wenda Cao, Yongliang Song, Hui Tian & Mingzhe Guo
Solar Physics volume 296, Article number: 184 (**2021**)
https://link.springer.com/content/pdf/10.1007/s11207-021-01928-9.pdf
https://doi.org/10.1007/s11207-021-01928-9
https://arxiv.org/pdf/2112.11756
Sausage waves have been frequently reported in solar magnetic structures such as sunspots, pores, and coronal loops. However, they have not been unambiguously identified in photospheric bright points (BPs). Using high-resolution TiO image sequences obtained with the Goode Solar Telescope at the Big Bear Solar Observatory, we analyzed four isolated BPs. It was found that their area and average intensity oscillate for several cycles in an in-phase fashion. The oscillation periods range from 100 to 200 seconds. We interpreted the phase relation as a signature of sausage waves, particularly slow waves, after discussing sausage-wave theory and the opacity effect.
6 August 2018

Expansion of High Speed Solar Wind Streams from Coronal Holes through the Inner Heliosphere

Tadhg M. **Garton**, Sophie A. Murray, Peter T. Gallagher
2018 *ApJL* **869** L12
https://arxiv.org/pdf/1811.11605.pdf
http://sci-hub.tw/10.3847/2041-8213/aaf39a
Coronal holes (CHs) are regions of open magnetic flux which are the source of high speed solar wind (HSSW) streams. To date, it is not clear which aspects of CHs are of most influence on the properties of the solar wind as it expands through the Heliosphere. Here, we study the relationship between CH properties extracted from AIA (Atmospheric Imaging Assembly) images using CHIMERA (Coronal Hole Identification via Multi-thermal Emission Recognition Algorithm) and HSSW measurements from ACE (Advanced Composition Explorer) at L1. For CH longitudinal widths $\Delta\theta_{CH}<67^\circ$, the peak SW velocity ($v_{max}$) is found to scale as $v_{max} \approx 330.8 + 5.7\, \Delta\theta_{CH}$~km~s^{-1}. For larger longitudinal widths ($\Delta\theta_{CH}>67^\circ$), v_{max} is found to tend to a constant value (∼710~km~s−1). Furthermore, we find that the duration of HSSW streams (Δt) are directly related to the longitudinal width of CHs (Δt_{SW}~≈~$0.09\Delta\theta_{CH}$) and that their longitudinal expansion factor is $f_{SW} \approx 1.2 \pm 0.1$. We also derive an expression for the coronal hole flux-tube expansion factor, f_{FT}, which varies as $f_{SW} \gtrsim f_{FT} \gtrsim 0.8$. These results enable us to estimate the peak speeds and durations of HSSW streams at L1 using the properties of CHs identified in the solar corona.

Automated Coronal Hole Identification via Multi-Thermal Intensity Segmentation

Tadhg M. **Garton**, Peter T. Gallagher, Sophie A. Murray
Journal of Space Weather and Space **2018**, 8, A02
https://arxiv.org/pdf/1711.11476.pdf
https://www.swsc-journal.org/articles/swsc/pdf/2018/01/swsc170041.pdf
Coronal holes (CH) are regions of open magnetic fields that appear as dark areas in the solar corona due to their low density and temperature compared to the surrounding quiet corona. To date, accurate identification and segmentation of CHs has been a difficult task due to their comparable intensity to local quiet Sun regions. Current segmentation methods typically rely on the use of single EUV passband and magnetogram images to extract CH information. Here, the Coronal Hole Identification via Multi-thermal Emission Recognition Algorithm (CHIMERA) is described, which analyses multi-thermal images from the Atmospheric Image Assembly (AIA) onboard the Solar Dynamics Observatory (SDO) to segment coronal hole boundaries by their intensity ratio across three passbands (171 \AA, 193 \AA, and 211 \AA). The algorithm allows accurate extraction of CH boundaries and many of their properties, such as area, position, latitudinal and longitudinal width, and magnetic polarity of segmented CHs. From these properties, a clear linear relationship was identified between the duration of geomagnetic storms and coronal hole areas. CHIMERA can therefore form the basis of more accurate forecasting of the start and duration of geomagnetic storms. **22 September 2016, 24 October 2016 , 31 October 2016, 29-31 Jan 2017**

Properties of stream interaction regions at Earth and Mars during the declining phase of SC 24

Paul **Geyer**, Manuela Temmer, Jingnan Guo, Stephan G. Heinemann
A&A **2021**
https://arxiv.org/pdf/2102.05948.pdf
We inspect the evolution of SIRs from Earth to Mars (distance range 1-1.5 AU) over the declining phase of solar cycle 24 (2014-2018). So far, studies only analyzed SIRs measured at Earth and Mars at different times. We compare existing catalogs for both heliospheric distances and arrive at a clean dataset for the identical time range. This allows a well-sampled statistical analysis and for the opposition phases of the planets an in-depth analysis of SIRs as they evolve with distance. We use in-situ solar wind data from OMNI and the MAVEN spacecraft as well as remote sensing data from SDO. A superposed epoch analysis is performed for bulk speed, proton density, temperature, magnetic field magnitude and total perpendicular pressure. Additionally, a study of events during the two opposition phases of Earth and Mars in the years 2016 and 2018 is conducted. SIR related coronal holes with their area as well as their latitudinal and longitudinal extent are extracted and correlated to the maximum bulk speed and duration of the corresponding high speed solar wind streams following the stream interaction regions. We find that while the entire solar wind HSS shows no expansion as it evolves from Earth to Mars, the crest of the HSS profile broadens by about 17%, and the magnetic field and total pressure by about 45% around the stream interface. The difference between the maximum and minimum values in the normalized superposed profiles increases slightly or stagnates from 1-1.5 AU for all parameters, except for the temperature. A sharp drop at zero epoch time is observed in the superposed profiles for the magnetic field strength at both heliospheric distances. Maximum solar wind speed has a stronger dependence on the latitudinal extent of the respective coronal hole than on its longitudinal extent. We arrive at an occurrence rate of fast forward shocks three times as high at Mars than at Earth. **2016-06-03, 06-29, 07-26, 08-21, 09-17**

Rearrangements of Open Magnetic Flux and Formation of Polar Coronal Holes in Cycle 24

E.M. **Golubeva**, A.V.Mordvinov
Solar Phys. 292:175 **2017**
https://arxiv.org/pdf/1711.01044.pdf
https://link.springer.com/content/pdf/10.1007%2Fs11207-017-1200-6.pdf
A method of synoptic map assimilation has been developed to study global rearrangements of open magnetic flux and formation of polar coronal holes (PCHs) in the current cycle. The analysis reveals ensembles of coronal holes (ECHs) which appear within unipolar magnetic regions associated with decaying activity complexes (ACs). The cause-effect relations between them explain asynchronous PCH formation observed at the northern and southern hemispheres of the Sun. Thus, the decay of large ACs, that were observed in 2014, led to formation of an extensive ECH, which then became the south PCH in mid-2015. Intricate structure of magnetic fields in the northern polar zone has impeded the north PCH formation, despite the fact that the dominant polarity at the North Pole reversed two years earlier than at the South Pole. The north PCH formed only by mid-2016 as the result of gradual merger of high-latitudinal ECHs associated with several decaying ACs.

Correction Solar Physics December **2017**, 292:190|

https://link.springer.com/content/pdf/10.1007%2Fs11207-017-1219-8.pdf

Decay of Activity Complexes, Formation of Unipolar Magnetic Regions and Coronal Holes in their Causal Relation

Elena **Golubeva**, Alexander Mordvinov
Solar Phys. **2016**
https://arxiv.org/pdf/1610.01767v1.pdf
North-south asymmetry of sunspot activity resulted in an asynchronous reversal of the Sun's polar fields in the current cycle. The asymmetry is also observed in the formation of polar coronal holes. A stable coronal hole was first formed at the South Pole, despite the later polar-field reversal there. The aim of this study is to understand processes making this situation possible. Synoptic magnetic maps from the Global Oscillation Network Group and corresponding coronal-hole maps from the Extreme ultraviolet Imaging Telescope aboard the Solar and Heliospheric Observatory and the Atmospheric Imaging Assembly aboard the Solar Dynamics Observatory are analyzed here to study a causal relationship between the decay of activity complexes, evolution of large-scale magnetic fields, and formation of coronal holes. Ensembles of coronal holes associated with decaying active regions and activity complexes are presented. These ensembles take part in global rearrangements of the Sun's open magnetic flux. In particular, the south polar coronal hole was formed from an ensemble of coronal holes that originated after the decay of multiple activity complexes observed during 2014.

Testing the Empirical Shock Arrival Model using Quadrature Observations
N. **Gopalswamy**, P. Mäkelä, H. Xie, and S. Yashiro
Space Weather, in press, **2013**
http://cdaw.gsfc.nasa.gov/publications/gopal/gopal2013SW_testESA.pdf
The empirical shock arrival (ESA) model was developed based on quadrature data from Helios (in-situ) and P-78 (remote-sensing) to predict the Sun-Earth travel time of coronal mass ejections (CMEs) [Gopalswamy et al. 2005a]. The ESA model requires earthward CME speed as input, which is not directly measurable from coronagraphs along the Sun-Earth line. The Solar Terrestrial Relations Observatory (STEREO) and the Solar and Heliospheric Observatory (SOHO) were in quadrature during 2010 - 2012, so the speeds of Earth-directed CMEs were observed with minimal projection effects. We identified a set of 20 full halo CMEs in the field of view of SOHO that were also observed in quadrature by STEREO. We used the earthward speed from STEREO measurements as input to the ESA model and compared the resulting travel times with the observed ones from L1 monitors. We find that the model predicts the CME travel time within about 7.3 hours, which is similar to the predictions by the ENLIL model. We also find that CME-CME and CME-coronal hole interaction can lead to large deviations from model predictions.
Table 1. List of shocks detected at L1 and the corresponding halo CMEs observed by SOHO
Table 2. List of events with coronal holes visible on the disk.

CME Interaction with Coronal Holes and their Interplanetary Consequences
N. **Gopalswamy**1, P. Mäkelä1,2, H. Xie1,2, S. Akiyama1,2, and S. Yashiro1,2
JGR, **2009**; **File;** J. Geophys. Res., Vol. 114, No. A3, A00A22
A significant number of interplanetary (IP) shocks (~17%) during cycle 23 were not followed by drivers. The number of such “driverless” shocks steadily increased with the solar cycle with 15%, 33%, and 52% occurring in the rise, maximum, and declining phase of the solar cycle. The solar sources of 15% of the driverless shocks were very close the central meridian of the Sun (within ~15o), which is quite unexpected. More interestingly, all the driverless shocks with their solar sources near the solar disk center occurred during the declining phase of solar cycle 23. When we investigated the coronal environment of the source regions of driverless shocks, we found that in each case there was at least one coronal hole nearby suggesting that the coronal holes might have deflected the associated coronal mass ejections (CMEs) away from the Sun-Earth line. The presence of abundant low-latitude coronal holes during the declining phase further explains why CMEs originating close to the disk center mimic the limb CMEs, which normally lead to driverless shocks due to purely geometrical reasons. We also examined the solar source regions of shocks with drivers. For these, the coronal holes were located such that they either had no influence on the CME trajectories, or they deflected the CMEs towards the Sun-Earth line. We also obtained the open magnetic field distribution on the Sun by performing a potential field source surface extrapolation to the corona. It was found that the CMEs generally move away from the open magnetic field regions. The CME-coronal hole interaction must be widespread in the declining phase, and may have a significant impact on the geoeffectiveness of CMEs.

Energetic Phenomena on the Sun
Nat **Gopalswamy**
E-print, Nov. **2007**
AIP Conf. Proc. , Kodai School on Solar Physics, edited by S. S. Hasan and D. Banerjee, V. 919, pp. 275-313, 2007; File
Solar flares, coronal mass ejections (CMEs), solar energetic particles (SEPs), and fast solar wind represent the energetic phenomena on the Sun.
This paper provides an **over view** of the energetic phenomena on the Sun including their origin interplanetary propagation and space weather consequences.

Microwave Enhancement in Coronal Holes: Statistical Properties.
Gopalswamy N, Shibasaki K, Salem M
(**2000**) JApA 21:413

Quantifying the Consistency and Characterizing the Confidence of Coronal Holes Detected by Active Contours without Edges (ACWE)
Jeremy A. **Grajeda**, Laura E. Boucheron, Michael S. Kirk, Andrew Leisner, C. Nick Arge
Solar Phys. 298, Article number: 133 **2023**
https://arxiv.org/pdf/2308.05679.pdf
https://link.springer.com/content/pdf/10.1007/s11207-023-02228-0.pdf

This paper presents an intramethod ensemble for coronal hole (CH) detection based on the Active Contours Without Edges (ACWE) segmentation algorithm. The purpose of this ensemble is to develop a confidence map that defines, for all on disk regions of a Solar extreme ultraviolet (EUV) image, the likelihood that each region belongs to a CH based on that region's proximity to, and homogeneity with, the core of identified CH regions. CHs are regions of open magnetic field lines, resulting in high speed solar wind. Accurate detection of CHs is vital for space weather prediction. By relying on region homogeneity, and not intensity (which can vary due to various factors including line of sight changes and stray light from nearby bright regions), to define the final confidence of any given region, this ensemble is able to provide robust, consistent delineations of the CH regions. Using the metrics of global consistency error (GCE), local consistency error (LCE), intersection over union (IOU), and the structural similarity index measure (SSIM), the method is shown to be robust to different spatial resolutions and different intensity resolutions. Furthermore, using the same metrics, the method is shown to be robust across short timescales, indicating self-consistent segmentations. Finally, the accuracy of the segmentations and confidence maps are validated by considering the skewness (i.e., unipolarity) of the underlying magnetic field. **2010-07-16-18, 2010-07-22-25, 2010-08-06-07, 2010-08-21, 2010-08-23-28, 2010-09-03-07, 2010-09-18-20, 2010-09-25, 2013-01-27-30, 2013-02-02, 2013-02-18**

Studying Ca ii K Line Profile Shapes and Dynamic Processes in the Solar Chromosphere at the Base of a Coronal Hole

S. A. **Grigoryeva**, I. P. Turova, O. A. Ozhogina

Solar Phys. Volume 291, Issue 7, pp 1977–2002 **2016**

We study Ca ii K profiles in structural features of the quiet chromosphere and plages using observations of two time series for two regions at the base of a coronal hole. One of the regions that we study has a low-brightness area where the reversal-free profile shape remains the same even over a spatial extent of about 16 arcsec. Such a profile shape is typical of low-temperature areas.

The analysis of the spectral composition of oscillations has revealed that all the chromospheric structures feature various combinations of periods: 3, 4, 5, and long. One rarely finds only a single period. In same-type structures, we cannot single out a dominant highest-power period; such may be any of the above periods. Periodic brightenings of the violet peak in the Ca ii K wing occur in both internetwork and network areas. Moreover, they do not arise from purely 3-min oscillations.

The integrated spectral power of oscillations throughout the whole area cut out by the spectrograph slit decreases with height from the temperature minimum region to the lower and middle chromosphere in 4.0 – 5.2 (4-min oscillations), 2.4 – 4.0 (5-min oscillations) and 1.1 – 16.0 mHz frequency bands. The oscillation power in the low-frequency band demonstrates a reverse tendency. The oscillation power in 5.2 – 6.8 mHz (3-min oscillations) decreases from the lower to middle chromosphere. This is the case for both regions at the base of a coronal hole. The integrated spectral power distribution in different chromospheric structures is complicated. Low-frequency oscillations are enhanced more often in peripheral areas of structures. Our observations do not corroborate the belief that 3-min oscillations prevail in internetwork and 5-min oscillations in network areas.

Source-dependent properties of two slow solar wind states

Léa **Griton**, Alexis P. Rouillard, Nicolas Poirier, Karine Issautier, Michel Moncuquet, Rui Pinto

ApJ **2021**

https://arxiv.org/pdf/2102.06568.pdf

Two states of the slow solar wind are identified from in-situ measurements by Parker Solar Probe (PSP) inside 50 solar radii from the Sun. At such distances the wind measured at PSP has not yet undergone significant transformation related to the expansion and propagation of the wind. We focus in this study on the properties of the quiet solar wind with no magnetic switchbacks. The two states differ by their plasma beta, flux and magnetic pressure. PSP's magnetic connectivity established with Potential Field Source Surface (PFSS) reconstructions, tested against extreme ultraviolet (EUV) and white-light imaging, reveals the two states correspond to a transition from a streamer to an equatorial coronal hole. The expansion factors of magnetic field lines in the streamer are 20 times greater than those rooted near the center of the coronal hole. The very different expansion rates of the magnetic field result in different magnetic pressures measured by PSP in the two plasma states. Solar wind simulations run along these differing flux tubes reproduce the slower and denser wind measured in the streamer and the more tenuous wind measured in the coronal hole. Plasma heating is more intense at the base of the streamer field lines rooted near the boundary of the equatorial hole than those rooted closer to the center of the hole. This results in a higher wind flux driven inside the streamer than deeper inside the equatorial hole. **March 31, 2019-April 5, 2019**

Coronal Bright Points as possible sources of density variations in the Solar Corona

Léa **Griton**, Rui F. Pinto, Nicolas Poirier, Athanasios Kouloumvakos, Michaël Lavarra, Alexis P. Rouillard

ApJ **893** 64 **2020**

https://arxiv.org/pdf/2003.05770.pdf

https://doi.org/10.3847/1538-4357/ab7b76
Recent analysis of high-cadence white-light images taken by the Solar-Terrestrial RElations Observatory (STEREO) near solar maximum has revealed that outflowing density structures are released in an ubiquitous manner in the solar wind. The present study investigates whether these density fluctuations could originate from the transient heating of the low corona observed during Coronal Bright Points (CBPs). We assume that part of the intense heating measured during CBPs occurs at the coronal base of open magnetic fields that channel the forming solar wind. We employ the solar wind model MULTI-VP to quantify the plasma compression induced by transient heating and investigate how the induced perturbation propagates to the upper corona. We show that for heating rates with statistics comparable to those observed during CBPs the compressive wave initially increases the local plasma density by a factor of up to 50% at 5 R⊙. The wave expands rapidly beyond 30 solar radii and the local enhancement in density decreases beyond. Based on the occurrence rates of CBPs measured in previous studies, we impose transient heating events at the base of thousands of open magnetic field lines to study the response of the entire 3-D corona. The simulated density cubes are then converted into synthetic white-light imagery. We show that the resulting brightness variations occupy all position angles in the images on timescales of hours. We conclude that a significant part of the ubiquitous brightness variability of the solar corona could originate in the strong transient heating of flux tubes induced by CBPs.

Observations of Dissipation of Slow Magneto-acoustic Waves in Polar Coronal Hole

G. R. **Gupta**
A&A, 568, A96, **2014**
http://arxiv.org/pdf/1407.1017v1.pdf
We focus on polar coronal hole region to find any evidence of dissipation of propagating slow magneto-acoustic waves. We obtained time-distance and frequency-distance maps along plume structure in polar coronal hole. We also obtained Fourier power maps of polar coronal hole in different frequency ranges in 171 \AA\ and 193 \AA\ passbands. We performed intensity distribution statistics in time domain at several locations in polar coronal hole. We find presence of propagating slow magneto-acoustic waves having temperature dependent propagation speeds. The wavelet analysis and Fourier power maps of polar coronal hole show that low-frequency waves are travelling longer distances (longer detection length) as compared to high-frequency waves. We found two distinct dissipation length scales of wave amplitude decay at two different height ranges (between 0-10 Mm and 10-70 Mm) along the observed plume structure. Dissipation length obtained at higher height range show some frequency dependence. Individual Fourier power spectrum at several locations show power-law distribution with frequency whereas probability density function (PDF) of intensity fluctuations in time show nearly Gaussian distributions. Propagating slow magneto-acoustic waves are getting heavily damped (small dissipation length) within the first 10 Mm distance. Beyond that waves are getting damped slowly with height. Frequency dependent dissipation length of wave propagation at higher heights may indicate possibility of wave dissipation due to thermal conduction, however, contribution from other dissipative parameters can not be ruled out. Power-law distributed power spectra were also found at lower heights in the solar corona which may provide a viable information on generation of longer period waves in the solar atmosphere. **2010 June 29**

Spectroscopic observations of propagating disturbances in a polar coronal hole: evidence of slow magneto-acoustic waves

G. R. **Gupta**1, L. Teriaca1, E. Marsch1,2, S. K. Solanki1,3 and D. Banerjee
A&A 546, A93 (**2012**)
Aims. We focus on detecting and studying quasi-periodic propagating features that have been interpreted in terms of both slow magneto-acoustic waves and of high-speed upflows.
Methods. We analyzed long-duration spectroscopic observations of the on-disk part of the south polar coronal hole taken on **1997 February 25** by the SUMER spectrometer onboard SOHO. We calibrated the velocity with respect to the off-limb region and obtained time-distance maps in intensity, Doppler velocity, and line width. We also performed a cross-correlation analysis on different time series curves at different latitudes. We studied average spectral line profiles at the roots of propagating disturbances and along the propagating ridges, and performed a red-blue asymmetry analysis.
Results. We clearly find propagating disturbances in intensity and Doppler velocity with a projected propagation speed of about 60 ± 4.8 km s-1 and a periodicity of ≈14.5 min. To our knowledge, this is the first simultaneous detection of propagating disturbances in intensity as well as in Doppler velocity in a coronal hole. During the propagation, an intensity enhancement is associated with a blueshifted Doppler velocity. These disturbances are clearly seen in intensity also at higher latitudes (i.e., closer to the limb), while disturbances in Doppler velocity become faint there. The spectral line profiles averaged along the propagating ridges are found to be symmetric, to be well fitted by a single Gaussian, and have no noticeable red-blue asymmetry.

Conclusions. Based on our analysis, we interpret these disturbances in terms of propagating slow magneto-acoustic waves.

ACCELERATING WAVES IN POLAR CORONAL HOLES AS SEEN BY EIS AND SUMER

G. R. **Gupta**[1,2], D. Banerjee[1], L. Teriaca[3], S. Imada[4], and S. Solanki[3,5]

Astrophysical Journal, 718:11–22, **2010** July

We present EIS*/Hinode* and SUMER*/SOHO* observations of propagating disturbances detected in coronal lines in inter-plume and plume regions of a polar coronal hole. The observation was carried out on 2007 November 13 as part of the JOP196/HOP045 program. The SUMER spectroscopic observation gives information about fluctuations in radiance and on both resolved (Doppler shift) and unresolved (Doppler width) line-of-sight velocities, whereas EIS 40_ wide slot images detect fluctuations only in radiance but maximize the probability of overlapping field of view between the two instruments. From distance–time radiance maps, we detect the presence of propagating waves in a polar inter-plume region with a period of 15–20 minutes and a propagation speed increasing from 130±14 km s^{-1} just above the limb to 330 ± 140 km s^{-1} around 160_ above the limb. These waves can be traced to originate from a bright region of the on-disk part of the coronal hole where the propagation speed is in the range of 25±1.3 to 38±4.5 km s^{-1}, with the same periodicity. These on-disk bright regions can be visualized as the base of the coronal funnels. The adjacent plume region also shows the presence of propagating disturbances with the same range of periodicity but with propagation speeds in the range of 135±18 to 165±43 km s^{-1} only. A comparison between the distance–time radiance map of the two regions indicates that the waves within the plumes are not observable (may be getting dissipated) far off-limb, whereas this is not the case in the inter-plume region. A correlation analysis was also performed to find out the time delay between the oscillations at several heights in the off-limb region, finding results consistent with those from the analysis of the distance–timemaps. To our knowledge, this result provides first spectroscopic evidence of the acceleration of propagating disturbances in the polar region close to the Sun (within 1.2
*R/R*_), which provides clues to the understanding of the origin of these waves.We suggest that the waves are likely either Alfv´enic or fast magnetoacoustic in the inter-plume region and slow magnetoacoustic in the plume region. This may lead to the conclusion that inter-plumes are a preferred channel for the acceleration of the fast solar wind

Short term topological changes of coronal holes associated with prominence eruptions and subsequent CMEs

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Advances in Space Research, Volume 51, Issue 10, **2013**, pp. 1824-1833

sci-hub.se/10.1016/j.asr.2012.03.008

We study the short-term topological changes of equatorial and polar coronal hole (CH) boundaries, such as a variation of their area and disintegration, associated to reconnection with nearby (within 15° distance) quiescent prominence magnetic fields leading to eruptions and subsequent Coronal Mass Ejections (CMEs). The examples presented here correspond to the recent solar minimum years 2008 and 2009. We consider a temporal window of one day between the CH topological changes and the start and end times of prominence eruptions and onset of CMEs. To establish this association we took into account observational conditions related to the instability of prominence/filaments, the occurrence of a CME, as well as the subsequent evolution after the CME. We found an association between short-term local topological changes in CH boundaries and the formation/disappearance of bright points near them, as well as, between short-term topological changes within the whole CH and eruptions of nearby quiescent prominences followed by the appearance of one or more CMEs. **2008/08/29, 2008/12/12, 2009/05/29**

IMPACT OF ACTIVE REGIONS ON CORONAL HOLE OUTFLOWS

Shadia Rifai **Habbal**,1 Isabelle F. Scholl,2,3 and Scott W. McIntosh4

Astrophysical Journal, 683:L75–L78, **2008**

http://www.journals.uchicago.edu/toc/apjl/2008/683/1

Establishing the sources of the fast and slow solar wind is important for understanding their drivers and their subsequent interaction in interplanetary space. Although coronal holes continue to be viewed as the main source of the fast solar wind, there is recent evidence that the quiet Sun provides other spatially concentrated sources. To identify the underlying physical characteristics of the outflow from coronal holes, solar disk observations from the *Solar and Heliospheric Observatory* (*SOHO*) are considered. These observations encompass photospheric line-of sight magnetic field measurements from the Michelson Doppler Imager (MDI), Fe x **171** passband imaging from °A the Extreme-ultraviolet Imaging Telescope (EIT), and Ne viii 770 spectral observations with outflows inferred °A from their corresponding Doppler blueshifts, at solar minimum and maximum and at different latitudes, from the

Solar Ultraviolet Measurement of Emitted Radiation (SUMER) instrument. The sharp variations of outflows within the SUMER field of view, referred to as velocity gradients, are introduced as a new diagnostic. It is shown that, in general, coronal holes are indistinguishable from the quiet Sun, whether in their outflows or their gradients. Surprisingly, however, when enhanced unbalanced magnetic flux from active regions extends into neighboring coronal holes, both outflows and their gradients become significantly enhanced within the coronal holes and along their boundaries. The same effect is observed in the quiet Sun, albeit to a lesser extent. These findings point to the possibility that active regions can lead to enhanced plasma outflows in neighboring coronal holes.

Characteristics of Nanoflare Heating in a Coronal Bright Point

Michael **Hahn**[1], Brandon Ho[2], and Daniel Wolf Savin[1]
2022 ApJ 936 113
https://iopscience.iop.org/article/10.3847/1538-4357/ac897f/pdf
We have obtained constraints on the nanoflare energy distribution and timing for the heating of a coronal bright point. Observations of the bright point were made using the Extreme Ultraviolet Imaging Spectrometer on Hinode in slot mode, which collects a time series of monochromatic images of the region leading to unambiguous temperature diagnostics. The Enthalpy-Based Thermal Evolution of Loops model was used to simulate nanoflare heating of the bright point and generate a time series of synthetic intensities. The nanoflare heating in the model was parameterized in terms of the power-law index α of the nanoflare energy distribution, which is $\propto E^{-\alpha}$; average nanoflare frequency f; and the number N of magnetic strands making up the observed loop. By comparing the synthetic and observed light curves, we inferred the region of the model parameter space (α, f, N) that was consistent with the observations. Broadly, we found that N and f are inversely correlated with one another, while α is directly correlated with either N or f. These correlations are likely a consequence of the region requiring a certain fixed energy input, which can be achieved in various ways by trading off among the different parameters. We also find hat a value of $\alpha > 2$ generally gives the best match between the model and observations, which indicates that the heating is dominated by low-energy events. Our method of using monochromatic images, focusing on a relatively simple structure, and constraining nanoflare parameters on the basis of statistical properties of the intensity provides a versatile approach to better understand the nature of nanoflares and coronal heating. **2008 December 9**

Density Fluctuations in a Polar Coronal Hole

Michael **Hahn**, Elke D'Huys, Daniel Wolf Savin
ApJ **860** 34 **2018**
https://arxiv.org/pdf/1804.10138.pdf
http://sci-hub.tw/http://iopscience.iop.org/0004-637X/860/1/34/
We have measured the root-mean-square (RMS) amplitude of intensity fluctuations, ΔI, in plume and interplume regions of a polar coronal hole. These intensity fluctuations correspond to density fluctuations. Using data from the \rev{Sun Watcher using Active Pixel System detector and Image Processing} (SWAP) on \textit{Project for Onboard Autonomy (Proba2)}, our results extend up to a height of about 1.35~$R_{\sun}$. One advantage of the RMS analysis is that it does not rely on a detailed evaluation of the power spectrum, which is limited by noise levels to low heights in the corona. The RMS approach can be performed up to larger heights where the noise level is greater, provided that the noise itself can be quantified. At low heights, both the absolute ΔI, and the amplitude relative to the mean intensity, ΔI/I, decrease with height. However, starting at about 1.2~$R_{\sun}$ ΔI/I increases, reaching 20--40\% by 1.35~$R_{\sun}$. This corresponds to density fluctuations of Δne/ne≈~10--20\%. The increasing relative amplitude implies that the density fluctuations are generated in the corona itself. One possibility is that the density fluctuations are generated by an instability of Alfv\'en waves. This generation mechanism is consistent with some theoretical models and with observations of Alfv\'en wave amplitudes in coronal holes. Although we find that the energy of the observed density fluctuations is small, these fluctuations are likely to play an important indirect role in coronal heating by promoting the reflection of Alfv\'en waves and driving turbulence.
2017/04/06-07

Evidence that Waves Heat Coronal Holes

Michael **Hahn** and Daniel Wolf Savin
EIS nugget of **2014**
http://solarb.mssl.ucl.ac.uk/SolarB/nuggets/nugget_2014jan.jsp
Using EIS observations of a coronal hole, we have found that Alfvén waves not only carry enough energy to heat the plasma and drive the fast solar wind, but also that this energy is dissipated at low enough heights for it to thermalize throughout the coronal hole. Alfvén waves have long been proposed as the energy source that heats the corona and drives the solar wind. But a challenge for wave-driven models has been to show that the waves damp at low enough heights in the corona. In order to heat the corona, the waves must be damped below about 2 $R_\odot$, that is, below the heights where heat conduction becomes inefficient and the solar wind becomes supersonic.

Observational Quantification of the Energy Dissipated by Alfvén Waves in a Polar Coronal Hole: Evidence that Waves Drive the Fast Solar Wind

M. **Hahn** and D. W. Savin

2013 ApJ 776 78

We present a measurement of the energy carried and dissipated by Alfvén waves in a polar coronal hole. Alfvén waves have been proposed as the energy source that heats the corona and drives the solar wind. Previous work has shown that line widths decrease with height in coronal holes, which is a signature of wave damping, but have been unable to quantify the energy lost by the waves. This is because line widths depend on both the non-thermal velocity v nt and the ion temperature T i. We have implemented a means to separate the T i and v nt contributions using the observation that at low heights the waves are undamped and the ion temperatures do not change with height. This enables us to determine the amount of energy carried by the waves at low heights, which is proportional to v nt. We find the initial energy flux density present was 6.7 ± 0.7 × 105 erg cm–2 s–1, which is sufficient to heat the coronal hole and accelerate the solar wind during the 2007-2009 solar minimum. Additionally, we find that about 85% of this energy is dissipated below 1.5 R ⊙, sufficiently low that thermal conduction can transport the energy throughout the coronal hole, heating it and driving the fast solar wind. The remaining energy is roughly consistent with what models show is needed to provide the extended heating above the sonic point for the fast solar wind. We have also studied T i, which we found to be in the range of 1-2 MK, depending on the ion species.

MEASUREMENTS OF ANISOTROPIC ION TEMPERATURES, NON-THERMAL VELOCITIES, AND DOPPLER SHIFTS IN A CORONAL HOLE

M. **Hahn** and D. W. Savin

2013 ApJ 763 106

We present a new diagnostic allowing one to measure the anisotropy of ion temperatures and non-thermal velocities, as well as Doppler shifts with respect to the ambient magnetic field. This method provides new results, as well as an independent test for previous measurements obtained with other techniques. Our spectral data come from observations of a low-latitude, on-disk coronal hole. A potential field source surface model was used to calculate the angle between the magnetic field lines and the line of sight for each spatial bin of the observation. A fit was performed to determine the line widths and Doppler shifts parallel and perpendicular to the magnetic field. For each line width component we derived ion temperatures T i, ⊥ and T i, ∥ and non-thermal velocities v nt, ⊥ and v nt, ∥. T i, ⊥ was cooler than off-limb polar coronal hole measurements, suggesting increasing collisional cooling with decreasing height. T i, ∥ is consistent with a uniform temperature of (1.8 ± 0.2) × 106 K for each ion. Since parallel ion heating is expected to be weak, this ion temperature should reflect the proton temperature. A comparison between our results and others implies a large proton temperature gradient around 1.02 R ⊙. The non-thermal velocities are thought to be proportional to the amplitudes of various waves. Our results for v nt, ⊥ agree with Alfvén wave amplitudes inferred from off-limb polar coronal hole line width measurements. Our v nt, ∥ results are consistent with slow magnetosonic wave amplitudes inferred from Fourier analysis of time-varying intensity fluctuations. Doppler shift measurements yield outflows of 5 km s–1 for ions formed over a broad temperature range. This differs from other studies that found a strong Doppler shift dependence on formation temperature.

EVIDENCE OF WAVE DAMPING AT LOW HEIGHTS IN A POLAR CORONAL HOLE

M. **Hahn1,** E. Landi2, and D. W. Savin

2012 ApJ 753 36

We have measured the widths of spectral lines from a polar coronal hole using the Extreme Ultraviolet Imaging Spectrometer on board Hinode. Polar coronal holes are regions of open magnetic field and the source of the fast solar wind. We find that the line widths decrease at relatively low heights. Previous observations have attributed such decreases to systematic effects, but we find that such effects are too small to explain our results. We conclude that the line narrowing is real. The non-thermal line widths are believed to be proportional to the amplitude of Alfvén waves propagating along these open field lines. Our results suggest that Alfvén waves are damped at unexpectedly low heights in a polar coronal hole. We derive an estimate on the upper limit for the energy dissipated between 1.1 R ⊙ and 1.3 R ⊙ and find that it is enough to account for up to 70% of that required to heat the polar coronal hole and accelerate the solar wind.

DIFFERENTIAL EMISSION MEASURE ANALYSIS OF A POLAR CORONAL HOLE DURING THE SOLAR MINIMUM IN 2007

M. **Hahn**1, E. Landi2 and D. W. Savin

2011 ApJ 736 101

We have performed a differential emission measure (DEM) analysis for a polar coronal hole observed during solar minimum in 2007. Five observations are analyzed spanning the coronal hole from the central meridian to the boundary with the quiet-Sun corona. The observed heights ranged from 1.05 to 1.20 R . The analysis shows that the plasma is not strictly isothermal anywhere, but rather has a high-temperature component that extends up to log T(K) = 6.2-6.3. The size and importance of this component depend on location, and its evolving magnitude with height marks the boundary between the coronal hole and the quiet corona, where it becomes dominant. The DEM of the coronal hole plasma below log T(K) = 6.0 decreases faster with height than that of the high-temperature component. We discuss the possible nature of the high-temperature component. Our results highlight the potential limitations of isothermal analyses. Such methods actually measure a DEM-weighted average temperature and as a result can infer artificial temperature gradients. Assuming the gas is isothermal along the line of sight can also yield incorrect electron densities. By revealing structures along the line of sight, a DEM analysis can also be used to more reliably interpret electron temperature and density measurements.

PROPERTIES OF A POLAR CORONAL HOLE DURING THE SOLAR MINIMUM IN 2007

M. **Hahn**[1], P. Bryans[2,5], E. Landi[3,6], M. P. Miralles[4], and D. W. Savin[1]

Astrophysical Journal, 725:774–786, **2010**

We report measurements of a polar coronal hole during the recent solar minimum using the Extreme Ultraviolet Imaging Spectrometer on *Hinode*. Five observations are analyzed that span the polar coronal hole from the central meridian to the boundary with the quiet-Sun corona. We study the observations above the solar limb in the height range of 1.03–1.20*R*_. The electron temperature T_e and emission measure (EM) are found using a geometric mean emission measure method. The EM derived from the elements Fe, Si, S, and Al are compared in order to measure relative coronal-to-photospheric abundance enhancement factors. We also studied the ion temperature T_i and the non-thermal velocity v_{nt} using the line profiles. All these measurements are compared to polar coronal hole observations from the previous (1996–1997) solar minimum and to model predictions for relative abundances. There are many similarities in the physical properties of the polar coronal holes between the two minima at these low
heights.We find that the electron density, T_e, and T_i are comparable in both minima. T_e shows a comparable gradient with height. Both minima show a decreasing T_i with increasing charge-to-mass ratio *q/M*. A previously observed upturn of T_i for ions above *q/M* > 0.25 was not found here. We also compared relative coronal-to-photospheric elemental abundance enhancement factors for a number of elements. These ratios were ~1 for both the low first ionization potential (FIP) elements Si and Al and the marginally high FIP element S relative to the low FIP element Fe, as is expected based on earlier observations and models for a polar coronal hole. These results are consistent with no FIP effect in a polar coronal hole.

A Uniform Series of Low-Latitude Coronal Holes in 1973–2018

A. **Hamada**, T. Asikainen & K. Mursula

Solar Physics volume 296, Article number: 40 (**2021**)

https://link.springer.com/content/pdf/10.1007/s11207-021-01781-w.pdf

https://doi.org/10.1007/s11207-021-01781-w

Coronal holes (CHs) are regions in the solar corona characterized by plasma density lower than in the surrounding quiet Sun. Therefore they appear dark in images of the solar atmosphere made, e.g., in extreme ultraviolet (EUV). Identifying CHs on solar images is difficult since CH boundaries are not sharp, but typically obscured by magnetic structures of surrounding active regions. Moreover, the areas, shapes, and intensities of CHs appear differently in different wavelengths. Coronal holes have been identified both visually by experienced observers and, more recently, by automated detection methods using different techniques. In this article, we apply a recent, robust CH identification algorithm to a new set of homogenized EUV synoptic maps based on four EUV lines measured by the Solar and Heliospheric Observatory/Extreme ultraviolet Imaging Telescope (SOHO/EIT) in 1996–2018 and the Solar Dynamics Observatory/Atmospheric Imaging Assembly (SDO/AIA) in 2010–2018 and create corresponding CH synoptic maps. We also use CHs of the hand-drawn McIntosh archive (McA) from 1973–2009 to extend the CH database to earlier times. We discuss the success of the four EUV lines to find CHs at high or low latitudes, and confirm that the combined EIT 195 Å/AIA 193 Å series applies best for both polar and low-latitude CH detection. While the polar CH detection suffers from the vantage-point limitation, the low-latitude CH areas extracted from this line correlate with the McA CH data very well. Using the simultaneous measurements between EIT and McA and EIT and AIA, we scale the different data series to the same level and form the longest uniform series of low-latitude CHs in 1973–2018. We find that, while the solar cycle maxima of low-latitude CHs in the descending phase of Solar Cycles 21–23 attain roughly similar values, the corresponding maximum during Solar Cycle 24 is reduced by a factor of two. This suggests that magnetic flux emergence is crucial for the formation of low-latitude CHs. **29 April 1994, 16 November 2016**

Automated identification of coronal holes from synoptic EUV maps

Amr **Hamada**, Timo Asikainen, Ilpo Virtanen, Kalevi Mursula

Solar Phys. 293:71 **2017**

https://arxiv.org/pdf/1712.01522.pdf

Coronal holes (CH) are regions of open magnetic field lines in the solar corona and the source of fast solar wind. Understanding the evolution of coronal holes is critical for solar magnetism as well as for accurate space weather forecasts. We study here the extreme ultraviolet (EUV) synoptic maps at three wavelengths (195A/193A, 171A and 304A) measured by Solar and Heliospheric Observatory/Extreme Ultraviolet Imaging Telescope (SOHO/EIT) and Solar Dynamics Observatory/Atmospheric Imaging Assembly (SDO/AIA) instruments. The two datasets are first homogenized by scaling the SDO/AIA data to the SOHO/EIT level by means of histogram equalization. We then develop a novel automated method to identify CHs from these homogenized maps by determining the intensity threshold of CH regions separately for each synoptic map. This is done by identifying the best location and size of an image segment, which optimally contains portions of coronal holes and the surrounding quiet Sun allowing us to detect the momentary intensity threshold. Our method is thus able to adjust itself to the changing scale size of coronal holes and to temporally varying intensities. To make full use of the information in the three wavelengths we construct, a composite CH distribution, which is more robust than distributions based on one wavelength. Using the composite CH dataset we discuss the temporal evolution of CHs during the solar cycles 23 and 24.

New Homogeneous Dataset of Solar EUV synoptic maps from SOHO/EIT and SDO/AIA

Amr **Hamada**, Timo Asikainen, Kalevi Mursula

Solar Phys. January **2020**, 295:2

https://arxiv.org/pdf/1910.13720.pdf

https://doi.org/10.1007/s11207-019-1563-y

Synoptic maps of solar EUV intensities have been constructed for many decades in order to display the distribution of the different EUV emissions across the solar surface, with each map representing one Carrington rotation (i.e., one rotation of the Sun). This paper presents a new solar EUV synoptic map dataset based on full-disk images from Solar and Heliospheric Observatory/Extreme Ultraviolet Imaging Telescope (SOHO/EIT) and Solar Dynamics Observatory/Atmospheric Imaging Assembly (SDO/AIA). In order to remove the significant and complicated drift of EIT and AIA EUV intensities due to sensor degradation, we construct the synoptic maps in standardized intensity scale. We describe a method of homogenizing the SOHO/EIT maps with SDO/AIA maps by transforming the EIT intensity histograms to AIA level. The new maps cover the years from 1996 to 2018 with 307 SOHO/EIT and 116 SDO/AIA synoptic maps, respectively. These maps provide a systematic and homogenous view of the entire solar surface in four EUV wavelengths, and are well suited, e.g., for studying long-term coronal hole evolution.

Solar Coronal Jets Extending to High Altitudes Observed During the 2017 August 21 Total Eclipse

Yoichiro **Hanaoka**, Ryuichi Hasuo, Tsukasa Hirose, Akiko C. Ikeda, Tsutomu Ishibashi, Norihiro Manago, Yukio Masuda, Sakuhiro Morita, Jun Nakazawa, Osamu Ohgoe, Yoshiaki Sakai, Kazuhiro Sasaki, Koichi Takahashi, Toshiyuki Toi

ApJ **2018**

https://arxiv.org/pdf/1805.04251.pdf

Coronal jets, which extend from the solar surface to beyond 2 R⨀, were observed in the polar coronal hole regions during the total solar eclipse on **2017 August 21**. In a time-series of white-light images of the corona spanning 70 minutes taken with our multi-site observations of this eclipse, six jets were found as narrow structures upwardly ejected with the apparent speed of about 450 km s−1 in polar plumes. On the other hand, extreme-ultraviolet (EUV) images taken with the Atmospheric Image Assembly of the Solar Dynamics Observatory show that all of the eclipse jets were preceded by EUV jets. Conversely, all the EUV jets whose brightness is comparable to ordinary soft X-ray jets and which occurred in the polar regions near the eclipse period were observed as eclipse jets. These results suggest that ordinary polar jets generally reach high altitudes and escape from the Sun as part of the solar wind.

Solar Wind Models from the Chromosphere to 1 AU

Viggo H. **Hansteen**, Marco Velli

Space Science Reviews, November **2012**, Volume 172, Issue 1-4, pp 89-121

Recent models of the fast solar wind are characterized by low coronal electron temperatures while proton, α-particle, and minor ion temperatures are expected to be quite high and generally anisotropic, including large temperatures perpendicular to the magnetic field and parallel beams. This entails that the electric field should be relatively unimportant and that solar wind outflows with both high asymptotic flow speeds but maintaining a low mass flux should be a natural outcome of plasma expansion along open polar magnetic field lines. In this chapter we will explain why such changes with respect to the classical, electron thermally driven solar wind have come about and outline the most important remaining concerning the astrophysics of coronal winds.

The progress we have seen in the last decade is largely due observations made with instruments onboard Ulysses (McComas et al. in Space Sci. Rev. 72:93, 1995) and SOHO (Fleck et al. in The SOHO Mission, Kluwer, Dordrecht, 1995). These observations have spawned a new understanding of solar wind energetics, and the consideration of the chromosphere, corona, and solar wind as a unified system.
We will begin by giving our own, highly biased, "pocket history" of solar wind theory highlighting the problems that had to be resolved in order to make the original Parker formulation of thermally driven winds conform with observational results. Central to this discussion are questions of how the wind's asymptotic flow speed and mass flux are set, but we will also touch upon higher order moments such as the ion and electron temperatures and heat fluxes as well as the possible role of Alfvén waves and particle effects in driving the solar wind outflow. Solar wind scaling laws will be discussed in the context of the origin of slow and fast wind streams.

Spectral Diagnostics of Solar Photospheric Bright Points

Q. **Hao**, C. Fang, M. D. Ding, Z. Li, W. Cao

ApJ 900 130 **2020**

https://arxiv.org/pdf/2007.09675.pdf

https://doi.org/10.3847/1538-4357/aba692

https://iopscience.iop.org/article/10.3847/1538-4357/aba692/pdf

By use of the high-resolution spectral data and the broadband imaging obtained with the Goode Solar Telescope at the Big Bear Solar Observatory on **2013 June 6**, the spectra of three typical photospheric bright points (PBPs) have been analyzed. Based on the Hα and Ca II 8542 Åline profiles, as well as the TiO continuum emission, for the first time, the non-LTE semi-empirical atmospheric models for the PBPs are computed. The attractive characteristic is the temperature enhancement in the lower photosphere. The temperature enhancement is about 200 -- 500 K at the same column mass density as in the atmospheric model of the quiet-Sun. The total excess radiative energy of a typical PBP is estimated to be 1×1027 - 2×1027 ergs, which can be regarded as the lower limit energy of the PBPs. The radiation flux in the visible continuum for the PBPs is about 5.5×1010 ergs cm−2 s−1. Our result also indicates that the temperature in the atmosphere above PBPs is close to that of a plage. It gives a clear evidence that PBPs may contribute significantly to the heating of the plage atmosphere. Using our semi-empirical atmospheric models, we estimate self-consistently the average magnetic flux density B in the PBPs. It is shown that the maximum value is about one kilo-Gauss, and it decreases towards both higher and lower layers, reminding us of the structure of a flux tube between photospheric granules.

Nonthermal Motions in a Polar Coronal Hole Measured with Hinode/EIS during an on-Orbit Partial Solar Eclipse on 2017 August 21

Hirohisa **Hara**

2019 ApJ 887 122

https://doi.org/10.3847/1538-4357/ab50bf

We have performed a spectroscopic observation over the south polar coronal hole (PCH) with the Hinode Extreme-ultraviolet (EUV) Imaging Spectrometer (EIS) during an on-orbit partial solar eclipse. In this partial eclipse, the Moon passed through the EIS observing area that was set in the south PCH at the height of 0.9–1.4 solar radii. Using the lunar occultation, we have corrected for the scattered light contamination from bright regions of the Sun that is present in the dark PCH emission line profiles. The nonthermal width of the corrected emission line profile in the PCH increases from the limb toward the high-altitude corona. It has also been confirmed that the nonthermal width tends to decrease beyond ~1.2 solar radii. These results are consistent with the model in which outward-propagating Alfvén waves start being dissipated at ~1.2 solar radii, as previously reported. The reduced energy within ~1.4 solar radii contributes to atmospheric heating and the initial acceleration for the solar wind in the low corona. The remaining energy flux at 1.4 solar radii may be dissipated in the distant corona and is sufficient to provide the additional acceleration required to drive the fast solar wind.

What Causes Faint Solar Coronal Jets from Emerging Flux Regions in Coronal Holes?

Abigail R. **Harden**, Navdeep K. Panesar, Ronald L. Moore, Alphonse C. Sterling, Mitzi L. Adams

ApJ **912** 97 **2021**

https://arxiv.org/pdf/2103.07813.pdf

https://doi.org/10.3847/1538-4357/abee19

Using EUV images and line-of-sight magnetograms from Solar Dynamics Observatory, we examine eight emerging bipolar magnetic regions (BMRs) in central-disk coronal holes for whether the emerging magnetic arch made any noticeable coronal jets directly, via reconnection with ambient open field as modeled by Yokoyama and Shibata (1995). During emergence, each BMR produced no obvious EUV coronal jet of normal brightness, but each produced one or more faint EUV coronal jets that are discernible in AIA 193 Å images. The spires of these jets are much fainter and usually narrower than for typical EUV jets that have been observed to be produced by minifilament eruptions in quiet regions and coronal holes. For each of 26 faint jets from the eight emerging BMRs, we examine whether the faint spire was evidently made a la Yokoyama and Shibata (1995). We find: (1) 16 of these faint spires evidently originate from sites of converging opposite-polarity magnetic flux and show base brightenings like those in minifilament-eruption-driven coronal jets, (2) the 10 other faint spires maybe were made by a burst of the external-magnetic-arcade-building reconnection of the emerging magnetic arch with the ambient open field, reconnection directly driven by the arch's emergence, but (3) none were unambiguously made by such emergence-driven reconnection. Thus, for these eight emerging BMRs the observations indicate that emergence-driven external reconnection of the emerging magnetic arch with ambient open field at most produces a jet spire that is much fainter than in previously-reported, much more obvious coronal jets driven by minifilament eruptions. **12 May 2012, 1 Jul 2012, 10 Jan 2015**

Table 1. The Emerging Bipolar Magnetic Regions and their Faint Jets (2012-2017)

Outflows at the Edges of Active Regions: Contribution to Solar Wind Formation?

L. K. **Harra**, T. Sakao, C. H. Mandrini, H. Hara, S. Imada, P. R. Young, L. van Driel–Gesztelyi, D. Baker

The Astrophysical Journal Letters

2008 April 1, Vol. 676, No. 2: pp. L147-L150б (doi: 10.1086/587485)

The formation of the slow solar wind has been debated for many years. In this Letter we show evidence of persistent outflow at the edges of an active region as measured by the EUV Imaging Spectrometer on board ***Hinode*.** The Doppler velocity ranged between 20 and 50 km s^{-1} and was consistent with a steady flow seen in the X-Ray Telescope. The latter showed steady, pulsing outflowing material and some transverse motions of the loops. We analyze the magnetic field around the active region and produce a coronal magnetic field model. We determine from the latter that the outflow speeds adjusted for line-of-sight effects can reach over 100 km s^{-1}. We can interpret this outflow as expansion of loops that lie over the active region, which may either reconnect with neighboring large-scale loops or are likely to open to the interplanetary space. This material constitutes at least part of the slow solar wind.

Tracking Movement of Long-lived Equatorial Coronal Holes from Analysis of Long-term McIntosh Archive Data

Jacob **Harris**1, Mausumi Dikpati2, Ian M. Hewins2, Sarah E. Gibson2, Scott W. McIntosh2, Subhamoy Chatterjee3, and Thomas A. Kuchar4

2022 ApJ 931 54

https://iopscience.iop.org/article/10.3847/1538-4357/ac67f2/pdf

Features at the Sun's surface and atmosphere are constantly changing due to its magnetic field. The McIntosh Archive provides a long-term (45 yr) record of these features, digitized from hand-drawn synoptic maps by Patrick McIntosh. Utilizing this data, we create stack plots for coronal holes, i.e., Hovmöller-type plots of latitude bands, for all longitudes, stacked in time, allowing tracking of coronal hole movement. Using a newly developed two-step method of centroid calculation, which includes a Fourier descriptor to represent a coronal hole's boundary and calculate the centroid by the use of Green's theorem, we calculate the centroids of 31 unique, long-lived equatorial coronal holes for successive Carrington rotations during the entire solar cycle 23, and estimate their slopes (time versus longitude) as the coronal holes evolve. We compute coronal hole centroid drift speeds from these slopes, and find an eastward (prograde) pattern that is actually retrograde with respect to the local differential rotation. By discussing the plausible physical mechanisms which could cause these long-lived equatorial coronal holes to drift retrograde, we identify either classical or magnetically modified westward-propagating solar Rossby waves, with a speed of a few tens to a few hundreds of meters per second, to be the best candidate for governing the drift of deep-rooted, long-lived equatorial coronal holes. To explore plausible physics of why long-lived equatorial coronal holes appear few in number during solar minimum/early rising phase more statistics are required, which will be studied in future. **28 Aug 2019, 28 Sep 2019**

Table 1 Positive Coronal Hole Patterns

Table 2 Negative Coronal Hole Patterns

POLAR CORONAL HOLES DURING CYCLES 22 AND 23

KAREN L. **HARVEY**1,† and FRANK RECELY2

Solar Physics **211:** 31–52, 2002.

http://www.springerlink.com/content/g8648247t510t515/fulltext.pdf

2.1. NSO/KP SYNOPTIC OBSERVATIONS

2.2. HE I 1083 NM CORONAL HOLES DEFINED

Conceptually, CHs are considered the low-density and low temperature regions in the corona (e.g., Harvey & Recely 2002), from which the solar wind is fast and the magnetic field is open.

Solar wind origins in coronal holes and in the quiet Sun (a Review)

J.-S. **He**, C.-Y. Tu, H. Tian and E. Marsch

Advances in Space Research

Volume 45, Issue 2, 15 January **2010**, Pages 303-309

Coronal hole (CH) and the quiet Sun (QS) are considered to account for sources of fast and slow solar wind streams, respectively. The differences between the solar wind streams flowing out from the CH and the QS are thought to be related with different plasma generation and acceleration mechanisms in the respective source regions. Here we review recent studies on the solar wind origin in the CH and the QS, compare the possible flow geometries and magnetic structures in these two kinds of solar regions, and summarize the physics associated with two different origin scenarios.

Thermal and magnetic field structure of near-equatorial coronal holes

M. **Hegde** and K. M. Hiremath

A&A, 688, A35 (**2024**)

https://www.aanda.org/articles/aa/pdf/2024/08/aa47082-23.pdf

Context. Coronal holes are low-density and unipolar magnetic field structures in the solar corona that trigger geomagnetic disturbances on the Earth. Hence, it is important to understand the genesis and evolutionary behavior of these coronal activity features during their passage across the solar disk.

Aims. We study the day-to-day latitudinal variations of thermal and magnetic field structures of near-equatorial coronal holes. For this purpose, eight years of full-disk SOHO/EIT 195 Å calibrated images were used.

Methods. Using the response curves of the SOHO/EIT channels and assuming thermodynamic equilibrium, we estimated the temperature structure of coronal holes. From the latitudinal variation in the magnetic pressure, we inferred the magnitude of the magnetic field structure of coronal holes.

Results. Except for the temperature T, we find that the variations in the average photon flux F, in the radiative energy E, in the area A, and in the magnitude of the magnetic field structure |B| of coronal holes depend on latitude. The typical average values of the estimated physical parameters are A ∼ 3.8(±0.5)×1020 cm2, F ∼ 2.3(±0.2)×1013 photons cm−2 s−1, E ∼ 2.32(±0.5)×103 ergs cm−2 s−1, T ∼ 0.94(±0.1)×106 K and |B|~0.01(±0.001) G.

Conclusions. When coronal holes are anchored in the convection zone, these activity features would be expected to rotate differentially. The thermal wind balance and isorotation of coronal holes with the solar plasma therefore implies a measurable temperature difference between the equator and the two poles. Contrary to this fact, the variation in the thermal structure of near-equatorial coronal holes is independent of latitude, which leads to the conclusion that coronal holes must rotate rigidly and are likely to be initially anchored below the tachocline. This confirms our previous study.

Coronal Hole Oscillations as Inferred From SDO/AIA Data

M. **Hegde**, K.M. Hiremath, Vijayakumar H. Doddamani

Advances in Space Research, **2014**

With high temporal resolution (12 sec) of about two hours duration, data of a coronal hole structure in 171Å, 193Å and 211Å taken from SDO/AIA images is considered for examination of oscillations. After estimating the total DN counts of a whole coronal hole structure in three wavelength bands, the resulting time series are subjected to FFT and wavelet analysis. Significant periods in all the three wavelength bands are detected that are mainly concentrated around 500 sec as a fundamental mode and its odd (167, 100, 71, 56, 46, 39, 33, 29, 26, 24 seconds) harmonics. Computed phases in all the three wavelengths band are estimated to be constant.

Evolution of an equatorial coronal hole structure and the released coronal hole wind stream: Carrington rotations 2039 to 2050

Verena **Heidrich-Meisner**, Thies Peleikis, Martin Kruse, Lars Berger and Robert F. Wimmer-Schweingruber

A&A 603, A84 (**2017**)

https://www.aanda.org/articles/aa/full_html/2017/07/aa30574-17/aa30574-17.html

Context. The Sun is a highly dynamic environment that exhibits dynamic behavior on many different timescales. Variability is observed both in closed and in open field line regions in the solar corona. In particular, coronal holes exhibit temporal and spatial variability. Signatures of these coronal dynamics are inherited by the coronal hole wind

streams that originate in these regions and can effect the Earth's magnetosphere. Both the cause of the observed variabilities and how these translate to fluctuations in the in situ observed solar wind is not yet fully understood.
Aims. During solar activity minimum the structure of the magnetic field typically remains stable over several Carrington rotations (CRs). But how stable is the solar magnetic field? Here, we address this question by analyzing the evolution of a coronal hole structure and the corresponding coronal hole wind stream emitted from this source region over 12 consecutive CRs in 2006.
Methods. To this end, we link in situ observations of Solar Wind Ion Composition Spectrometer (SWICS) onboard the Advanced Composition Explorer (ACE) with synoptic maps of Michelson Doppler imager (MDI) on the Solar and Heliospheric Observatory (SOHO) at the photospheric level through a combination of ballistic back-mapping and a potential field source surface (PFSS) approach. Together, these track the evolution of the open field line region that is identified as the source region of a recurring coronal hole wind stream. Under the assumptions of the freeze-in scenario for charge states in the solar wind, we derive freeze-in temperatures and determine the order in which the different charge state ratios of ion pairs appear to freeze-in. We call the combination of freeze-in temperatures derived from in situ observed ion density ratios and freeze-in order a minimal electron temperature profile and investigate its variability.
Results. The in situ properties and the PFSS model together probe the lateral magnetic field configuration, the minimal temperature profiles allow to constrain the radial structure. We find that the shape of the open field line region and to some extent also the solar wind properties are influenced by surrounding more dynamic closed loop regions. We show that the freeze-in order can change within a coronal hole wind stream on small timescales and illustrate a mechanism that can cause changes in the freeze-in order. The inferred minimal temperature profile is variable even within coronal hole wind and is in particular most variable in the outer corona.

The short term stability and tilting motion of a well-observed low-latitude solar coronal hole

Stephan G. **Heinemann**, Stefan J. Hofmeister, James A. Turtle, Jens Pomoell, Eleanna Asvestari, Alphonse C. Sterling, Andrea Diercke, Cooper Downs

A&A 679, A100 **2023**

https://arxiv.org/pdf/2309.11100.pdf

https://www.aanda.org/articles/aa/pdf/2023/11/aa47180-23.pdf

The understanding of the solar magnetic coronal structure is tightly linked to the shape of open field regions, specifically coronal holes. A dynamically evolving coronal hole coincides with the local restructuring of open to closed magnetic field, which leads to changes in the interplanetary solar wind structure. By investigating the dynamic evolution of a fast-tilting coronal hole, we strive to uncover clues about what processes may drive its morphological changes, which are clearly visible in EUV filtergrams. Using combined 193A and 195A EUV observations by AIA/SDO and EUVI/STEREO_A, in conjunction with line-of-sight magnetograms taken by HMI/SDO, we track and analyze a coronal hole over 12 days to derive changes in morphology, area and magnetic field. We complement this analysis by potential field source surface modeling to compute the open field structure of the coronal hole. We find that the coronal hole exhibits an apparent tilting motion over time that cannot solely be explained by solar differential rotation. It tilts at a mean rate of ~3.2°/day that accelerates up to ~5.4°/day. At the beginning of May, the area of the coronal hole decreases by more than a factor of three over four days (from ~13 * 10^9 km^2 to ~4 * 10^9 km^2), but its open flux remains constant (~2 * 10^20 Mx). Further, the observed evolution is not reproduced by modeling that assumes the coronal magnetic field to be potential. In this study, we present a solar coronal hole that tilts at a rate that has yet to be reported in literature. The rate exceeds the effect of the coronal hole being advected by either photospheric or coronal differential rotation. Based on the analysis we find it likely that this is due to morphological changes in the coronal hole boundary caused by ongoing interchange reconnection and the interaction with a newly emerging ephemeral region in its vicinity. **2021-04-24-27, 2021-04-28-30, 2021-05-02-05**

How to Estimate the Far-Side Open Flux using STEREO Coronal Holes

Stephan G. **Heinemann**, Manuela Temmer, Stefan J. Hofmeister, Aleksandar Stojakovic, Laurent Gizon, Dan Yang

Solar Phys. **296**, Article number: 141 **2021**

https://arxiv.org/pdf/2109.02375.pdf

https://link.springer.com/content/pdf/10.1007/s11207-021-01889-z.pdf

https://doi.org/10.1007/s11207-021-01889-z

Global magnetic field models use as input synoptic data, which usually show "aging effects" as the longitudinal 360° information is not obtained simultaneously. Especially during times of increased solar activity, the evolution of the magnetic field may yield large uncertainties. A significant source of uncertainty is the Sun's magnetic field on the side of the Sun that is not visible to the observer. Various methods have been used to complete the picture: synoptic charts, flux-transport models, and far side helioseismology. In this study, we present a new method to estimate the far-side open flux within coronal holes using STEREO EUV observations. First, we correlate the structure of the photospheric magnetic field as observed with the Helioseismic and Magnetic Imager on board the Solar Dynamics Observatory (HMI/SDO) with features in the transition region. From the 304A intensity distribution, which we found to be specific to coronal holes, we derive an empirical estimate for the open flux. Then we use a large sample of 313 SDO coronal hole observations to verify this relation. Finally, we perform a cross-instrument calibration from SDO to STEREO data to enable the estimation of the open flux at solar longitudes not visible from Earth. We find that the properties of strong, unipolar magnetic elements in the photosphere, which determine the coronal hole's open flux, can be approximated by open fields in the transition region. We find that structures below a threshold of 78% (STEREO) or 94% (SDO) of the solar disk median intensity as seen in 304A filtergrams are reasonably well correlated with the mean magnetic flux density of coronal holes (cc = 0.59). Using the area covered by these structures (A_of) and the area of the coronal hole (A_ch), we model the open magnetic flux of a coronal hole as |Phi_ch| = 0.25 A_ch exp(0.032 A_of) with an estimated uncertainty of 40 to 60%. **May 29, 2013**

Statistical Approach on Differential Emission Measure of Coronal Holes using the CATCH Catalog

Stephan G. **Heinemann**, Jonas Saqri, Astrid M. Veronig, Stefan J. Hofmeister & Manuela Temmer
Solar Physics volume 296, Article number: 18 (**2021**)
https://arxiv.org/pdf/2102.13396.pdf
https://link.springer.com/content/pdf/10.1007/s11207-020-01759-0.pdf
Coronal holes are large-scale structures in the solar atmosphere that feature a reduced temperature and density in comparison to the surrounding quiet Sun and are usually associated with open magnetic fields. We perform a differential emission measure analysis on the 707 non-polar coronal holes in the Collection of Analysis Tools for Coronal Holes (CATCH) catalog to derive and statistically analyze their plasma properties (i.e. temperature, electron density, and emission measure). We use intensity filtergrams of the six coronal EUV filters from the Atmospheric Imaging Assembly onboard the Solar Dynamics Observatory, which cover a temperature range from ≈105.5≈105.5 to 107.5 K107.5 K. Correcting the data for stray and scattered light, we find that all coronal holes have very similar plasma properties with an average temperature of 0.94±0.18 MK0.94±0.18 MK, a mean electron density of (2.4±0.7)×108 cm−3(2.4±0.7)×108 cm−3, and a mean emission measure of (2.8±1.6)×1026 cm−5(2.8±1.6)×1026 cm−5. The temperature distribution within the coronal holes was found to be largely uniform, whereas the electron density shows a 30 to 40% linear decrease from the boundary towards the inside of the coronal hole. At distances greater than 20″ (≈15 Mm≈15 Mm) from the nearest coronal hole boundary, the density also becomes statistically uniform. The coronal hole temperature may show a weak solar-cycle dependency, but no statistically significant correlation of plasma properties with solar-cycle variations could be determined throughout the observed period between 2010 and 2019. **September 8, 2015**

A statistical study of the long-term evolution of coronal hole properties as observed by SDO

S. G. **Heinemann**1, V. Jerčić1,2, M. Temmer1, S. J. Hofmeister1, M. Dumbović1,3, S. Vennerstrom4, G. Verbanac5 and A. M. Veronig1,6
A&A 638, A68 (**2020**)
https://www.aanda.org/articles/aa/pdf/2020/06/aa37613-20.pdf
Context. Understanding the evolution of coronal holes is especially important when studying the high-speed solar wind streams that emanate from them. Slow- and high-speed stream interaction regions may deliver large amounts of energy into the Earth's magnetosphere-ionosphere system, cause geomagnetic storms, and shape interplanetary space.
Aims. By statistically investigating the long-term evolution of well-observed coronal holes we aim to reveal processes that drive the observed changes in the coronal hole parameters. By analyzing 16 long-living coronal holes observed by the Solar Dynamic Observatory, we focus on coronal, morphological, and underlying photospheric magnetic field characteristics, and investigate the evolution of the associated high-speed streams.
Methods. We use the Collection of Analysis Tools for Coronal Holes to extract and analyze coronal holes using 193 Å EUV observations taken by the Atmospheric Imaging Assembly as well as line–of–sight magnetograms observed by the Helioseismic and Magnetic Imager. We derive changes in the coronal hole properties and look for correlations with coronal hole evolution. Further, we analyze the properties of the high–speed stream signatures near 1AU from OMNI data by manually extracting the peak bulk velocity of the solar wind plasma.
Results. We find that the area evolution of coronal holes shows a general trend of growing to a maximum followed by a decay. We did not find any correlation between the area evolution and the evolution of the signed magnetic flux or signed magnetic flux density enclosed in the projected coronal hole area. From this we conclude that the magnetic flux within the extracted coronal hole boundaries is not the main cause for its area evolution. We derive coronal hole area change rates (growth and decay) of (14.2 ± 15.0)×108 km2 per day showing a reasonable anti-correlation (ccPearson = −0.48) to the solar activity, approximated by the sunspot number. The change rates of the signed mean magnetic flux density (27.3 ± 32.2 mG day−1) and the signed magnetic flux (30.3 ± 31.5 1018 Mx day−1) were also

found to be dependent on solar activity (ccPearson = 0.50 and ccPearson = 0.69 respectively) rather than on the individual coronal hole evolutions. Further we find that the relation between coronal hole area and high-speed stream peak velocity is valid for each coronal hole over its evolution, but we see significant variations in the slopes of the regression lines. **May 29, 2013**

2.2. Coronal hole detection and **extraction**

Statistical Analysis and Catalog of Non-polar Coronal Holes Covering the SDO-Era Using CATCH

Stephan G. **Heinemann**, Temmer Manuela, Heinemann Niko, Dissauer Karin, Samara Evangelia, Jerčić Veronika, Stefan J. Hofmeister, Astrid M Veronig

Solar Phys. 294:144 **2019**

https://arxiv.org/pdf/1907.01990.pdf **File**

https://link.springer.com/content/pdf/10.1007%2Fs11207-019-1539-y.pdf

Coronal holes are usually defined as dark structures seen in the extreme ultraviolet and X-ray spectrum which are generally associated with open magnetic fields. Deriving reliably the coronal hole boundary is of high interest, as its area, underlying magnetic field, and other properties give important hints as regards high speed solar wind acceleration processes and compression regions arriving at Earth. In this study we present a new threshold-based extraction method, which incorporates the intensity gradient along the coronal hole boundary, which is implemented as a user-friendly SSW-IDL GUI. The Collection of Analysis Tools for Coronal Holes (CATCH) enables the user to download data, perform guided coronal hole extraction and analyze the underlying photospheric magnetic field. We use CATCH to analyze non-polar coronal holes during the SDO-era, based on 193 Å filtergrams taken by the Atmospheric Imaging Assembly (AIA) and magnetograms taken by the Heliospheric and Magnetic Imager (HMI), both on board the Solar Dynamics Observatory (SDO). Between 2010 and 2019 we investigate 707 coronal holes that are located close to the central meridian. We find coronal holes distributed across latitudes of about ±60∘±60∘, for which we derive sizes between 1.6×1091.6×109 and 1.8×1011 km21.8×1011 km2. The absolute value of the mean signed magnetic field strength tends towards an average of 2.9±1.92.9±1.9 G. As far as the abundance and size of coronal holes is concerned, we find no distinct trend towards the northern or southern hemisphere. We find that variations in local and global conditions may significantly change the threshold needed for reliable coronal hole extraction and thus, we can highlight the importance of individually assessing and extracting coronal holes. **2010-06-13, 2011-10-26, 2012-06-25, 2012-08-22, May 29, 2013, August 31, 2014, 2015-03-05, 2017-12-02,**

3-Phase Evolution of a Coronal Hole,
Part II: The Magnetic Field

S.G. **Heinemann**, S.J. Hofmeister, A.M. Veronig, M. Temmer

ApJ **863** 29 **2018**

https://arxiv.org/pdf/1806.10052.pdf

http://sci-hub.tw/http://iopscience.iop.org/article/10.3847/1538-4357/aad095/meta

We investigate the magnetic characteristics of a persistent coronal hole (CH) extracted from EUV imagery using HMI filtergrams over the timerange February 2012-October 2012. The magnetic field, its distribution as well as the magnetic fine structure in form of flux tubes (FT) are analyzed in different evolutionary states of the CH. We find a strong linear correlation between the magnetic properties (e.g. signed/unsigned magnetic field strength) and area of the CH. As such, the evolutionary pattern in the magnetic field clearly follows the three-phase evolution (growing, maximum and decaying phase) as found from EUV data (Part I). This evolutionary process is most likely driven by strong FTs with a mean magnetic field strength exceeding 50 G. During the maximum phase they entail up to 72% of the total signed magnetic flux of the CH, but only cover up to 3.9% of the total CH area, whereas during the growing and decaying phase, strong FTs entail 54-60% of the signed magnetic flux and cover around 1-2% of the CHs total area. We conclude that small scale-structures of strong unipolar magnetic field are the fundamental building blocks of a CH and govern its evolution.

Three-Phase Evolution of a Coronal Hole,
Part I: 360° remote sensing and in-situ observations

S.G. **Heinemann**, M. Temmer, S.J. Hofmeister, A.M. Veronig, S. Vennerstroem

ApJ **861** 151 **2018** DOI 10.3847/1538-4357/aac897

https://arxiv.org/pdf/1806.09495.pdf

We investigate the evolution of a well-observed, long-lived, low-latitude coronal hole (CH) over 10 solar rotations in the year 2012. By combining EUV imagery from STEREO-A/B and SDO we are able to track and study the entire evolution of the CH having a continuous 360deg coverage of the Sun. The remote sensing data are investigated together with in-situ solar wind plasma and magnetic field measurements from STEREO-A/B, ACE and WIND. From this we obtain how different evolutionary states of the CH as observed in the solar atmosphere (changes in EUV intensity and area) affect the properties of the associated high-speed stream measured at 1AU. Most distinctly pronounced for the CH area, three development phases are derived: a) growing, b) maximum, and c) decaying phase. During these phases the CH area a) increases over a duration of around three months from about 1·1010km2 to 6·1010km2, b) keeps a rather constant area for about one month of >9·1010km2, and c) finally decreases in the following three months below 1·1010km2 until the CH cannot be identified anymore. The three phases manifest themselves also in the EUV intensity and in in-situ measured solar wind proton bulk velocity. Interestingly, the three phases are related to a different range in solar wind speed variations and we find for the growing phase a range of 460−600~km~s−1, for the maximum phase 600−720~km~s−1, and for the decaying phase a more irregular behavior connected to slow and fast solar wind speed of 350−550~km~s−1.

The Evolution of Coronal Holes over Three Solar Cycles Using the McIntosh Archive

Ian M. **Hewins**, Sarah E. Gibson, David F. Webb, Robert H. McFadden, Thomas A. Kuchar, Barbara A. Emery & Scott W. McIntosh

Solar Physics volume 295, Article number: 161 (**2020**)

https://link.springer.com/content/pdf/10.1007/s11207-020-01731-y.pdf

Using the McIntosh Archive of solar features, we analyze the evolution of coronal holes over more than three solar cycles. We demonstrate that coronal-hole positions and lifetimes change significantly on time scales from months to years, and that the pattern of these changes is clearly linked to the solar-activity cycle. We demonstrate that the lifetimes of low-latitude coronal holes are usually less than one rotation but may extend to almost three years. When plotted over time, the positions of low-latitude coronal holes that remain visible for over one rotation track the sunspot butterfly diagram in terms of their positions on the Sun over a solar cycle. Finally, we confirm that coronal holes do not in general rigidly rotate.

Plasma properties and Stokes profiles during the lifetime of a photospheric magnetic bright point⋆

R. L. **Hewitt**1, S. Shelyag2, M. Mathioudakis1 and F. P. Keenan

A&A 565, A84 (**2014**)

Aims. In this paper we aim to investigate the evolution of plasma properties and Stokes parameters in photospheric magnetic bright points using 3D magneto-hydrodynamical simulations and radiative diagnostics of solar granulation.

Methods. Simulated time-dependent radiation parameters and plasma properties were investigated throughout the evolution of a bright point. Synthetic Stokes profiles for the FeI 630.25 nm line were calculated, which also allowed the evolution of the Stokes-I line strength and Stokes-V area and amplitude asymmetries to be investigated.

Results. Our results are consistent with theoretical predictions and published observations describing convective collapse, and confirm this as the bright point formation process. Through degradation of the simulated data to match the spatial resolution of SOT, we show that high spatial resolution is crucial for the detection of changing spectro-polarimetric signatures throughout a magnetic bright point’s lifetime. We also show that the signature downflow associated with the convective collapse process tends towards zero as the radiation intensity in the bright point peaks, because of the magnetic forces present restricting the flow of material in the flux tube.

The Formation of Heliospheric Arcs of Slow Solar Wind

A. K. **Higginson**, S. K. Antiochos, C. R. DeVore, P. F. Wyper, T. H. Zurbuchen

2017

https://arxiv.org/pdf/1701.08797v1.pdf

A major challenge in solar and heliospheric physics is understanding how highly localized regions, far smaller than 1 degree at the Sun, are the source of solar-wind structures spanning more than 20 degrees near Earth. The Sun's atmosphere is divided into magnetically open regions, coronal holes, where solar-wind plasma streams out freely and fills the solar system, and closed regions, where the plasma is confined to coronal loops. The boundary between these regions extends outward as the heliospheric current sheet (HCS). Measurements of plasma composition imply that the solar wind near the HCS, the so-called slow solar wind, originates in closed regions, presumably by the processes of field-line opening or interchange reconnection. Mysteriously, however, slow wind is also often seen far from the HCS. We use high-resolution, three-dimensional magnetohydrodynamic simulations to calculate the dynamics of a coronal hole whose geometry includes a narrow corridor flanked by closed field and which is driven by supergranule-like flows at the coronal-hole boundary. We find that these dynamics result in the formation of giant arcs of closed-field plasma that extend far from the HCS and span tens of degrees in latitude and longitude at Earth, accounting for the slow solar wind observations.

Dynamics of Coronal-Hole Boundaries

A. K. **Higginson**, S. K. Antiochos, C. R. DeVore, P. F. Wyper, T. H. Zurbuchen

2017 ApJ 837 113

https://arxiv.org/pdf/1611.04968v1.pdf

Remote and in-situ observations suggest that the slow solar wind consists of plasma from the hot, closed-field corona that is released onto open magnetic field lines. The Separatrix-Web (S-Web) theory for the slow wind proposes that photospheric motions, at the scale of supergranules, are responsible for generating dynamics at coronal-hole boundaries, which result in the inferred necessary transfer of plasma from closed to open field lines. We use 3D magnetohydrodynamic (MHD) simulations to determine the effect of photospheric flows on the open and closed magnetic flux of a model corona with a dipole magnetic field and an isothermal solar wind. We find that a supergranular-scale photospheric motion at the boundary between the coronal hole and helmet streamer results in prolific and efficient interchange reconnection between open and closed flux. This reconnection acts to smooth the large- and small-scale structure introduced by the photospheric flows. Magnetic flux near the coronal-hole boundary experiences multiple interchange events, with some flux interchanging over fifty times in one day. Additionally, we find that this interchange reconnection occurs all along the coronal-hole boundary, even producing a lasting change in magnetic-field connectivity in regions that were not driven by the applied photospheric motions. Our results imply that interchange reconnection is the dominant form of dynamics along open-closed boundaries and should be ubiquitous in the Sun and heliosphere. We discuss the implications of our simulations for understanding the observed properties of the slow solar wind, with particular focus on the global-scale consequences of interchange reconnection.

Testing the background solar wind modelled by EUHFORIA

J. **Hinterreiter** (1,2), J. Magdalenic (3), M. Temmer (2), C. Verbeke (4), I.C. Jeberaj (3,4), E. Samara (3,4), E. Asvestari (2,5), S. Poedts (4), J. Pomoell (5), E. Kilpua (5), L. Rodriguez (3), C. Scolini (3,4), A. Isavnin (4

Solar Phys. **2019**

https://arxiv.org/pdf/1907.07461.pdf

In order to address the growing need for the more accurate space weather predictions, a new model named EUHFORIA (EUropean Heliospheric FORecasting Information Asset) was recently developed (Pomoell and Poedts, 2018). We present the first results of the solar wind modeling with EUHFORIA and identify possible limitation of its present set up. Using the basic EUHFORIA 1.0.4. model setup with the default input parameters, we modeled background solar wind (no coronal mass ejections) and compared obtained results with ACE, in situ observations. For the need of statistical study we developed a technique of combining daily EUHFORIA runs into continuous time series. Using the combined time series we performed statistical study of the solar wind for years 2008 (low solar activity) and 2012 (high solar activity) with the focus on the in situ speed and density. We find for the low activity phase a better match between model results and observations compared to the considered high activity time interval. The quality of the modeled solar wind parameters is found to be very variable. Therefore, to better understand obtained results we also qualitatively inspected characteristics of coronal holes, sources of the studied fast streams. We discuss how different characteristics of the coronal holes and input parameters to EUHFORIA influence the modeled fast solar wind, and suggest the possibilities for the improvements of the model. **2012 May 7**

Thermal and magnetic field structure of near equatorial coronal holes

K. M. **Hiremath**, Manjunath Hegde

2022

https://arxiv.org/pdf/2204.04410.pdf

We use full-disk, SOHO/EIT 195 Å calibrated images to measure latitudinal and day to day variations of area and average photon fluxes of the near equatorial coronal holes. In addition, energy emitted by the coronal holes with their temperature and strength of magnetic field structures are estimated. By analyzing data of 2001-2008, we find that variations of average area (A), photon flux (F), radiative energy (E) and temperature (T) of coronal holes are independent of latitude. Whereas inferred strength of magnetic field structure of the coronal holes is dependent on the latitudes and varies from low near the equator to high near both the poles. Typical average values of estimated physical parameters are: A∼3.8(±0.5)×1020 cm2,F∼2.3(±0.2)×1013 photonscm−2sec−1,E∼2.32(±0.5)×103 ergscm−2sec−1 and T∼0.94 (±0.1)×106 K. Average strength of magnetic field structure of coronal hole at the corona is estimated to be ∼ 0.08±0.02 Gauss. If coronal holes are anchored in the convection zone, one would expect they should rotate differentially. Hence, thermal wind balance and isorotation of coronal holes with the solar plasma implies the temperature difference between the equator and both the poles. Contrary to this fact, variation of thermal structure of near equatorial coronal holes is independent of latitude leading to a conclusion that coronal holes must rotate rigidly that are likely to be anchored initially below the tachocline confirming our previous study (ApJ, 763, 137, 2013). **01-01-2001**

Rotation rate of high latitude and near polar coronal holes

K. M. **Hiremath**, Manjunath Hegde, K. R. Varsha

2022

https://arxiv.org/pdf/2204.04193.pdf

For the period of 1997-2006, coronal holes detected in the SOHO/EIT 195 Å full disk calibrated images are used to compute the rotation rates of high latitude and near polar coronal holes and, their latitudinal variation is investigated. We find that, for different latitude zones between 80o north and 75o south, for all their area, the number of days observed on the solar disk, and their latitudes, coronal holes rotate rigidly. Estimated magnitudes of sidereal rotation rate of the coronal holes are: 13.051±0.206 deg/day for the equator, 12.993±0.064 deg/day in the region of higher latitudes and, 12.999±0.329 deg/day near the polar regions. For all the latitudes and the area, we have also investigated the annual variation of rotation rates of these coronal holes. We find that, for all the years, coronal holes rotate rigidly and their magnitude of equatorial, high latitude and polar region rotation rates are independent of magnitude of solar activity. **15-10-1997, 13-10-2001**

ROTATION RATES OF CORONAL HOLES AND THEIR PROBABLE ANCHORING DEPTHS

K. M. **Hiremath** and M. Hegde

2013 ApJ 763 137

From 2001-2008, we use full-disk, SOHO/EIT 195 Å calibrated images to determine latitudinal and day-to-day variations of the rotation rates of coronal holes (CHs). We estimate the weighted average of heliographic coordinates such as latitude and longitude from the central meridian on the observed solar disk. For different latitude zones between 40° north and 40° south, we compute rotation rates and find that, irrespective of their area, the number of days observed on the solar disk, and their latitudes, CHs rotate rigidly. Combined for all the latitude zones, we also find that CHs rotate rigidly during their evolution history. In addition, for all latitude zones, CHs follow a rigid body rotation law during their first appearance. Interestingly, the average first rotation rate (~438 nHz) of CHs, computed from their first appearance on the solar disk, matches the rotation rate of the solar interior only below the tachocline.

Cross-Calibration of TIMED SEE and SOHO EIT Irradiances

R.A. **Hock** · F.G. Eparvier

Solar Phys (2008) 250: 207–219, **File**

http://www.springerlink.com/content/p7l5p76352505730/fulltext.pdf

Absolutely calibrated solar images are necessary for a variety of solar physics problems, such as the identification of solar variability sources and the derivation of differential emission measure (DEM) maps. SOHO EIT is absolutely calibrated by using TIMED SEE spectra to provide a method of determining physical values of irradiance for EIT images. EIT images from 1 April 2002 to 15 March 2005 in the **28.4- and 30.4-nm** channels are compared to SEE daily spectra from the same time period. The resulting fitted EIT irradiances are well correlated to SEE irradiance measurements and are within the uncertainties of both instruments. The new cross-calibration results are compared to the currently used calibration based on the UARS SUSIM Mg II index.

How the area of solar coronal holes affects the properties of high-speed solar wind streams near Earth: An analytical model

Stefan J. **Hofmeister**1,2,3, Eleanna Asvestari4, Jingnan Guo5,6, Verena Heidrich-Meisner5, Stephan G. Heinemann7, Jasmina Magdalenic8,9, Stefaan Poedts8,10, Evangelia Samara8,9, Manuela Temmer1, Susanne Vennerstrom11, Astrid Veronig1,12, Bojan Vršnak13 and Robert Wimmer-Schweingruber5

A&A 659, A190 (**2022**)

https://arxiv.org/pdf/2203.15689

https://www.aanda.org/articles/aa/pdf/2022/03/aa41919-21.pdf

https://doi.org/10.1051/0004-6361/202141919

Since the 1970s it has been empirically known that the area of solar coronal holes affects the properties of high-speed solar wind streams (HSSs) at Earth. We derive a simple analytical model for the propagation of HSSs from the Sun to Earth and thereby show how the area of coronal holes and the size of their boundary regions affect the HSS velocity, temperature, and density near Earth. We assume that velocity, temperature, and density profiles form across the HSS cross section close to the Sun and that these spatial profiles translate into corresponding temporal profiles in a given radial direction due to the solar rotation. These temporal distributions drive the stream interface to the preceding slow solar wind plasma and disperse with distance from the Sun. The HSS properties at 1 AU are then given by all HSS plasma parcels launched from the Sun that did not run into the stream interface at Earth distance. We show that the velocity plateau region of HSSs as seen at 1 AU, if apparent, originates from the center region of the HSS close to the Sun, whereas the velocity tail at 1 AU originates from the trailing boundary region. Small HSSs can be described to entirely consist of boundary region plasma, which intrinsically results in smaller peak velocities. The peak velocity of HSSs at Earth further depends on the longitudinal width of the HSS close to the Sun. The shorter the longitudinal width of an HSS close to the Sun, the more of its "fastest" HSS plasma parcels from the HSS core and trailing boundary region have impinged upon the stream interface with the preceding slow solar wind, and the smaller is the peak velocity of the HSS at Earth. As the longitudinal width is statistically correlated to the area of coronal holes, this also explains the well-known empirical relationship between coronal hole areas and HSS peak velocities. Further, the temperature and density of HSS plasma parcels at Earth depend on their radial expansion from the Sun to Earth. The radial expansion is determined by the velocity gradient across the HSS boundary region close to the Sun and gives the velocity-temperature and density-temperature relationships at Earth their specific shape. When considering a large number of HSSs, the assumed correlation between the HSS velocities and temperatures close to the Sun degrades only slightly up to 1 AU, but the correlation between the velocities and densities is strongly disrupted up to 1 AU due to the radial expansion. Finally, we show how the number of particles of the piled-up slow solar wind in the stream interaction region depends on the velocities and densities of the HSS and preceding slow solar wind plasma.

On the Dependency between the Peak Velocity of High-speed Solar Wind Streams near Earth and the Area of Their Solar Source Coronal Holes

Stefan J. **Hofmeister**1, Astrid M. Veronig1,2, Stefaan Poedts3,4, Evangelia Samara3,5, and Jasmina Magdalenic5

2020 ApJL 897 L17

https://sci-hub.tw/https://iopscience.iop.org/article/10.3847/2041-8213/ab9d19

https://arxiv.org/pdf/2007.02625

The relationship between the peak velocities of high-speed solar wind streams near Earth and the areas of their solar source regions, i.e., coronal holes, has been known since the 1970s, but it is still physically not well understood. We perform 3D magnetohydrodynamic (MHD) simulations using the European Heliospheric Forecasting Information Asset (EUHFORIA) code to show that this empirical relationship forms during the propagation phase of high-speed streams from the Sun to Earth. For this purpose, we neglect the acceleration phase of high-speed streams, and project the areas of coronal holes to a sphere at 0.1 au. We then vary only the areas and latitudes of the coronal holes. The velocity, temperature, and density in the cross section of the corresponding high-speed streams at 0.1 au are set to constant, homogeneous values. Finally, we propagate the associated high-speed streams through the inner heliosphere using the EUHFORIA code. The simulated high-speed stream peak velocities at Earth reveal a linear dependence on the area of their source coronal holes. The slopes of the relationship decrease with increasing latitudes of the coronal holes, and the peak velocities saturate at a value of about 730 km s^{-1}, similar to the observations. These findings imply that the empirical relationship between the coronal hole areas and high-speed stream peak velocities does not describe the acceleration phase of high-speed streams, but is a result of the high-speed stream propagation from the Sun to Earth.

Photospheric magnetic structure of coronal holes⋆

Stefan J. **Hofmeister**1, Dominik Utz1, Stephan G. Heinemann1, Astrid Veronig1,2 and Manuela Temmer1

A&A 629, A22 (**2019**)

https://arxiv.org/pdf/1909.03806.pdf

https://sci-hub.se/https://www.aanda.org/articles/aa/abs/2019/09/aa35918-19/aa35918-19.html

In this study, we investigate in detail the photospheric magnetic structure of 98 coronal holes using line-of-sight magnetograms of SDO/HMI, and for a subset of 42 coronal holes using HINODE/SOT G-band filtergrams. We divided the magnetic field maps into magnetic elements and quiet coronal hole regions by applying a threshold at ±25 G. We find that the number of magnetic bright points in magnetic elements is well correlated with the area of the magnetic elements (cc = 0.83 ± 0.01). Further, the magnetic flux of the individual magnetic elements inside coronal holes is related to their area by a power law with an exponent of 1.261 ± 0.004 (cc = 0.984 ± 0.001). Relating the magnetic elements to the overall structure of coronal holes, we find that on average (69 ± 8)% of the overall unbalanced magnetic flux of the coronal holes arises from long-lived magnetic elements with lifetimes > 40 h. About (22 ± 4)% of the unbalanced magnetic flux arises from a very weak background magnetic field in the quiet coronal hole regions with a mean magnetic field density of about 0.2−1.2 G. This background magnetic field is correlated to the flux of the magnetic elements with lifetimes of > 40 h (cc = 0.88 ± 0.02). The remaining flux arises from magnetic elements with lifetimes < 40 h. By relating the properties of the magnetic elements to the overall properties of the coronal holes, we find that the unbalanced magnetic flux of the coronal holes is completely determined by the total area that the long-lived magnetic elements cover (cc = 0.994 ± 0.001).

HMI Science Nuggets #131 Sept **2019** http://hmi.stanford.edu/hminuggets/?p=3072

The Dependence of the Peak Velocity of High-Speed Solar Wind Streams as Measured in the Ecliptic by ACE and the STEREO satellites on the Area and Co-latitude of Their Solar Source Coronal Holes

Stefan J. **Hofmeister**, Astrid Veronig, Manuela Temmer, Susanne Vennerstrom, Bernd Heber and Bojan Vršnak

JGR Volume123, Issue3 March **2018** Pages 1738-1753
https://arxiv.org/pdf/1804.09579.pdf

We study the properties of **115 coronal holes** in the time range from August 2010 to March 2017, the peak velocities of the corresponding high-speed streams as measured in the ecliptic at 1 AU, and the corresponding changes of the Kp index as marker of their geoeffectiveness. We find that the peak velocities of high-speed streams depend strongly on both the areas and the co-latitudes of their solar source coronal holes with regard to the heliospheric latitude of the satellites. Therefore, the co-latitude of their source coronal hole is an important parameter for the prediction of the high-speed stream properties near the Earth. We derive the largest solar wind peak velocities normalized to the coronal hole areas for coronal holes located near the solar equator and that they linearly decrease with increasing latitudes of the coronal holes. For coronal holes located at latitudes $\gtrsim$60°, they turn statistically to zero, indicating that the associated high-speed streams have a high chance to miss the Earth. Similarly, the Kp index per coronal hole area is highest for the coronal holes located near the solar equator and strongly decreases with increasing latitudes of the coronal holes. We interpret these results as an effect of the three-dimensional propagation of high-speed streams in the heliosphere; that is, high-speed streams arising from coronal holes near the solar equator propagate in direction toward and directly hit the Earth, whereas solar wind streams arising from coronal holes at higher solar latitudes only graze or even miss the Earth.

Characteristics of Low-latitude Coronal Holes near the Maximum of Solar Cycle 24

Stefan J. **Hofmeister**1, Astrid Veronig1, Martin A. Reiss1, Manuela Temmer1, Susanne Vennerstrom2, Bojan Vršnak3, and Bernd Heber4

2017 ApJ 835 268 DOI: 10.3847/1538-4357/835/2/268
https://arxiv.org/pdf/1702.02050.pdf
http://iopscience.iop.org.sci-hub.cc/0004-637X/835/2/268/

We investigate the statistics of 288 low-latitude coronal holes extracted from SDO/AIA-193 filtergrams over the time range of 2011 January 01–2013 December 31. We analyze the distribution of characteristic coronal hole properties, such as the areas, mean AIA-193 intensities, and mean magnetic field densities, the local distribution of the SDO/AIA-193 intensity and the magnetic field within the coronal holes, and the distribution of magnetic flux tubes in coronal holes. We find that the mean magnetic field density of all coronal holes under study is 3.0 ± 1.6 G, and the percentaged unbalanced magnetic flux is 49 ± 16%. The mean magnetic field density, the mean unsigned magnetic field density, and the percentaged unbalanced magnetic flux of coronal holes depend strongly pairwise on each other, with correlation coefficients cc > 0.92. Furthermore, we find that the unbalanced magnetic flux of the coronal holes is predominantly concentrated in magnetic flux tubes: 38% (81%) of the unbalanced magnetic flux of coronal holes arises from only 1% (10%) of the coronal hole area, clustered in magnetic flux tubes with field strengths >50 G (10 G). The average magnetic field density and the unbalanced magnetic flux derived from the magnetic flux tubes correlate with the mean magnetic field density and the unbalanced magnetic flux of the overall coronal hole (cc > 0.93). These findings give evidence that the overall magnetic characteristics of coronal holes are governed by the characteristics of the magnetic flux tubes. **30 May 2013**

Coronal Bright Points Associated with Minifilament Eruptions

Junchao **Hong**, Yunchun Jiang, Jiayan Yang, Yi Bi, Haidong Li, Bo Yang1, and Dan Yang

2014 ApJ 796 73

Coronal bright points (CBPs) are small-scale, long-lived coronal brightenings that always correspond to photospheric network magnetic features of opposite polarity. In this paper, we subjectively adopt 30 CBPs in a coronal hole to study their eruptive behavior using data from the Atmospheric Imaging Assembly (AIA) and the Helioseismic and Magnetic Imager (HMI) on board the Solar Dynamics Observatory. About one-quarter to one-third of the CBPs in the coronal hole go through one or more minifilament eruption(s) (MFE(s)) throughout their lifetimes. The MFEs occur in temporal association with the brightness maxima of CBPs and possibly result from the convergence and cancellation of underlying magnetic dipoles. Two examples of CBPs with MFEs are analyzed in detail, where minifilaments appear as dark features of a cool channel that divide the CBPs along the neutral lines of the dipoles beneath. The MFEs show the typical rising movements of filaments and mass ejections with brightenings at CBPs, similar to large-scale filament eruptions. Via differential emission measure analysis, it is found that CBPs are heated dramatically by their MFEs and the ejected plasmas in the MFEs have average temperatures close to the

pre-eruption BP plasmas and electron densities typically near 109 cm–3. These new observational results indicate that CBPs are more complex in dynamical evolution and magnetic structure than previously thought.

Signatures of coronal hole substructure in the solar wind: combined Solar Orbiter remote sensing and in situ measurements

T. S. **Horbury**, R. Laker, L. Rodriguez, K. Steinvall, M. Maksimovic, S. Livi, D. Berghmans, F. Auchere, A. N. Zhukov, Yu. V. Khotyaintsev, L. Woodham, L. Matteini, J. Stawarz, T. Woolley, S. D. Bale, A. Rouillard, H. O'Brien, V. Evans, V. Angelini, C. Owen, S. K. Solanki, B. Nicula, D. Muller, I. Zouganelis

A&A **2021**

https://arxiv.org/pdf/2104.14960.pdf

Context. The Sun's complex corona is the source of the solar wind and interplanetary magnetic field. While the large scale morphology is well understood, the impact of variations in coronal properties on the scale of a few degrees on properties of the interplanetary medium is not known. Solar Orbiter, carrying both remote sensing and in situ instruments into the inner solar system, is intended to make these connections better than ever before. Aims. We combine remote sensing and in situ measurements from Solar Orbiter's first perihelion at 0.5 AU to study the fine scale structure of the solar wind from the equatorward edge of a polar coronal hole with the aim of identifying characteristics of the corona which can explain the in situ variations. Methods. We use in situ measurements of the magnetic field, density and solar wind speed to identify structures on scales of hours at the spacecraft. Using Potential Field Source Surface mapping we estimate the source locations of the measured solar wind as a function of time and use EUI images to characterise these solar sources. Results. We identify small scale stream interactions in the solar wind with compressed magnetic field and density along with speed variations which are associated with corrugations in the edge of the coronal hole on scales of several degrees, demonstrating that fine scale coronal structure can directly influence solar wind properties and drive variations within individual streams. Conclusions. This early analysis already demonstrates the power of Solar Orbiter's combined remote sensing and in situ payload and shows that with future, closer perihelia it will be possible dramatically to improve our knowledge of the coronal sources of fine scale solar wind structure, which is important both for understanding the phenomena driving the solar wind and predicting its impacts at the Earth and elsewhere. **19-24 June 2020**

Asymmetry of the spectral lines of the coronal hole and quiet Sun in the transition region

Razieh **Hosseini**, Pradeep Kayshap, Nasibe Alipour, Hossein Safari

MNRAS **2024**

https://arxiv.org/pdf/2402.01628.pdf

The asymmetry of line profiles, i.e., the secondary component, is crucial to understanding the energy release of coronal holes (CH), quiet sun (QS), and bright points (BPs). We investigate the asymmetry of Si IV 1393.75 Å of the transition-region (TR) line recorded by Interface Region Imaging Spectrometer (IRIS) and co-spatial-temporal Atmospheric Imaging Assembly (AIA) and Helioseismic and Magnetic Imager (HMI) data onboard Solar Dynamics Observatory (SDO) for three time series on **26 April 2015, 24 July 2014, 26 July 2014**. Most asymmetric profiles are in the complex magnetic field regions of the networks. The asymmetric profiles are fitted with both single and double Gaussian models. The mean value of Doppler velocity of the second component is almost zero (with a significant standard deviation) in QS/CH, which may indicate that the physical process to trigger the secondary Gaussian originates at the formation height of Si IV. While the mean Doppler velocity from secondary Gaussian in BPs is around +4.0 km/s (redshifted). The non-thermal velocities of the secondary Gaussian in all three regions are slightly higher than the single Gaussian. The statistical investigation leads to the prevalence of blueshifted secondary components in QS/CH. However, secondary Gaussian in the BPs redshifted, i.e., the BPs redshift behavior could be interpreted due to the site of reconnection located above the formation height of the Si IV line. The peak intensity of the second component for all three regions is likely to follow a power law that is a signature of the small-scale flaring-like trigger mechanism.

Transition region bright dots in active regions observed by the Interface Region Imaging Spectrograph

Zhenyong **Hou**, Zhenghua Huang, Lidong Xia, Bo Li, Maria S. Madjarska, Hui Fu

AIP Conference Proceedings **2018**

https://arxiv.org/pdf/1803.08294.pdf

The Interface Region Imaging Spectrograph (IRIS) reveals numerous small-scale (sub-arcsecond) brightenings that appear as bright dots sparkling the solar transition region in active regions. Here, we report a statistical study on these transition region bright dots. We use an automatic approach to identify 2742 dots in a Si IV raster image. We find that the average spatial size of the dots is 0.8 arcsec2 and most of them are located in the faculae area. Their Doppler velocities obtained from the Si IV 1394 {\AA} line range from -20 to 20 km/s. Among these 2742 dots, 1224 are predominantly blue-shifted and 1518 are red-shifted. Their nonthermal velocities range from 4 to 50 km/s with an average of 24 km/s. We speculate that the bright dots studied here are small-scale impulsive energetic events that can heat the active region corona. **2014 February 16**

Statistical Study of Ejections in Coronal Hole Regions As Possible Sources of Solar Wind Switchbacks and Small-scale Magnetic Flux Ropes

Nengyi **Huang**1,2, Sophia D'Anna1, and Haimin Wang1,2

2023 ApJL 946 L17

https://iopscience.iop.org/article/10.3847/2041-8213/acc0f1/pdf

The omnipresence of transient fluctuations in the solar wind, such as switchbacks (SBs) and small-scale magnetic flux ropes (SMFRs), have been well observed by the in situ observation of Parker Solar Probe (PSP), yet their sources are not clear. Possible candidates fall into two categories: solar origin and in situ generation in the solar wind. Among the solar-origin scenarios, the small-scale activities (such as ejections and eruptions) in coronal hole (CH) regions, where solar wind originates, are suggested as candidates. Using full-disk extreme ultraviolet images from Atmospheric Imaging Assembly on board the Solar Dynamic Observatory, we identify small-scale ejections in CH regions during PSP Encounters 5, 7, and 8, and study their statistical properties. These ejections belong to two categories: standard jets and blowout jets. With 27,832 ejections identified in 24 days (about 2/3 of them are blowout jets), we updated the expected frequency for PSP to detect their counterparts in the heliospace. The ejections we identified are comparable to the frequency of PSP-detected SMFRs, but they are insufficient to serve as the only producer of SBs or SB patches. Certain smaller events missed by this study, such as jetlets, may fill the gap. **2020-01-23, 2020-06-09-10, 2021-04-29**

Existence of The Closed Magnetic Field Lines Crossing The Coronal Hole Boundaries

Guan-Han **Huang**, Chia-Hsien Lin, Lou-Chuang Lee

ApJ **933** 237 **2022**

https://arxiv.org/pdf/2206.05477.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/ac7786/pdf

Coronal holes (CHs) are regions with unbalanced magnetic flux, and have been associated with open magnetic field (OMF) structures. However, it has been reported that some CHs do not intersect with OMF regions. To investigate the inconsistency, we apply a potential-field (PF) model to construct the magnetic fields of the coronal holes. As a comparison, we also use a thermodynamic magnetohydrodynamic (MHD) model to synthesize coronal images, and identify CHs from the synthetic images. The results from both the potential-field CHs and synthetic MHD CHs reveal that there is a significant percentage of closed field lines extending beyond the CH boundaries and more than 50% (17%) of PF (MHD) CHs do not contain OMF lines. The boundary-crossing field lines are more likely to be found in the lower latitudes during active times. While they tend to be located slightly closer than the non-boundary-crossing ones to the CH boundaries, nearly 40% (20%) of them in PF (MHD) CHs are not located in the boundary regions. The CHs without open field lines are often smaller and less unipolar than those with open field lines. The MHD model indicates higher temperature variations along the boundary-crossing field lines than the non-boundary crossing ones. The main difference between the results of the two models is that the dominant field lines in the PF and MHD CHs are closed and open field lines, respectively.

HMI Science Nuggets #185 Aug **2022** http://hmi.stanford.edu/hminuggets/?p=3997

Population of Bright Plume Threads in Solar Polar Coronal Holes

Zhenghua **Huang**, Quanhao Zhang, Lidong Xia, Li Feng, Hui Fu, Weixin Liu, Mingzhe Sun, Youqian Qi, Dayang Liu, Qingmin Zhang, Bo Li

Solar Phys. **296**, Article number: 22 **2021**

https://arxiv.org/pdf/2101.03768.pdf

https://link.springer.com/content/pdf/10.1007/s11207-021-01773-w.pdf

Coronal holes are well accepted to be source regions of the fast solar wind. As one of the common structures in coronal holes, coronal plumes might contribute to the origin of the nascent solar wind. To estimate the contribution of coronal plumes to the nascent solar wind, we make the first attempt to estimate their populations in solar polar coronal holes. By comparing the observations viewed from two different angles taken by the twin satellites of STEREO and the results of Monte Carlo simulations, we estimate about 16--27 plumes rooted in an area of 4×104 arcsec2 of the polar coronal holes near the solar minimum, which occupy about 2--3.4% of the area. Based on these values, the contribution of coronal plumes to the nascent solar wind has also been discussed. A further investigation indicates that more precise number of coronal plumes can be worked out with observations from three or more viewing angles. **10 Sep 2007**

Formation and Eruption of a Mini-sigmoid Originating in Coronal Hole

Z. W. **Huang**, X. Cheng, Y. N. Su, T. Liu, M. D. Ding

2019 ApJ 887 130
https://doi.org/10.3847/1538-4357/ab4f83
https://arxiv.org/pdf/1912.10404.pdf
In this paper, we study in detail the evolution of a mini-sigmiod originating in a cross-equatorial coronal hole, where the magnetic field is mostly open and seriously distinct from the closed background field above active-region sigmoids. The source region first appeared as a bipole, which subsequently experienced a rapid emergence followed by a long-term decay. Correspondingly, the coronal structure initially appeared as arc-like loops, then gradually sheared and transformed into continuously sigmoidal loops, mainly owing to flux cancellation near the polarity inversion line. The temperature of J-shaped and sigmoidal loops is estimated to be about 2.0×106 K, greater than that of the background coronal hole. Using the flux-rope insertion method, we further reconstruct the nonlinear force-free fields that well reproduces the transformation of the potential field into a sigmoidal field. The fact that the sheared and sigmoidal loops are mainly concentrated at around the high-Q region implies that the reconnection most likely takes place there to form the sigmoidal field and heat the plasma. Moreover, the twist of sigmoidal field lines is estimated to be around 0.8, less than the values derived for the sigmoids from active regions. However, the sigmoidal flux may quickly enter an unstable regime at the very low corona (<10 Mm) due to the open background field. The results suggest that the mini-sigmoid, at least the one in our study, has the same formation and eruption process as the large-scale one, but is significantly influenced by the overlying flux. **2017 January 28-31**

Examination of the EUV Intensity in the Open Magnetic Field Regions Associated with Coronal Holes

Guan-Han **Huang**1, Chia-Hsien Lin1, and Lou-Chuang Lee1
2019 ApJ 874 45
https://doi.org/10.3847/1538-4357/ab06f0
Coronal holes can be identified as the regions with magnetic field lines extending far away from the Sun, or the darkest regions in EUV/X-ray images with predominantly unipolar magnetic fields. A comparison between the locations of our determined regions with open magnetic field lines (OMF) and regions with low EUV intensity (LIR) reveals that only 12% of the OMF regions coincide with the LIRs. The aim of this study is to investigate the conditions leading to the different brightnesses of OMF regions, and to provide a means to predict whether an OMF region would be bright or dark. Examining the statistical distribution profiles of the magnetic field expansion factor (f s) and Atmospheric Imaging Assembly 193 Å intensity (I 193) reveals that both profiles are approximately log-normal. The analysis of the spatial and temporal distributions of f sand I 193 indicates that the bright OMF regions often are inside or next to regions with closed field lines, including quiet-Sun regions and regions with strong magnetic fields. Examining the relationship between I 193 and f s reveals a weak positive correlation between log I 193 and log f s , with a correlation coefficient ≈0.39. As a first-order approximation, the positive relationship is determined to be log I 193 = 0.62 log f s + 1.51 based on the principle of the whitening/dewhitening transformation. This linear relationship is demonstrated to increase the consistency between the OMF regions and LIRs from 12% to 23%.

Solar Open Flux Migration from Pole to Pole: Magnetic Field Reversal

Huang, G.-H., Lin, C.-H., and Lee, L.C.
SCIENTIfIC REPORTS | 7: 9488 **2017**
http://www.nature.com.sci-hub.cc/articles/s41598-017-09862-2
Coronal holes are solar regions with low soft X-ray or low extreme ultraviolet intensities. The magnetic fields from coronal holes extend far away from the Sun, and thus they are identified as regions with open magnetic field lines. Coronal holes are concentrated in the polar regions during the sunspot minimum phase, and spread to lower latitude during the rising phase of solar activity. In this work, we identify coronal holes with outward and inward open magnetic fluxes being in the opposite poles during solar quiet period. We find that during the sunspot rising phase, the outward and inward open fluxes perform pole-to-pole trans-equatorial migrations in opposite directions. The migration of the open fluxes consists of three parts: open flux areas migrating across the equator, new open flux areas generated in the low latitude and migrating poleward, and new open flux areas locally generated in the polar region. All three components contribute to the reversal of magnetic polarity. The percentage of contribution from each component is different for different solar cycle. Our results also show that the sunspot number is positively correlated with the lower-latitude open magnetic flux area, but negatively correlated with the total open flux area.

Coronal hole boundaries at small scales: IV. SOT view-Magnetic field properties of small-scale transient brightenings in coronal holes

Z. **Huang**, M. S. Madjarska, J. G. Doyle, D. A. Lamb
E-print, Oct **2012**; A&A, 548, A62 (**2012**)
We study the magnetic properties of small-scale transients in coronal holes and a few in the quiet Sun identified in X-ray observations in paper II and analysed in spectroscopic data in paper III. We aim to investigate the role of small-scale transients in the evolution of the magnetic field in an equatorial coronal

hole. Two sets of observations of an equatorial coronal hole and another two in quiet-Sun regions were analysed using longitudinal magnetograms taken by the Solar Optical Telescope. An automatic feature tracking program, SWAMIS, was used to identify and track the magnetic features. Each event was then visually analysed in detail. In both coronal holes and quiet-Sun regions, all brightening events are associated with bipolar regions and caused by magnetic flux emergence followed by cancellation with the pre-existing and/or newly emerging magnetic flux. In the coronal hole, 19 of 22 events have a single stable polarity which does not change its position in time. In eleven cases this is the dominant polarity. The dominant flux of the coronal hole form the largest concentration of magnetic flux in terms of size while the opposite polarity is distributed in small concentrations. We found that in the coronal hole the number of magnetic elements of the dominant polarity is four times higher than the non-dominant one. The supergranulation configuration appears to preserve its general shape during approximately nine hours of observations although the large concentrations (the dominant polarity) in the network did evolve and/or were slightly displaced, and their strength either increased or decreased. The emission fluctuations/radiance oscillations seen in the X-ray bright points are associated with reoccurring magnetic cancellation in the footpoints. Unique observations of an X-ray jet reveal similar magnetic behaviour in the footpoints, i.e. cancellation of the opposite polarity magnetic flux. We found that the magnetic flux cancellation rate during the jet is much higher than in bright points. Not all magnetic cancellations result in an X-ray enhancement, suggesting that there is a threshold of the amount of magnetic flux involved in a cancellation above which brightening would occur at X-ray temperatures. Our study demonstrates that the magnetic flux in coronal holes is continuously ?recycled? through magnetic reconnection which is responsible for the formation of numerous small-scale transient events. The open magnetic flux forming the coronal-hole phenomenon is largely involved in these transient features. The question on whether this open flux is transported as a result of the formation and evolution of these transient events, however, still remains open. (online materials of this paper is available at http://star.arm.ac.uk/highlights/2012/603/bpmag.html)

Coronal holes as seen in soft X-rays by Yohkoh

H.S. **Hudson**

Davos (2002?); File

A Multi-wavelength Analysis of Small-scale Brightenings Observed by IRIS

Llŷr Dafydd **Humphries**1 and Huw Morgan1

2021 ApJ 922 226

https://doi.org/10.3847/1538-4357/ac2951

Small-scale brightenings in solar atmospheric observations are a manifestation of heating and/or energy transport events. We present statistical characteristics of brightenings from a new detection method applied to 1330, 1400, and 2796 Å IRIS slit-jaw image time series. A total of 2377 events were recorded that coexist in all three channels, giving high confidence that they are real. Of these, ≈1800 were spatially coherent, equating to event densities of ∼9.7 × 10−5 arcsec−2 s−1 within a 90" × 100" FOV over 34.5 minutes. Power-law indices estimates are determined for total brightness (2.78 < α < 3.71), maximum brightness (3.84 < α < 4.70), and average area (4.31 < α < 5.70) distributions. Duration and speed distributions do not obey a power law. A correlation is found between the events' spatial fragmentation, area, and duration, and a weak relationship with total brightness, showing that larger/longer-lasting events are more likely to fragment during their lifetime. Speed distributions show that all events are in motion, with an average speed of ∼7 km s−1. The events' spatial trajectories suggest that cooler 2796 Å events tend to appear slightly later and occupy a different position/trajectory than the hotter channel results. This suggests that either many of these are impulsive events caused by reconnection, with subsequent rapid cooling, or that the triggering.

Machine-learning approach to identification of coronal holes in solar disk images and synoptic maps

Egor **Illarionov**, Alexander Kosovichev, Andrey Tlatov

ApJ **903** 115 **2020**

https://arxiv.org/pdf/2006.08529.pdf

https://doi.org/10.3847/1538-4357/abb94d

Identification of solar coronal holes (CHs) provides information both for operational space weather forecasting and long-term investigation of solar activity. Source data for the first problem are typically most recent solar disk observations, while for the second problem it is convenient to consider solar synoptic maps. Motivated by the idea that the concept of CHs should be similar for both cases we investigate universal models that can learn a CHs segmentation in disk images and reproduce the same segmentation in synoptic maps. We demonstrate that Convolutional Neural Networks (CNN) trained on daily disk images provide an accurate CHs segmentation in synoptic maps and their pole-centric projections. Using this approach we construct a catalog of synoptic maps for the period of 2010-20 based on SDO/AIA observations in the 193 Angstrom wavelength. The obtained CHs synoptic maps are compared with magnetic synoptic maps in the time-latitude and time-longitude diagrams. The initial results demonstrate that while in some cases the CHs are associated with magnetic flux transport events there are other mechanisms contributing to the CHs formation and evolution. To stimulate further investigations the catalog of synoptic maps is published in open access.

See **Catalogue** https://sun.njit.edu/#/coronal_holes

Segmentation of coronal holes in solar disk images with a convolutional neural network

E. **Illarionov**, A. Tlatov

MNRAS Volume 481, Issue 4, p.5014-5021 **2018**

https://arxiv.org/pdf/1809.05748.pdf

Current coronal holes segmentation methods typically rely on image thresholding and require non-trivial image pre- and post-processing. We have trained a neural network that accurately isolates CHs from SDO/AIA 193 Angstrom solar disk images without additional complicated steps. We compare results with publicly available catalogues of CHs and demonstrate stability of the neural network approach. In our opinion, this approach can outperform hand-engineered solar image analysis and will have a wide application to solar data. In particular, we investigate long-term variations of CH indices within the solar cycle 24 and observe increasing of CH areas in about three times from minimal values in the maximum of the solar cycle to maximal values during the declining phase of the solar cycle.

January 30, 2017, March 17, 2017, March 19, 2018

See **Catalogue** https://sun.njit.edu/#/coronal_holes

Identification of Coronal Holes on AIA/SDO images using unsupervised Machine Learning

Fadil **Inceoglu**, Yuri Y. Shprits, Stephan G. Heinemann, Stefano Bianco

ApJ **930** 118 **2022**

https://arxiv.org/pdf/2203.10491.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/ac5f43/pdf

Through its magnetic activity, the Sun governs the conditions in Earth's vicinity, creating space weather events, which have drastic effects on our space- and ground-based technology. One of the most important solar magnetic features creating the space weather is the solar wind, that originates from the coronal holes (CHs). The identification of the CHs on the Sun as one of the source regions of the solar wind is therefore crucial to achieve predictive capabilities. In this study, we used an unsupervised machine learning method, k-means, to pixel-wise cluster the passband images of the Sun taken by the Atmospheric Imaging Assembly on {\it the Solar Dynamics Observatory} (AIA/SDO) in 171 Å, 193 Å\,, and 211 Å\,in different combinations. Our results show that the pixel-wise k-means clustering together with systematic pre- and post-processing steps provides compatible results with those from complex methods, such as CNNs. More importantly, our study shows that there is a need for a CH database that a consensus about the CH boundaries are reached by observers independently. This database then can be used as the "ground truth", when using a supervised method or just to evaluate the goodness of the models. **5 Nov 2012, 11 Nov 2015, 7-8 Dec 2016**

Characteristics of ephemeral coronal holes

Andrew R. **Inglis**, Rachel E. O'Connor, W. Dean Pesnell, Michael S. Kirk, Nishu Karna

ApJ **880** 98 **2019**

https://arxiv.org/pdf/1906.01757.pdf

sci-hub.se/10.3847/1538-4357/ab27c1

Small-scale ephemeral coronal holes may be a recurring feature on the solar disk, but have received comparatively little attention. These events are characterized by compact structure and short total lifetimes, substantially less than a solar disk crossing. We present a systematic search for these events, using Atmospheric Imaging Assembly EUV image data from the Solar Dynamics Observatory, covering the time period 2010 - 2015. Following strict criteria, this search yielded four clear examples of the ephemeral coronal hole phenomenon. The properties of each event are characterized, including their total lifetime, growth and decay rates, and areas. The magnetic properties of these events are also determined using Helioseismic and Magnetic Imager data. Based on these four events, ephemeral coronal holes experience rapid initial growth of up to 3000 Mm2/hr, while the decay phases are typically more gradual. Like conventional coronal holes, the mean magnetic field in each ephemeral coronal hole displays a consistent polarity, with mean magnetic flux densities generally < 10 G. No evidence of a corresponding signature is seen in solar wind data at 1 AU. Further study is needed to determine whether ephemeral coronal holes are under-reported events or a truly rare phenomenon. **2010 October 26, 2012-09-03, 2014-04-30, 2015-06-24**

Improved forecasts of solar wind parameters using the Kalman filter

Innocenti, M. E.; Lapenta, G.; Vrsnak, B.; Crespon, F.; Skandrani, C.; Temmer, M.; Veronig, A.; Bettarini, L.; Markidis, S.; Skender, M.

Space Weather, Vol. 9, No. 10, S10005, **2011**

Data assimilation through Kalman filtering is a powerful statistical tool that allows researchers to combine modeling and observations and thus to increase the degree of knowledge of a given system. The application of this technique to an empirical solar wind forecasting model which enables the forecasting of solar wind parameters from coronal hole observations is here described and discussed. The forecasts for the solar wind proton velocity and temperature and for the magnetic field magnitude with and without data assimilation are validated against Advanced Composition Explorer observations, and it is shown that Kalman filtering can improve the quality of the forecasts and extend the period of applicability of the baseline model. In a subset of cases, some degree of robustness toward solar transient activity not accounted for in the original model is also provided.

Recent Voyager Evidence for Rapid Transport of Flare-Generated Disturbances by Polar Coronal Hole Streams

D S **Intriligator**1, W D Miller1, J Intriligator1,2, W Webber3, W Sun4, T Detman1, M Dryer1 and C Deehr4

Journal of Physics: Conference Series, Volume 900, Number 1 012010 **2017**

http://iopscience.iop.org/article/10.1088/1742-6596/900/1/012010/pdf

Disturbances observed by Voyagers 1 and 2 during the past five years or more may have been transported by plasma emitted from polar coronal holes, thereby having travelled much faster from the Sun to the termination shock than previously recognized. Estimating the average speed to the shock as 750 km/s has produced consistently good associations between solar flares, or groups of them, and dynamic pressure increases at Voyager 2 and plasma wave events at Voyager 1. Furthermore, magnetograph observations confirm that polar coronal holes were present around the times of the flares to which the events at the Voyagers have been attributed. These calculations also provide revised estimates of the transport of heliospheric current sheet fluctuations. We discuss the possibilities that extrapolations from past observations and simulations based on them may provide insight into currently challenging issues and possible future developments. **Aug. 9, 2011 Sept. 6, 2011, Mar. 10, 2012, Jul. 12, 2012 Jul. 23, 2012, Dec. 14, 2012, Jun. 10, 2014, Dec. 13, 2014 Dec. 17, 2014, Feb. 21, 2015**

An Investigation of Properties of the Coronal Holes Producing HSSs InProCH

D. Beşliu **Ionescu**1, 2 and G. Mariș Muntean1

SCOSTEP/PRESTO NEWSLETTER Vol. 39, April **2024**

https://scostep.org/wp-content/uploads/2024/04/SCOSTEP_PRESTO_Newsletter_Vol39_high_reso.pdf

We have prepared a database that is available online at http://observer.astro.ro/ inproch/. This database contains coronal holes (CHs) observed during the descending phase of solar cycle 24 (SC24), specifically the period from Apr 2015 to Jul 2017, extended by three months before and after this interval.

Kinetic Evolution of Coronal Hole Protons by Imbalanced Ion-cyclotron Waves: Implications for Measurements by Solar Probe Plus

Philip A. **Isenberg** and Bernard J. Vasquez

2015 ApJ 808 119

We extend the kinetic guiding-center model of collisionless coronal hole protons presented in Isenberg & Vasquez to consider driving by imbalanced spectra of obliquely propagating ion-cyclotron waves. These waves are assumed to be a small by-product of the imbalanced turbulent cascade to high perpendicular wavenumber, and their total intensity is taken to be 1% of the total fluctuation energy. We also extend the kinetic solutions for the proton distribution function in the resulting fast solar wind to heliocentric distances of 20 solar radii, which will be attainable by the Solar Probe Plus spacecraft. We consider three ratios of outward-propagating to inward-propagating resonant intensities: 1, 4, and 9. The self-consistent bulk flow speed reaches fast solar wind values in all cases, and these speeds are basically independent of the intensity ratio. The steady-state proton distribution is highly organized into nested constant-density shells by the resonant wave-particle interaction. The radial evolution of this kinetic distribution as the coronal hole plasma flows outward is understood as a competition between the inward- and outward-directed large-scale forces, causing an effective circulation of particles through the ($v_\parallel$, $v_\perp$) phase space and a characteristic asymmetric shape to the distribution. These asymmetries are substantial and persist to the outer limit of the model computation, where they should be observable by the Solar Probe Plus instruments.

The Dynamic Character of the Polar Solar Wind

B. V. **Jackson**, H.-S. Yu, A. Buffington, and P. P. Hick

2014 ApJ 793 54

The Solar and Heliospheric Observatory (SOHO) Large Angle and Spectrometric Coronagraph C2 and Solar Terrestrial Relations Observatory (STEREO) COR2A coronagraph images, when analyzed using correlation tracking techniques, show a surprising result in places ordinarily thought of as "quiet" solar wind above the poles in coronal hole regions. **Instead of the static well-ordered flow and gradual**

acceleration normally expected, coronagraph images show outflow in polar coronal holes consisting of a mixture of intermittent slow and fast patches of material. We compare measurements of this highly variable solar wind from C2 and COR2A images and show that both coronagraphs measure essentially the same structures. Measurements of the mean velocity as a function of height of these structures are compared with mass flux determinations of the solar wind outflow in the large polar coronal hole regions and give similar results.

Migration of Ca II H bright points in the internetwork

S. **Jafarzadeh**1⋆, R. H. Cameron1, S. K. Solanki1,2, A. Pietarila3, A. Feller1, A. Lagg1 and A. Gandorfer

A&A 563, A101 (**2014**)

Context. The migration of magnetic bright point-like features (MBP) in the lower solar atmosphere reflects the dispersal of magnetic flux as well as the horizontal flows of the atmospheric layer they are embedded in.
Aims. We analyse trajectories of the proper motion of intrinsically magnetic, isolated internetwork Ca ii H MBPs (mean lifetime 461 ± 9 s) to obtain their diffusivity behaviour.
Methods. We use seeing-free high spatial and temporal resolution image sequences of quiet-Sun, disc-centre observations obtained in the Ca ii H 3968 Å passband of the Sunrise Filter Imager (SuFI) onboard the Sunrise balloon-borne solar observatory. Small MBPs in the internetwork are automatically tracked. The trajectory of each MBP is then calculated and described by a diffusion index (γ) and a diffusion coefficient (D). We also explore the distribution of the diffusion indices with the help of a Monte Carlo simulation.
Results. We find γ = 1.69 ± 0.08 and D = 257 ± 32 km2 s-1 averaged over all MBPs. Trajectories of most MBPs are classified as super-diffusive, i.e. γ > 1, with the determined γ being the largest obtained so far to our knowledge. A direct correlation between D and timescale (τ) determined from trajectories of all MBPs is also obtained. We discuss a simple scenario to explain the diffusivity of the observed, relatively short-lived MBPs while they migrate within a small area in a supergranule (i.e. an internetwork area). We show that the scatter in the γ values obtained for individual MBPs is due to their limited lifetimes.
Conclusions. The super-diffusive MBPs can be described as random walkers (due to granular evolution and intergranular turbulence) superposed on a large systematic (background) velocity, caused by granular, mesogranular, and supergranular flows.

Coronal Dynamic Activities in the Declining Phase of a Solar Cycle

Minhwan **Jang**, T. N. Woods, Sunhak Hong, G. S. Choe

2016 ApJL 833 L11

https://arxiv.org/pdf/1610.02944v2.pdf

It has been known that some solar activity indicators show a double-peak feature in their evolution through a solar cycle, which is not conspicuous in sunspot number. In this letter, we investigate the high solar dynamic activity in the declining phase of the sunspot cycle by examining the evolution of polar and low latitude coronal hole areas and the statistics of splitting and merging events of coronal holes and coronal mass ejections detected by SOHO/LASCO C3 in solar cycle 23. Although the total coronal hole area is at its maximum near the sunspot minimum, in which polar coronal holes prevail, it shows a comparable second maximum in the declining phase of the cycle, in which low latitude coronal holes are dominant. The events of coronal hole splitting or merging, which are attributed to surface motions of magnetic fluxes, are also mostly populated in the declining phase of the cycle. The far-reaching C3 coronal mass ejections are also over-populated in the declining phase of the cycle. From these results we suggest that solar dynamic activities due to the horizontal motions of magnetic fluxes extend far in the declining phase of the sunspot cycle. **Хорошее Введение.**

Multi-channel coronal hole detection with convolutional neural networks

R. **Jarolim**, A.M. Veronig, S. Hofmeister, S.G. Heinemann, M. Temmer, T. Podladchikova, K. Dissauer

A&A 652, A13 **2021**

https://arxiv.org/pdf/2104.14313.pdf

https://www.aanda.org/articles/aa/pdf/2021/08/aa40640-21.pdf

https://doi.org/10.1051/0004-6361/202140640

We develop a reliable, fully automatic method for the detection of coronal holes, that provides consistent full-disk segmentation maps over the full solar cycle and can perform in real-time. We use a convolutional neural network to identify the boundaries of coronal holes from the seven EUV channels of the Atmospheric Imaging Assembly (AIA) as well as from line-of-sight magnetograms from the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO). For our primary model (Coronal Hole RecOgnition Neural Network Over multi-Spectral-data; CHRONNOS) we use a progressively growing network approach that allows for efficient training, provides detailed segmentation maps and takes relations across the full solar-disk into account. We provide a thorough evaluation for performance, reliability and consistency by comparing the model results to an independent manually curated test set. Our model shows good agreement to the manual labels with an intersection-over-union (IoU) of 0.63. From the total of 261 coronal holes with an area >1.5·1010 km2 identified during the time range 11/2010 - 12/2016, 98.1% were correctly detected by our model. The evaluation over almost the full solar cycle no. 24 shows that our model provides reliable coronal hole detections, independent of the level of solar activity. From the direct comparison over short time scales of days to weeks, we find that our model exceeds human performance in terms of consistency and reliability. In addition, we train our model to identify coronal holes from each channel separately and show that the neural network provides the best performance with the combined channel information, but that coronal hole segmentation maps can be also obtained solely from line-of-sight magnetograms. **2015-04-02, 2016-12-04-08**

Image Processing Methods for Coronal Hole Segmentation, Matching, and Map Classification

V. **Jatla**, M.S. Pattichis, C.N. Arge

IEEE Transactions on Image Processing 29 (**2019**): 1641-1653

https://arxiv.org/pdf/2201.01380.pdf

The paper presents the results from a multi-year effort to develop and validate image processing methods for selecting the best physical models based on solar image observations. The approach consists of selecting the physical models based on their agreement with coronal holes extracted from the images. Ultimately, the goal is to use physical models to predict geomagnetic storms. We decompose the problem into three subproblems: (i) coronal hole segmentation based on physical constraints, (ii) matching clusters of coronal holes between different maps, and (iii) physical map classification. For segmenting coronal holes, we develop a multi-modal method that uses segmentation maps from three different methods to initialize a level-set method that evolves the initial coronal hole segmentation to the magnetic boundary. Then, we introduce a new method based on Linear Programming for matching clusters of coronal holes. The final matching is then performed using Random Forests. The methods were carefully validated using consensus maps derived from multiple readers, manual clustering, manual map classification, and method validation for 50 maps. The proposed multi-modal segmentation method significantly outperformed SegNet, U-net, Henney-Harvey, and FCN by providing accurate boundary detection. Overall, the method gave a 95.5% map classification accuracy. **8-7-2010**

Automatic Segmentation of Coronal Holes in Solar Images and Solar Prediction Map Classification

Venkatesh **Jatla**

Thesis **2016**

https://arxiv.org/pdf/2207.10070.pdf

Solar image analysis relies on the detection of coronal holes for predicting disruptions to earth's magnetic field. The coronal holes act as sources of solar wind that can reach the earth. Thus, coronal holes are used in physical models for predicting the evolution of solar wind and its potential for interfering with the earth's magnetic field. Due to inherent uncertainties in the physical models, there is a need for a classification system that can be used to select the physical models that best match the observed coronal holes.

The physical model classification problem is decomposed into three subproblems. First, he thesis develops a method for coronal hole segmentation. Second, the thesis develops methods for matching coronal holes from different maps. Third, based on the matching results, the thesis develops a physical map classification system.

A level-set segmentation method is used for detecting coronal holes that are observed in extreme ultra-violet images (EUVI) and magnetic field images. For validating the segmentation approach, two independent manual segmentations were combined to produce 46 consensus maps. Overall, the level-set segmentation approach produces significant improvements over current approaches.

Physical map classification is based on coronal hole matching between the physical maps and (i) the consensus maps (semi-automated), or (ii) the segmented maps (fully-automated). Based on the matching results, the system uses area differences,shortest distances between matched clusters, number and areas of new and missing coronal hole clusters to classify each map. The results indicate that the automated segmentation and classification system performs better than individual humans.

About the relative importance of compressional heating and current dissipation for the formation of coronal X-ray bright points A114

S. **Javadi**, J. Büchner, A. Otto and J. C. Santos

A&A 529, A114 (**2011**)

Context. The solar corona is heated to high temperatures of the order of 106 K. The coronal energy budget and specifically possible mechanisms of coronal heating (wave, DC-electric fields, etc.) are poorly understood. This is particularly true for the formation of X-ray bright points (BPs) is concerned.
Aims. We aim to investigate the energy budget, particularly the relative role and contribution of adiabatic compression versus current dissipation to the formation of coronal BPs.
Methods. Our three-dimensional resistive MHD simulation starts with the extrapolation of the observed magnetic field from SOHO/MDI magnetograms, which are associated with a BP observed on 19 December 2006 by Hinode. The initial radially non-uniform plasma density and temperature distribution agrees with an equilibrium model of the chromosphere and corona. The plasma motion is included in the model as a source of energy for coronal heating.
Results. Our investigation of the energy conversion owing to Lorentz force, pressure gradient force, and Ohmic current dissipation for this bright point shows the minor effect of Joule heating compared with the work done by pressure gradient force in increasing the thermal energy by adiabatic compression. Especially at the time when the temperature enhancement above the bright point starts to form, compressional effects are quite dominant over the direct Joule heating.
Conclusions. Choosing non-realistic high resistivity in compressible MHD models for a simulation of solar corona can lead to unphysical consequences for the energy balance analysis, especially when local thermal energy enhancements are being considered.

Automatic Method for Identifying Photospheric Bright Points and Granules Observed by Sunrise

M. **Javaherian**, H. Safari, A. Amiri, S. Ziaei

Solar Physics, Volume 289, Issue 10, pp 3969-3983, **2014**

E-print, July **2014**

http://arxiv.org/pdf/1407.2447v1.pdf

In this study, we propose methods for the automatic detection of photospheric features (bright points and granules) from ultra-violet (UV) radiation, using a feature-based classifier. The methods use quiet-Sun observations at 214 nm and 525 nm images taken by Sunrise on **9 June 2009**. The function of region growing and mean shift procedure are applied to segment the bright points (BPs) and granules, respectively. Zernike moments of each region are computed. The Zernike moments of BPs, granules, and other features are distinctive enough to be separated using a support vector machine (SVM) classifier. The size distribution of BPs can be fitted with a power-law slope −1.5. The peak value of granule sizes is found to be about 0.5 arcsec2. The mean value of the filling factor of BPs is 0.01, and for granules it is 0.51. There is a critical scale for granules so that small granules with sizes smaller than 2.5 arcsec2 cover a wide range of brightness, while the brightness of large granules approaches unity. The mean value of BP brightness fluctuations is estimated to be 1.2, while for granules it is 0.22. Mean values of the horizontal velocities of an individual BP and an individual BP within the network were found to be 1.6 km s−1 and 0.9 km s−1, respectively. We conclude that the effect of individual BPs in releasing energy to the photosphere and maybe the upper layers is stronger than what the individual BPs release into the network.

Life time evolution of coronal holes

Veronika **Jerčić**, Stephan G. Heinemann, Manuela Temmer, Mateja Dumbović, Susanne Vennerstroem, Giuliana Verbanac, Stefan J. Hofmeister Astrid M. Veronig

Solar Phys. **2019**

https://arxiv.org/pdf/1907.02795.pdf

We investigate the evolution of eight well-observed persistent coronal holes (CHs) with life spans of 5-12 solar rotations, that were observed between 2010 and 2015. The aim is to increase our understanding of the evolution of CHs, as well as to investigate the basic physical mechanisms that govern the CH behaviour over its lifetime. Using combined AIA/SDO and HMI/SDO data, we derive several CH parameters such as area, intensity, and magnetic field characteristics as function of time. Using in-situ data from the ACE satellite located at L1, we study the corresponding solar wind plasma measurements. We find that 6 out of 8 CHs in our data set reveal a steady increase in the area followed by a decrease. The average absolute change of area between two points in the growing phase of the regular CHs is (10.2 +/- 3.5) x 10^8 km^2 per day, while for the decaying phase is (8.6 +/- 3.7) x 10^8 km^2 per day. For those CHs we found that the CH magnetic field strength is strongly related to the amount of area strong flux tubes contribute to the CH area. However, there is no correlation between the magnetic field and the total CH area itself, hence, the magnetic field variation follows a different evolutionary pattern. With the in-situ proton bulk speed, we derive for the growing area phase a strong correlation (Pearson cc = 0.69) and for the decaying phase a moderate one (cc = 0.45).

Table 1.: List of 8 CHs under study with their minimum and maximum mean intensity and area.

A Study of Magnetic Bright Points in the Na I D1 Line

D. B. **Jess**, M. Mathioudakis, D. J. Christian, P. J. Crockett, and F. P. Keenan

Astrophysical Journal Letters, 719:L134–L139, **2010**

High-cadence, multiwavelength, optical observations of solar magnetic bright points (MBPs), captured at the disk center using the ROSA and IBIS imaging systems on the Dunn Solar Telescope, are presented. MBPs manifesting in the Na i D_1 core are found to preferentially exist in regions containing strong downflows, in addition to cospatial underlying photospheric magnetic field concentrations. Downdrafts within Na i D_1 bright points exhibit speeds of up to 7 km s^{-1}, with preferred structural symmetry in intensity, magnetic field, and velocity profiles about the bright point center. Excess intensities associated with *G*-band and Ca ii K observations of MBPs reveal a power-law trend when plotted as a function of the magnetic flux density. However, Na i D_1 observations of the same magnetic features indicate an intensity plateau at weak magnetic field strengths below ≈150 G, suggesting the presence of a two-component heating process: one which is primarily acoustic and the other predominantly magnetic. We suggest that this finding is related to the physical expansion of magnetic flux tubes, with weak field strengths (≈50 G) expanding by ~76%, compared to a ~44% expansion when higher field strengths (≈150 G) are present. These observations provide the first experimental evidence of rapid downdrafts in Na i D_1 MBPs and reveal the nature of a previously unresolved intensity plateau associated with these structures.

Investigation of intergranular bright points from the New Vacuum Solar Telescope

Kai-Fan **Ji**, Jian-ping Xiong, Yong-yuan Xiang, Song Feng, Hui Deng, Feng Wang, Yun-Fei Yang

Research in Astron. Astrophys. **201**5

http://arxiv.org/pdf/1512.00737v1.pdf

Six high-resolution TiO-band image sequences from the New Vacuum Solar Telescope (NVST) are used to investigate the properties of intergranular bright points (igBPs). We detect the igBPs using a Laplacian and morphological dilation algorithm (LMD) and track them using a three-dimensional segmentation algorithm automatically, and then investigate the morphologic, photometric and dynamic properties of igBPs, in terms of equivalent diameter, the intensity contrast, lifetime, horizontal velocity, diffusion index, motion range and motion type. The statistical results confirm the previous studies based on G-band or TiO-band igBPs from the other telescopes. It illustrates that the TiO data from the NVST have a stable and reliable quality, which are suitable for studying the igBPs. In addition, our method is feasible to detect and track the igBPs in the TiO data from the NVST. With the aid of the vector magnetograms obtained from the Solar Dynamics Observatory /Helioseismic and Magnetic Imager, the properties of igBPs are found to be influenced by their embedded magnetic environments strongly. The area coverage, the size and the intensity contrast values of igBPs are generally larger in the regions with higher magnetic flux. However, the dynamics of igBPs, including the horizontal velocity, the diffusion index, the ratio of motion range and the index of motion type are generally larger in the regions with lower magnetic flux. It suggests that the absence of strong magnetic fields in the medium makes it possible for the igBPs to look smaller and weaker, diffuse faster, move faster and further in a straighter path.

Damping and power spectra of quasi-periodic intensity disturbances above a solar polar coronal hole

Fangran **Jiao**, Lidong Xia, Zhenghua Huang, Bo Li, Hui Fu, Ding Yuan, Kalugodu Chandrashekhar

Research in Astron. Astrophys. **2016**

http://arxiv.org/pdf/1602.04883v1.pdf

We study intensity disturbances above a solar polar coronal hole seen in the AIA 171 \AA\ and 193 \AA\ passbands, aiming to provide more insights into their physical nature. The damping and power spectra of the intensity disturbances with frequencies from 0.07 mHz to 10.5 mHz are investigated. The damping of the intensity disturbances tends to be stronger at lower frequencies, and their damping behavior below 980" (for comparison, the limb is at 945") is different from what happens above. No significant difference is found between the damping of the intensity disturbances in the AIA 171 \AA\ and that in the AIA 193 \AA. The indices of the power spectra of the intensity disturbances are found to be slightly smaller in the AIA 171 \AA\ than in the AIA 193 \AA, but the difference is within one sigma deviation. An additional enhanced component is present in the power spectra in a period range of 8--40 minutes at lower heights. While the power spectra of spicule is highly correlated with its associated intensity disturbance, it suggests that the power spectra of the intensity disturbances might be a mixture of spicules and wave activities. We suggest that each intensity disturbance in the polar coronal hole is possibly a series of independent slow magnetoacoustic waves triggered by spicular activities. **5-6 Aug 2010**

Sources of quasi-periodic propagating disturbances above a solar polar coronal hole

Fang-Ran **Jiao**, Li-Dong Xia, Bo Li, Zheng-Hua Huang, Xing Li, Kalugodu Chandrashekhar, Chao-Zhou Mou, Hui Fu

2015 *ApJ* **809** L17

http://arxiv.org/pdf/1507.08440v1.pdf

Quasi-periodic propagating disturbances (PDs) are ubiquitous in polar coronal holes on the Sun. It remains unclear as to what generates PDs. In this work, we investigate how the PDs are generated in the solar atmosphere by analyzing a fourhour dataset taken by the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO). We find convincing evidence that spicular activities in the solar transition region as seen in the AIA 304 {\AA} passband are responsible for PDs in the corona as revealed in the AIA 171 {\AA} images. We conclude that spicules are an important source that triggers coronal PDs. **5-6 August 2010**

SYNOPTIC MAPPING OF CHROMOSPHERIC MAGNETIC FLUX

C. L. **Jin**1,3, J. W. Harvey2, and A. Pietarila

2013 ApJ 765 79

We used daily full-disk Ca II 854.2 nm magnetograms from the Synoptic Optical Long Term Investigations of the Sun (SOLIS) facility to study the chromospheric magnetic field from 2006 April through 2009 November. We determined and corrected previously unidentified zero offsets in the SOLIS magnetograms. By tracking the disk passages of stable unipolar regions, the measured net flux densities were found to systematically decrease from the disk center to the limb by a factor of about two. This decrease was modeled using a thin flux tube model with a difference in signal formation height between the center and limb sides. Comparison of photospheric and chromospheric observations shows that their differences are largely due to horizontal spreading of magnetic flux with increasing height. The north polar magnetic field decreased nearly linearly with time during our study period while the south polar field was nearly constant. We used the annual change in the viewing angle of the polar regions to estimate the radial and meridional components of the polar fields and found that the south polar fields were tilted away from the pole. Synoptic maps of the chromospheric radial flux density distribution were used as boundary conditions for extrapolation of the field from the chromosphere into the corona. A comparison of modeled and observed coronal hole boundaries and coronal streamer positions showed better agreement when using the chromospheric rather than the photospheric synoptic maps.

Do Solar Coronal Holes Affect the Properties of Solar Energetic Particle Events?

S. W. **Kahler**, C. N. Arge, S. Akiyama, N. Gopalswamy

Solar Physics, February **2014**, Volume 289, Issue 2, pp 657-673; **File**

The intensities and timescales of gradual solar energetic particle (SEP) events at 1 AU may depend not only on the characteristics of shocks driven by coronal mass ejections (CMEs), but also on large-scale coronal and interplanetary structures. It has long been suspected that the presence of coronal holes (CHs) near the CMEs or near the 1-AU magnetic footpoints may be an important factor in SEP events. We used a group of 41 E≈ 20 MeV SEP events with origins near the solar central meridian to search for such effects. First we investigated whether the presence of a CH directly between the sources of the CME and of the magnetic connection at 1 AU is an important factor. Then we searched for variations of the SEP events among different solar wind (SW) stream types: slow, fast, and transient. Finally, we considered the separations between CME sources and CH footpoint connections from 1 AU determined from four-day forecast maps based on Mount Wilson Observatory and the National Solar Observatory synoptic magnetic-field maps and the Wang–Sheeley–Arge model of SW propagation. The observed in-situ magnetic-field polarities and SW speeds at SEP event onsets tested the forecast accuracies employed to select the best SEP/CH connection events for that analysis. Within our limited sample and the three analytical treatments, we found no statistical evidence for an effect of CHs on SEP event peak intensities, onset times, or rise times. The only exception is a possible enhancement of SEP peak intensities in magnetic clouds. **Table**

TRACE Observations of Changes in Coronal Hole Boundaries

S. **Kahler**, P. Jibben2 and E. E. DeLuca

Solar Phys. Volume 262, Number 1 / March, **2010**, p. 135-147

Solar coronal holes (CHs) are large regions of the corona magnetically open to interplanetary space. The nearly rigid north – south CH boundaries (CHBs) of equatorward extensions of polar CHs are maintained while the underlying photospheric fields rotate differentially, so interchange magnetic reconnection is presumed to be occurring continually at the CHBs. The time and size scales of the required reconnection events at CHBs have not been established from previous observations with soft X-ray images. We use TRACE 195 Å observations on **9 December 2000** of a long-lived equatorial extension of the negative-polarity north polar CH to look for changes of ≳ 5 arcsec to > 20 arcsec at the western CHB. Brightenings and dimmings are observed on both short (≈ 5 minutes) and long (≈ 7 hours) time scales, but the CHB maintains its quasi-rigid location. The transient CHB changes do not appear associated with either magnetic field enhancements or the changes in those field enhancements observed in magnetograms from the Michelson Doppler Imager (MDI) on SOHO. In seven hours of TRACE observations we find no examples of the energetic jets similar to those observed to occur in magnetic reconnection in polar plumes. The lack of dramatic changes in the diffuse CHB implies that gradual magnetic reconnection occurs high in the corona with large (≳ 10°) loops and/or weak coronal fields. We compare our results with recent observations of active regions at CHBs. We also discuss how the magnetic polarity symmetry surrounding quasi-rigid CHs implies an asymmetry in the interchange reconnection process and a possible asymmetry in the solar wind composition from the eastern and western CHB source regions.

Identifying 8 mm Radio Brightenings During the Solar Activity Minimum

Juha **Kallunki**, Merja Tornikoski & Irene Björklund

Solar Physics volume 295, Article number: 105 (**2020**)

https://link.springer.com/content/pdf/10.1007/s11207-020-01673-5.pdf

Strong solar radio brightenings have been extensively studied in the past, and their correlation to the sunspots and active regions are already well known. But even when the Sun is ostensibly quiet, there is practically always some activity that can be detected in the radio domain. In this article we investigate these semi-active features at 8 mm using the radio telescope at Aalto University Metsähovi Radio Observatory. The observations were made between May and September 2019 when the solar activity was very low, and for our detailed study we chose dates when no active regions were identified on the solar surface by the National Oceanic and Atmospheric Administration. The brightness temperature of these radio regions during this quiescent period of solar activity is at maximum approximately 250 K above the quiet-Sun level. We compared our millimeter data with data taken in extreme ultraviolet, and we found that **these weak radio brightenings are mostly related to coronal hole features and magnetic bright points.** We also found that there are two different categories of bright points: those with and without flux tube structure. The formation of the weak radio brightenings is comparable to the stronger radio brightenings: the rising fluxes from the weak photospheric features can be detected as a radio source. **30 May 2019, 2 June 2019, 16 June 2019**

Table 2 A summary of detected radio brightenings at 8 mm that correlate with coronal holes (2019).

Temporal evolution of microflares in bright points

Suguru **Kamio**

EIS Science Nugget for 1st July **2011**

http://msslxr.mssl.ucl.ac.uk:8080/SolarB/nuggets/nugget_2011jul.jsp

Recent observations by Hinode during the solar activity minimum revealed that quiet regions and coronal holes are not really quiet. X-ray bright points are found all over the Sun, and they occasionally undergo impulsive brightenings or microflares. Improved resolution of Hinode EIS and XRT allows us to follow a temporal evolution of the microflares. It is interesting to note that microflares in bright points and large flares in active regions share some common characteristics.

Evolution of microflares associated with bright points in coronal holes and in quiet regions

S. **Kamio**, W. Curdt, L. Teriaca and D. E. Innes

A&A, Volume 529, A21, May **2011**

Aims. We aim to find similarities and differences between microflares at coronal bright points found in quiet regions and coronal holes, and to study their relationship with large scale flares.

Methods. Coronal bright points in quiet regions and in coronal holes were observed with Hinode/EIS using the same sequence. Microflares associated with bright points are identified from the X-ray lightcurve. The temporal variation of physical properties was traced in the course of microflares.

Results. The lightcurves of microflares indicated an impulsive peak at hot emission followed by an enhancement at cool emission, which is compatible with the cooling model of flare loops. The density was found to increase at the rise of the impulsive peak, supporting chromospheric evaporation models. A notable difference is found in the surroundings of microflares; diffuse coronal jets are produced above microflares in coronal holes while coronal dimmings are formed in quiet regions.

Conclusions. The microflares associated with bright points share common characteristics to active region flares. The difference in the surroundings of microflares are caused by open and closed configurations of the pre-existing magnetic field.

Distribution of jets and magnetic fields in a coronal hole

S. **Kamio**1, 2, H. Hara1, T. Watanabe1, and W. Curdt2

A&A 502, 345-353 (**2009**)

DOI: 10.1051/0004-6361/200811125

Context. Recent observations of ubiquitous jets in coronal holes suggest that they play an important role in coronal heating and solar wind acceleration.

Aims. The aim of our study is to understand the magnetic connectivity and the formation of jets in coronal holes.

The study of jets also helps to understand the magnetic field configuration in the coronal hole.
Methods. A coordinated observation between EIS and SUMER was carried out in a polar coronal hole to investigate both the transition region and the corona. Spectropolarimeter (SP) data allowed us to examine the relationship between the distribution of jets and magnetic fields in the photosphere.
Results. Coronal jets as well as explosive events and cool upflows were identified from EIS and SUMER data. The location of these events are correlated with network fields in the photosphere.
Conclusions. Footpoints of coronal jets are connected to patches of vertical kG fields in the photosphere, which are thought to anchor open fields in the upper corona. Explosive events and cool upflows occur in network regions which harbor low-lying fields in the transition region.

Velocity Structure of Jets in a Coronal Hole

S. **Kamio**, H. Hara, T. Watanabe, K. Matsuzaki, K. Shibata, L. Culhane, and H. P. Warren
*Publ. Astron. Soc. Japan 59, pp.S757-S762 (**2007**)*
[Abstract], [HTML], [PDF(1249kb)], [PS.gz(5354kb)]

SOLAR WIND AND CORONAL BRIGHT POINTS INSIDE CORONAL HOLES

Nina V. **Karachik** and Alexei A. Pevtsov
2011 ApJ 735 47
Observations of 108 coronal holes (CHs) from 1998-2008 were used to investigate the correlation between fast solar wind (SW) and several parameters of CHs. Our main goal was to establish the association between coronal bright points (CBPs; as sites of magnetic reconnection) and fast SW. Using in situ measurements of the SW, we have connected streams of the fast SW at 1 AU with their source regions, CHs. We studied a correlation between the SW speed and selected parameters of CHs: total area of the CH, total intensity inside the CH, fraction of area of the CH associated with CBPs, and their integrated brightness inside each CH. In agreement with previous studies, we found that the SW speed most strongly correlates with the total area of the CHs. The correlation is stronger for the non (de)projected areas of CHs (which are measured in image plane) suggesting that the near-equatorial parts of CHs make a larger contribution to the SW measured at near Earth orbit. This correlation varies with solar activity. It peaks for periods of moderate activity, but decreases slightly for higher or lower levels of activity. A weaker correlation between the SW speed and other studied parameters was found, but it can be explained by correlating these parameters with the CH's area. We also studied the spatial distribution of CBPs inside 10 CHs. We found that the density of CBPs is higher in the inner part of CHs. As such, results suggest that although the reconnection processes occurring in CBPs may contribute to the fast SW, they do not serve as the main mechanism of wind acceleration.

FORMATION OF CORONAL HOLES ON THE ASHES OF ACTIVE REGIONS

Nina V. **Karachik**[1], Alexei A. Pevtsov[1], and Valentyna I. Abramenko[2]
Astrophysical Journal, 714:1672–1678, **2010** May
We investigate the formation of isolated non-polar coronal holes (CHs) on the remnants of decaying active regions (ARs) at the minimum/early ascending phase of sunspot activity. We follow the evolution of four bipolar ARs and measure several parameters of their magnetic fields including total flux, imbalance, and compactness. As regions decay, their leading and following polarities exhibit different dissipation rates: loose polarity tends to dissipate faster than compact polarity. As a consequence, we see a gradual increase in flux imbalance inside a dissipating bipolar region, and later a formation of a CH in place of more compact magnetic flux. Out of four cases studied in detail, two CHs had formed at the following polarity of the decaying bipolar AR, and two CHs had developed in place of the leading polarity field. All four CHs contain a significant fraction of magnetic field of their corresponding AR. Using potential field extrapolation, we show that the magnetic field lines of these CHs were closed on the polar CH at the North, which at the time of the events was in imbalance with the polar CH at the South. This topology suggests that the observed phenomenon may play an important role in transformation of toroidal magnetic field to poloidal field, which is a key step in transitioning from an old solar cycle to a new one. The timing of this observed transition may indicate the end of solar cycle 23 and the beginning of cycle 24.

Temperature variability in X-ray bright points observed with Hinode/XRT

R. **Kariyappa**[1,2], E. E. DeLuca[2], S. H. Saar[2], L. Golub[2], L. Damé[3], A. A. Pevtsov[4] and B. A. Varghese[1]
A&A 526, A78 (**2011**)
Aims. We investigate the variability in temperature as a function of time among a sample of coronal X-ray bright points (XBPs).

Methods. We analysed a 7-h (17:00–24:00 UT) long time sequence of soft X-ray images observed almost simultaneously in two filters (Ti_poly and Al_mesh) on April 14, 2007 with X-ray telescope (XRT) onboard the Hinode mission. We identified and selected 14 XBPs for a detailed analysis. The light curves of XBPs were derived using the SolarSoft library in IDL. The temperature of XBPs was determined using the calibrated temperature response curves of the two filters by means of the intensity ratio method.
Results. We find that the XBPs show a high variability in their temperature and that the average temperature ranges from 1.1 MK to 3.4 MK. The variations in temperature are often correlated with changes in average X-ray emission. It is evident from the results of time series that the XBP heating rate can be highly variable on short timescales, suggesting that it has a reconnection origin.

Intensity oscillations and heating of the coronal X-ray bright points from Hinode/XRT

R. **Kariyappa** and B. A. Varghese
A&A 485, 289–292 (**2008**)
DOI: 10.1051/0004-6361:20079127
We analysed a 7 h long time sequence of the soft X-ray images obtained on April 14, 2007 with a 2 min cadence using the X-Ray Telescope (XRT) on-board the Hinode mission.

A Study of an Equatorial Coronal Hole Observed at the First Parker Solar Probe Perihelion

Nishu **Karna**1, Mitchell A. Berger2, Mahboubeh Asgari-Targhi1, Kristoff Paulson1, and Ken'ichi Fujiki3
2022 ApJ 925 62
https://iopscience.iop.org/article/10.3847/1538-4357/ac3c46/pdf
https://doi.org/10.3847/1538-4357/ac3c46
In this study, we present an observational analysis of a coronal hole (CH) observed on 2018 November 1 and solar wind (SW) that originated from it, using the Solar Dynamics Observatory, the Parker Solar Probe (PSP) observations at 68 solar radii, ACE and WIND data at 1 au, and interplanetary scintillation (IPS) observations from 0.2 to 1 au. The CH-originated SW stream was observed by L1 on 2018 November 4 and by PSP on 2018 November 15. We examined the CH for nine Carrington Rotations (CR) and find that the SW stream to reach L1 varied from one CR to other. We find that the pressure, temperature, and magnetic fields increase as the speed of the SW increases and the density decreases with distance. We noticed suprathermal particle enhancement at and after the stream interaction region in both PSP and L1 observations, but the enhancement lasted longer in PSP compared to measurements made at L1. The multiple-rotation observations of the CH imply that any differences in observations between PSP and spacecraft at L1 are due to the radial evolution of the solar wind stream rather than of the CH or the source plasma itself. In addition, IPS measured the radio signal irregularities driven by the SW. Furthermore, we employed a standard analytical model to extrapolate the magnetic field at larger heights. We find that the extrapolated magnetic field at 68 $R_\odot$ and 1 au matches well with the magnetic field measured by PSP and OMNI. **2018-10-07, 2018 November 1, 2018-11-04, 2018-12-01, 2018-12-28, 2019-01-23**

A Study of Equatorial Coronal Holes during the Maximum Phase of Four Solar Cycles

Mahendra Lal **Karna**1, Nishu Karna2, Steven H. Saar2, W. Dean Pesnell3, and Edward E. DeLuca2
2020 ApJ 901 124
https://doi.org/10.3847/1538-4357/abafae
The 11 yr solar cycle (SC) is characterized by periodic changes in solar activity indicators such as the number of sunspots, coronal holes, and active regions (ARs), as well as the occurrence rate of solar energetic events such as filament eruptions, flares, and coronal mass ejections. In this work we performed a statistical study of the equatorial coronal holes (ECHs) and ARs during the maximum phase of the last four SCs: SC 21 (1979–1982), SC 22 (1989–1992), SC 23 (1999–2002), and SC 24 (2012–2015). We compared the number of ECHs and ARs, separations between their centroids, solar wind speed, pressure, and the number of intense geomagnetic storm (IGS) data over these four cycles. We note a strong anticorrelation between the number of ARs and ECHs. We found that the number of close ARs and ECHs, solar wind speed, and the number of IGS increases with average sunspot maximum number for even cycles and decreases with average sunspot maximum for odd cycles. Also, we find strong odd–even trends in the relation between the wind properties and the numbers of close AR and ECH. These results obtained from the annual average data suggest a possible link between ECH and AR proximity and the solar wind phenomena, though odd–even trends point to the importance of other effects (e.g., Sun–Earth magnetic alignment) as well.

The Formation and Maintenance of the Dominant Southern Polar Crown Cavity of Cycle 24

N. **Karna**1,2, J. Zhang2, and W. D. Pesnell

2017 ApJ 835 13

In this article, we report a study of the longest-lived polar crown cavity of Solar Cycle 24, using an observation from 2013, and propose a physical mechanism to explain its sustained existence. We used high temporal and spatial resolution observations from the Atmospheric Imaging Assembly (AIA) and the Helioseismic Magnetic Imager (HMI) instruments on board the Solar Dynamics Observatory (SDO) to explore the structure and evolution of the cavity. Although it existed for more than a year, we examined the circumpolar cavity in great detail from 2013 March 21 to 2013 October 31. Our study reinforces the existing theory of formation of polar crown filaments that involves two basic processes to form any polar crown cavity as well as the long-lived cavity that we studied here. First, the underlying polarity inversion line (PIL) of the circumpolar cavity is formed between (1) the trailing part of dozens of decayed active regions distributed in different longitudes and (2) the unipolar magnetic field in the polar coronal hole. Second, the long life of the cavity is sustained by the continuing flux cancellation along the PIL. The flux is persistently transported toward the polar region through surface meridional flow and diffusion. The continuing flux cancellation leads to the shrinking of the polar coronal hole.

Using Polar Coronal Hole Area Measurements to Determine the Solar Polar Magnetic Field Reversal in Solar Cycle 24

N. **Karna**, S. A. Hess Webber, W. D. Pesnell

Solar Phys., Volume 289, Issue 9, pp 3381-3390, **2014**

An analysis of solar polar coronal hole (PCH) areas since the launch of the Solar Dynamics Observatory (SDO) shows how the polar regions have evolved during Solar Cycle 24. We present PCH areas from mid-2010 through 2013 using data from the Atmospheric Imager Assembly (AIA) and Helioseismic and Magnetic Imager (HMI) instruments onboard SDO. Our analysis shows that both the northern and southern PCH areas have decreased significantly in size since 2010. Linear fits to the areas derived from the magnetic-field properties indicate that, although the northern hemisphere went through polar-field reversal and reached solar-maximum conditions in mid-2012, the southern hemisphere had not reached solar-maximum conditions in the polar regions by the end of 2013. Our results show that solar-maximum conditions in each hemisphere, as measured by the area of the polar coronal holes and polar magnetic field, will be offset in time.

Reconnection-Driven Coronal-Hole Jets with Gravity and Solar Wind

J. T. **Karpen**, C. R. DeVore, S. K. Antiochos, E. Pariat

2017 *ApJ* **834** 62

http://arxiv.org/pdf/1606.09201v1.pdf

Coronal-hole jets occur ubiquitously in solar coronal holes, at EUV and X-ray bright points associated with intrusions of minority magnetic polarity. The embedded-bipole model for these jets posits that they are driven by explosive, fast reconnection between the stressed closed field of the embedded bipole and the open field of the surrounding coronal hole. Previous numerical studies in Cartesian geometry, assuming uniform ambient magnetic field and plasma while neglecting gravity and solar wind, demonstrated that the model is robust and can produce jet-like events in simple configurations. We have extended these investigations by including spherical geometry, gravity, and solar wind in a nonuniform, coronal hole-like ambient atmosphere. Our simulations confirm that the jet is initiated by the onset of a kink-like instability of the internal closed field, which induces a burst of reconnection between the closed and external open field, launching a helical jet. Our new results demonstrate that the jet propagation is sustained through the outer corona, in the form of a traveling nonlinear Alfven wave front trailed by slower-moving plasma density enhancements that are compressed and accelerated by the wave. This finding agrees well with observations of white-light coronal-hole jets, and can explain microstreams and torsional Alfven waves detected in situ in the solar wind. We also use our numerical results to deduce scaling relationships between properties of the coronal source region and the characteristics of the resulting jet, which can be tested against observations.

Center-to-limb variations in coronal hole and quiet Sun regions obtained with IRIS spectroscopic observations

Pradeep **Kayshap**, Peter R. Young

MNRAS Volume 526, Issue 1, November 2023, Pages 383–390, **2023**

https://arxiv.org/pdf/2309.06360

https://doi.org/10.1093/mnras/stad2761

The center-to-limb variations (CLV) of Gaussian fit parameters of the transition region Si~{\sc iv} 1402.77~Å spectral line in quiet Sun (QS) and coronal hole (CH) regions are presented. The results are derived from a full-disk mosaic scan obtained by the Interface Region Imaging Spectrograph on **24 September 2017**. The CLV for a CH transition region line has not previously been reported, and the parameters are found to show variations consistent with the QS. The intensity increases towards the limb, consistent with an increasing plasma column depth due to line-of-sight effects. The Doppler velocity is normalized to be zero at the limb for both QS and CH and increases

to +4.8~\kms\ (redshift) at disk center for CH and +5.2~\kms\ for QS. Non-thermal broadening in the CH decreases from a maximum of 24~\kms\ at the limb to 10~\kms\ at disk center. For QS the broadening decreases from 25~\kms\ at the limb to 14~\kms\ at disk center. Both Doppler velocities and non-thermal velocities vary linearly with cosθ, where θ is the heliocentric angle. The QS results for both parameters are consistent with earlier work.
IRIS Nugget Dec 2023 https://iris.lmsal.com/nugget

Quite-Sun and Coronal Hole in \ion{Mg}{2}~k line as observed by IRIS

Pradeep **Kayshap**, Durgesh Tripathi, Sami K. Solanki, Hardi Peter
ApJ **864** 21 **2018**
https://arxiv.org/pdf/1807.03494.pdf

Coronal holes (CHs) regions are dark in comparison to the quiet-Sun (QS) at the coronal temperatures. However, at chromospheric and transition region (TR) temperatures, QS and CHs are hardly distinguishable. In this study we have used the \ion{Mg}{2}~2796.35~{\AA} spectral line recorded by the Interface Region Imaging Spectrometer (IRIS) to understand the similarities and differences in the QS and CH at chromospheric levels. Our analysis reveals that the emission from \ion{Mg}{2}~k3 \& k2v that originates in the chromosphere is significantly lower in CH than in QS for the regions with similar magnetic field strength. The wing emissions of \ion{Mg}{2}~k that originates from the photospheric layer, however, do not show any difference between QS and CH. The difference in \ion{Mg}{2}~k3 intensities between QS and CH increases with increasing magnetic field strength. We further studied the effects of spectral resolution on these differences and found that the difference in the intensities decreases with decreasing spectral resolution. For a resolution of 11~{\AA}, the difference completely disappears. These findings are not only important for mass and energy supply from the chromosphere to the corona but also provides essential ingredients for the modelling of the solar spectral irradiance for the understanding of the Sun-climate relationships.

Diagnostics of Coronal Bright Points using IRIS, AIA, and HMI Observations

P. **Kayshap**, B. N. Dwivedi
Solar Physics August **2017**, 292:108

We perform the detailed imaging and spectroscopic analysis of two coronal bright points (CBPs). These CBPs are dominated by bright dots or elongated bright features. Their rapid temporal variations lead to a continuous change in their overall morphology at chromospheric and transition-region (TR) temperatures. A 3D potential magnetic field extrapolation predicts the dominance of magnetic loops in the extent of both CBPs, which are clearly visible at the Si iv 1393.75 Å line formation temperature. Short, low-lying magnetic loops or loop segments are the integral parts of these CBPs at TR temperature. A correlation between the various parameters of Mg ii resonance lines (e.g. intensity, Doppler velocity, velocity gradient) is present in the region of magnetic loops or loop segments. However, a quiet-Sun (QS) region does not show any correlation. Doppler velocities as well as the full width at half maximum (FWHM) of these lines are very prominent in the magnetic loops and loop segments compared to the Doppler velocities and FWHM in the QS region. Higher red-shifts and FWHM at TR temperatures are directly related to the dominance of the energy release process in these regions in the framework of the nanoflare model. A magnetogram from the HelioseismicandMagnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO) reveals the existence of two opposite magnetic polarities in the extent of both CBPs, which is a very well established result. We find that one CBP is formed by the convergence of two opposite magnetic polarities, while the other is triggered by the emergence of a new magnetic field prior to the onset of this CBP.

Diagnostics of the Coronal Hole and the adjacent Quiet Sun by The Hinode/EUV Imaging Spectrometer (EIS)

P. **Kayshap**, D. Banerjee, A.K. Srivastava
Solar Phys., Volume 290, Issue 10, pp 2889-2908 **2015**
http://arxiv.org/pdf/1409.1037v1.pdf

A comparison between a Coronal Hole (CH) and the adjacent Quiet-Sun (QS) has been performed using spectroscopic diagnostics of Hinode/ the EUV Imaging Spectrometer (EIS). Coronal funnels play an important role in the formation and propagation of the nascent fast solar wind. Applying Gaussian fitting procedures to the observed line profiles, Doppler velocity, intensity, line width (FWHM) and electron density have been estimated over CH and adjacent QS region of a North Polar Coronal Hole (NPCH). The aim of this study is to identify the coronal funnels based on spectral signatures. Excess width regions (excess FWHM above a threshold level) have been identified in QS and CH. The plasma flow inversion (average red-shifts changing to blue-shifts at a specific height) in CH and excess width regions of QS take place at ~ 5.01×105 K. Furthermore, high density concentration in excess width regions of QS provides an indication that these regions are the footprints of coronal funnels. We have also found that non-thermal velocities of CH are higher in comparison to QS confirming that the CHs are the source regions of fast solar wind. Doppler and non-thermal velocities as recorded by different temperature lines have been also compared with previously published results. As we go from lower to upper solar atmosphere, down-flows are dominated in lower atmosphere while coronal lines are dominated by up-flows with a maximum value of ~

10-12 km s−1 in QS. Non-thermal velocity increases first but after Log Te = 5.47 it decreases further in QS. This trend can be interpreted as a signature of the dissipation of Alfv\'en waves, while increasing trend as reported earlier may attribute to the signature of the growth of Alfv\'en waves at lower heights. Predominance of occurrence of nano-flares around O {\sc vi} formation temperature could also explain non-thermal velocity trend.

High-resolution spectropolarimetric observations of the temporal evolution of magnetic fields in photospheric bright points

Peter H. **Keys**, Aaron Reid, Mihalis Mathioudakis, Sergiy Shelyag, Vasco M. J. Henriques, Rebecca L. Hewitt, Dario Del Moro, Shahin Jafarzadeh, David B. Jess, Marco Stangalini

A&A 633, A60 (**2020**)

https://arxiv.org/pdf/1911.08436.pdf

https://doi.org/10.1051/0004-6361/201936545

Context. Magnetic bright points (MBPs) are dynamic, small-scale magnetic elements often found with field strengths of the order of a kilogauss within intergranular lanes in the photosphere. Aims. Here we study the evolution of various physical properties inferred from inverting high-resolution full Stokes spectropolarimetry data obtained from ground-based observations of the quiet Sun at disc centre. Methods. Using automated feature-tracking algorithms, we studied 300 MBPs and analysed their temporal evolution as they evolved to kilogauss field strengths. These properties were inferred using both the NICOLE and SIR Stokes inversion codes. We employ similar techniques to study radiative magnetohydrodynamical simulations for comparison with our observations. Results. Evidence was found for fast (~30 - 100s) amplification of magnetic field strength (by a factor of 2 on average) in MBPs during their evolution in our observations. Similar evidence for the amplification of fields is seen in our simulated data. Conclusions. Several reasons for the amplifications were established, namely, strong downflows preceding the amplification (convective collapse), compression due to granular expansion and mergers with neighbouring MBPs. Similar amplification of the fields and interpretations were found in our simulations, as well as amplification due to vorticity. Such a fast amplification will have implications for a wide array of topics related to small-scale fields in the lower atmosphere, particularly with regard to propagating wave phenomena in MBPs. **2014 July 27**

The magnetic properties of photospheric magnetic bright points with high resolution spectropolarimetry

Peter H. **Keys**, Aaron Reid, Mihalis Mathioudakis, Sergiy Shelyag, Vasco M. J. Henriques, Rebecca L. Hewitt, Dario Del Moro, Shahin Jafarzadeh, David B. Jess, Marco Stangalini

MNRAS **2019**

https://arxiv.org/pdf/1906.07687.pdf

Magnetic bright points are small-scale magnetic elements ubiquitous across the solar disk, with the prevailing theory suggesting that they form due to the process of convective collapse. Employing a unique full Stokes spectropolarimetric data set of a quiet Sun region close to disk centre obtained with the Swedish Solar Telescope, we look at general trends in the properties of magnetic bright points. In total we track 300 MBPs in the data set and we employ NICOLE inversions to ascertain various parameters for the bright points such as line-of-sight magnetic field strength and line-of-sight velocity, for comparison. We observe a bimodal distribution in terms of maximum magnetic field strength in the bright points with peaks at ~480 G and ~1700 G, although we cannot attribute the kilogauss fields in this distribution solely to the process of convective collapse. Analysis of MURaM simulations does not return the same bimodal distribution. However, the simulations provide strong evidence that the emergence of new flux and diffusion of this new flux play a significant role in generating the weak bright point distribution seen in our observations. **2014 July 27**

Dynamic properties of bright points in an active region

Peter H. **Keys**, Mihalis Mathioudakis, David B. Jess, Duncan H. Mackay, Francis P. Keenan

A&A, 566, A99, **2014**

http://arxiv.org/pdf/1405.3923v1.pdf

Context. Bright points (BPs) are small-scale, magnetic features ubiquitous across the solar surface. Previously, we have observed and noted their properties for quiet Sun regions. Here, we determine the dynamic properties of BPs using simultaneous quiet Sun and active region data. Methods. High spatial and temporal resolution G-band observations of active region AR11372 were obtained with the Rapid Oscillations in the Solar Atmosphere instrument at the Dunn Solar Telescope. Three subfields of varying polarity and magnetic flux density were selected with the aid of magnetograms obtained from the Helioseismic and Magnetic Imager on board the Solar Dynamics Observatory. Bright points within these subfields were subsequently tracked and analysed.
Results. It is found that BPs within active regions display attenuated velocity distributions with an average horizontal velocity of ~0.6 km/s, compared to the quiet region which had an average velocity of 0.9 km/s. Active region BPs are also ~21% larger than quiet region BPs and have longer average lifetimes (~132s) than their quiet

region counterparts (88 s). No preferential flow directions are observed within the active region subfields. The diffusion index (gamma) is estimated at ~1.2 for the three regions.
Conclusions. We confirm that the dynamic properties of BPs arise predominately from convective motions. The presence of stronger field strengths within active regions is the likely reason behind the varying properties observed. We believe that larger amounts of magnetic flux will attenuate BP velocities by a combination of restricting motion within the intergranular lanes and by increasing the number of stagnation points produced by inhibited convection. Larger BPs are found in regions of higher magnetic flux density and we believe that lifetimes increase in active regions as the magnetic flux stabilises the BPs. **2011 December 10**

THE VELOCITY DISTRIBUTION OF SOLAR PHOTOSPHERIC MAGNETIC BRIGHT POINTS

P. H. **Keys**1, M. Mathioudakis1, D. B. Jess1, S. Shelyag1, P. J. Crockett1, D. J. Christian2 and F. P. Keenan

2011 ApJ 740 L40

We use high spatial resolution observations and numerical simulations to study the velocity distribution of solar photospheric magnetic bright points. The observations were obtained with the Rapid Oscillations in the Solar Atmosphere instrument at the Dunn Solar Telescope, while the numerical simulations were undertaken with the MURaM code for average magnetic fields of 200 G and 400 G. We implemented an automated bright point detection and tracking algorithm on the data set and studied the subsequent velocity characteristics of over 6000 structures, finding an average velocity of approximately 1 km s–1, with maximum values of 7 km s–1. Furthermore, merging magnetic bright points were found to have considerably higher velocities, and significantly longer lifetimes, than isolated structures. By implementing a new and novel technique, we were able to estimate the background magnetic flux of our observational data, which is consistent with a field strength of 400 G.

Sources of the Slow Solar Wind During the Solar Cycle 23/24 Minimum

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Solar Phys. **2016**

We investigate the characteristics and the sources of the slow (\({<}\,450~\mbox{km}\,\mbox{s}^{-1}\)) solar wind during the four years (2006 – 2009) of low solar activity between Solar Cycles 23 and 24. We used a comprehensive set of in-situ observations in the near-Earth solar wind (Wind and ACE) and removed the periods when large-scale interplanetary coronal mass ejections were present. The investigated period features significant variations in the global coronal structure, including the frequent presence of low-latitude active regions in 2006 – 2007, long-lived low- and mid-latitude coronal holes in 2006 – mid-2008 and mostly the quiet Sun in 2009. We examined Carrington rotation averages of selected solar plasma, charge state, and compositional parameters and distributions of these parameters related to the quiet Sun, active region Sun, and the coronal hole Sun. While some of the investigated parameters (e.g. speed, the C+6/C+4 and He/H ratios) show clear variations over our study period and with solar wind source type, some (Fe/O) exhibit very little changes. Our results highlight the difficulty of distinguishing between the slow solar wind sources based on the inspection of solar wind conditions.

Comparing the Sun Watcher Using Active Pixel System Detector and Image Processing Instrument to the Atmosphere Imaging Assembly Instrument Through Measurements of Polar Coronal Holes

Michael S. F. **Kirk**, W. Dean Pesnell, C. Nickolos Arge, Matthew J. West & Raphael Attié

Solar Physics volume 297, Article number: 42 (**2022**)

https://link.springer.com/content/pdf/10.1007/s11207-022-01979-6.pdf

The PRoject for OnBoard Autonomy 2/Sun Watcher using Active pixel system detector and image Processing (PROBA2/SWAP) instrument images the full-disk extreme ultraviolet (EUV) Sun using a complementary metal-oxide semiconductor active-pixel sensor (CMOS-APS) detector with a filter centered on a 174 Å passband at a cadence of one to two minutes. In contrast, the Atmosphere Imaging Assembly (AIA) instrument onboard the Solar Dynamics Observatory (SDO) has a passband filter centered on 171 Å and uses a charge-coupled device (CCD) detector to make full-disk observations of the EUV corona. The images that these two telescope designs produce are visually quite similar in active regions, coronal loops, and the quiet corona. This work takes a deeper look at the stability of the most difficult coronal features to capture in an image: polar coronal holes. Polar coronal holes are the longest-lived features on the Sun and are critical to understand the global state of the solar corona, but because of an oblique viewing angle, obstruction due to the coronal plasma scale height and lack of ground-truth magnetic-field measurements make reliable segmentation of polar holes difficult. We use perimeter tracing to make consistent measurements of a polar-hole's perimeter and area in both SWAP 174 Å and AIA 171 Å images. The generated time series of coronal-hole parameters rarely agree with each other. Direct comparison of polar-hole measurements generated by these two imagers allows us to simultaneously analyze the physical properties of polar coronal holes and to identify systematic differences between the two different instruments.

Automated detection of EUV Polar Coronal Holes during Solar Cycle 23

M.S. **Kirk** · W.D. Pesnell · C.A. Young · S.A. Hess Webber

Solar Phys (**2009**) 257: 99–112, DOI 10.1007/s11207-009-9369-y

A new method for automated detection of polar coronal holes is presented. This method, called perimeter tracing, uses a series of 171, 195, and 304 Å full disk images from the Extreme ultraviolet Imaging Telescope (EIT) on SOHO over solar cycle 23 to measure the perimeter of polar coronal holes as they appear on the limbs. Perimeter tracing minimizes line-of-sight obscurations caused by the emitting plasma of the various wavelengths by taking measurements at the solar limb. Perimeter tracing also allows for the polar rotation period to emerge organically from the data as 33 days. We have called this the Harvey rotation rate and count Harvey rotations starting 4 January 1900. From the measured perimeter, we are then able to fit a curve to the data and derive an area within the line of best fit. We observe the area of the northern polar hole area in 1996, at the beginning of solar cycle 23, to be about 4.2% of the total solar surface area and about 3.6% in 2007. The area of the southern polar hole is observed to be about 4.0% in 1996 and about 3.4% in 2007. Thus, both the north and south polar hole areas are no more than 15% smaller now than they were at the beginning of cycle 23. This compares to the polar magnetic field measured to be about 40% less now than it was a cycle ago.

Temporal Evolution of Solar Wind Ion Composition and their Source Coronal Holes during the Declining Phase of Cycle 23. I. Low-latitude Extension of Polar Coronal Holes

Yuan-Kuen **Ko**, Karin Muglach, Yi-Ming Wang, Peter R. Young, and Susan T. Lepri

2014 ApJ 787 121

We analyzed 27 solar wind (SW) intervals during the declining phase of cycle 23, whose source coronal holes (CHs) can be unambiguously identified and are associated with one of the polar CHs. We found that the SW ions have a temporal trend of decreasing ionization state, and such a trend is different between the slow and fast SW. The photospheric magnetic field, both inside and at the outside boundary of the CH, also exhibits a trend of decrease with time. However, EUV line emissions from different layers of the atmosphere exhibit different temporal trends. The coronal emission inside the CH generally increases toward the CH boundary as the underlying field increases in strength and becomes less unipolar. In contrast, this relationship is not seen in the coronal emission averaged over the entire CH. For C and O SW ions that freeze-in at lower altitude, stronger correlation between their ionization states and field strength (both signed and unsigned) appears in the slow SW, while for Fe ions that freeze-in at higher altitude, stronger correlation appears in the fast SW. Such correlations are seen both inside the CH and at its boundary region. On the other hand, the coronal electron temperature correlates well with the SW ion composition only in the boundary region. Our analyses, although not able to determine the likely footpoint locations of the SW of different speeds, raise many outstanding questions for how the SW is heated and accelerated in response to the long-term evolution of the solar magnetic field.

Discriminant analysis of solar bright points and faculae II. Contrast and morphology analysis

P. **Kobel**, J. Hirzberger, S. K. Solanki

http://arxiv.org/pdf/1410.5354v1.pdf

Taken at a high spatial resolution of 0.1 arcsec, Bright Points (BPs) are found to coexist with faculae in images and the latter are often resolved as adjacent striations. Understanding the properties of these different features is fundamental to carrying out proxy magnetometry. To shed light on the relationship between BPs and faculae, we studied them separately after the application of a classification method, developed and described in a previous paper) on active region images at various heliocentric angles. In this Paper, we explore different aspects of the photometric properties of BPs and faculae, namely their G-band contrast profiles, their peak contrast in G-band and continuum, as well as morphological parameters. We find that: (1) the width of the contrast profiles of the classified BPs and faculae are consistent with studies of disk center BPs at and limb faculae, which indirectly confirms the validity of our classification, (2) the profiles of limb faculae are limbward skewed on average, while near disk center they exhibit both centerward and limbward skewnesses due to the distribution of orientations of the faculae, (3) the relation between the peak contrasts of BPs and faculae and their apparent area discloses a trend reminiscent of magnetogram studies. The skewness of facular profiles provides a novel constraint for 3D MHD models of faculae. As suggested by the asymmetry and orientation of their contrast profiles, faculae near disk center could be induced by inclined fields, while apparent BPs near the limb seem to be in fact small faculae misidentified. The apparent area of BPs and faculae could be possibly exploited for proxy magnetometry.

Discriminant analysis of solar bright points and faculae
I. Classification method and center-to-limb distribution
P. **Kobel**1, J. Hirzberger1, S. K. Solanki1, 2, A. Gandorfer1, and V. Zakharov1
A&A 502, 303-314 (**2009**)
Context. While photospheric magnetic elements appear mainly as Bright Points (BPs) at the disk center and as faculae near the limb, high-resolution images reveal the coexistence of BPs and faculae over a range of heliocentric angles. This is not explained by a "hot wall" effect through vertical flux tubes, and suggests that the transition from BPs to faculae needs to be quantitatively investigated.
Aims. To achieve this, we made the first recorded attempt to discriminate BPs and faculae, using a statistical classification approach based on Linear Discriminant Analysis (LDA). This paper gives a detailed description of our method, and shows its application on high-resolution images of active regions to retrieve a center-to-limb distribution of BPs and faculae.
Methods. Bright "magnetic" features were detected at various disk positions by a segmentation algorithm using simultaneous G-band and continuum information. By using a selected sample of those features to represent BPs and faculae, suitable photometric parameters were identified for their discrimination. We then carried out LDA to find a unique discriminant variable, defined as the linear combination of the parameters that best separates the BPs and faculae samples. By choosing an adequate threshold on that variable, the segmented features were finally classified as BPs and faculae at all the disk positions.
Results. We thus obtained a Center-to-Limb Variation (CLV) of the relative number of BPs and faculae, revealing the predominance of faculae at all disk positions except close to disk center ($\mu \geq$ 0.9).
Conclusions. Although the present dataset suffers from limited statistics, our results are consistent with other observations of BPs and faculae at various disk positions. The retrieved CLV indicates that at high resolution, faculae are an essential constituent of active regions all across the solar disk. We speculate that the faculae near disk center as well as the BPs away from disk center are associated with inclined fields.

Monitoring Holes in the Sun's Corona
Susanna **Kohler**
http://aasnova.org/2016/08/31/monitoring-holes-in-the-suns-corona/

Multiwavelength study of on-disk coronal-hole jets with IRIS and SDO observations
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A&A, 690, A11 (**2024**)
https://doi.org/10.1051/0004-6361/202348446
https://www.aanda.org/articles/aa/pdf/2024/10/aa48446-23.pdf
https://arxiv.org/pdf/2407.02291
Context. Solar jets are an important field of study, as they may contribute to the mass and energy transfer from the lower to the upper atmosphere.
Aims. We use the Interface Region Imaging Spectrograph (IRIS) and Solar Dynamic Observatory (SDO) observations to study two small-scale jets (jet 1 and jet 2) originating in the same on-disk coronal hole observed in October 2013.
Methods. We combine dopplergrams, intensity maps, and line width maps derived from IRIS Si IV 1393.755 Å spectra along with images from the Atmospheric Imaging Assembly (AIA) on SDO to describe the dynamics of the jets. Images from AIA, with the use of the emission measure loci technique and rectangular differential emission measure (DEM) distributions, provide estimations of the plasma temperatures. We used the O IV 1399.77 Å, 1401.16 Å spectral lines from IRIS to derive electron densities.
Results. For jet 1, the SDO images show a small mini-filament 2 minutes before the jet eruption, while jet 2 originates at a pre-existing coronal bright point. The analysis of asymmetric spectral profiles of the Si IV 1393.755 Å and 1402.770 Å lines reveals the existence of two spectral components at both regions. One of the components can be related to the background plasma emission originating outside the jet, while the secondary component represents higher-energy plasma flows associated with the jets. Both jets exhibit high densities of the order of 1011 cm−3 at their base and 1010 cm−3 at the spire, respectively, as well as similar average nonthermal velocities of ∼50–60 km/s. However, the two jets show differences in their length, duration, and plane-of-sky velocity. Finally, the DEM analysis reveals that both jets exhibit multithermal distributions.
Conclusions. This work presents a comprehensive description of the thermal parameters and the dynamic evolution of two jets. The locations of the asymmetric profiles possibly indicate the areas of energy release triggering the jets.
October 9, 2013

Observational Evidence of Interchange Reconnection between a Solar Coronal Hole and a Small Emerging Active Region

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2018 ApJL 863 L22
http://sci-hub.tw/http://iopscience.iop.org/article/10.3847/2041-8213/aad777/meta
In this Letter, we present a case study of interchange reconnection between a coronal hole (CH) and a small emerging active region. The small active region emerges at the edge of the CH. Following the emergence of the small active region, the expansion of the arcade loops connecting the negative and the positive polarities of the active region can be clearly seen in 211 and 171 Å observations. During the emergence, the active region develops loop connections to the boundary of the CH, leading to its retreat. The latter has fast and slow phases at speeds of about 2.3 km s−1and 0.4 km s−1, respectively. By the end, these newly formed closed loops occupy most of the pre-emergence CH. From the line-of-sight magnetograms observed by Solar Dynamics Observatory/Helioseismic and Magnetic Imager, the magnetic polarity in the CH is mainly positive and the leading sunspot of the active region has negative polarity. It is consistent with the condition of interchange reconnection. Moreover, the potential field source surface model is used to extrapolate the coronal magnetic fields. From a sequence of extrapolation potential fields, it is clear that the open fields in the CH close down, and the closed field at the east of the active region becomes an open field. These observations and the extrapolations of the potential fields suggest that interchange reconnection occurs between the CH and the small emerging active region and is driven by the flux emergence process. **2016 December 17**

Coronal bright point statistics

I. Lifetime, shape, and coronal co-rotation⋆

I. **Kraus**1, Ph.-A. Bourdin1,2, J. Zender3, M. Bergmann3,4 and A. Hanslmeier1
A&A 678, A184 (**2023**)
https://www.aanda.org/articles/aa/pdf/2023/10/aa46312-23.pdf
https://arxiv.org/pdf/2311.01408.pdf
Context. The corona of the Sun is the part of the solar atmosphere with temperatures of over one million Kelvin, which needs to be heated internally in order to exist. This heating mechanism remains a mystery; we see large magnetically active regions in the photosphere lead to strong extreme UV (EUV) emission in the corona. On much smaller scales (on the order of tens of Mm), there are bipolar and multipolar regions that can be associated with evenly sized coronal bright points (CBPs).
Aims. Our aim was to study the properties of CBPs in a statistical sense and to use continuous data from the SDO spacecraft, which makes it possible to track CBPs over their whole lifetime. Furthermore, we tested various rotation-speed profiles for CBPs in order to find out if the lower corona is co-rotating with the photosphere. Then we compiled a database with about 346 CBPs together with information of their sizes, shapes, appearance and disappearance, and their visibility in the EUV channels of the AIA instrument. We want to verify our methods with similar previous studies.
Methods. We used the high-cadence data of the largest continuous SDO observation interval in 2015 to employ an automated tracking algorithm for CBPs. Some of the information (e.g., the total lifetime, the characteristic shape, and the magnetic polarities below the CBPs) still requires human interaction.
Results. In this work we present statistics on fundamental properties of CBPs along with some comparison tables that relate, for example, the CBP lifetime with their shape. CBPs that are visible in all AIA channels simultaneously seem to be brighter in total and also have a stronger heating, and hence a higher total radiation flux. We compared the EUV emission visibility in different AIA channels with the CBP's shape and lifetime. From the tracking algorithm we confirm a strict co-rotation of the CBPs with the photospheric differential rotation.
Conclusions. The tracked CBPs have a typical lifetime of about 1–6 h, while the hottest and brightest ones seem to exist for significantly longer time, up to 24 h. Furthermore, the merging of two CBPs seems not to have an influence on the overall size of the persisting CBP. Finally, fainter and cooler CBPs tend to have only weaker magnetic polarities, which clearly supports a coronal bright point heating mechanism based on magnetic energy dissipation.
14 August 2015

SHORT-TERM EVOLUTION OF CORONAL HOLE BOUNDARIES

Larisza D. **Krista**, Peter T. Gallagher and D. Shaun Bloomfield
2011 ApJ 731 L26
http://arxiv.org/pdf/1103.2660v1.pdf
The interaction of open and closed field lines at coronal hole (CH) boundaries is widely accepted to be due to interchange magnetic reconnection. To date, it is unclear how the boundaries vary on short timescales and at what

velocity this occurs. Here, we describe **an automated boundary tracking method used to determine CH boundary** displacements on short timescales. The boundary displacements were found to be isotropic and to have typical expansion/contraction speeds of ≤2 km s–1, which indicate magnetic reconnection rates of ≤3 × 10–3. The observed displacements were used in conjunction with the interchange reconnection model to derive typical diffusion coefficients of ≤3 × 1013 cm2 s–1. These results are consistent with an interchange reconnection process in the low corona driven by the random granular motions of open and closed fields in the photosphere. **8 Sept 2008**

Automated Coronal Hole Detection Using Local Intensity Thresholding Techniques

Larisza D. **Krista** · Peter T. Gallagher

Solar Phys (2009) 256: 87–100, DOI 10.1007/s11207-009-9357-2, **2009, File**

STEREO SCIENCE RESULTS AT SOLAR MINIMUM

We identify coronal holes using a histogram-based intensity thresholding technique and compare their properties to fast solar wind streams at three different points in the heliosphere. The thresholding technique was tested on EUV and X-ray images obtained using instruments onboard STEREO, SOHO and *Hinode*. The full-disk images were transformed into Lambert equal-area projection maps and partitioned into a series of overlapping sub-images from which local histograms were extracted. The histograms were used to determine the threshold for the low intensity regions, which were then classified as coronal holes or filaments using magnetograms from the SOHO/MDI. For all three instruments, the local thresholding algorithm was found to successfully determine coronal hole boundaries in a consistent manner. Coronal hole properties extracted using the segmentation algorithm were then compared with *in situ* measurements of the solar wind at ~1 AU from ACE and STEREO. Our results indicate that flux tubes rooted in coronal holes expand super-radially within 1 AU and that larger (smaller) coronal holes result in longer (shorter) duration high speed solar wind streams.

Height variation of magnetic field and plasma flows in isolated bright points

Christoph **Kuckein**

A&A 630, A139 **2019**

https://arxiv.org/pdf/1909.05550.pdf

sci-hub.se/10.1051/0004-6361/201935856

The expansion with height of the solar photospheric magnetic field and the plasma flows is investigated for three isolated bright points (BPs). The BPs were observed simultaneously with 3 instruments at the GREGOR telescope: (1) filtergrams in the blue with HiFI, (2) imaging spectroscopy of Na I D2 at 5890 A with GFPI, and (3) slit spectropolarimetry with GRIS. Inversions were carried out for the Si I 10827 A Stokes profiles. BPs are identified in Ca II H and blue continuum filtergrams. They are also detected in the blue wing of Na I D2 and Si I 10827 A, as well as in Ca I 10839 A line-core images. We carried out two studies to validate the expansion of the magnetic field with height. First, we compare the photospheric Stokes V signals of two different spectral lines that are sensitive to different optical depths (Ca I vs. Si I). The area at which the Stokes V signal is significantly large is almost three times larger for the Si I line - sensitive to higher layers - than for the Ca I one. Second, the inferred line-of-sight (LOS) magnetic fields at two optical depths (log tau = -1.0 vs. -2.5) from the Si I line reveal spatially broader fields in the higher layer, up to 51% more extensive in one of the BPs. The dynamics of BPs are tracked along the Na I D2 and Si I lines. The inferred flows from Na I D2 Doppler shifts are slow in BPs (< 1 km/s). The Si I line shows intriguing Stokes profiles with important asymmetries. The analysis of these profiles unveils the presence of two components, a fast and a slow one, within the same resolution element. The faster one, with a smaller filling factor of 0.3, exhibits LOS velocities of about 6 km/s. The slower component is slightly blueshifted. The present work provides observational evidence for the expansion of the magnetic field with height. Moreover, fast flows are likely present in BPs but are often hidden because of observational limitations. **2018 May 04, 2018 May 09**

New Evidence on the Origin of Solar Wind Microstreams/Switchbacks

Pankaj **Kumar**, Judith T. Karpen, Vadim M. Uritsky, Craig E. Deforest, Nour E. Raouafi, C. Richard DeVore, Spiro K. Antiochos

ApJL **2023**

https://arxiv.org/pdf/2305.06914.pdf

Microstreams are fluctuations in the solar wind speed and density associated with polarity-reversing folds in the magnetic field (also denoted switchbacks). Despite their long heritage, the origin of these microstreams/switchbacks remains poorly understood. For the first time, we investigated periodicities in microstreams during Parker Solar Probe (PSP) Encounter 10 to understand their origin. Our analysis was focused on the inbound corotation interval on **2021 November 19-21**, while the spacecraft dove toward a small area within a coronal hole (CH). Solar Dynamics Observatory remote-sensing observations provide rich context for understanding the PSP in-situ data. Extreme ultraviolet images from the Atmospheric Imaging Assembly reveal numerous recurrent jets occurring within the region that was magnetically connected to PSP during intervals that contained microstreams. The periods derived from the fluctuating radial velocities in the microstreams (approximately 3, 5, 10, and 20 minutes) are consistent with the periods measured in the emission intensity of the jetlets at the base of the CH plumes, as well as in larger coronal jets and in the plume fine structures. Helioseismic and Magnetic Imager magnetograms reveal the presence of myriad embedded bipoles, which are known sources of reconnection-driven jets on all scales. Simultaneous enhancements in the PSP proton flux and ionic (3He, 4He, Fe, O) composition during the microstreams further support the connection with jetlets and jets. In keeping with prior observational and numerical studies of impulsive coronal activity, we conclude that quasiperiodic jets generated by interchange/breakout reconnection at CH bright points and plume bases are the most likely sources of the microstreams/switchbacks observed in the solar wind.

Multiwavelength Study of Equatorial Coronal-Hole Jets

Pankaj **Kumar**, Judith T. Karpen, Spiro K. Antiochos, Peter F. Wyper, C. Richard DeVore, Craig E. DeForest

ApJ **2019**

https://arxiv.org/pdf/1902.00922.pdf

Jets (transient/collimated plasma ejections) occur frequently throughout the solar corona and contribute mass/energy to the corona and solar wind. By combining numerical simulations and high-resolution observations, we have made substantial progress recently on determining the energy buildup and release processes in these jets. Here we describe a study of 27 equatorial coronal-hole jets using Solar Dynamics Observatory/AIA and HMI observations on **2013 June 27-28 and 2014 January 8-10**. Out of 27 jets, 18 (67%) are associated with mini-filament ejections; the other 9 (33%) do not show mini-filament eruptions but do exhibit mini-flare arcades and other eruptive signatures. This indicates that every jet in our sample involved a filament-channel eruption. From the complete set of events, 6 jets (22%) are apparently associated with tiny flux-cancellation events at the polarity inversion line, and 2 jets (7%) are associated with sympathetic eruptions of filaments from neighboring bright points. Potential-field extrapolations of the source-region photospheric magnetic fields reveal that all jets originated in the fan-spine topology of an embedded bipole associated with an extreme ultraviolet coronal bright point. Hence, all our jets are in agreement with the breakout model of solar eruptions. We present selected examples and discuss the implications for the jet energy build-up and initiation mechanisms.

Evidence For The Magnetic Breakout Model in an Equatorial Coronal-Hole Jet

Pankaj **Kumar**, Judith T. Karpen, Spiro K. Antiochos, Peter F. Wyper, C. Richard DeVore, Craig E. DeForest

ApJ **2018**

https://arxiv.org/pdf/1801.08582.pdf

Small, impulsive jets commonly occur throughout the solar corona, but are especially visible in coronal holes. Evidence is mounting that jets are part of a continuum of eruptions that extends to much larger coronal mass ejections and eruptive flares. Because coronal-hole jets originate in relatively simple magnetic structures, they offer an ideal testbed for theories of energy buildup and release in the full range of solar eruptions. We analyzed an equatorial coronal-hole jet observed by SDO/AIA on **09 January 2014**, in which the magnetic-field structure was consistent with the embedded-bipole topology that we identified and modeled previously as an origin of coronal jets. In addition, this event contained a mini-filament, which led to important insights into the energy storage and release mechanisms. SDO/HMI magnetograms revealed footpoint motions in the primary minority-polarity region at the eruption site, but show negligible flux emergence or cancellation for at least 16 hours before the eruption. Therefore, the free energy powering this jet probably came from magnetic shear concentrated at the polarity inversion line within the embedded bipole. We find that the observed activity sequence and its interpretation closely match the predictions of the breakout jet model, strongly supporting the hypothesis that the breakout model can explain solar eruptions on a wide range of scales.

THREE-DIMENSIONAL STRUCTURE AND EVOLUTION OF EXTREME-ULTRAVIOLET BRIGHT POINTS OBSERVED BY STEREO/SECCHI/EUVI

Ryun-Young **Kwon**1,2, Jongchul Chae3, Joseph M. Davila2, Jie Zhang4, Yong-Jae Moon5, Watanachak Poomvises1,2, and Shaela I. Jones

2012 ApJ 757 167

We unveil the three-dimensional structure of quiet-Sun EUV bright points and their temporal evolution by applying a triangulation method to time series of images taken by SECCHI/EUVI on board the STEREO twin spacecraft. For this study we examine the heights and lengths as the components of the three-dimensional structure of EUV bright points and their temporal evolutions. Among them we present three bright points which show three distinct changes in the height and length: decreasing, increasing, and steady. We show that the three distinct changes are consistent with the motions (converging, diverging, and shearing, respectively) of their photospheric magnetic flux concentrations. Both growth and shrinkage of the magnetic fluxes occur during their lifetimes and they are dominant in the initial and later phases, respectively. They are all multi-temperature loop systems which have hot loops (~106.2 K) overlying cooler ones (~106.0 K) with cool legs (~104.9 K) during their whole evolutionary histories. Our results imply that the multi-thermal loop system is a general character of EUV bright points. We conclude that

EUV bright points are flaring loops formed by magnetic reconnection and their geometry may represent the reconnected magnetic field lines rather than the separator field lines.

STEREOSCOPIC DETERMINATION OF HEIGHTS OF EXTREME ULTRAVIOLET BRIGHT POINTS USING DATA TAKEN BY SECCHI/EUVI ABOARD *STEREO*

Ryun-Young **Kwon**1, Jongchul Chae1, and Jie Zhang2

Astrophysical Journal, 714:130–137, **2010** May

We measure the heights of EUV bright points (BPs) above the solar surface by applying a stereoscopicmethod to the data taken by the *Solar TErrestrial RElations Observatory/*SECCHI/Extreme UltraViolet Imager (EUVI).We have developed a three-dimensional reconstruction method for point-like features such as BPs using the simple principle that the position of a point in the three-dimensional space is specified as the intersection of two lines of sight. From a set of data consisting of EUVI 171 Å, 195 Å, 284 Å, and 304Å images taken on 11 days arbitrarily selected during a period of 14 months, we have identified and analyzed 210 individual BPs that were visible on all four passband images and smaller than 30 Mm. The BPs seen in the 304Å images have an average height of 4.4 Mm, and are often associated with the legs of coronal loops. In the 171 Å, 195 Å, and 284Å images the BPs appear loop-shaped, and have average heights of 5.1, 6.7, and 6.1 Mm, respectively. Moreover, there is a tendency that overlying loops are filled with hotter plasmas. The average heights of BPs in 171 Å, 195 Å, and 284Å passbands are roughly twice the corresponding average lengths. Our results support the notion that an EUV BP represents a system of small loops with temperature stratification like flaring loops, being consistent with the magnetic reconnection origin.

Magnetic Field-Constrained Ensemble Image Segmentation of Coronal Holes in Chromospheric Observations

Jaime A. **Landeros**, Michael S. Kirk, C. Nick Arge, Laura E. Boucheron, Jie Zhang, Vadim M. Uritsky, Jeremy A. Grajeda, Matthew Dupertuis

Solar Phys. **2024**

https://arxiv.org/pdf/2405.04731

Coronal Holes (CHs) are large-scale, low-density regions in the solar atmosphere which may expel high-speed solar wind streams that incite hazardous, geomagnetic storms. Coronal and solar wind models can predict these high-speed streams and the performance of the coronal model can be validated against segmented CH boundaries. We present a novel method named Sub-Transition Region Identification of Ensemble Coronal Holes (STRIDE-CH) to address prominent challenges in segmenting CHs with Extreme Ultraviolet (EUV) imagery. Ground-based, chromospheric He I 10830 Å line imagery and underlying Fe I photospheric magnetograms are revisited to disambiguate CHs from filaments and quiet Sun, overcome obscuration by coronal loops, and complement established methods in the community which use space-borne, coronal EUV observations. Classical computer vision techniques are applied to constrain the radiative and magnetic properties of detected CHs, produce an ensemble of boundaries, and compile these boundaries in a confidence map that quantifies the likelihood of CH presence throughout the solar disk. This method is science-enabling towards future studies of CH formation and variability from a mid-atmospheric perspective. **July 14, 2003, June 11, 2012**

THE OFF-DISK THERMAL STRUCTURE OF A POLAR CORONAL HOLE

Enrico **Landi**

Astrophysical Journal, 685:1270–1276, 2008

http://www.journals.uchicago.edu/doi/pdf/10.1086/591225

The thermal structure of the coronal portion of coronal holes is a key factor in the modeling of the source regions and acceleration mechanisms of the fast solar wind. Studies aimed at this region are best carried out on observations outside the disk, where the chromosphere and transition region are not included in the line of sight. In the past, many off-disk studies measured the line-of-sight temperature using line intensity ratios, a method that cannot provide information on the distribution of material with temperature; a few off-disk DEM determinations are also available, which are limited to a few heights only. No EM loci study has been carried out to the best of our knowledge. In this paper we use SOHO SUMER deep-exposure spectra of a polar coronal hole observed in 1996 to carry out a systematic investigation of the thermal structure of the emitting plasma as a function of distance from the limb, making use of the EM loci technique. Instrument-scattered light limits our investigation to distances in the 1.03–1.17 R_ range, where we find that the plasma is close to isothermal along the line of sight, with temperature slowly increasing with distance from the limb.

In Situ Signatures of Interchange Reconnection between Magnetic Clouds and Open Magnetic Fields: A Mechanism for the Erosion of Polar Coronal Holes?

Benoit **Lavraud**, Mathew J. Owens and Alexis P. Rouillard

Solar Physics, Volume 270, Number 1, 285-296, **2011, File**

We outline a method to determine the direction of solar open flux transport that results from the opening of magnetic clouds (MCs) by interchange reconnection at the Sun based solely on in-situ observations. This method uses established findings about i) the locations and magnetic polarities of emerging MC footpoints, ii) the hemispheric dependence of the helicity of MCs, and iii) the occurrence of interchange reconnection at the Sun being signaled by uni-directional suprathermal electrons inside MCs. Combining those observational facts in a statistical analysis of MCs during solar cycle 23 (period 1995−2007), we show that the time of disappearance of the northern polar coronal hole (1998−1999), permeated by an outward-pointing magnetic field, is associated with a peak in the number of MCs originating from the northern hemisphere and connected to the Sun by outward-pointing magnetic field lines. A similar peak is observed in the number of MCs originating from the southern hemisphere and connected to the Sun by inward-pointing magnetic field lines. This pattern is interpreted as the result of interchange reconnection occurring between MCs and the open field lines of nearby polar coronal holes. This reconnection process closes down polar coronal hole open field lines and transports these open field lines equatorward, thus contributing to the global coronal magnetic field reversal process. These results will be further constrainable with the rising phase of solar cycle 24.

Photospheric Abundances of Polar Jets on the Sun Observed by Hinode

Kyoung-Sun **Lee**1, David H. Brooks2, and Shinsuke Imada

2015 ApJ 809 114

Many jets are detected at X-ray wavelengths in the Sun's polar regions, and the ejected plasma along the jets has been suggested to contribute mass to the fast solar wind. From in situ measurements in the magnetosphere, it has been found that the fast solar wind has photospheric abundances while the slow solar wind has coronal abundances. Therefore, we investigated the abundances of polar jets to determine whether they are the same as that of the fast solar wind. For this study, we selected 22 jets in the polar region observed by Hinode/EUV Imaging Spectroscopy (EIS) and X-ray Telescope (XRT) simultaneously on **2007 November 1–3**. We calculated the First Ionization Potential (FIP) bias factor from the ratio of the intensity between high (S) and low (Si, Fe) FIP elements using the EIS spectra. The values of the FIP bias factors for the polar jets are around 0.7–1.9, and 75% of the values are in the range of 0.7–1.5, which indicates that they have photospheric abundances similar to the fast solar wind. The results are consistent with the reconnection jet model where photospheric plasma emerges and is rapidly ejected into the fast wind.

Coronal Field Opens at Lower Height During the Solar Cycles 22 and 23 Minimum Periods: IMF Comparison Suggests the Source Surface Should Be Lowered<<<

C. O. **Lee**, J. G. Luhmann, J. T. Hoeksema, X. Sun, C. N. Arge & I. Pater

Solar Physics, Volume 269, Number 2, 367-388, **2011**

The solar cycle 23 minimum period has been characterized by a weaker solar and interplanetary magnetic field. This provides an ideal time to study how the strength of the photospheric field affects the interplanetary magnetic flux and, in particular, how much the observed interplanetary fields of different cycle minima can be understood simply from differences in the areas of the coronal holes, as opposed to differences in the surface fields within them. In this study, we invoke smaller source surface radii in the potential-field source-surface (PFSS) model to construct a consistent picture of the observed coronal holes and the near-Earth interplanetary field strength as well as polarity measurements for the cycles 23 and 22 minimum periods. Although the source surface value of 2.5 $R_\odot$ is typically used in PFSS applications, earlier studies have shown that using smaller source surface heights generates results that better match observations during low solar activity periods. We use photospheric field synoptic maps from Mount Wilson Observatory (MWO) and find that the values of $\approx$ 1.9 $R_\odot$ and $\approx$ 1.8 $R_\odot$ for the cycles 22 and 23 minimum periods, respectively, produce the best results. The larger coronal holes obtained for the smaller source surface radius of cycle 23 somewhat offsets the interplanetary consequences of the lower magnetic field at their photospheric footpoints. For comparison, we also use observations from the Michelson Doppler Imager (MDI) and find that the source surface radius of $\approx$ 1.5 $R_\odot$ produces better results for cycle 23, rather than $\approx$ 1.8 $R_\odot$ as suggested from MWO observations. Despite this difference, our results obtained from MWO and MDI observations show a qualitative consistency regarding the origins of the interplanetary field and suggest that users of PFSS models may want to consider using these smaller values for their source surface heights as long as the solar activity is low.

TURBULENT PAIR DISPERSION OF PHOTOSPHERIC BRIGHT POINTS

F. **Lepreti**1,2, V. Carbone1,3, V. I. Abramenko4, V. Yurchyshyn4, P. R. Goode4, V. Capparelli1, and A. Vecchio

2012 ApJ 759 L17

Observations of solar granulation obtained with the New Solar Telescope of Big Bear Solar Observatory are used to study the turbulent pair dispersion of photospheric bright points in a quiet-Sun area, a coronal hole, and an active region plage. In all the three magnetic environments, it is found that the pair mean-squared separation Δ2(t) follows a power-law timescaling Δ2(t) ~ t η in the range 10 s t 400 s. The power-law index is found to be η 1.5 for all the three investigated regions. It is shown that these results can be explained in the same framework as the classical Batchelor theory, under the hypothesis that the observed range of timescales corresponds to a non-asymptotic regime in which the photospheric bright points keep the memory of their initial separations.

Dark Halos around Solar Active Regions. I. Emission properties of the Dark Halo around NOAA 12706

Serena Maria **Lezzi**, Vincenzo Andretta, Mariarita Murabito, Giulio Del Zanna

A&A **2023**

https://arxiv.org/pdf/2309.11956.pdf

Dark areas around active regions (ARs) have been first observed in chromospheric lines more than a century ago and are now associated to the H{\alpha} fibril vortex around ARs. Nowadays, large areas surrounding ARs with reduced emission relative to the Quiet Sun (QS) are also observed in spectral lines emitted in the transition-region (TR) and low-corona. For example, they are clearly seen in the SDO/AIA 171 Å images. We name these chromospheric and TR/coronal dark regions as Dark Halos (DHs). Coronal DHs are poorly studied and, because their origin is still unknown, to date it is not clear if they are related to the chromospheric fibrillar ones. Furthermore, they are often mistaken for Coronal Holes (CHs). Our goal is to characterize the emission properties of a DH by combining, for the first time, chromospheric, TR and coronal observations in order to provide observational constraints for future studies on the origin of DHs. This study also aims at investigating the different properties of DHs and CHs and at providing a quick-look recipe to distinguish between them. We study the DH around AR NOAA 12706 and the southern CH, that were on the disk on **2018 April 22**, by analyzing IRIS full-disk mosaics, SDO/AIA filtergrams and SDO/HMI magnetograms. Fibrils are observed all around the AR core in the chromospheric Mg II h&k IRIS mosaics, most clearly in the h3 and k3 features. The TR emission in the DH is much lower compared to QS area, unlike in the CH. Moreover, the DH is much more extended in the low-corona than in the chromospheric Mg II h3 and k3 images. Finally, the intensities, emission measure, spectral profile, non-thermal velocity and average magnetic field strength measurements clearly show that DHs and CHs exhibit different characteristics and therefore should be considered as distinct types of structures on the Sun. **2018 April 22, 13 Apr 2019, 5 May 2019**

Moving structures in ultraviolet bright points: observations from Solar Orbiter/EUI

Dong **Li**

A&A 662, A7 **2022**

https://arxiv.org/pdf/2204.02047

https://www.aanda.org/articles/aa/pdf/2022/06/aa42884-21.pdf

Moving structures have been detected in coronal bright points and in a solar flare in active regions, which were bi-directional, symmetrical, simultaneous, and quasi-periodic (Ning & Guo 2014; Ning 2016; Li et al. 2016a). They could be regarded as observational evidence of plasma outflows via magnetic reconnection. In this article, we explored pairs of moving structures in fifteen ultraviolet bright points (UBPs), which were observed in the quiet Sun or inside a small active region on **19 November 2020**, and measured by the High Resolution (HRI) Telescopes of the Extreme Ultraviolet Imager (EUI) on board the Solar Orbiter (SolO) in two passbands, HRIEUV 174 Å and HRILy{\alpha} 1216 Å. Moving structures observed in ten UBPs as starting from their bright cores and propagating toward two ends, are interpreted as diverging motions of bi-directional moving structures. These moving structures are also characterized by simultaneity and symmetry and in the case of seven UBPs they exhibit quasi-periodicity. They could be generated by outflows after magnetic reconnections. Moving structures seen in another five UBPs as originating from double ends and moving closer, and merging together, are manifested as converging motions, which might be caused by inflows through the magnetic reconnection, or might be interpreted as upflows driven by the chromospheric evaporation.

The Bi-directional Moving Structures in a Coronal Bright Point

Dong **Li**, Zongjun Ning, Yingna Su

Ap&SS September **2016**, 361:301

http://arxiv.org/pdf/1608.01534v1.pdf

We report the bi-directional moving structures in a coronal bright point (CBP) on **2015 July 14**. It is observed by the Atmospheric Imaging Assembly (AIA) onboard Solar Dynamics Observatory (SDO). This CBP has a lifetime of about 10 minutes, and a curved shape. The observations show that many bright structures are moving intermittently outward from the CBP brightness core. Such moving structures are clearly seen at AIA 171, 193, 211, 131, 94, 335 and 304 A, slit-jaw (SJI) 1330 and 1400 A. In order to analyze these moving structures, the CBP is cut along the moving direction with a curved slit from the AIA and SJI images. Then we can obtain the time-distance slices, including the intensity and intensity-derivative diagrams, from which, the moving structures are recognized as the oblique streaks, and they are characterized by the bi-direction, simultaneity, symmetry, and periodicity. The average speed is around 300 km/s, while the typically period is about 90 s. All these features (including the bi-directional flows and their periodicity) can be detected simultaneously at all the 9 wavelengths. This CBP takes place at the site between a small pair of magnetic polarities. High time resolution observations show that they are moving close to each other during its lifetime. These facts support the magnetic reconnection model of the CBP and the bi-directional moving structures could be the observational outflows after the reconnection. Therefore, they can be as the direct observation evidence of the magnetic reconnection.

Subarcsecond Bright Points and Quasi-periodic Upflows Below a Quiescent Filament Observed by the IRIS

Ting **Li**, Jun Zhang

A&A **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**

Solar Open Flux Migration from Pole to Pole: Magnetic Field Reversal

Chia-Hsien **Lin**

HMI Science Nuggets #101 June **2018** http://hmi.stanford.edu/hminuggets/?p=2516

Solar open magnetic flux (OMF) regions are the regions with magnetic field lines extending far away from the Sun. They represent the largest-scale magnetic-field structure of the Sun. Their “open” magnetic field configuration allows plasma to flow into the interplanetary space. Therefore, they are major source regions for high-speed solar wind streams (HSS), which can cause significant geomagnetic activity at the Earth[1]. Observed in soft X-ray and certain extreme ultraviolet (EUV) wavelength, OMF regions often appear dark, and are called coronal holes[2]/sup>.

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**

Coronal Hole Detection and Open Magnetic Flux

J. A. **Linker**, S. G. Heinemann, M. Temmer, M. J. Owens, R. M. Caplan, C. N. Arge, E. Asvestari, V. Delouille, C. Downs, S. J. Hofmeister, I. C. Jebaraj, M. Madjarska, R. Pinto, J. Pomoell, E. Samara, C. Scolini, B. Vrsnak

ApJ **918** 21 **2021**
https://arxiv.org/pdf/2103.05837.pdf
https://iopscience.iop.org/article/10.3847/1538-4357/ac090a/pdf
https://doi.org/10.3847/1538-4357/ac090a
Many scientists use coronal hole (CH) detections to infer open magnetic flux. Detection techniques differ in the areas that they assign as open, and may obtain different values for the open magnetic flux. We characterize the uncertainties of these methods, by applying six different detection methods to deduce the area and open flux of a near-disk center CH observed on 9/19/2010, and applying a single method to five different EUV filtergrams for this CH. Open flux was calculated using five different magnetic maps. The standard deviation (interpreted as the uncertainty) in the open flux estimate for this CH was about 26%. However, including the variability of different magnetic data sources, this uncertainty almost doubles to 45%. We use two of the methods to characterize the area and open flux for all CHs in this time period. We find that the open flux is greatly underestimated compared to values inferred from in-situ measurements (by 2.2-4 times). We also test our detection techniques on simulated emission images from a thermodynamic MHD model of the solar corona. We find that the methods overestimate the area and open flux in the simulated CH, but the average error in the flux is only about 7%. The full-Sun detections on the simulated corona underestimate the model open flux, but by factors well below what is needed to account for the missing flux in the observations. Under-detection of open flux in coronal holes likely contributes to the recognized deficit in solar open flux, but is unlikely to resolve it. **September 19, 2010**

The Open Flux Problem

J. A. **Linker**, R. M. Caplan, C. Downs, P Riley, Z Mikic, R. Lionello, C. J. Henney, C. N. Arge, Y. Liu, M. L. Derosa, A. Yeates, M. J. Owens
2017 ApJ 848 70
https://arxiv.org/pdf/1708.02342.pdf
The heliospheric magnetic field is of pivotal importance in solar and space physics. The field is rooted in the Sun's photosphere, where it has been observed from ground- and space-based observatories for over four decades. Global maps of the solar magnetic field based on full disk magnetograms are commonly used as boundary conditions for coronal and solar wind models. Two primary observational constraints on the models are (1) the open field regions in the model should approximately correspond to coronal holes observed in emission, and (2) the magnitude of the open magnetic flux in the model should match that inferred from in situ spacecraft measurements. In this study, we calculate both MHD and PFSS solutions using fourteen different magnetic maps produced from five different types of observatory magnetograms, for the time period surrounding July, 2010. We have found that for all of the model/map combinations, models that have coronal hole areas close to observations underestimate the interplanetary magnetic flux, or, conversely, for models to match the interplanetary flux, the modeled open field regions are larger than coronal holes observed in EUV emission. In an alternative approach, we estimate the open magnetic flux entirely from solar observations by combining automatically detected coronal holes for Carrington rotation 2098 with observatory synoptic magnetic maps for this time period. We show that this method also underestimates the interplanetary magnetic flux. Our results imply that either typical observatory maps underestimate the Sun's magnetic flux, or a significant portion of the open magnetic flux is not rooted in regions that are obviously dark in EUV and X-ray emission**. July 8, 2010, 16 June-13 July 2010**

THE EVOLUTION OF OPEN MAGNETIC FLUX DRIVEN BY PHOTOSPHERIC DYNAMICS

Jon A. **Linker**1, Roberto Lionello1, Zoran Mikić1, Viacheslav S. Titov1 and Spiro K. Antiochos2
2011 ApJ 731 110
The coronal magnetic field is of paramount importance in solar and heliospheric physics. Two profoundly different views of the coronal magnetic field have emerged. In quasi-steady models, the predominant source of open magnetic field is in coronal holes. In contrast, in the interchange model, the open magnetic flux is conserved, and the coronal magnetic field can only respond to the photospheric evolution via interchange reconnection. In this view, the open magnetic flux diffuses through the closed, streamer belt fields, and substantial open flux is present in the streamer belt during solar minimum. However, Antiochos and coworkers, in the form of a conjecture, argued that truly isolated open flux cannot exist in a configuration with one heliospheric current sheet—it will connect via narrow corridors to the polar coronal hole of the same polarity. This contradicts the requirements of the interchange model. We have performed an MHD simulation of the solar corona up to 20 R to test both the interchange model and the Antiochos conjecture. We use a synoptic map for Carrington rotation 1913 as the boundary condition for the model, with two small bipoles introduced into the region where a positive polarity extended coronal hole forms. We introduce flows at the photospheric boundary surface to see if open flux associated with the bipoles can be moved into the closed-field region. Interchange reconnection does occur in response to these motions. However, we find that the open magnetic flux cannot be simply injected into closed-field regions—the flux eventually closes down and disconnected flux is created. Flux either opens or closes, as required, to maintain topologically distinct open- and closed-field regions, with no indiscriminate mixing of the two. The early evolution conforms to the Antiochos

conjecture in that a narrow corridor of open flux connects the portion of the coronal hole that is nearly detached by one of the bipoles. In the later evolution, a detached coronal hole forms, in apparent violation of the Antiochos conjecture. Further investigation reveals that this detached coronal hole is actually linked to the extended coronal hole by a separatrix footprint on the photosphere of zero width. Therefore, the essential idea of the conjecture is preserved, if we modify it to state that coronal holes in the same polarity region are always linked, either by finite width corridors or separatrix footprints. The implications of these results for interchange reconnection and the sources of the slow solar wind are briefly discussed.

Unusually low density regions in the compressed slow wind: Solar wind transients of small coronal hole origin

Yong C.-M. **Liu**1, Zhaohui Qi1,2, Jia Huang3, Chi Wang1,2, Hui Fu4, Berndt Klecker5, Linghua Wang6 and Charles J. Farrugia7

A&A 635, A49 (**2020**)

https://doi.org/10.1051/0004-6361/201935884

We report on two small solar wind transients embedded in the corotating interaction region, characterized by surprisingly lower proton density compared with their surrounding regions. In addition to lower density, these two small solar wind transients showed other interesting features like higher proton temperature, higher alpha-proton ratios, and lower charge states (C+6/C+5 and O+7/O+6). A synthesized picture for event One combining the observations by STEREO B, ACE, and Wind showed that this small solar transient has an independent magnetic field. Back-mapping links the origin of the small solar transient to a small coronal hole on the surface of the Sun. Considering these special features and the back-mapping, we conclude that such small solar wind transients may have originated from a small coronal hole at low latitudes.

Manifestations of bright points observed in G-band and Ca II H by Hinode/SOT

Yanxiao **Liu**, Ning Wu, Jun Lin

RAA Vol 18, No 10 125 **2018**

http://www.raa-journal.org/raa/index.php/raa/article/view/4185

An algorithm was developed for identifying and tracking a magnetic bright point, or bright point (BP) for short, observed in both the photosphere (G-band) and chromosphere (Ca II H), as well as for pairing a photospheric BP (PBP) with its conjugate chromospheric BP (CBP). Two sets of data observed by Hinode/SOT in the quiet Sun near the disk center were analyzed. About 278 PBP-CBP pairs were identified and tracked. Lifetimes of both the PBPs and CBPs follow an exponential distribution with average lifetimes of 174 s and 163 s, respectively. We found that the differences in appearance time, in disappearance time and in lifetime of the two kinds of BPs all follow Gaussian distributions,which may indicate that the mechanisms of PBP and CBP formation/disintegration are different. However, the lifetimes of PBPs and CBPs are positively correlated with one another, with a correlation coefficient of 0.8. Furthermore, we calculated the horizontal displacement between the PBP and its conjugate CBP, which follows a Gaussian function with an average and standard deviation of (67.7 ± 67.7) km. We also calculated the amplitude of the flux tube shape change which might be caused by MHD waves propagating along the flux tube, and found that it follows an exponential distribution very well.

Studies of Isolated and Non-isolated Photospheric Bright Points in an Active Region Observed by the New Vacuum Solar Telescope

Yanxiao **Liu**1,2,3, Yongyuan Xiang1,3, Robertus Erdélyi4,5, Zhong Liu1,3, Dong Li6,7,Zongjun Ning6,7, Yi Bi1,2,3, Ning Wu8, and Jun Lin1,3

2018 ApJ 856 17

http://sci-hub.tw/10.3847/1538-4357/aab150

Properties of photospheric bright points (BPs) near an active region have been studied in TiO λ7058 Å images observed by the New Vacuum Solar Telescope of the Yunnan Observatories. We developed a novel recognition method that was used to identify and track 2010 BPs. The observed evolving BPs are classified into isolated (individual) and non-isolated (where multiple BPs are observed to display splitting and merging behaviors) sets. About 35.1% of BPs are non-isolated. For both isolated and non-isolated BPs, the brightness varies from 0.8 to 1.3 times the average background intensity and follows a Gaussian distribution. The lifetimes of BPs follow a log-normal distribution, with characteristic lifetimes of (267 ± 140) s and (421 ± 255) s, respectively. Their size also follows log-normal distribution, with an average size of about (2.15 ± 0.74) × 104 km2 and (3.00 ± 1.31) × 104 km2 for area, and (163 ± 27) km and (191 ± 40) km for diameter, respectively. Our results indicate that regions with strong background magnetic field have higher BP number density and higher BP area coverage than regions with weak background field. Apparently, the brightness/size of BPs does not depend on the background field. Lifetimes in regions with strong background magnetic field are shorter than those in regions with weak background field, on average. **2013 May 21**

Plasma dynamics in solar macrospicules from high-cadence EUV observations

I.P. **Loboda**, S.A. Bogachev

A&A **2016**

https://arxiv.org/pdf/1610.07536v1.pdf

Macrospicules are relatively large spicule-like formations found mainly over the polar coronal holes when observing in the transition region spectral lines. In this study, we took advantage of the two short series of observations in the He II 304 \r{A} line obtained by the TESIS solar observatory with a cadence of up to 3.5 s to study the dynamics of macrospicules in unprecedented detail. We used a one-dimensional hydrodynamic method based on the assumption of their axial symmetry and on a simple radiative transfer model to reconstruct the evolution of the internal velocity field of 18 macrospicules from this dataset. Besides the internal dynamics, we studied the motion of the apparent end points of the same 18 macrospicules and found 15 of them to follow parabolic trajectories with high precision which correspond closely to the obtained velocity fields. We found that in a clear, unperturbed case these macrospicules move with a constant deceleration inconsistent with a purely ballistic motion and have roughly the same velocity along their entire axis, with the obtained decelerations typically ranging from 160 to 230 m/s^2, and initial velocities from 80 to 130 km/s. We also found a propagating acoustic wave for one of the macrospicules and a clear linear correlation between the initial velocities of the macrospicules and their decelerations, which indicates that they may be driven by magneto-acoustic shocks. Finally, we inverted our previous method by taking velocities from the parabolic fits to give rough estimates of the percentage of mass lost by 12 of the macrospicules. We found that typically from 10 to 30% of their observed mass fades out of the line (presumably being heated to higher coronal temperatures) with three exceptions of 50% and one of 80%.

Deceleration and dispersion of large-scale coronal bright fronts

D. M. **Long**, P. T. Gallagher, R. T. J. McAteer and D. S. Bloomfield

A&A 531, A42 (**2011**)

http://arxiv.org/pdf/1104.4334v1.pdf

Context. One of the most dramatic manifestations of solar activity are large-scale coronal bright fronts (CBFs) observed in extreme ultraviolet (EUV) images of the solar atmosphere. To date, the energetics and kinematics of CBFs remain poorly understood, due to the low image cadence and sensitivity of previous EUV imagers and the limited methods used to extract the features.

Aims. In this paper, the trajectory and morphology of CBFs was determined in order to investigate the varying properties of a sample of CBFs, including their kinematics and pulse shape, dispersion, and dissipation.

Methods. We have developed a semi-automatic intensity profiling technique to extract the morphology and accurate positions of CBFs in 2.5–10 min cadence images from STEREO/EUVI. The technique was applied to sequences of 171 Å and 195 Å images from STEREO/EUVI in order to measure the wave properties of four separate CBF events.

Results. Following launch at velocities of ~240–450 km s-1 each of the four events studied showed significant negative acceleration ranging from ~−290 to −60 m s-2. The CBF spatial and temporal widths were found to increase from ~50 Mm to ~200 Mm and ~100 s to ~1500 s respectively, suggesting that they are dispersive in nature. The variation in position-angle averaged pulse-integrated intensity with propagation shows no clear trend across the four events studied. These results are most consistent with CBFs being dispersive magnetoacoustic waves.

Coronal Holes and Open Magnetic Flux over Cycles 23 and 24

Chris **Lowder**, Jiong Qiu, Robert Leamon

Solar Phys. 292:18 **2017**

https://arxiv.org/pdf/1612.07595v1.pdf

As the observational signature of the footprints of solar magnetic field lines open into the heliosphere, coronal holes provide a critical measure of the structure and evolution of these lines. Using a combination of Solar and Heliospheric Observatory / Extreme ultraviolet Imaging Telescope (SOHO/EIT), Solar Dynamics Observatory / Atmospheric Imaging Assembly (SDO/AIA) and Solar Terrestrial Relations Observatory / Extreme Ultraviolet Imager (STEREO/EUVI A/B) extreme ultraviolet (EUV) observations spanning 1996-2015 (nearly two solar cycles), coronal holes are automatically detected and characterized. Coronal hole area distributions show distinct behavior in latitude, defining the domain of polar and low-latitude coronal holes. The northern and southern polar regions show a clear asymmetry, with a lag between hemispheres in the appearance and disappearance of polar coronal holes.

Measurements of EUV Coronal Holes and Open Magnetic Flux

Lowder, C., Qiu, J., Leamon, R. & Liu, Y.
E-print, Feb **2014**; **2014** ApJ 783 142; **File**
http://arxiv.org/pdf/1502.06038v1.pdf
Coronal holes are regions on the Sun's surface that map the footprints of open magnetic field lines. We have developed an automated routine to detect and track boundaries of long-lived coronal holes using full-disk extreme-ultraviolet (EUV) images obtained by SOHO/EIT, SDO/AIA, and STEREO/EUVI. We measure coronal hole areas and magnetic flux in these holes, and compare the measurements with calculations by the potential field source surface (PFSS) model. It is shown that, from 1996 through 2010, the total area of coronal holes measured with EIT images varies between 5% and 17% of the total solar surface area, and the total unsigned open flux varies between (2-5)? 1022 Mx. The solar cycle dependence of these measurements is similar to the PFSS results, but the model yields larger hole areas and greater open flux than observed by EIT. The AIA/EUVI measurements from 2010-2013 show coronal hole area coverage of 5%-10% of the total surface area, with significant contribution from low latitudes, which is under-represented by EIT. AIA/EUVI have measured much enhanced open magnetic flux in the range of (2-4)? 1022 Mx, which is about twice the flux measured by EIT, and matches with the PFSS calculated open flux, with discrepancies in the location and strength of coronal holes. A detailed comparison between the three measurements (by EIT, AIA-EUVI, and PFSS) indicates that coronal holes in low latitudes contribute significantly to the total open magnetic flux. These low-latitude coronal holes are not well measured with either the He I 10830 line in previous studies, or EIT EUV images; neither are they well captured by the static PFSS model. The enhanced observations from AIA/EUVI allow a more accurate measure of these low-latitude coronal holes and their contribution to open magnetic flux. **2010-06-29**

Full Surface Automated Coronal Hole Detection and Characterization to Constrain Global Magnetic Field Models

Lowder, C., Qiu, J., Leamon, R. & Liu, Y.
American Astronomical Society, AAS Meeting #220, #411.06; **File of the 10-page paper**
One of the primary mission goals of the Solar Terrestrial Relations Observatory (STEREO) : Extreme Ultraviolet Imager (EUVI) is to provide full extreme-ultraviolet (EUV) coverage of the solar surface in conjunction with the Solar and Heliospheric Observatory (SOHO) : Extreme Ultraviolet Imaging Telescope (EIT) or the Solar Dynamics Observatory (SDO) : Atmospheric Imaging Assembly (AIA). Now, five years after launch, su_cient orbital separation has occurred for this to come to fruition. Using EUV images from STEREO:EUVI in 195A and SDO:AIA in 193A, we can create full surface maps of coronal holes. Our method employs an intensity thresholding technique in conjunction with line-of-sight magnetic field measurements to automatically distinguish filament channels. This full surface coverage provides a unique opportunity to compare observed coronal holes with the predicted open magnetic field regions from both potential field models in addition to non-potential models. Our method is able to detect and characterize both long-term coronal hole structures, as well as shorter lived, transient coronal holes. Here, this method is described in detail, with comparisons drawn between observed coronal hole boundaries and open-field boundaries derived from models. In addition, quantities that are crucially dependent on these boundaries are considered, namely the open magnetic flux.

Solar Cycle Variability in Coronal Holes and their Effects on Solar Wind Sources

J.G. **Luhmann**, Yan Li, C.O. Lee, L.K. Jian, C.N. Arge, P. Riley
Space Weather e2022SW003110 **Volume20, Issue10** **2022**
https://doi.org/10.1029/2022SW003110
https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2022SW003110
https://doi.org/10.1029/2022SW003110
Various upstream spacecraft have now observed the solar wind conditions affecting the Earth since the 1970s, covering over four solar activity cycles. These measurements provide a long term picture of the related patterns in large scale incident plasma and magnetic field parameters of interest for both interpreting cycles in geospace effects, and understanding how the Sun controls our space environment. This paper focuses on the latter, in part to provide context at the start of the new solar cycle 25, and toward establishing connections between the 1 AU ecliptic solar wind behavior and the unprecedented near-Sun measurements of heliospheric features on Parker Solar Probe (PSP) and Solar Orbiter (SolO). Magnetograph data-based PFSS models provide a basic picture of how the solar wind sources, including those that give rise to corotating high speed streams in the ecliptic, have changed since the beginning of the record of regular solar wind measurements. In particular, they suggest the contributions from low to mid latitude coronal holes dominate the observed cycles (21-24), especially the weaker cycles (23 and 24), impacting upstream measurement interpretations, modeling, and forecasting considerations. For example, recurring features are affected by differential rotation of the Sun's surface field, which through its effects on the corona, can produce solar wind streams reappearing at ~25 to 30 day intervals instead of at the canonical 27.3 day Carrington rotation rate. In addition, the conditions that lead to the corotating stream structure that can dominate periods of low solar activity are seen to be more complicated than suggested by the simple concepts of early studies. The overall

results illustrate where in the cycles well-defined, long-lived large scale structures can be expected, and the advantages of synoptic displays of 1 AU solar wind parameters for anticipating timings of recurring features.

Centennial evolution of monthly solar wind speeds: Fastest monthly solar wind speeds from long-duration coronal holes†

R. **Lukianova**, L. Holappa, K. Mursula

JGR **2017**

https://arxiv.org/pdf/1702.03924.pdf

High speed solar wind streams (HSSs) are very efficient drivers of geomagnetic activity at high latitudes. In this paper we use a recently developed ΔH parameter of geomagnetic activity, calculated from the night-side hourly magnetic field measurements of the Sodankylä observatory, as a proxy for solar wind (SW) speed at monthly time resolution in 1914-2014 (solar cycles 15-24). The seasonal variation in the relation between monthly ΔH and solar wind speed is taken into account by calculating separate regressions between ΔH and SW speed for each month. Thereby, we obtain a homogeneous series of proxy values for monthly solar wind speed for the last 100 years. We find that the strongest HSS-active months of each solar cycle occur in the declining phase, in years 1919, 1930, 1941, 1952, 1959, 1973, 1982, 1994 and 2003. Practically all these years are the same or adjacent to the years of annual maximum solar wind speeds. This implies that the most persistent coronal holes, lasting for several solar rotations and leading to the highest annual SW speeds, are also the sources of the highest monthly SW speeds. Accordingly, during the last 100 years, there were no coronal holes of short duration (of about one solar rotation) that would produce faster monthly (or solar rotation) averaged solar wind than the most long-living coronal holes in each solar cycle produce.

A New Forecasting Index for SolarWind Velocity Based on EIT 284 Å Observations

Bingxian **Luo** · Qiuzhen Zhong · Siqing Liu · Jiancun Gong

Solar Phys, **2008,** 250: 159–170

DOI 10.1007/s11207-008-9198-4

http://www.springerlink.com/content/q2455h105773547m/fulltext.pdf

Abstract Various solar wind forecasting methods have been developed during the past decade, such as the Wang – Sheeley model and the Hakamada – Akasofu – Fry Version 2 (HAFv2) model. Also, considerable correlation has been found between the solar wind speed *v* and the coronal hole (CH) area A_M on the visible side of the Sun, showing quantitative improvement of forecasting accuracy in low CME activity periods (*e.g.*, Vršnak, Temmer, and Veronig, *Solar Phys.* **240**, 315, 2007a). Properties of lower layers of the solar atmosphere are good indications of the subsequent interplanetary and geomagnetic activities. We analyze the SOHO/EIT 284 Å images and construct a new forecasting factor (Pch) from the brightness of the solar EUV emission, and a good correlation is found between the Pch factor and the 3-day-lag solar wind velocity (*v*) probed by the ACE spacecraft. The main difference between the Pch and A_M factor is that Pch does not depend on the CH-boundary estimate and can reflect both the area and brightness of CH. A simple method of forecasting the solar wind speed near Earth in low CME activity periods is presented. Between Pch and *v* from 21 November until 26 December 2003, the linear correlation coefficient is $R = 0.89$. For comparison we also analyze the data in the same period (DOY 25 – 125, 2005) as Vršnak, Temmer, and Veronig (*Solar Phys.* **240**, 315, 2007a), who used the CH areas A_M for predicting the solar wind parameters. In this period the correlation coefficient between Pch and *v* is $R = 0.70$, whereas for A_M and *v* the correlation coefficient is $R = 0.62$. The average relative difference between the calculated and the observed values is $|\delta| \approx 12.15\%$. Furthermore, for the ten peaks during the analysis period, Pch and *v* show a correlation coefficient of $R = 0.78$, and the average relative difference between the calculated and the observed peak values is $|\delta| \approx 5.83\%$.Moreover, the Pch factor can eliminate personal bias in the forecasting process, which existed in the method using CH area as input parameter, because CH area depends on the CH-boundary estimate but Pch does not. Until now the CH-boundary could not be easily determined since no quantitative criteria can be used to precisely locate CHs from observations, which led to differences in forecasting accuracy.

The Occurrence of Coronal Holes during the Sunspot Cycle

H. **Machiya**, S.-I. Akasofu

JASTP, **2014**, 113, Pages 44-46

http://dx.doi.org/10.1016/j.jastp.2014.03.004

In order to learn the nature of coronal holes for a long period, magnetic disturbances represented by the geomagnetic index C9 (though proxy for coronal holes) for the period from 1884 to 2002 are examined, selecting only those that recur every 27 days during at least six solar rotation periods and separating the rising and declining phases, and also distinguishing one and two coronal holes in one solar rotation. It was found that the occurrence of coronal holes per year (N) during both the rising and the declining phases tends to be more frequent for greater numbers of the peak value of sunspots (R) in each sunspot cycle. The frequency per year is about twice as large for the declining phase as for the rising phase. The N - R relationship is 0.0080R + 0.302 for the rising phase and 0.0152R + 0.203 for the declining phase.

Corrigendum: Volume 119, November 2014, Pages 229

SCSS-Net: Solar Corona Structures Segmentation by Deep Learning

Šimon **Mackovjak**, Martin Harman, Viera Maslej-Krešňáková, Peter Butka

MNRAS **2021**

https://arxiv.org/pdf/2109.10834

Structures in the solar corona are the main drivers of space weather processes that might directly or indirectly affect the Earth. Thanks to the most recent space-based solar observatories, with capabilities to acquire high-resolution images continuously, the structures in the solar corona can be monitored over the years with a time resolution of minutes. For this purpose, we have developed a method for automatic segmentation of solar corona structures observed in EUV spectrum that is based on a deep learning approach utilizing Convolutional Neural Networks. The available input datasets have been examined together with our own dataset based on the manual annotation of the target structures. Indeed, the input dataset is the main limitation of the developed model's performance. Our \textit{SCSS-Net} model provides results for coronal holes and active regions that could be compared with other generally used methods for automatic segmentation. Even more, it provides a universal procedure to identify structures in the solar corona with the help of the transfer learning technique. The outputs of the model can be then used for further statistical studies of connections between solar activity and the influence of space weather on Earth.

26 January 2016, 28 June 2018, June 30, 2018

4.1 Segmentation of coronal holes

Parker Solar Probe Observations of Suprathermal Electron Flux Enhancements Originating from Coronal Hole Boundaries

Allan R **Macneil**, Mathew J Owens, Laura Berčič, Adam J Finley

MNRAS Volume 498, Issue 4, Pages 5273–5283, **2020**

https://arxiv.org/pdf/2009.01558.pdf

Reconnection between pairs of solar magnetic flux elements, one open and the other a closed loop, is theorised to be a crucial process for both maintaining the structure of the corona and producing the solar wind. This 'interchange reconnection' is expected to be particularly active at the open-closed boundaries of coronal holes (CHs). Previous analysis of solar wind data at 1AU indicated that peaks in the flux of suprathermal electrons at slow-fast stream interfaces may arise from magnetic connection to the CH boundary, rather than dynamic effects such as compression. Further, offsets between the peak and stream interface locations are suggested to be the result of interchange reconnection at the source. As a preliminary test of these suggestions, we analyse two solar wind streams observed during the first Parker Solar Probe (PSP) perihelion encounter, each associated with equatorial CH boundaries (one leading and one trailing with respect to rotation). Each stream features a peak in suprathermal electron flux, the locations and associated plasma properties of which are indicative of a solar origin, in agreement with previous suggestions from 1AU observations. Discrepancies between locations of the flux peaks and other features suggest these peaks may too be shifted by source region interchange reconnection. Our interpretation of each event is compatible with a global pattern of open flux transport, although random footpoint motions or other explanations remain feasible. These exploratory results highlight future opportunities for statistical studies regarding interchange reconnection and flux transport at CH boundaries with modern near-Sun missions. **2018.11.05-13**

Active Region Modulation of Coronal Hole Solar Wind

Allan R. **Macneil**1,2, Christopher J. Owen2, Deborah Baker2, David H. Brooks3, Louise K. Harra2,4,5, David M. Long2, and Robert T. Wicks2,6

2019 ApJ 887 146

https://doi.org/10.3847/1538-4357/ab5586

Active regions (ARs) are a candidate source of the slow solar wind (SW), the origins of which are a topic of ongoing research. We present a case study that examines the processes by which SW is modulated in the presence of an AR in the vicinity of the SW source. We compare properties of SW associated with a coronal hole (CH)–quiet Sun boundary to SW associated with the same CH but one Carrington rotation later, when this region bordered the newly emerged NOAA AR 12532. Differences found in a range of in situ parameters are compared between these rotations in the context of source region mapping and remote sensing observations. Marked changes exist in the structure and composition of the SW, which we attribute to the influence of the AR on SW production from the CH boundary. These unique observations suggest that the features that emerge in the AR-associated wind are consistent with an increased occurrence of interchange reconnection during SW production, compared with the initial quiet Sun case.

21 Apr 2016

Hinode/ EIS Nugget, Mar **2020** http://solarb.mssl.ucl.ac.uk/SolarB/nuggets/nugget_2020apr.jsp

2016-03-24, 2016-04-20

Photospheric magnetic flux and coronal emission properties of small-scale bright and faint loops in the quiet Sun⋆

Maria S. **Madjarska**1,2, Klaus Galsgaard3 and Thomas Wiegelmann1

A&A 678, A32 (**2023**)

https://www.aanda.org/articles/aa/pdf/2023/10/aa47058-23.pdf

Context. The study explores the photospheric magnetic properties of bright and faint small-scale loop systems in the solar atmosphere of the quiet Sun, also known as X-ray or coronal bright points.

Aims. To understand how plasma confined in small-scale loops is heated to million degrees, the loop-associated photospheric and coronal magnetic flux properties should be known because the magnetic field is generally assumed to be the main energy source or waveguide. This and follow-up studies aim to provide a qualitative and quantitative investigation of these magnetic properties and their impact on the heating of plasma to million degrees.

Methods. We used quasi-temporal imaging observations taken in the 193 Å channel of the Atmospheric Imaging Assembly (AIA) and line-of-sight magnetograms from the Helioseismic Magnetic Imager (HMI) on board the Solar Dynamics Observatory. The observations cover 48 h of data at a 6 min cadence with a field of view of 400″ × 400″, from which 90 loop systems (of which 83 are CBPs) were extracted and analysed in full detail.

Results. We obtain the evolution properties of both faint and bright small-scale loop systems (SSLSs) related to either magnetic flux emergence or magnetic flux coalescence and a chance encounter of magnetic fluxes. We estimate the lifetimes of the two loop systems and the impact of the magnetic flux evolution on their life span. The photospheric magnetic flux associated with SSLSs confining plasma heated to coronal temperatures is found to cover at least two orders of magnitude from 3.0 × 1018 Mx to 1.8 × 1020 Mx. The analysis of the maximum intensity of SSLSs during their lifetime shows numerous spikes of intensity that are identified as small (a few AIA pixels) compact brightenings associated with cancelling magnetic fluxes. Most of them are identified as microflares. The intensity flux range of these spikes is reported. The coronal intensity flux evolution of SSLSs is strongly correlated with the total unsigned photospheric magnetic flux evolution when there is little or no contamination in the selected field of view of the SSLSs by unrelated magnetic fluxes or intensity features. We report on the footpoint separation and change during the lifetime of the faint and bright SSLSs. The magnetic flux emergence and decay rates of some of the SSLSs are also provided in this study.

Conclusions. The power-law index α of the logarithm of the total unsigned magnetic flux and the total intensity for the full lifetime of SSLSs is 1.10 ± 0.02, compared with 1.14 ± 0.03 for a previous study of the whole disc in the same intensity range (Fe XII 193–195 Å). This indicates that the emission of the corona of the quiet Sun at ∼1.25 MK is mostly confined to small-scale loops (some brighter, others fainter). Therefore, it is imperative to understand the mechanism that heats the plasma in these loops.

Eruptions from coronal bright points: A spectroscopic view by IRIS of a mini-filament eruption, QSL reconnection, and reconnection-driven outflows

Maria S. **Madjarska**, Duncan H. Mackay, Klaus Galsgaard, Thomas Wiegelmann, Haixia Xie

A&A 660, A45 **2022**

https://arxiv.org/pdf/2202.00370.pdf

https://www.aanda.org/articles/aa/pdf/2022/04/aa42439-21.pdf

https://doi.org/10.1051/0004-6361/202142439

The present study investigates a mini-filament eruption associated with cancelling magnetic fluxes. The eruption originates from a small-scale loop complex commonly known as a Coronal Bright Point (CBP). The event is uniquely recorded in both the imaging and spectroscopic data taken with IRIS. We analyse IRIS spectroscopic and slit-jaw imaging observations as well as images taken in the extreme-ultraviolet channels of AIA, and line-of-sight magnetic-field data from HMI onboard the SDO. We also employ an NLFFF relaxation approach based on the HMI magnetogram time series. We identify a strong small-scale brightening as a micro-flare in a CBP. The mini-eruption manifests with the ejection of hot (CBP loops) and cool (mini-filament) plasma recorded in both the imaging and spectroscopic data. The micro-flare is preceded by the appearance of an elongated bright feature in the IRIS slit-jaw 1400 A images located above the polarity inversion line. The micro-flare starts with an IRIS pixel size brightening and propagates bi-directionally along the elongated feature. We detect in both the spectral and imaging IRIS data and AIA data, strong flows along and at the edges of the elongated feature which we believe represent reconnection outflows. Both edges of the elongated feature that wrap around the edges of the erupting MF evolve into a J-type shape creating a sigmoid appearance. A quasi-separatrix layer (QSL) is identified in the vicinity of the polarity inversion line by computing the squashing factor Q in different horizontal planes of the NLFFF model. The QSL reconnection site has the same spectral appearance as the so-called explosive events identified by strong blue- and red-shifted emission, thus answering a long outstanding question about the true nature of this spectral phenomenon.

2017 April 5

The chromospheric component of coronal bright points: Coronal and chromospheric responses to magnetic-flux emergence

Maria S. **Madjarska**, Jongchul Chae, Fernando Moreno-Insertis, Zhenyong Hou, Daniel Nobrega-Siverio, Hannah Kwak, Klaus Galsgaard, Kyuhyoun Cho

A&A 646, A107 (**2021**)

https://arxiv.org/pdf/2012.09426.pdf

https://doi.org/10.1051/0004-6361/202039329

We investigate the chromospheric counterpart of small-scale coronal loops constituting a coronal bright point (CBP) and its response to a photospheric magnetic-flux increase accompanied by co-temporal CBP heating. We used co-observations from the AIA and HMI/SDO, together with data from the Fast Imaging Solar Spectrograph taken in the Halpha and Ca II 8542 lines. We used a new multi-layer spectral inversion technique to derive the temporal variations of the temperature of the Halpha loops (HLs). We find that the counterpart of the CBP, as seen at chromospheric temperatures, is composed of a bundle of dark elongated features named in this work Halpha loops, which constitute an integral part of the CBP loop magnetic structure. An increase in the photospheric magnetic flux due to flux emergence is accompanied by a rise of the coronal emission of the CBP loops, that is a heating episode. We also observe enhanced chromospheric activity associated with the occurrence of new HLs and mottles. While the coronal emission and magnetic flux increases appear to be co-temporal, the response of the Halpha counterpart of the CBP occurs with a small delay of less than 3 min. A sharp temperature increase is found in one of the HLs and in one of the CBP footpoints estimated at 46% and 55% with respect to the pre-event values, also starting with a delay of less than 3~min following the coronal heating episode. The low-lying CBP loop structure remains non-potential for the entire observing period. The magnetic topological analysis of the overlying corona reveals the presence of a coronal null point at the beginning and towards the end of the heating episode. The delay in the response of the chromospheric counterpart of the CBP suggests that the heating may have occurred at coronal heights. **13-14 Jun 2017**

Eruptions from coronal hole bright points: observations and non-potential modelling

Maria S. **Madjarska**, Klaus Galsgaard, Duncan H. Mackay, Kostadinka Koleva, Momchil Dechev

A&A 643, A19 **2020**

https://arxiv.org/pdf/2009.04628.pdf

https://www.aanda.org/articles/aa/pdf/2020/11/aa38287-20.pdf

A single case study of a CBP in an equatorial coronal hole with an exceptionally large size is investigated to extend our understanding of the formation of mini-filaments, their destabilisation and the origin of the eruption triggering the formation of jet-like features recorded in the extreme-ultraviolet (EUV) and X-ray emission. We aim to explore the nature of the so-called micro-flares in CBPs associated with jets in coronal holes and mini coronal mass ejections in the quiet Sun. Co-observations from the Atmospheric Imaging Assembly (AIA) and Helioseismic Magnetic Imager (HMI) on board the Solar Dynamics Observatory, and GONG Halpha images are used together with a Non-Linear Force Free Field (NLFFF) relaxation approach, where the latter is based on a time series of HMI line-of-sight magnetograms. A mini-filament (MF) that formed beneath the CBP arcade around 3-4 h before the eruption is seen in the Halpha and EUV AIA images to lift up and erupt triggering the formation of an X-ray jet. No significant photospheric magnetic flux concentration displacement (convergence) is observed and neither is magnetic flux cancellation between the two main magnetic polarities forming the CBP in the time period leading to the MF liftoff. The CBP micro-flare is associated with three flare kernels that formed shortly after the MF liftoff. No observational signature is found for reconnection beneath the erupting MF. The applied NLFFF modelling successfully reproduces both the CBP loop complex as well as the magnetic flux rope that hosts the MF during the build-up to the eruption. **2013 October 12**

Coronal bright points **Review**

Madjarska, M.S.

Living Rev. Solar Phys. (**2019**) 16: 2

https://link.springer.com/content/pdf/10.1007%2Fs41116-019-0018-8.pdf

Coronal bright points (CBPs) are a fundamental class of solar activity. They represent a set of low-corona small-scale loops with enhanced emission in the extreme-ultraviolet and X-ray spectrum that connect magnetic flux concentrations of opposite polarities. CBPs are one of the main building blocks of the solar atmosphere outside active regions uniformly populating the solar atmosphere including active region latitudes and coronal holes. Their plasma properties classify them as downscaled active regions. Most importantly, their simple structure and short lifetimes of less than 20 h that allow to follow their full lifetime evolution present a unique opportunity to investigate outstanding questions in solar physics including coronal heating. The present Living Review is the first review of this essential class of solar phenomena and aims to give an overview of the current knowledge about the CBP general, plasma and magnetic properties. Several transient dynamic phenomena associated with CBPs are also briefly introduced. The observationally derived energetics and the theoretical modelling that aims at explaining the CBP formation and eruptive behaviour are reviewed. **22 Feb 2018**

Coronal hole boundaries at small scales: III. EIS and SUMER views

M.S. **Madjarska**, Z. Huang, J.G. Doyle and S. Subramanian

E-print, July **2012**, A&A, 545, A67 (**2012**)

We report on the plasma properties of small-scale transient events identified in the quiet Sun, coronal holes and their boundaries. We aim at deriving the physical characteristics of events which were identified as small-scale transient brightenings in XRT images. We use spectroscopic co-observations from SUMER/SoHO and EIS/Hinode combined with high cadence imaging data from XRT/Hinode. We measure Doppler shifts using single and multiple Gauss fits of transition region and coronal lines as well as electron densities and temperatures. We combine co-temporal imaging and spectroscopy to separate brightening expansions from plasma flows. The transient brightening events in coronal holes and their boundaries were found to be very dynamical producing high density outflows at large speeds. Most of these events represent X-ray jets from pre-existing or newly emerging coronal bright points at X-ray temperatures. The average electron density of the jets is log10Ne ≈8.76 cm−3 while in the flaring site it is log10Ne ≈9.51 cm−3. The jet temperatures reach a maximum of 2.5 MK but in the majority of the cases the temperatures do not exceed 1.6 MK. The footpoints of jets have temperatures of a maximum of 2.5 MK though in a single event scanned a minute after the flaring the measured temperature was 12 MK. The jets are produced by multiple microflaring in the transition region and corona. Chromospheric emission was only detected in their footpoints and was only associated with downflows. The Doppler shift measurements in the quiet Sun transient brightenings confirmed that these events do not produce jet-like phenomena. The plasma flows in these phenomena remain trapped in closed loops. We can conclude that the dynamic day-by-day and even hour-by-hour small-scale evolution of coronal hole boundaries reported in paper I is indeed related to coronal bright points. The XRT observations reported in paper II revealed that these changes are associated with the dynamic evolution of coronal bright points producing multiple jets during their lifetime until their full disappearance. We demonstrated here through spectroscopic EIS and SUMER co-observations combined with high-cadence imaging information that the co-existence of open and closed magnetic fields results in multiple energy depositions which propel high density plasma along open magnetic field lines. We conclude from the physical characteristics obtained in this study that X-ray jets are an important candidate for the source of the slow solar wind. This, however, does not exclude the possibility that these jets are also the microstreams observed in the fast solar wind as recently suggested.

Can coronal hole spicules reach coronal temperatures?⋆

M. S. **Madjarska**, K. Vanninathan and J. G. Doyle

A&A 532, L1 (**2011**)

Aims. The present study aims to provide observational evidence of whether coronal hole spicules reach coronal temperatures.

Methods. We combine multi-instrument co-observations obtained with the SUMER/SoHO and with the EIS/SOT/XRT/Hinode.

Results. The analysed three large spicules were found to be comprised of numerous thin spicules that rise, rotate, and descend simultaneously forming a bush-like feature. Their rotation resembles the untwisting of a large flux rope. They show velocities ranging from 50 to 250 kms-1. We clearly associated the red- and blue-shifted emissions in transition region lines not only with rotating but also with rising and descending plasmas. Our main result is that these spicules although very large and dynamic, are not present in the spectral lines formed at temperatures above 300 000 K.

Conclusions. In this paper we present the analysis of three Ca ii H large spicules that are composed of numerous dynamic thin spicules but appear as macrospicules in lower resolution EUV images. We found no coronal counterpart of these and smaller spicules. We believe that the identification of phenomena that have very different origins as macrospicules is due to the interpretation of the transition region emission, and especially the He ii emission, wherein both chromospheric large spicules and coronal X-ray jets are present. We suggest that the recent observation of spicules in the coronal AIA/SDO 171 Å and 211 Å channels probably comes from the existence of transition region emission there.

Movie is available in electronic form at http://www.aanda.org

Large X-ray jet simultaneously observed by SUMER, EIS, XRT, and EUVI Ahead and Behind

Maria S. **Madjarska**

Hinode/EIS Nugget –April **2011**

http://msslxr.mssl.ucl.ac.uk:8080/SolarB/nuggets/nugget_2011apr.jsp

The Hinode and STEREO satellites are now revealing, in unprecedented detail, one of the phenomena hidden from our view since the loss of the Yohkoh satellite: EUV/X-ray jets or jet-like events from coronal bright points. In this nugget we discuss the very rare circumstance of a jet-like event which was simultaneously observed by two spectrometers and several imagers. It was co-registered with the EUV Imaging Spectrometer (EIS) and the X-ray Telescope (XRT) onboard Hinode, the Solar Ultraviolet Measurements of Emitted Radiation (SUMER) spectrometer onboard SoHO and the EUV Imagers (EUVI) onboard the twin STEREO satellites. The spectrometers took observations in spectral lines with formation temperatures from 10,000 K to 12 MK. The alignment of all instruments is described in Madjarska (2011). **2007 November 14**

Coronal hole boundaries evolution at small scales: I. EIT 195 A and TRACE 171 A view

M.S. **Madjarska** & T. Wiegelmann

E-print, June **2009**; A&A, 503, 991-997 (**2009**), DOI: 10.1051/0004-6361/200912066

Aims. We aim at studying the small-scale evolution at the boundaries of an equatorial coronal hole connected with a channel of open magnetic flux with the polar region and an ?isolated? one in the extreme-ultraviolet spectral range. We intend to determine the spatial and temporal scale of these changes.

Methods. Imager data from TRACE in the Fe IX/X 171 A passband and EIT on-board Solar and Heliospheric Observatory in the Fe XII 195 A passband were analysed.

Results. We found that small-scale loops known as bright points play an essential role in coronal holes boundaries evolution at small scales. Their emergence and disappearance continuously expand or contract coronal holes. The changes appear to be random on a time scale comparable with the lifetime of the loops seen at these temperatures. No signature was found for a major energy release during the evolution of the loops.

Conclusions. Although coronal holes seem to maintain their general shape during a few solar rotations, a closer look at their day-by-day and even hour-by-hour evolution demonstrates a significant dynamics. The small-scale loops (10"?40" and smaller) which are abundant along coronal hole boundaries have a contribution to the small-scale evolution of coronal holes. Continuous magnetic reconnection of the open magnetic field lines of the coronal hole and the closed field lines of the loops in the quiet Sun is more likely to take place.

EVIDENCE OF MAGNETIC RECONNECTION ALONG CORONAL HOLE BOUNDARIES

M. S. **Madjarska**,1 J. G. Doyle,2 and L. van Driel-Gesztelyi1,3,4

The Astrophysical Journal, 603:L57–L59, **2004**.

http://www.journals.uchicago.edu/doi/pdf/10.1086/383030

The present study reveals for the first time the existence of bidirectional jets, which are a signature of magnetic reconnection, occurring along coronal hole boundaries.

The jets' number density along coronal hole boundaries was found to be about 4–5 times higher with respect to the quiet Sun.

Could Switchbacks Originate in the Lower Solar Atmosphere? I. Formation Mechanisms of Switchbacks

Norbert **Magyar**1,2, Dominik Utz3,4, Robertus Erdélyi5,6,7, and Valery M. Nakariakov1,8

2021 ApJ 911 75

https://arxiv.org/pdf/2103.03726.pdf

https://doi.org/10.3847/1538-4357/abec49

The recent rediscovery of magnetic field switchbacks or deflections embedded in the solar wind flow by the Parker Solar Probe mission lead to a huge interest in the modeling of the formation mechanisms and origin of these switchbacks. Several scenarios for their generation were put forth, ranging from lower solar atmospheric origins by reconnection, to being a manifestation of turbulence in the solar wind, and so on. Here we study some potential formation mechanisms of magnetic switchbacks in the lower solar atmosphere, using three-dimensional magnetohydrodynamic (MHD) numerical simulations. The model is that of an intense flux tube in an open magnetic field region, aiming to represent a magnetic bright point opening up to an open coronal magnetic field structure, e.g., a coronal hole. The model is driven with different plasma flows in the photosphere, such as a fast up-shooting jet, as well as shearing flows generated by vortex motions or torsional oscillations. In all scenarios considered, we witness the formation of magnetic switchbacks in regions corresponding to chromospheric heights. Therefore, photospheric plasma flows around the foot-points of intense flux tubes appear to be suitable drivers for the formation of magnetic switchbacks in the lower solar atmosphere. Nevertheless, these switchbacks do not appear to be able to enter the coronal heights of the simulation in the present model. In conclusion, based on the presented simulations, switchbacks measured in the solar wind are unlikely to originate from photospheric or chromospheric dynamics.

Coronal Hole Influence on the Observed Structure of Interplanetary CMEs

Pertti **Makela**, Nat Gopalswamy, Hong Xie, Amaal A. Mohamed, Sachiko Akiyama, Seiji Yashiro

E-print, Jan **2013**; Solar Phys. Volume 284, Issue 1, pp 59-75, **2013**, **File**

We report on the coronal hole (CH) influence on the **54 magnetic cloud (MC) and non-MC associated coronal mass ejections (CMEs)** selected for studies during the Coordinated Data Analysis Workshops (CDAWs) focusing on the question if all CMEs are flux ropes. All selected CMEs originated from source regions located between longitudes 15E-15W. Xie, Gopalswamy, and St. Cyr (2013, Solar Phys., doi:10.1007/s11207-012-0209-0) found that these MC and non-MC associated CMEs are on average deflected towards and away from the Sun-Earth line respectively. We used a CH influence parameter (CHIP) that depends on the CH area, average magnetic field strength, and distance from the CME source region to describe the influence of all on-disk CHs on the erupting CME. We found that for CHIP values larger than 2.6 G the MC and non-MC events separate into two distinct groups where MCs (non-MCs) are deflected towards (away) from the disk center. Division into two groups was also observed when the distance to the nearest CH was less than 3.2x10^5 km. At CHIP values less than 2.6 G or at distances of the nearest CH larger than 3.2x10^5 km the deflection distributions of the MC and non-MCs started to overlap, indicating diminishing CH influence. These results give support to the idea that all CMEs are flux ropes, but those observed to be non-MCs at 1 AU could be deflected away from the Sun-Earth line by nearby CHs, making their flux rope structure unobservable at 1 AU.

Table; 18 October 1999, 6 December 1997, 9 April 2001, 12 May 1997, 13 April 1999, 17 February 2000, 25 July 2000 MC, 15 March 2002 MC

Alfvén waves in coronal holes: formation of discontinuities in inhomogeneous magnetic fields

F. **Malara**

A&A 549, A54 (**2013**)

Context. Solar wind fluctuations are characterized by discontinuities. The nature and properties of these structures have been largely studied in the literature, and different mechanisms have been proposed to explain their formation.
Aims. We investigate the evolution of Alfvénic perturbations propagating in the inhomogeneous magnetic field of a coronal open-field region, in order to study both the way that small-scale structures are generated and the possible formation of discontinuities.
Methods. We constructed a model for the equilibrium magnetic field in a coronal hole. The model represents a potential field with a complex structure: regions of opposite polarity or of only the dominant polarity are present at low or high altitudes, respectively. The evolution of small-amplitude Alfvén waves in the inhomogeneous structure is studied by employing a WKB approach that describes how the perturbation wavevector and the wave phase vary along magnetic lines.
Results. We find that small-scale structures form in the perturbation at relatively low altitudes (~3 × 104 km) above the coronal base. An initially monochromatic perturbation develops a steep power-law spectrum with slope $\alpha \simeq 2.3$, which is strongly anisotropic with a predominance of quasi-perpendicular wavevectors. Small-scale structures are localized around separatrices of the magnetic structures. In many cases they contain quasi-perpendicular rotational discontinuities that can propagate to the upper corona, eventually reaching the solar wind.
Conclusions. The considered mechanism could be responsible for forming a fraction of the population of discontinuities detected in the solar wind.

A highly dynamic small-scale jet in a polar coronal hole

Sudip **Mandal**, Lakshmi Pradeep Chitta, Hardi Peter, Sami K. Solanki, Regina Aznar Cuadrado, Luca Teriaca, Udo Schühle, David Berghmans, Frèdèric Auchère

A&A 664, A28 **2022**

https://arxiv.org/pdf/2206.02236.pdf

https://www.aanda.org/articles/aa/pdf/2022/08/aa43765-22.pdf

We present an observational study of the plasma dynamics at the base of a solar coronal jet, using high resolution extreme ultraviolet imaging data taken by the Extreme Ultraviolet Imager **on board Solar Orbiter**, and by the Atmospheric Imaging Assembly on board Solar Dynamics Observatory. We observed multiple plasma ejection events over a period of ∼1 hour from a dome-like base that is ca.~4 Mm wide and is embedded in a polar coronal hole. Within the dome below the jet spire, multiple plasma blobs with sizes around 1--2 Mm propagate upwards to dome apex with speeds of the order of the sound speed (ca.~120~km~s−1). Upon reaching the apex, some of these blobs initiate flows with similar speeds towards the other footpoint of the dome. At the same time, high speed super-sonic outflows (∼230~km~s−1) are detected along the jet spire. These outflows as well as the intensity near the dome apex appear to be repetitive. Furthermore, during its evolution, the jet undergoes many complex morphological changes including transitions between the standard and blowout type eruption. These new observational results highlight the underlying complexity of the reconnection process that powers these jets and also provide insights into the plasma response when subjected to rapid energy injection. **2021-Sep-14**

Internetwork chromospheric bright grains observed with IRIS

Juan **Martínez-Sykora**, Luc Rouppe van der Voort, Mats Carlsson et al.
ApJ, **2015**
http://arxiv.org/pdf/1502.03490v1.pdf
The Interface Region Imaging Spectrograph (IRIS) reveals small-scale rapid brightenings in the form of bright grains all over coronal holes and the quiet sun. These bright grains are seen with the IRIS 1330 \AA, 1400 \AA\ and 2796 \AA\ slit-jaw filters. We combine coordinated observations with IRIS and from the ground with the Swedish 1-m Solar Telescope (SST) which allows us to have chromospheric (Ca II 8542 \AA, Ca II H 3968 \AA, H\alpha, and Mg II k 2796 \AA), and transition region (C II 1334 \AA, Si IV 1402) spectral imaging, and single-wavelength Stokes maps in Fe I 6302 \AA at high spatial (0.33"), temporal and spectral resolution. We conclude that the IRIS slit-jaw grains are the counterpart of so-called acoustic grains, i.e., resulting from chromospheric acoustic waves in a non-magnetic environment. We compare slit-jaw images with spectra from the IRIS spectrograph. We conclude that the grain intensity in the 2796 \AA\ slit-jaw filter comes from both the Mg II k core and wings. The signal in the C II and Si IV lines is too weak to explain the presence of grains in the 1300 and 1400 \AA\ slit-jaw images and we conclude that the grain signal in these passbands comes mostly from the continuum. Even though weak, the characteristic shock signatures of acoustic grains can often be detected in IRIS C II spectra. For some grains, spectral signature can be found in IRIS Si IV. This suggests that upward propagating acoustic waves sometimes reach all the way up to the transition region. 2013 September 22

Statistical Evidence for Small-Scale Interchange Reconnection at a Coronal Hole Boundary

Emily I. **Mason**, Vadim M. Uritsky
ApJ **937** L19 **2022**
https://arxiv.org/pdf/2209.02833.pdf
https://iopscience.iop.org/article/10.3847/2041-8213/ac9124/pdf
Much of coronal hole (CH) research is focused upon determining the boundary and calculating the open flux as accurately as possible. However, the observed boundary itself is worthy of investigation, and holds important clues to the physics transpiring at the interface between the open and closed fields. This Letter reports a powerful new method, an application of the correlation integral which we call correlation dimension mapping (CDM), by which the irregularity of a CH boundary can be objectively quantified. This method highlights the most important spatial scales involved in boundary dynamics, and also allows for easy temporal analysis of the boundary. We apply this method to an equatorial CH bounded on two sides by helmet streamers and on the third by a small pseudostreamer, which we observed at maximum cadence for an hour on **2015 June 4**. We argue that the relevant spatial scales are in the range of ∼5−20 Mm, and we find that boundary complexity depends measurably upon the nature of the neighboring closed structure. The boundary along the pseudostreamer shows signs of highly-localized, intermittent complexity variability, likely associated with abrupt changes in the magnetic topology, which would be elegantly explained by interchange reconnection. By contrast, the helmet streamer boundary supports long-lived high-complexity regions. These findings support the recent predictions of interchange reconnection occurring at very small scales in the corona.

Differences in physical properties of coronal bright points and their ALMA counterparts within and outside coronal holes

F. **Matković**, R. Brajša, M. Temmer, S. G. Heinemann, H.-G. Ludwig, S. H. Saar, C. L. Selhorst, I. Skokić, D. Sudar
A&A 670, A146 **2023**
https://arxiv.org/pdf/2212.09443.pdf
https://www.aanda.org/articles/aa/pdf/2023/02/aa44160-22.pdf
This study investigates and compares brightness and area of coronal bright points (CBPs) inside and outside of coronal holes (CHs) using the single-dish Band 6 observations by the Atacama Large Millimeter/submillimeter Array (ALMA), combined with extreme-ultraviolet (EUV) 193 A∘ filtergrams obtained by the Atmospheric Imaging Assembly (AIA) and magnetograms obtained by the Helioseismic and Magnetic Imager (HMI), both on board Solar Dynamics Observatory (SDO). The CH boundaries were extracted from the SDO/AIA images using the Collection of Analysis Tools for Coronal Holes (CATCH) and CBPs were identified in the SDO/AIA, SDO/HMI, and ALMA data. Measurements of brightness and areas in both ALMA and SDO/AIA images were conducted for CBPs within CHs and quiet Sun regions outside CHs. A statistical analysis of the measured physical properties resulted in a lower average CBP brightness in both ALMA and SDO/AIA data for CBPs within the CHs. Depending on the CBP sample size, the difference in intensity for the SDO/AIA data, and brightness temperature for the ALMA data, between the CBPs inside and outside CHs ranged from between 2σ and 4.5σ, showing a statistically significant difference between those two CBP groups. For CBP areas, CBPs within the CH boundaries showed smaller areas on average, with the observed difference between the two CBP groups between 1σ and 2σ for the SDO/AIA data, and up to 3.5σ for the ALMA data, indicating that CBP areas are also significantly different. Given the measured properties, we conclude that the CBPs inside CHs tend to be less bright on average, but also smaller in comparison to those outside of CHs. This conclusion might point to the specific physical conditions and properties of the local

CH region around a CBP limiting the maximum achievable intensity (temperature) and size of a CBP. **2017-04-16, 2017-04-22**

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.

Recent Observations of Plasma and Alfvénic Wave Energy Injection at the Base of the Fast Solar Wind

Scott W. **McIntosh**

Space Science Reviews, November **2012**, Volume 172, Issue 1-4, pp 69-87

We take stock of recent observations that identify the episodic plasma heating and injection of Alfvénic energy at the base of fast solar wind (in coronal holes). The plasma heating is associated with the occurrence of chromospheric spicules that leave the lower solar atmosphere at speeds of order 100 km/s, the hotter coronal counterpart of the spicule emits radiation characteristic of root heating that rapidly reaches temperatures of the order of 1 MK. Furthermore, the same spicules and their coronal counterparts (“Propagating Coronal Disturbances”; PCD) exhibit large amplitude, high speed, Alfvénic (transverse) motion of sufficient energy content to accelerate the material to high speeds. We propose that these (disjointed) heating and accelerating components form a one-two punch to supply, and then accelerate, the fast solar wind. We consider some compositional constraints on this concept, extend the premise to the slow solar wind, and identify future avenues of exploration.

THE SPECTROSCOPIC FOOTPRINT OF THE FAST SOLAR WIND

Scott W. **McIntosh**1, Robert J. Leamon2,4 and Bart De Pontieu

2011 ApJ 727, 7

We analyze a large, complex equatorial coronal hole (ECH) and its immediate surroundings with a focus on the roots of the fast solar wind. We start by demonstrating that our ECH is indeed a source of the fast solar wind at 1 AU by examining in situ plasma measurements in conjunction with recently developed measures of magnetic conditions of the photosphere, inner heliosphere, and the mapping of the solar wind source region. We focus the bulk of our analysis on interpreting the thermal and spatial dependence of the non-thermal line widths in the ECH as measured by SOHO/SUMER by placing the measurements in context with recent studies of ubiquitous Alfvén waves in the solar atmosphere and line profile asymmetries (indicative of episodic heating and mass loading of the coronal plasma) that originate in the strong, unipolar magnetic flux concentrations that comprise the supergranular network. The results presented in this paper are consistent with a picture where a significant portion of the energy responsible for the transport of heated mass into the fast solar wind is provided by episodically occurring small-scale events (likely driven by magnetic reconnection) in the upper chromosphere and transition region of the strong magnetic flux regions that comprise the supergranular network.

GENERATION OF QUASI-PERIODIC WAVES AND FLOWS IN THE SOLAR ATMOSPHERE BY OSCILLATORY RECONNECTION

J. A. **McLaughlin**1, G. Verth1, V. Fedun2 and R. Erdélyi

2012 ApJ 749 30

We investigate the long-term evolution of an initially buoyant magnetic flux tube emerging into a gravitationally stratified coronal hole environment and report on the resulting oscillations and outflows. We perform 2.5-dimensional nonlinear numerical simulations, generalizing the models of McLaughlin et al. and Murray et al. We find that the physical mechanism of oscillatory reconnection naturally generates quasi-periodic vertical outflows, with a transverse/swaying aspect. The vertical outflows consist of both a periodic aspect and evidence of a positively directed flow. The speed of the vertical outflow (20-60 km s–1) is comparable to those reported in the observational literature. We also perform a parametric study varying the magnetic strength of the buoyant flux tube and find a range of associated periodicities: 1.75-3.5 minutes. Thus, the mechanism of oscillatory reconnection may provide a physical explanation to some of the high-speed, quasi-periodic, transverse outflows/jets recently reported by a multitude of authors and instruments.

Properties of Ion-Cyclotron Waves in the Open Solar Corona

R. **Mecheri**

Solar Physics, January **2013**, Volume 282, Issue 1, pp 133-146

Remote observations of coronal holes have strongly suggested the resonant interactions of ion-cyclotron waves with ions as a principal mechanism for plasma heating and acceleration of the fast solar wind. In order to study these waves, a WKB (Wentzel–Kramers–Brillouin) linear perturbation analysis is used in the frame work of a collisionless multi-fluid model where we consider in addition to protons a second ion component made of alpha particles. We consider a non-uniform background plasma describing a funnel region in the open coronal holes and we use the ray tracing Hamiltonian-type equations to compute the ray path of the waves and the spatial variation of their properties. At low frequency (smaller than the proton cyclotron frequency), the results showed a distinct behavior of the two ion-cyclotron modes found in our calculations, namely the first one propagates anisotropically guided along the magnetic field lines while the second one propagates isotropically with no preferred direction.

Coronal ion-cyclotron beam instabilities within the multi-fluid description

R. **Mecheri** and E. Marsch

A&A 474, 609-615 (2007), DOI: 10.1051/0004-6361:20077648

Spectroscopic observations and theoretical models suggest resonant wave-particle interactions, involving high-frequency ion-cyclotron waves, as the principal mechanism for heating and accelerating ions in the open coronal holes.

We demonstrate that in typical coronal hole conditions and assuming realistic values of the beam velocity, the free energy provided by the ion beam propagating parallel to the ambient field can drive micro-instabilities through resonant ion-cyclotron excitation.

Characteristics of EUV Solar Coronal Bright Points Using Time Series Analyses

Mahdieh **Mehrabian**, Bardia Kaki, Yusefali Abedini

2019

https://arxiv.org/pdf/1901.06597.pdf

Coronal bright points (CBPs) as characteristics of the solar corona are small-scale bright features ubiquitously observed at extreme ultraviolet passbands. Here, we focused on time series of CBPs in the periods of their lifetimes. We used Solar Dynamic Observatory (SDO) / Atmospheric Imaging Assembly (AIA) taken at 171 and 193 Å. Using image processing methods, CBPs were extracted from data and tracked during their lifetimes. We found that CBPs observed in 171 Åhave more lifetimes than those of observed at 193 Å. CBPs at 171 Åare more fluctuated in intensity and appeared as highly density number (DN) features than 193 ÅCBPs. It was found that about 75% of CBPs are firstly achieved their peak at 171 Å, and then, after 12 seconds two minutes are achieved to their peak at 193 Å. Computing Pearson correlation for time series of CBPs at both wavelengths where the correlation reaches at maximum value gives information about time delay of magnetic reconnection about 40 seconds from one layer to the other one. **2011-02-13**

Improvements to the Empirical Solar Wind Forecast (ESWF) model

D. **Milošić**, M. Temmer, S. G. Heinemann, T. Podladchikova, A. Veronig & B. Vršnak

Solar Physics volume 298, Article number: 45 (**2023**)

https://link.springer.com/content/pdf/10.1007/s11207-022-02102-5.pdf

The empirical solar wind forecast (ESWF) model in its current version 2.0 runs as a space-safety service in the frame of ESA's Heliospheric Weather Expert Service Centre. The ESWF model forecasts the solar-wind speed at Earth with a lead time of 4 days. The algorithm uses an empirical relation found between the area of solar coronal-holes (CHs), as observed in EUV within a 15∘15∘ meridional slice, and the in-situ measured solar-wind speed at 1 AU. This relation however, forecasts Gaussian type speed profiles, as the CH rotates in and out of the meridional slice, causing some discrepancy in the timing between forecasted and observed solar-wind speed. With adaptations to the ESWF 2.0 algorithm we improve the precision and accuracy of the ESWF speed profiles. For that we implement compression and rarefaction effects occurring between solar-wind streams of different velocities in interplanetary space. By considering the propagation times for plasma parcels between the Sun and Earth and their interactions, we achieve the asymmetrical shape of the speed profile that is characteristic of high-speed streams (HSS). By further implementing CH segmentation, co-latitude information and dynamic thresholding, we find that the newly developed ESWF 3.2 performs significantly better than ESWF 2.0. For a sample of 294 different HSSs, we derive a relative increase in hits of the timing and peak velocity by 13.9%13.9%. The Pearson correlation coefficient increases by 14.3%14.3% from 0.35 to 0.40. 2015-02-12

The relation between coronal holes and coronal mass ejections during the rise, maximum, and declining phases of Solar Cycle 23

Mohamed, A. A.; Gopalswamy, N.; Yashiro, S.; Akiyama, S.; Mдkelд, P.; Xie, H.; Jung, H.
J. Geophys. Res., Vol. 117, No. A1, A01103, **2012, File**
http://dx.doi.org/10.1029/2011JA016589
We study the interaction between coronal holes (CHs) and coronal mass ejections (CMEs) using a resultant force exerted by all the coronal holes present on the disk and is defined as the coronal hole influence parameter (CHIP). The CHIP magnitude for each CH depends on the CH area, the distance between the CH centroid and the eruption region, and the average magnetic field within the CH at the photospheric level. The CHIP direction for each CH points from the CH centroid to the eruption region. We focus on Solar Cycle 23 CMEs originating from the disk center of the Sun (central meridian distance ≤15°) and resulting in magnetic clouds (MCs) and non-MCs in the solar wind. The CHIP is found to be the smallest during the rise phase for MCs and non-MCs. The maximum phase has the largest CHIP value (2.9 G) for non-MCs. The CHIP is the largest (5.8 G) for driverless (DL) shocks, which are shocks at 1 AU with no discernible MC or non-MC. These results suggest that the behavior of non-MCs is similar to that of the DL shocks and different from that of MCs. In other words, the CHs may deflect the CMEs away from the Sun-Earth line and force them to behave like limb CMEs with DL shocks. This finding supports the idea that all CMEs may be flux ropes if viewed from an appropriate vantage point.

Bipolar Ephemeral Active Regions, Magnetic Flux Cancellation, and Solar Magnetic Explosions

Ronald L. **Moore**, Navdeep K. Panesar, Alphonse C. Sterling, Sanjiv K. Tiwari
2022 ApJ 933 12
https://iopscience.iop.org/article/10.3847/1538-4357/ac6181/pdf
https://arxiv.org/ftp/arxiv/papers/2203/2203.13287.pdf
We examine the cradle-to-grave magnetic evolution of 10 bipolar ephemeral active regions (BEARs) in solar coronal holes, especially aspects of the magnetic evolution leading to each of 43 obvious microflare events. The data are from Solar Dynamics Observatory: 211 A coronal EUV images and line-of-sight photospheric magnetograms. We find evidence that (1) each microflare event is a magnetic explosion that results in a miniature flare arcade astride the polarity inversion line (PIL) of the explosive lobe of the BEARs anemone magnetic field; (2) relative to the BEAR's emerged flux-rope omega loop, the anemone's explosive lobe can be an inside lobe, an outside lobe, or an inside & outside lobe; (3) 5 events are confined explosions, 20 events are mostly-confined explosions, and 18 events are blowout explosions, which are miniatures of the magnetic explosions that make coronal mass ejections (CMEs); (4) contrary to the expectation of Moore et al (2010), none of the 18 blowout events explode from inside the BEARs omega loop during the omega loops emergence; (5) before and during each of the 43 microflare events there is magnetic flux cancellation at the PIL of the anemone's explosive lobe. From finding evident flux cancellation at the underlying PIL before and during all 43 microflare events - together with BEARs evidently being miniatures of all larger solar bipolar active regions - we expect that in essentially the same way, flux cancellation in sunspot active regions prepares and triggers the magnetic explosions for many major flares and CMEs. **2012 06/30, 2012 July 1, 2013 February 27, 2 May 2013**
Tables

Magnetic Untwisting in Solar Jets that Go into the Outer Corona in Polar Coronal Holes

Ronald L. **Moore**, Alphonse C. Sterling, David A. Falconer
ApJ **806** 11 **2015**
http://arxiv.org/ftp/arxiv/papers/1504/1504.03700.pdf
We study 14 large solar jets observed in polar coronal holes. In EUV movies from SDO/AIA, each jet appears similar to most X-ray jets and EUV jets that erupt in coronal holes, but each is exceptional in that it goes higher than most, so high that it is observed in the outer corona beyond 2.2 RSun in images from the SOHO/LASCO/C2 coronagraph. From AIA He II 304 {\AA} movies and LASCO/C2 running-difference images of these high-reaching jets, we find: (1) the front of the jet transits the corona below 2.2 RSun at a speed typically several times the sound speed; (2) each jet displays an exceptionally large amount of spin as it erupts; (3) in the outer corona, most of the jets display measureable swaying and bending of a few degrees in amplitude; in three jets the swaying is discernibly oscillatory with a period of order 1 hour. These characteristics suggest that the driver in these jets is a magnetic-untwisting wave that is basically a large-amplitude (i.e., non-linear) torsional Alfven wave that is put into the

reconnected open field in the jet by interchange reconnection as the jet erupts. From the measured spinning and swaying we estimate that the magnetic-untwisting wave loses most of its energy in the inner corona below 2.2 RSun. We point out that the torsional waves observed in Type-II spicules might dissipate in the corona in the same way as the magnetic-untwisting waves in our big jets and thereby power much of the coronal heating in coronal holes.
2010 Aug 11, 2011 April 9

Decay of activity complexes and the formation of coronal holes

A. V. **Mordvinov**, S. A. Yazev

Astronomy Reports June 2013, Volume 57, Issue 6, pp 448-457

Analysis of long-term measurements of solar magnetic fields and the flux of UV radiation from the Sun indicates a cause-effect relationship between activity complexs, their residual magnetic fields, and coronal holes. A comparison of the background magnetic fields of the Sun and the evolution of former activity complexes reveals unipolar magnetic regions that form after the decay of these complexes. The latitude and time evolution of unipolar magnetic regions in solar cycles 21–24 is studied. A North-South asymmetry in solar activity is manifest in the distribution of unipolar regions migrating toward higher latitudes. It is shown that, when residual magnetic fields of the opposite polarity reach the polar regions, this leads to a sign change of the polar magnetic field and a decrease in the area of polar coronal holes, or even their complete disappearance. These interactions can explain the triple sign change of the polar magnetic field of the Sun in cycle 21 and the short-term polarity reversals observed in 2010 and 2011.

PLASMA JETS AND ERUPTIONS IN SOLAR CORONAL HOLES: A THREE-DIMENSIONAL FLUX EMERGENCE EXPERIMENT

F. **Moreno-Insertis**1,2 and K. Galsgaar

2013 ApJ 771 20

A three-dimensional (3D) numerical experiment of the launching of a hot and fast coronal jet followed by several violent eruptions is analyzed in detail. These events are initiated through the emergence of a magnetic flux rope from the solar interior into a coronal hole. We explore the evolution of the emerging magnetically dominated plasma dome surmounted by a current sheet and the ensuing pattern of reconnection. A hot and fast coronal jet with inverted-Y shape is produced that shows properties comparable to those frequently observed with EUV and X-ray detectors. We analyze its 3D shape, its inhomogeneous internal structure, and its rise and decay phases, lasting for some 15-20 minutes each. Particular attention is devoted to the field line connectivities and the reconnection pattern. We also study the cool and high-density volume that appears to encircle the emerged dome. The decay of the jet is followed by a violent phase with a total of five eruptions. The first of them seems to follow the general pattern of tether-cutting reconnection in a sheared arcade, although modified by the field topology created by the preceding reconnection evolution. The two following eruptions take place near and above the strong-field concentrations at the surface. They show a twisted, Ω-loop-like rope expanding in height, with twist being turned into writhe, thus hinting at a kink instability (perhaps combined with a torus instability) as the cause of the eruption. The succession of a main jet ejection and a number of violent eruptions that resemble mini-CMEs and their physical properties suggest that this experiment may provide a model for the blowout jets recently proposed in the literature.

JETS IN CORONAL HOLES: *HINODE* OBSERVATIONS AND THREE-DIMENSIONAL COMPUTER MODELING

F. **Moreno-Insertis**,1 K. Galsgaard,2 and I. Ugarte-Urra3

The Astrophysical Journal, 673:L211–L214, **2008**
http://www.journals.uchicago.edu/doi/pdf/10.1086/527560

Recent observations of coronal hole areas with the XRT and EIS instruments on board the *Hinode* satellite have shown with unprecedented detail the launching of fast, hot jets away from the solar surface. In some cases these events coincide with episodes of flux emergence from beneath the photosphere. In this Letter we show results of a three-dimensional numerical experiment of flux emergence from the solar interior into a coronal hole and compare them with simultaneous XRT and EIS observations of a jet-launching event that accompanied the appearance of a bipolar region in MDI magnetograms. The magnetic skeleton and topology that result in the experiment bear a strong resemblance to linear force-free extrapolations of the *SOHO*/MDI magnetograms. A thin current sheet is formed at the boundary of the emerging plasma. A jet is launched upward along the open reconnected field lines with values of temperature, density, and velocity in agreement with the XRT and EIS observations. Below the jet, a split-vault structure results with two chambers: a shrinking one containing the emerged field loops and a growing one with loops produced by the reconnection. The ongoing reconnection leads to a horizontal drift of the vault-and-jet structure. The timescales, velocities, and other plasma properties in the experiment are consistent with recent statistical studies of this type of event made with *Hinode* data.

The Fine-scale Structure of Polar Coronal Holes

R. J. **Morton**1 and R. Cunningham1

2023 ApJ 954 90

https://iopscience.iop.org/article/10.3847/1538-4357/acea7c/pdf

Coronal holes are thought to be composed of relatively broad columnar structures known as plumes. Here, we demonstrate that the plumes (and interplumes) in polar coronal holes are composed of fine-scale filamentary structure, with average scales of 2"–10". The fine structure is the off-limb analog of the previously found "plumelets" of Uritsky et al. The off-limb observations enable an examination of the fine structure without the influence of the underlying atmosphere along the line of sight. Hence, we show that the fine-scale structure is present at least until the edge of the field of view of the Solar Dynamics Observatory. The fine structure is found to have spatial distribution that follows a k^{-1} power law perpendicular to the inferred magnetic field direction. For a small sample of the fine structure, the cross-sectional profiles are measured as a function of height. In some cases, the measurements indicate that the fine structure expands super-radially, consistent with existing models of polar field expansion and the expansion of the plumes. We discuss the implications of the presence of the fine structure with respect to understanding wave propagation in the coronal holes and their contribution to powering the solar wind.

Eruptions from quiet Sun coronal bright points. I. Observations

Chauzhou **Mou**, Maria S. Madjarska, Klaus Galsgaard, Lidong Xia

A&A **2018**

https://arxiv.org/pdf/1808.04541.pdf

Observations of the full lifetime of CBPs in data taken with the AIA on board SDO in four passbands, He II 304 A, Fe IX/X 171 A, Fe XII 193 A, and Fe XVIII 94 A are investigated for the occurrence of plasma ejections, micro-flaring, mini-filament eruptions and mini coronal mass ejections (mini-CMEs). First and foremost, our study shows that the majority (76%) of quiet Sun CBPs (31 out of 42 CBPs) produce at least one eruption during their lifetime. From 21 eruptions in 11 CBPs, 18 occur in average ~17 hrs after the CBP formation for an average lifetime of the CBPs in AIA 193 A of ~21 hrs. This time delay in the eruption occurrence coincides in each BP with the convergence and cancellation phase of the CBP bipole evolution during which the CBPs become smaller until they fully disappear. The remaining three happen 4 - 6 hrs after the CBP formation. In sixteen out of 21 eruptions the magnetic convergence and cancellation involve the CBP main bipoles, while in three eruptions one of the BP magnetic fragments and a pre-existing fragment of opposite polarity converge and cancel. In one BP with two eruptions cancellation was not observed. The CBP eruptions involve in most cases the expulsion of chromospheric material either as elongated filamentary structure (mini-filament, MF) or a volume of cool material (cool plasma cloud, CPC), together with the CBP or higher overlying hot loops. Coronal waves were identified during three eruptions. A micro-flaring is observed beneath all erupting MFs/CPCs. It remains uncertain whether the destabilised MF causes the micro-flaring or the destabilisation and eruption of the MF is triggered by reconnection beneath the filament. In most eruptions, the cool erupting plasma obscures partially or fully the micro-flare until the erupting material moves away from the CBP. From 21 eruptions 11 are found to produce mini-CMEs. **2011 January 1-3**
Table 1. General information on the QS BPs associated with eruptions (Jan 2011).

Magnetic flux supplement to coronal bright points

Chaozhou **Mou**, Zhenghua Huang, Lidong Xia, Maria S. Madjarska, Bo Li, Hui Fu, Fangran Jiao, Zhenyong Hou

ApJ 818 9 **2016**

http://arxiv.org/pdf/1511.09215v1.pdf

Coronal bright points (BPs) are associated with magnetic bipolar features (MBFs) and magnetic cancellation. Here, we investigate how BP-associated MBFs form and how the consequent magnetic cancellation occurs. We analyse longitudinal magnetograms from the Helioseismic and Magnetic Imager to investigate the photospheric magnetic flux evolution of 70 BPs. From images taken in the 193 A passband of the Atmospheric Imaging Assembly (AIA) we dermine that the BPs' lifetimes vary from 2.7 to 58.8 hours. The formation of the BP MBFs is found to involve three processes, namely emergence, convergence and local coalescence of the magnetic fluxes. The formation of a MBF can involve more than one of these processes. Out of the 70 cases, flux emergence is the main process of a MBF buildup of 52 BPs, mainly convergence is seen in 28, and 14 cases are associated with local coalescence. For MBFs formed by bipolar emergence, the time difference between the flux emergence and the BP appearance in the AIA 193 A passband varies from 0.1 to 3.2 hours with an average of 1.3 hours. While magnetic cancellation is found in all 70 BPs, it can occur in three different ways: (I) between a MBF and small weak magnetic features (in 33 BPs); (II) within a MBF with the two polarities moving towards each other from a large distance (34 BPs); (III) within a MBF whose two main polarities emerge in the same place simultaneously (3 BPs). While a MBF builds up the skeleton of a BP, we find that the magnetic activities responsible for the BP heating may involve small weak fields. **31 Dec 2010, 1-2 Jan 2011**

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.

The Photospheric Footpoints of Solar Coronal Hole Jets

K. **Muglach**1,2

2021 ApJ 909 133

https://doi.org/10.3847/1538-4357/abd5ad

We study the photospheric footpoints of a set of 35 coronal jets in a coronal hole as observed by Hinode/EIS. We use SDO/AIA data to coalign the spectroscopic EIS data with SDO/HMI line-of-sight magnetograms and calculate the plane-of-sky flow field using local correlation tracking (LCT) on SDO/HMI white light images. The jets are put into categories according to the changes observed in the photospheric magnetic flux at the footpoints of the coronal bright point where the jets originate: flux cancellation, complex flux changes (flux appearance/emergence and cancellation), and no flux changes. We also present three jets in detail. Observed magnetic flux evolution, LCT flow field structure and location of the jet footpoints at supergranular boundaries do not support the flux emergence scenario used in most jet simulations and are also not consistent with a rotational photospheric driver. Detailed numerical jet simulations using our observed photospheric features, in particular converging flows and flux cancellation do not currently exist, although such models would provide a realistic eruptive event scenario.

Simulations of emerging flux in a coronal hole: oscillatory reconnection:

M.═J. **Murray**, L. van Driel-Gesztelyi and D. Baker

A&A 494 (**2009**) 329-337

http://www.aanda.org/10.1051/0004-6361:200810406

Context. Observations and simulations show that reconnection will take place when a flux tube emerges into a coronal hole, which is characterised by magnetic fieldlines “open” towards interplanetary space. Although the mechanism by which reconnection is initiated has been thoroughly studied, the long-term evolution of this reconnecting magnetic system remains unreported.

Aims. We aim to understand the long-term evolution of the reconnecting flux tube and coronal hole system and, in particular, to ascertain whether it can reach an equilibrium state in which all reconnection has ceased. By determining the evolution in this particular scenario, we aim to be able to select a subset from the broad spectrum of reconnecting systems, which will undergo the same progression to equilibrium.

Methods. Using a 2.5-dimensional numerical magnetohydrodynamic (MHD) code, we evolve a simple stratified atmospheric domain, which is endowed with a vertical magnetic field, representing the interior of a coronal hole, and a horizontal buoyant flux tube that is placed near the bottom of the domain. To investigate the long-term evolution of the system, we continue to study the domain long after the flux tube has emerged and reconnection has commenced between the magnetic fields of the flux tube and coronal hole.

Results. We find that a series of reconnection reversals (or oscillatory reconnection) takes place, whereby reconnection occurs in distinct bursts and the inflow and outflow magnetic fields of one burst of reconnection become the outflow and inflow fields in the following burst of reconnection, respectively. During each burst of reconnection the gas pressure in the bounded outflow regions increases above the level of that in the inflow regions and, eventually, gives rise to a reconnection reversal. In consecutive bursts of reconnection, the contrast in the gas pressure across the boundaries of the inflow and outflow regions decreases and, over time, the system settles towards equilibrium. Once the equilibrium state is reached, all reconnection ceases. This is the first reported instance of oscillatory reconnection initiated in a self-consistent manner, and the signatures of the mechanism compare favourably with observations of select flux emergence events and with solar and stellar flares.

Conclusions. Across the broader spectrum of reconnecting systems, oscillatory reconnection will only occur if the outflow regions are quasi-bounded during each burst of reconnection. The swaying outflow jet and periodic heating signatures of oscillatory reconnection are exceedingly similar to those exhibited by MHD modes and, in many observations, distinction between the two mechanisms may be impossible.

Seasonal solar wind speeds for the last 100 years: Unique coronal hole structures during the peak and demise of the Grand Modern Maximum

Kalevi **Mursula**, Lauri Holappa, Renata Lukianova

2016

https://arxiv.org/pdf/1612.04941v1.pdf

Solar coronal holes are sources of high-speed solar wind streams, which cause persistent geomagnetic activity especially at high latitudes. Here we estimate seasonal solar wind speeds at 1 AU for the last 100 years using high-latitude geomagnetic measurements and show that they give information on the long-term evolution of important structures of the solar large-scale magnetic field, such as persistent coronal holes. We find that the centennial evolution of solar wind speed at 1 AU is different for equinoxes and solstices, reflecting differences in the evolution of polar coronal hole extensions and isolated low-latitude coronal holes. Equinoctial solar wind speeds had their centennial maximum in 1952, during the declining phase of solar cycle 18, verifying that polar coronal holes had exceptionally persistent extensions just before the peak of the Grand Modern Maximum of solar activity. On the other hand, solstice speeds had their centennial maximum during the declining phase of solar cycle 23 due to large low-latitude coronal holes. A similar configuration of seasonal speeds as in cycle 23 was not found earlier, not even during the less active cycles of early 20th century. Therefore the exceptional occurrence of persistent, isolated low-latitude coronal holes in cycle 23 is not related to the absolute level of sunspot activity but, most likely, to the demise of the Grand Modern Maximum.

Occurrence of high-speed solar wind streams over the Grand Modern Maximum

Kalevi **Mursula**, Renata Lukianova, Lauri Holappa

2015 *ApJ* **801** 30

http://arxiv.org/pdf/1501.05010v1.pdf

In the declining phase of the solar cycle, when the new-polarity fields of the solar poles are strengthened by the transport of same-signed magnetic flux from lower latitudes, the polar coronal holes expand and form non-axisymmetric extensions toward the solar equator. These extensions enhance the occurrence of high-speed solar wind streams (HSS) and related co-rotating interaction regions in the low-latitude heliosphere, and cause moderate, recurrent geomagnetic activity in the near-Earth space. Here, using a novel definition of geomagnetic activity at high (polar cap) latitudes and the longest record of magnetic observations at a polar cap station, we calculate the annually averaged solar wind speeds as proxies for the effective annual occurrence of HSS over the whole Grand Modern Maximum (GMM) from 1920s onwards. We find that a period of high annual speeds (frequent occurrence of HSS) occurs in the declining phase of each solar cycle 16-23. For most cycles the HSS activity clearly maximizes during one year, suggesting that typically only one strong activation leading to a coronal hole extension is responsible for the HSS maximum. We find that the most persistent HSS activity occurred in the declining phase of solar cycle 18. This suggests that cycle 19, which marks the sunspot maximum period of the GMM, was preceded by exceptionally strong polar fields during the previous sunspot minimum. This gives interesting support for the validity of solar dynamo theory during this dramatic period of solar magnetism.

Two Populations of Sunspots: Differential Rotation

Yu. A. **Nagovitsyn**, A. A. Pevtsov, A. A. Osipova

Astronomy Letters March **2018**, Volume 44, Issue 3, pp 202–211

Pis'ma v Astronomicheskii Zhurnal, 2018, Vol. 44, No. 3, pp. 229–238.

To investigate the differential rotation of sunspot groups using the Greenwich data, we propose an approach based on a statistical analysis of the histograms of particular longitudinal velocities in different latitude intervals. The general statistical velocity distributions for all such intervals are shown to be described by two rather than one normal distribution, so that two fundamental rotation modes exist simultaneously: fast and slow. The differentiality of rotation for the modes is the same: the coefficient at sin2 in Faye's law is 2.87–2.88 deg/day, while the equatorial rotation rates differ significantly, 0.27 deg/day. On the other hand, an analysis of the longitudinal velocities for the previously revealed two differing populations of sunspot groups has shown that small short-lived groups (SSGs) are associated with the fast rotation mode, while large long-lived groups (LLGs) are associated with both fast and slow modes. The results obtained not only suggest a real physical difference between the two populations of sunspots but also give new empirical data for the development of a dynamo theory, in particular, for the theory of a spatially distributed dynamo.

Association of Calcium Network Bright Points with Underneath Photospheric Magnetic Patches

Nancy **Narang**, Dipankar Banerjee, Kalugodu Chandrashekhar, Vaibhav Pant

Solar Physics April **2019**, 294:40
https://link.springer.com/content/pdf/10.1007%2Fs11207-019-1419-5.pdf
Recent dedicated Hinode polar region campaigns revealed the presence of concentrated kilogauss patches of the magnetic field in the polar regions of the Sun, which are also shown to be correlated with facular bright points at the photospheric level. In this work, we demonstrate that this spatial intermittency of the magnetic field persists even up to the chromospheric heights. The small-scale bright elements visible in the bright network lanes of the solar network structure as seen in the Ca ii H images are termed network bright points. We use special Hinodecampaigns devoted to the observation of polar regions of the Sun to study the polar network bright points during the phase of the last extended solar minimum. We use Ca ii H images of chromosphere observed by the Solar Optical Telescope. For magnetic field information, level-2 data of the spectro-polarimeter is used. We observe a considerable association between the polar network bright points and magnetic field concentrations. The intensity of such bright points is found to be correlated well with the photospheric magnetic field strength underneath with a linear relation existing between them.

Statistical Study of Network Jets Observed in the Solar Transition Region: a Comparison Between Coronal Holes and Quiet-Sun Regions

Nancy **Narang**, Rebecca T. Arbacher, Hui Tian, Dipankar Banerjee , Steven R. Cranmer, Ed E. DeLuca, Sean McKillop
Solar Phys. **2016**
http://arxiv.org/pdf/1604.06295v1.pdf
Recent IRIS observations have revealed a prevalence of intermittent small-scale jets with apparent speeds of 80--250 kms−1, emanating from small-scale bright regions inside network boundaries of coronal holes. We find that these network jets appear not only in coronal holes but also in quiet-sun regions. Using IRIS 1330 Å (C II) slit-jaw images, we extracted several parameters of these network jets, e.g. apparent speed, length, lifetime, and increase in foot-point brightness. Using several observations, we find that some properties of the jets are very similar, but others are obviously different between the quiet Sun and coronal holes. For example, our study shows that the coronal-hole jets appear to be faster and longer than those in the quiet Sun. This can be directly attributed to a difference in the magnetic configuration of the two regions, with open magnetic field lines rooted in coronal holes and magnetic loops often present in the quiet Sun. We also detected compact bright loops that are most likely transition region loops and are mostly located in quiet-Sun regions. These small loop-like regions are generally devoid of network jets. In spite of different magnetic structures in the coronal hole and quiet Sun in the transition region, there appears to be no substantial difference for the increase in footpoint brightness of the jets, which suggests that the generation mechanism of these network jets is very likely the same in both regions. **2014-01-23-24, 2014-01-29, 2014-02-12**

Numerical simulations of the emerging plasma blob into a solar coronal hole

Anamaria **Navarro**, K. Murawski, D. Wojcik, F. D. Lora-Clavijo
MNRAS 489, No. 2, 2769-2774 (**2019**)
https://arxiv.org/pdf/1910.11814.pdf
https://academic.oup.com/mnras/article/489/2/2769/5561488
We numerically simulate emergence of a magnetic plasma blob into a solar coronal hole. This blob may be associated with granulation and therefore it has a weak magnetic field. Two-dimensional simulations are performed using the MAGNUS code which solves magnetohydrodynamic equations, taking into account magnetic resistivity and thermal conduction. As a result of the interaction of the emerging blob with the ambient plasma, the magnetic lines experience reconnection with the blob getting flattened and deformed with time. Additionally, this process launches a vertical outflow of hot plasma and the chromosphere in its response increases its temperature. We perform parametric studies by varying the magnitude of the magnetic field of the blob and observing the net heating of the chromosphere. These studies are inspired by realistic simulations of granulation made with the use of two-fluid JOANNA code. In these simulations a number of magnetic blobs are detected in the convection zone and in the photosphere. From the numerical results, we conclude that as a result of granulation operating in a solar quiet region the emerging blob may trigger very complex dynamics in the upper regions of the solar atmosphere, and the associated outflows may be a source of heating of the chromosphere and possibly the solar corona.

EVIDENCE FOR POLAR X-RAY JETS AS SOURCES OF MICROSTREAM PEAKS IN THE SOLAR WIND

Marcia **Neugebauer**
2012 ApJ 750 50
It is proposed that the interplanetary manifestations of X-ray jets observed in solar polar coronal holes during periods of low solar activity are the peaks of the so-called microstreams observed in the fast polar solar wind. These microstreams exhibit velocity fluctuations of ±35 km s–1, higher kinetic temperatures, slightly higher proton fluxes, and slightly higher abundances of the low-first-ionization-potential element iron relative to oxygen ions than the

average polar wind. Those properties can all be explained if the fast microstreams result from the magnetic reconnection of bright-point loops, which leads to X-ray jets which, in turn, result in solar polar plumes. Because most of the microstream peaks are bounded by discontinuities of solar origin, jets are favored over plumes for the majority of the microstream peaks.

The Merging of a Coronal Dimming and the Southern Polar Coronal Hole

Nawin **Ngampoopun**1, David M. Long1,2, Deborah Baker1, Lucie M. Green1, Stephanie L. Yardley1,3,4, Alexander W. James1,5, and Andy S. H. To

2023 ApJ 950 150

https://arxiv.org/pdf/2305.06106.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/acd44e/pdf

We report on the merging between the southern polar coronal hole and an adjacent coronal dimming induced by a coronal mass ejection on **2022 March 18**, resulting in the merged region persisting for at least 72 hr. We use remote sensing data from multiple co-observing spacecraft to understand the physical processes during this merging event. The evolution of the merger is examined using Extreme-UltraViolet (EUV) images obtained from the Atmospheric Imaging Assembly on board the Solar Dynamic Observatory and Extreme Ultraviolet Imager, which is on board the Solar Orbiter spacecraft. The plasma dynamics are quantified using spectroscopic data obtained from the EUV Imaging Spectrometer on board Hinode. The photospheric magnetograms from the Helioseismic and Magnetic Imager are used to derive the magnetic field properties. To our knowledge, this work is the first spectroscopical analysis of the merging of two open-field structures. We find that the coronal hole and the coronal dimming become indistinguishable after the merging. The upflow speeds inside the coronal dimming become more similar to that of a coronal hole, with a mixture of plasma upflows and downflows observable after the merging. The brightening of the bright points and the appearance of coronal jets inside the merged region further imply ongoing reconnection processes. We propose that component reconnection between the coronal hole and coronal dimming fields plays an important role during this merging event because the footpoint switching resulting from the reconnection allows the coronal dimming to intrude onto the boundary of the southern polar coronal hole.

Mult-viewpoint Observations of a Widely Distributed Solar Energetic Particle Event: the Role of EUV Waves and Shock Signatures

Alexander **Nindos**∗1 , Athanasios Kouloumvakos1 , Spiros Patsourakos1 , Angelos Vourlidas2 , Anastasios Anastasiadis3 , Alexander Hillaris4 , and Ingmar Sandberg3

CESRA **2016** p.38

http://cesra2016.sciencesconf.org/conference/cesra2016/pages/CESRA2016_prog_abs_book_v3.pdf

On **2012 March 7**, two large eruptive events occurred in the same active region within 1 hr from each other. Each consisted of an X-class flare, a coronal mass ejection (CME), an extreme-ultraviolet (EUV) wave, and a shock wave. The eruptions gave rise to a major solar energetic particle (SEP) event observed at widely separated (˜120◦) points in the heliosphere. From multi-viewpoint energetic proton recordings we determine the proton release times at STEREO B and A (STB, STA) and the first Lagrange point (L1) of the Sun–Earth system. Using EUV and white-light data, we determine the evolution of the EUV waves in the low corona and reconstruct the global structure and kinematics of the first CME's shock, respectively. We compare the energetic proton release time at each spacecraft with the EUV waves' arrival times at the magnetically connected regions and the timing and location of the CME shock. We find that the first flare/CME is responsible for the SEP event at all three locations. The proton release at STB is consistent with arrival of the EUV wave and CME shock at the STB footpoint. The proton release time at L1 was significantly delayed compared to STB. Three-dimensional modeling of the CME shock shows that the particle release at L1 is consistent with the timing and location of the shock's western flank. This indicates that at L1 the proton release did not occur in low corona but farther away from the Sun. However, the extent of the CME shock fails to explain the SEP event observed at STA. A transport process or a significantly distorted interplanetary magnetic field may be responsible.

Investigation of the Moving Structures in a Coronal Bright Point

Zongjun **Ning**1,2 and Yang Guo

2014 ApJ 794 79

We have explored the moving structures in a coronal bright point (CBP) observed by the Solar Dynamic Observatory Atmospheric Imaging Assembly (AIA) on **2011 March 5**. This CBP event has a lifetime of ~20 minutes and is bright with a curved shape along a magnetic loop connecting a pair of negative and positive fields. AIA imaging observations show that a lot of bright structures are moving intermittently along the loop legs toward the two footpoints from the CBP brightness core. Such moving bright structures are clearly seen at AIA 304 Å. In order to analyze their features, the CBP is cut along the motion direction with a curved slit which is wide enough to cover the bulk of the CBP. After integrating the flux along the slit width, we get the spacetime slices at nine AIA wavelengths. The oblique streaks starting from the edge of the CBP brightness core are identified as moving bright structures, especially on the derivative images of the brightness spacetime slices. They seem to originate from the same position near the loop top. We find that these oblique streaks are bi-directional, simultaneous, symmetrical, and periodic. The average speed is about 380 km s–1, and the period is typically between 80 and 100 s. Nonlinear force-free field extrapolation shows the possibility that magnetic reconnection takes place during the CBP, and our findings indicate that these moving bright structures could be the observational outflows after magnetic reconnection in the CBP.

North-South asymmetry in the magnetic deflection of polar coronal hole jets

Nistico G., Zimbardo G., Patsourakos S., Bothmer V., Nakariakov V. M.

A&A 583, A127 **2015**

http://www2.warwick.ac.uk/fac/sci/physics/research/cfsa/people/nistico/publications/paper_ns_asymmetry.pdf
http://arxiv.org/pdf/1508.01072v1.pdf

Context. Measurements of the magnetic field in the interplanetary medium, of the sunspots area, and of the heliospheric current sheet position, reveal a possible North-South asymmetry in the magnetic field of the Sun. This asymmetry could cause the bending of the heliospheric current sheet of the order of 5--10 deg in the southward direction, and it appears to be a recurrent characteristic of the Sun during the minima of solar activity.
Aims. We study the North-South asymmetry as inferred from measurements of the deflection of polar coronal hole jets when they propagate throughout the corona.
Methods. Since the corona is an environment where the magnetic pressure is greater than the kinetic pressure ($\beta \ll 1$), we can assume that magnetic field controls the dynamics of plasma. On average, jets during their propagation follow the magnetic field lines, highlighting its local direction. The average jet deflection is studied both in the plane perpendicular to the line of sight, and, for a reduced number of jets, in three dimensional space. The observed jet deflection is studied in terms of an axisymmetric magnetic field model comprising dipole (g1), quadrupole (g2), and esapole (g3) moments.
Results. We measured the position angles at 1 $R_\odot$ and at 2 $R_\odot$ of the 79 jets from the catalogue of Nistico09, based on the STEREO ultraviolet and white-light coronagraph observations during the solar minimum period March 2007-April 2008. We found that the propagation is not radial, in agreement with the deflection due to magnetic field lines. Moreover, the amount of the deflection is different between jets over the north and those from the south pole. Comparison of jet deflections and field line tracing shows that a ratio $g2/g1 \simeq -0.5$ for the quadrupole and a ratio $g3/g1 \simeq 1.6-2.0$ for the esapole can describe the field. The presence of a non-negligible quadrupole moment confirms the North-South asymmetry of the solar magnetic field for the considered period.
Conclusions. We find that the magnetic deflection of jets is larger in the North than in the South of the order of 25-40%, with an asymmetry which is consistent with a southward deflection of the heliospheric current sheet of the order of 10 deg, consistent with that inferred from other, independent, datasets and instruments. **2007-06-07**

Determination of temperature maps of EUV coronal hole jets

Giuseppe **Nisticò**a, , 1, , Spiros Patsourakosb, , Volker Bothmerc, , Gaetano Zimbardoa,

Advances in Space Research

Volume 48, Issue 9, 1 November **2011**, Pages 1490-1498

Coronal hole jets are fast ejections of plasma occurring within coronal holes, observed at Extreme-UltraViolet (EUV) and X-ray wavelengths. Recent observations of jets by the STEREO and Hinode missions show that they are transient phenomena which occur at much higher rates than large-scale impulsive phenomena like flares and Coronal Mass Ejections (CMEs). In this paper we describe some typical characteristics of coronal jets observed by the SECCHI instruments of STEREO spacecraft. We show an example of 3D reconstruction of the helical structure for a south pole jet, and present how the angular distribution of the jet position angles changes from the Extreme-UltraViolet-Imager (EUVI) field of view to the CORonagraph1 (COR1) (height 2.0 R) heliocentric distance field of view. Then we discuss a preliminary temperature determination for the jet plasma by using the filter ratio method at 171 and 195 Å and applying a technique for subtracting the EUV background radiation. The results show that jets are characterized by electron temperatures ranging between 0.8 and 1.3 MK. We present the thermal structure of the jet as temperature maps and we describe its thermal evolution.

Observational features of equatorial coronal hole jets,

Nistic`o, G., Bothmer, V., Patsourakos, S., and Zimbardo, G.:

Ann. Geophys., 28, 687-696, **2010**. http://www.ann-geophys.net/28/687/2010/

Collimated ejections of plasma called "coronal hole jets" are commonly observed in polar coronal holes. However, such coronal jets are not only a specific features of polar coronal holes but they can also be found in coronal holes appearing at lower heliographic latitudes. In this paper we present some observations of "equatorial coronal hole jets" made up with data provided by the STEREO/SECCHI instruments during a period comprising March 2007 and December 2007. The jet events are selected by requiring at least some visibility in both COR1 and EUVI instruments. We report 15 jet events, and we discuss their main features. For one event, the uplift velocity has been determined as about 200 km s^{-1}, while the deceleration rate appears to be about 0.11 km s^{-2}, less than solar gravity. The average jet visibility time is about 30 min, consistent with jet observed in polar regions. On the basis of the present dataset, we provisionally conclude that there are not substantial physical differences between polar and equatorial coronal hole jets.

Characteristics of EUV Coronal Jets Observed with STEREO/SECCHI

G. **Nisticò** · V. Bothmer · S. Patsourakos · G. Zimbardo

Solar Phys (**2009**) 259: 87–108, **File**

In this paper we present the first comprehensive statistical study of EUV coronal jets observed with the SECCHI (Sun Earth Connection Coronal and Heliospheric Investigation) imaging suites of the two STEREO spacecraft. A catalogue of 79 polar jets is presented, identified from simultaneous EUV and white-light coronagraph observations, taken during the time period March 2007 to April 2008, when solar activity was at a minimum. The twin spacecraft angular separation increased during this time interval from 2 to 48 degrees. The appearances of the coronal jets were always correlated with underlying small-scale chromospheric bright points. A basic characterization of the morphology and identification of the presence of helical structure were established with respect to recently proposed models for their origin and temporal evolution. Though each jet appeared morphologically similar in the coronagraph field of view, in the sense of a narrow collimated outward flow of matter, at the source region in the low corona the jet showed different characteristics, which may correspond to different magnetic structures. A classification of the events with respect to previous jet studies shows that amongst the 79 events there were 37 *Eiffel tower*-type jet events, commonly interpreted as a small-scale (~35 arc sec) magnetic bipole reconnecting with the ambient unipolar open coronal magnetic fields at its loop tops, and 12 *lambda*-type jet events commonly interpreted as reconnection with the ambient field happening at the bipole footpoints. Five events were termed *micro-CME*-type jet events because they resembled the classical coronal mass ejections (CMEs) but on much smaller scales. The remaining 25 cases could not be uniquely classified. Thirty-one of the total number of events exhibited a helical magnetic field structure, indicative for a torsional motion of the jet around its axis of propagation. A few jets are also found in equatorial coronal holes. In this study we present sample events for each of the jet types using both, STEREO A and STEREO B, perspectives. The typical lifetimes in the SECCHI/EUVI (*Extreme UltraViolet Imager*) field of view between 1.0 to 1.7 *R*_ and in SECCHI/COR1 field of view between 1.4 to 4 *R*_ are obtained, and the derived speeds are roughly estimated. In summary, the observations support the assumption of continuous small-scale reconnection as an intrinsic feature of the solar corona, with its role for the heating of the corona, particle acceleration, structuring and acceleration of the solar wind remaining to be explored in more detail in further studies.

Geomagnetic storm forecasting from solar coronal holes

Simona **Nitti**, Tatiana Podladchikova, Stefan J. Hofmeister, Astrid M. Veronig, Giuliana Verbanac, Mario Bandić

MNRAS Volume 519, Issue 2, February **2023**, Pages 3182–3193,
https://arxiv.org/pdf/2211.16572.pdf
https://doi.org/10.1093/mnras/stac3533

Coronal holes (CHs) are the source of high-speed streams (HSSs) in the solar wind, whose interaction with the slow solar wind creates corotating interaction regions (CIRs) in the heliosphere. Whenever the CIRs hit the Earth, they can cause geomagnetic storms. We develop a method to predict the strength of CIR/HSS-driven geomagnetic storms directly from solar observations using the CH areas and associated magnetic field polarity. First, we build a dataset comprising the properties of CHs on the Sun, the associated HSSs, CIRs, and orientation of the interplanetary magnetic field (IMF) at L1, and the strength of the associated geomagnetic storms by the geomagnetic indices Dst and Kp. Then, we predict the Dst and Kp indices using a Gaussian Process model, which accounts for the annual variation of the orientation of Earth's magnetic field axis. We demonstrate that the polarity of the IMF at L1 associated with CIRs is preserved in around 83% of cases when compared to the polarity of their CH sources. Testing our model over the period 2010-2020, we obtained a correlation coefficient between the predicted and observed Dst index of R = 0.63/0.73, and Kp index of R = 0.65/0.67, for HSSs having a polarity towards/away from the Sun. These findings demonstrate the possibility of predicting CIR/HSS-driven geomagnetic storms directly from solar observations and extending the forecasting lead time up to several days, which is relevant for enhancing space weather predictions. **2017 June 13**

Deciphering the solar coronal heating: Energizing small-scale loops through surface convection

D. **Nóbrega-Siverio**, F. Moreno-Insertis, K Galsgaard, K. Krikova, L. Rouppe van der Voort, R. Joshi, M. S. Madjarska
ApJL Volume 958, Issue 2, id.L38 **2023**
https://arxiv.org/pdf/2311.11912.pdf
https://iopscience.iop.org/article/10.3847/2041-8213/ad0df0/pdf
The solar atmosphere is filled with clusters of hot small-scale loops commonly known as Coronal Bright Points (CBPs). These ubiquitous structures stand out in the Sun by their strong X-ray and/or extreme-ultraviolet (EUV) emission for hours to days, which makes them a crucial piece when solving the solar coronal heating puzzle. In addition, they can be the source of coronal jets and small-scale filament eruptions. Here we present a novel 3D numerical model using the Bifrost code that explains the sustained CBP heating for several hours. We find that stochastic photospheric convective motions alone significantly stress the CBP magnetic field topology, leading to important Joule and viscous heating concentrated around the CBP's inner spine at a few megameters above the solar surface. We also detect continuous upflows with faint EUV signal resembling observational dark coronal jets and small-scale eruptions when Hα fibrils interact with the reconnection site. We validate our model by comparing simultaneous CBP observations from SDO and SST with observable diagnostics calculated from the numerical results for EUV wavelengths as well as for the Hα line using the Multi3D synthesis code. Additionally, we provide synthetic observables to be compared with Hinode, Solar Orbiter, and IRIS. Our results constitute a step forward in the understanding of the many different facets of the solar coronal heating problem. ***2022 July 1***

RHESSI Science Nuggets #462 **2023** **Coronal Bright Points**

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https://sprg.ssl.berkeley.edu/~tohban/wiki/index.php/Coronal_Bright_Points

A 2D Model for Coronal Bright Points: Association with Spicules, UV bursts, Surges and EUV Coronal Jets

D. **Nóbrega-Siverio**, F. Moreno-Insertis
ApJ **935** L21 **2022**
https://arxiv.org/pdf/2208.04308.pdf
https://iopscience.iop.org/article/10.3847/2041-8213/ac85b6/pdf
Coronal Bright Points (CBPs) are ubiquitous structures in the solar atmosphere composed of hot small-scale loops observed in EUV or X-Rays in the quiet Sun and coronal holes. They are key elements to understand the heating of the corona; nonetheless, basic questions regarding their heating mechanisms, the chromosphere underneath, or the effects of flux emergence in these structures remain open. We have used the Bifrost code to carry out a 2D experiment in which a coronal-hole magnetic nullpoint configuration evolves perturbed by realistic granulation. To compare with observations, synthetic SDO/AIA, Solar Orbiter EUI-HRI, and IRIS images have been computed. The experiment shows the self-consistent creation of a CBP through the action of the stochastic granular motions alone, mediated by magnetic reconnection in the corona. The reconnection is intermittent and oscillatory, and it leads to coronal and transition-region temperature loops that are identifiable in our EUV/UV observables. During the CBP lifetime, convergence and cancellation at the surface of its underlying opposite polarities takes place. The chromosphere below the CBP shows a number of peculiar features concerning its density and the spicules in it. The final stage of the CBP is eruptive: magnetic flux emergence at the granular scale disrupts the CBP topology, leading to different ejections, such as UV bursts, surges, and EUV coronal jets. Apart from explaining observed CBP features, our results pave the way for further studies combining simulations and coordinated observations in different atmospheric layers.

Coronal voids and their magnetic nature

J.D. **Nölke**, S.K. Solanki, J. Hirzberger, H. Peter, L.P. Chitta, F. Kahil, +++
A&A **2023**
https://arxiv.org/pdf/2309.09789.pdf
Extreme ultraviolet (EUV) observations of the quiet solar atmosphere reveal extended regions of weak emission compared to the ambient quiescent corona. The magnetic nature of these coronal features is not well understood. We study the magnetic properties of the weakly emitting extended regions, which we name coronal voids. In particular, we aim to understand whether these voids result from a reduced heat input into the corona or if they are associated with mainly unipolar and possibly open magnetic fields, similar to coronal holes. We defined the coronal voids via an intensity threshold of 75% of the mean quiet-Sun (QS) EUV intensity observed by the high-resolution EUV channel (HRIEUV) of the Extreme Ultraviolet Imager on Solar Orbiter. The line-of-sight magnetograms of the same solar region recorded by the High Resolution Telescope of the Polarimetric and Helioseismic Imager allowed us to compare the photospheric magnetic field beneath the coronal voids with that in other parts of the QS. The coronal voids studied here range in size from a few granules to a few supergranules and on average exhibit a reduced intensity of 67% of the mean value of the entire field of view. The magnetic flux density in the photosphere below the voids is 76% (or more) lower than in the surrounding QS. Specifically, the coronal voids show much weaker or no network structures. The detected flux imbalances fall in the range of imbalances found in QS areas of the same

size. Conclusions. We conclude that coronal voids form because of locally reduced heating of the corona due to reduced magnetic flux density in the photosphere. This makes them a distinct class of (dark) structure, different from coronal holes. **2021 February 23**

Magnetohydrostatic model for a coronal hole

V. N. **Obridko** & A. A. Solov’ev

Astronomy Reports, Volume 55, Number 12, 1144-1154, **2011**

Astronomicheskii Zhurnal, **2011**, Vol. 88, No. 12, pp. 1238–1248.

A model treating a solar coronal hole as an axially symmetrical magnetic formation that is in equilibrium with the surrounding medium is proposed. The model is applicable in the lower corona (to heights of the order of several hundreds of Mm), where the influence of the solar-wind outflow on the state of the system can still be neglected. The magnetic field of the coronal hole is comprised of a relatively weak open flux that varies with height, which extends into interplanetary space, and a closed field, whose flux closes at the chromosphere near the coronal hole. Simple analytical formulas are obtained, which demonstrate for a given equilibrium configuration of the plasma and field the main effect of interest—the lowering of the temperature and density of the gas in the coronal hole compared to their values in the corona at the same geometric height. In particular, it is shown that, at heights of several tens of Mm, the temperature and density of the plasma in the coronal hole are roughly half the corresponding values at the same height in the corona, if the cross-sectional radius of the hole exceeds the scale height in the corona by roughly a factor of 1.5: $R_h \approx 1.5H(T_0)$. In the special case when $R_h \approx H(T_0)$, the plasma temperature in the hole is equal to the coronal temperature, and the darkening of the coronal hole is due only to an appreciable reduction of the plasma density in the hole, compared to the coronal density. An analogy of the properties of coronal holes and sunspots is discussed, based on the similarity of the magnetic structures of these formations. In spite of the fundamental difference in the mechanisms for energy transport in coronal holes and sunspots, the equilibrium distributions of the plasma parameters in these formations are determined only by the magnetic and gravitational forces, giving rise to a number of common properties, due to their similar magnetic structures.

Relationship between the Parameters of Coronal Holes and High-Speed Solar Wind Streams over an Activity Cycle

V. N. **Obridko** and B. D. Shelting

Solar Physics, Volume 270, Number 1, 297-310, **2011, File**

https://link.springer.com/content/pdf/10.1007/s11207-011-9753-2.pdf

The comparison of the brightness and area of coronal holes (CH) to the solar wind speed, which was started by Obridko et al. (Solar Phys. 260, 191, 2009a) has been continued. While the previous work was dealing with a relatively short time interval 2000–2006, here we have analyzed the data on coronal holes observed in the Sun throughout activity Cycle 23. A catalog of equatorial coronal holes has been compiled, and their brightness and area variations during the cycle have been analyzed. It is shown that CH is not merely an undisturbed zone between the active regions. The corona heating mechanism in CH seems to be essentially the same as in the regions of higher activity. The reduced brightness is the result of a specific structure with the magnetic field being quasi-radial at as low an altitude as $1.1R_{\odot}$ or a bith
adequate choice of the photometric boundaries, the CH area and brightness indices display a fairly high correlation (0.6–0.8) with the solar wind velocity throughout the cycle, except for two years, which deviate dramatically – 2001 and 2007, i.e., the maximum and the minimum of the cycle. The mean brightness of the darkest part of CH, where the field lines are nearly radial at low altitudes, is of the order of 18–20% of the solar brightness, while the brightness of the other parts of the CH is 30–40%. The solar wind streams originate at the base of the coronal hole, which acts as an ejecting nozzle. The solar wind parameters in CH are determined at the level where the field lines are radial.

Open magnetic fields on the Sun and solar wind parameters at the Earth’s orbit<<<

V. N. **Obridko**, B. D. Shelting & I. M. Livshits

Astronomy Reports, Volume 55, Number 3, 284-291, **2011**

(Original Russian Text © V.N. Obridko, B.D. Shelting, I.M. Livshits, 2011, published in Astronomicheskii Zhurnal, 2011, Vol. 88, No. 3, pp. 313–320, 2011.)

https://link.springer.com/content/pdf/10.1134/S1063772911030048.pdf

It is shown that the parameters of the solar-wind magnetic field are determined by regions in coronal holes at distances of 1.1–1.4 solar radii, where the field lines are radial at low heights. Expanding further in a narrow nozzle or funnel, the field lines become radial throughout the unipolar region at 2.5 solar radii. Hence, the traditional approach of comparing the characteristics of the interplanetary field at the Earth’s orbit and at the corresponding helio-projection point on the Sun is not quite correct. It gives good results for the signs and sector structure of the field; however, the magnitude of the field is formed in a more extensive area. Taking this into account, we can correlate the field values on the Sun with the interplanetary magnetic field (IMF), and thus explain the absence of weak fields in the vicinity of the IMF neutral line (the two-peaked nature of the distribution).

Contrast of Coronal Holes and Parameters of Associated SolarWind Streams

V.N. **Obridko** · B.D. Shelting · I.M. Livshits · A.B. Asgarov

Solar Phys (**2009**) 260: 191–206, **File**

https://link.springer.com/content/pdf/10.1007/s11207-009-9435-5.pdf

It is shown that the contrast of coronal holes, just as their size, determines the velocity of the solar wind streams. Fully calibrated EIT images of the Sun have been used. About 450 measurements in 284 Å have been analyzed. The time interval under examination covers about 1500 days in the declining phase of cycle 23. All coronal holes recorded for this interval in the absence of coronal mass ejections (CMEs) have been studied. The comparison with some other parameters (*e.g.* density, temperature, magnetic field) was carried out. The correlations with the velocity are rather high (0.70 – 0.89), especially during the periods of moderate activity, and could be used for everyday forecast. The contrast of coronal holes is rather small.

Study of the solar coronal hole rotation

N.B. **Oghrapishvili**, S.R. Bagashvili, D.A. Maghradze, T.Z. Gachechiladze, D.R. Japaridze, B.M. Shergelashvili, T.G. Mdzinarishvili, B.B. Chargeishvili

Advances in Space Research Volume 61, Issue 12, 15 June **2018**   Pages 3039-3050

https://reader.elsevier.com/reader/sd/02EE56D3C491CFBFE443F5F6BF71080936129C948050B72DBBC3F51090D27088792A07A05A47F2E08A65C8F51ECC2D7E

Rotation of coronal holes is studied using data from SDO/AIA for 2014 and 2015. A new approach to the treatment of data is applied. Instead of calculated average angular velocities of each coronal hole centroid and then grouping them in latitudinal bins for calculating average rotation rates of corresponding latitudes, we compiled instant rotation rates of centroids and their corresponding heliographic coordinates in one matrix for further processing. Even unfiltered data showed clear differential nature of rotation of coronal holes. We studied possible reasons for distortion of data by the limb effects to eliminate some discrepancies at high latitudes caused by the high order of scattering of data in that region. A study of the longitudinal distribution of angular velocities revealed the optimal longitudinal interval for the best result. We examined different methods of data filtering and realized that filtration using targeting on the local medians of data with a constant threshold is a more acceptable approach that is not biased towards a predefined notion of an expected result. The results showed a differential pattern of rotation of coronal holes.

Comparative Analysis of a Transition Region Bright Point with a Blinker and Coronal Bright Point Using Multiple EIS Emission Lines

N. Brice **Orange**, Hakeem M. Oluseyi, David L. Chesny, Maulik Patel, Katie Hesterly, Lauren Preuss, Chantale Neira, Niescja E. Turner

Solar Physics, May **2014**, Volume 289, Issue 5, pp 1557-1584

Since their discovery 20 year ago, transition region bright points have never been observed spectroscopically. Bright point properties have not been compared with similar transition region and coronal structures. In this work we have investigated three transient quiet Sun brightenings including a transition region bright point (TR BP), a coronal bright point (CBP) and a blinker. We use time-series observations of the extreme-ultraviolet emission lines of a wide range of temperature T (logT=5.3 – 6.4) from the EUV Imaging Spectrometer (EIS) onboard the Hinode satellite. We present the EIS temperature maps and Doppler maps, which are compared with magnetograms from the Michelson Doppler Imager (MDI) onboard the SOHO satellite. Doppler velocities of the TR BP and blinker are ≤ 25 km s−1, which is typical of transient TR phenomena. The Doppler velocities of the CBP were found to be ≤ 20 km s−1 with exception of those measured at logT=6.2 where a distinct bi-directional jet is observed. From an EM loci analysis we find evidence of single and double isothermal components in the TR BP and CBP, respectively. TR BP and CBP loci curves are characterized by broad distributions suggesting the existence of unresolved structure. By comparing and contrasting the physical characteristics of the events we find that the BP phenomena are an indication of multi-scaled self-similarity, given the similarities in both their underlying magnetic field configuration and evolution in relation to EUV flux changes. In contrast, the blinker phenomena and the TR BP are sufficiently dissimilar in their observed properties as to constitute different event classes. Our work is an indication that the measurement of similar characteristics across multiple event types holds class-predictive power, and is a significant step towards automated solar atmospheric multi-class classification of unresolved transient EUV sources. Finally, the analysis performed here establishes a connection between solar quiet region CBPs and jets. **22-01-2008**

Ion Heating in Inhomogeneous Expanding Solar Wind Plasma: The Role of Parallel and Oblique Ion-Cyclotron Waves

Ozak, N.; Ofman, L.; Vi?as, A.-F.

2015

http://arxiv.org/pdf/1407.4622v2.pdf

Remote sensing observations of coronal holes show that heavy ions are hotter than protons and their temperature is anisotropic. In-situ observations of fast solar wind streams provide direct evidence for turbulent Alfvén wave spectrum, left-hand polarized ion-cyclotron waves, and He^++ - proton drift in the solar wind plasma, which can produce temperature anisotropies by resonant absorption and perpendicular heating of the ions. Furthermore, the solar wind is expected to be inhomogeneous on decreasing scales approaching the Sun. We study the heating of solar wind ions in inhomogeneous plasma with a 2.5D hybrid code. We include the expansion of the solar wind in an inhomogeneous plasma background, combined with the effects of a turbulent wave spectrum of Alfvénic fluctuations and initial ion-proton drifts. We study the influence of these effects on the perpendicular ion heating and cooling and on the spectrum of the magnetic fluctuations in the inhomogeneous background wind. We find that inhomogeneities in the plasma lead to enhanced heating compared to the homogenous solar wind, and the generation of significant power of oblique waves in the solar wind plasma. The cooling effect due to the expansion is not significant for super-Alfvénic drifts, and is diminished further when we include an inhomogenous background density. We reproduce the ion temperature anisotropy seen in observations and previous models, which is present regardless of the perpendicular cooling due to solar wind expansion. We conclude that small scale inhomogeneities in the inner heliosphere can significantly affect resonant wave ion heating.

Searching for a Solar Source of Magnetic-Field Switchbacks in Parker Solar Probe's First Encounter

D. de **Pablos**, T. Samanta, S. T. Badman, C. Schwanitz, S. M. Bahauddin, L. K. Harra, G. Petrie, C. Mac Cormack, C. H. Mandrini, N. E. Raouafi, V. Martinez Pillet & M. Velli

Solar Physics volume 297, Article number: 90 (**2022**)

https://link.springer.com/content/pdf/10.1007/s11207-022-02022-4.pdf

Parker Solar Probe observations show ubiquitous magnetic-field reversals closer to the Sun, often referred to as "switchbacks". The switchbacks have been observed before in the solar wind near 1 AU and beyond, but their occurrence was historically rare. PSP measurements below ∼ 0.2 AU show that switchbacks are, however, the most prominent structures in the "young" solar wind. In this work, we analyze remote-sensing observations of a small equatorial coronal hole to which PSP was connected during the perihelion of Encounter 1. We investigate whether some of the switchbacks captured during the encounter were of coronal origin by correlating common switchback in situ signatures with remote observations of their expected coronal footpoint. We find strong evidence that timescales present in the corona are relevant to the outflowing, switchback-filled solar wind, as illustrated by strong linear correlation. We also determine that spatial analysis of the observed region is optimal, as the implied average solar-wind speed more closely matches that observed by PSP at the time. We observe that hemispherical structures are strongly correlated with the radial proton velocity and the mass flux in the solar wind. The above findings suggest that a subpopulation of the switchbacks are seeded at the corona and travel into interplanetary space. **29 Oct-2 Nov 2018**

Magnetic Flux Emergence in a Coronal Hole

Judith **Palacios**, Dominik Utz, Stefan Hofmeister, et al.

Solar Physics volume 295, Article number: 64 (**2020**)

https://arxiv.org/pdf/2006.11779.pdf

https://link.springer.com/content/pdf/10.1007/s11207-020-01629-9.pdf

A joint campaign of various space-borne and ground-based observatories, comprising the Japanese Hinode mission (Hinode Observing Plan 338, 20 – 30 September 2017), the GREGOR solar telescope, and the Vacuum Tower Telescope (VTT), investigated numerous targets such as pores, sunspots, and coronal holes. In this study, we focus on the coronal hole region target. On 24 September 2017, a very extended non-polar coronal hole developed patches of flux emergence, which contributed to the decrease of the overall area of the coronal hole. These flux emergence patches erode the coronal hole and transform the area into a more quiet-Sun-like area, whereby bipolar magnetic structures play an important role. Conversely, flux cancellation leads to the reduction of opposite-polarity magnetic fields and to an increase in the area of the coronal hole.

Other global coronal hole characteristics, including the evolution of the associated magnetic flux and the aforementioned area evolution in the EUV, are studied using data of the Helioseismic and Magnetic Imager (HMI) and Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO). The interplanetary medium parameters of the solar wind display values compatible with the presence of the coronal hole. Furthermore, a particular transient is found in those parameters. **24-27 Sep 2017**

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.

Large-scale Magnetic Funnels in the Solar Corona

Olga **Panasenco**1, Marco Velli2, and Aram Panasenco

2019 ApJ 873 25

https://doi.org/10.3847/1538-4357/ab017c

We describe open coronal magnetic fields with a specific geometry—large-scale coronal magnetic funnels—that are found to play an important role in coronal dynamics. Coronal magnetic funnels can be attributed to three main factors: (i) the presence of pseudostreamer(s), (ii) the presence of filament channels, and (iii) the presence of active regions in the close vicinity of a pseudostreamer. The geometry of magnetic funnels displays a strongly nonmonotonic expansion below 2 R ⊙. We present a detailed study of a funnel arising from a double pseudostreamer near the equator, formed between a triplet of coronal holes of the same polarity. By following the evolution of these coronal holes we find that the pseudostreamer and, therefore, funnel topology, changes when two coronal holes have merged together. The funnel geometry of the open magnetic field becomes smoother, with a monotonic expansion factor, after this merging. The presence of magnetic funnels is indirectly confirmed by the appearance of coronal cloud prominences in the solar corona, typically in the 304 Å passband, as a result of colder plasma debris falling back toward the Sun in the wake of eruptions in the surrounding atmosphere. The coronal clouds appear suspended at heights of 1.2–1.3 R ⊙, coinciding with the region of strongest gradients in the magnetic field. By studying the evolution of funnel open magnetic fields over several solar rotations we find a direct relation between the presence of coronal clouds high in the solar corona and the coincident existence of funnel magnetic fields below them.

Magnetic Flux Cancelation as the Trigger of Solar Coronal-Hole Coronal Jets

Navdeep K. **Panesar**, Alphonse C. Sterling, Ronald L. Moore

ApJ **853** 189 **2018**

https://arxiv.org/pdf/1801.05344.pdf

We investigate in detail the magnetic cause of minifilament eruptions that drive coronal-hole jets. We study 13 random on-disk coronal hole jet eruptions, using high resolution X-ray images from Hinode/XRT, EUV images from SDO/AIA, and magnetograms from SDO/HMI. For all 13 events, we track the evolution of the jet-base region and find that a minifilament of cool (transition-region-temperature) plasma is present prior to each jet eruption. HMI magnetograms show that the minifilaments reside along a magnetic neutral line between majority-polarity and minority-polarity magnetic flux patches. These patches converge and cancel with each other, with an average cancelation rate of ~0.6 X 10$^18 Mx hr^{-1} for all 13 jets. Persistent flux cancelation at the neutral line eventually destabilizes the minifilament field, which erupts outward and produces the jet spire. Thus, we find that all 13 coronal-hole-jet-driving minifilament eruptions are triggered by flux cancelation at the neutral line. These results are in agreement with our recent findings Panesar et al 2016b for quiet-region jets, where flux cancelation at the underlying neutral line triggers the minifilament eruption that drives each jet. Thus from that study of quiet-Sun jets and this study of coronal hole jets, we conclude that flux cancelation is the main candidate for triggering quiet region and coronal hole jets. **2012 July 02, 2017 Jan 03**

Table 1. Timing and location for the observed coronal-hole jets

Study of Coronal Jets During Solar Minimum Based on STEREO/SECCHI Observations

A.R. **Paraschiv** · D.A. Lacatus · T. Badescu · M.G. Lupu · S. Simon · S.G. Sandu · M. Mierla · M.V. Rusu

Solar Phys (**2010**) 264: 365–375

During the 2007 – 2008 minimum of solar activity, the internally occulted coronagraphs
SECCHI-COR1 onboard the STEREO space mission recorded numerous jet-like

ejections over a great range of latitudes. We have found more than 10000 white-light jets in the above-mentioned period. Sometimes they can be identified on the disk with bright points observed in ultraviolet images by EUVI. In this study we present a catalog consisting of jets observed by the SECCHI-COR1 instrument and their association with lower coronal activity (bright points, UV jets). Furthermore, their association with bright points in the context of previously proposed models is discussed. From the complete catalog we have selected 106 jets observed in both STEREO-A and STEREO-B images for which it is possible to derive their kinematics and point of origin.
Supplemental HTML http://springerlink.com/content/506kp8h485618873/11207_2010_Article_9584_ESM.html

Fast magnetoacoustic wave trains in coronal holes

D. J. **Pascoe**1, V. M. Nakariakov1,2,3 and E. G. Kupriyanova3
A&A 568, A20 (**2014**)
Context. Rapidly propagating coronal EUV disturbances recently discovered in the solar corona are interpreted in terms of guided fast magnetoacoustic waves. Fast magnetoacoustic waves experience geometric dispersion in waveguides, which causes localised, impulsive perturbations to develop into quasi-periodic wave trains.
Aims. We consider the formation of fast wave trains in a super-radially expanding coronal hole modelled by a magnetic funnel with a field-aligned density profile that is rarefied in comparison to the surrounding plasma. This kind of structure is typical of coronal holes, and it forms a fast magnetoacoustic anti-waveguide as a local maximum in the Alfvén speed.
Methods. We performed 2D MHD numerical simulations for impulsively generated perturbations to the system. Both sausage and kink perturbations are considered and the role of the density contrast ratio investigated.
Results. The anti-waveguide funnel geometry refracts wave energy away from the structure. However, in this geometry the quasi-periodic fast wave trains are found to appear, too, and so can be associated with the observed rapidly propagating coronal EUV disturbances. The wave trains propagate along the external edge of the coronal hole. The fast wave trains generated in coronal holes exhibit less dispersive evolution than in the case of a dense waveguide.
Conclusions. We conclude that an impulsive energy release localised in a coronal plasma inhomogeneity develops into a fast wave train for both kink and sausage disturbances and for both waveguide and anti-waveguide transverse plasma profiles.

Evolution of coronal hole solar wind in the inner heliosphere: Combined observations by Solar Orbiter and Parker Solar Probe

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A&A 668, A189 (**2022**)
https://doi.org/10.1051/0004-6361/202243989
https://www.aanda.org/articles/aa/pdf/2022/12/aa43989-22.pdf
We study the radial evolution, from 0.1 AU to the Earth, of a homogeneous recurrent fast wind, coming from the same source on the Sun, by means of new measurements by both Solar Orbiter and Parker Solar Probe. With respect to previous radial studies, we extend, for the first time, the analysis of a recurrent fast stream at distances never reached prior to the Parker Solar Probe mission. Confirming previous findings, the observations show: (i) a decrease in the radial trend of the proton density that is slower than the one expected for a radially expanding plasma, due to the possible presence of a secondary beam in the velocity distribution function; (ii) a deviation for the magnetic field from the Parker prediction, supported by the strong Alfvénicity of the stream at all distances; and (iii) a slower decrease in the proton temperature with respect to the adiabatic prediction, suggesting the local presence of external heating mechanisms. Focusing on the radial evolution of the turbulence, from the inertial to the kinetic range along the turbulent cascade, we find that the slopes, in both frequency ranges, strongly depend on the different turbulence observed by the two spacecraft, namely a mostly parallel turbulence in the Parker Solar Probe data and a mostly perpendicular turbulence in the Solar Orbiter intervals. Moreover, we observe a decrease in the level of intermittency for the magnetic field during the expansion of the stream. Furthermore, we perform, for the first time, a statistical analysis of coherent structures around proton scales at 0.1 AU and we study how some of their statistical properties change from the Sun to the Earth. As expected, we find a higher occurrence of events in the Parker Solar Probe measurements than in the Solar Orbiter data, considering the ratio between the intervals length and the proton characteristic scales at the two radial distances. Finally, we complement this statistical analysis with two case studies of current sheets and vortex-like structures detected at the two radial distances, and we find that structures that belong to the same family have similar characteristics at different radial distances. This work provides an insight into the radial evolution of the turbulent character of solar wind plasma coming from coronal holes.

LOW-LATITUDE CORONAL HOLES, DECAYING ACTIVE REGIONS, AND GLOBAL CORONAL MAGNETIC STRUCTURE

G. J. D. **Petrie**1 and K. J. Haislmaie

2013 ApJ 775 100

We study the relationship between decaying active-region magnetic fields, coronal holes, and the global coronal magnetic structure using Global Oscillations Network Group synoptic magnetograms, Solar TErrestrial RElations Observatory extreme-ultraviolet synoptic maps, and coronal potential-field source-surface models. We analyze 14 decaying regions and associated coronal holes occurring between early 2007 and late 2010, 4 from cycle 23 and 10 from cycle 24. We investigate the relationship between asymmetries in active regions' positive and negative magnetic intensities, asymmetric magnetic decay rates, flux imbalances, global field structure, and coronal hole formation. Whereas new emerging active regions caused changes in the large-scale coronal field, the coronal fields of the 14 decaying active regions only opened under the condition that the global coronal structure remained almost unchanged. This was because the dominant slowly varying, low-order multipoles prevented opposing-polarity fields from opening and the remnant active-region flux preserved the regions' low-order multipole moments long after the regions had decayed. Thus, the polarity of each coronal hole necessarily matched the polar field on the side of the streamer belt where the corresponding active region decayed. For magnetically isolated active regions initially located within the streamer belt, the more intense polarity generally survived to form the hole. For non-isolated regions, flux imbalance and topological asymmetry prompted the opposite to occur in some cases.

Long- and Short-Term Evolutions of Magnetic Field Fluctuations in High-Speed Streams

Gilbert **Pi**, Alexander Pitňa, Zdenek Němeček, Jana Šafránková, Jih-Hong Shue & Ya-Hui Yang

Solar Physics volume 295, Article number: 84 (**2020**)

https://link.springer.com/content/pdf/10.1007/s11207-020-01646-8.pdf

High-speed streams (HSSs) are believed to be only slightly affected by different interactions on their path from the Sun to Earth and thus the analysis of their observations can provide information on the structure and temporal variations of the magnetic field and plasma parameters at the source region. We have chosen three coronal holes supplying 14 HSSs recorded by Wind in 2008. For each HSS, we have calculated the average magnetic field and plasma parameters as well as power spectral densities (PSDs) of magnetic field fluctuations in the MHD and kinetic ranges to investigate their long- and short-term variations. We suggest that long-term variations are connected with a time evolution of the source region on the time scale of solar rotations. On the other hand, the short-term variations would reflect a longitudinal structure of the coronal hole. Our study reveals that coronal holes are very stable source of HSSs and their temporal evolution on short- and long-time scales is negligible. This is true for the average parameters as well as for the fluctuation power and PSDs. Observed correlations between bulk and/or thermal velocity and PSD parameters are consistent with already published results. We suggest that they do not originate in the source region but they can be mostly attributed to interaction with the ambient slow wind that affects even the HSS core. **4–12 January 2008**

Table 1 List of HSS events and the related CHs (2008)

Effects of different coronal hole geometries on simulations of the interaction between coronal waves and coronal holes

I. **Piantschitsch**[1,2,3], J. Terradas[1,2], E. Soubrie[2,4], S. G. Heinemann[5], S. J. Hofmeister[6], R. Soler[1,2] and M. Temmer[3]

A&A, 687, A200 (**2024**)

https://www.aanda.org/articles/aa/pdf/2024/07/aa48003-23.pdf

The geometry of a coronal hole (CH) affects the density profile of the reflected part of an incoming global coronal wave (CW). In this study, we perform for the first time magnetohydrodynamic (MHD) simulations of fast-mode MHD waves that interact with CHs of different geometries, such as circular, elliptic, convex, and concave shapes. We analysed the effect of these geometries on the density profiles of the reflected waves, and we generated the corresponding simulation-based time-distance plots. Within these time-distance plots, we determined regions that exhibit specific density features, such as large reflected density amplitudes. In a further step, these interaction features can be compared to actual observed CW–CH interaction events, which will enable us to explain interaction parameters of the observed interaction events, such as the density structure of the reflected wave. These parameters are usually difficult to understand comprehensively based on an analysis of the measurements alone. Moreover, we show that the interaction between a concave CH and CWs, whose density profile includes an enhanced as well as a depleted wave part, can lead to reflected density amplitudes that are more than twice larger than the incoming density amplitudes. Another effect of the interplay between the constructive and destructive interference of the reflected wave parts is a strongly depleted region in the middle of the CW–CH interaction process. In addition, we show that the choice of the path that is used to generate the time-distance plots is important and that this choice affects the interpretation of the CW–CH interaction results.

Role of initial density profiles in simulations of coronal wave-coronal hole interactions⋆

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https://arxiv.org/pdf/2308.08928.pdf
https://www.aanda.org/articles/aa/pdf/2023/11/aa46871-23.pdf
Interactions between global coronal waves (CWs) and coronal holes (CHs) reveal many interesting features of reflected waves and coronal hole boundaries (CHB). However, such interactions have scarcely been studied thus far. Magnetohydrodynamic (MHD) simulations can help us to better understand what is happening during these interaction events and thus to achieve a broader understanding of the parameters involved. In this study, we performed the first 2D MHD simulations of a CW–CH interaction that include a realistic initial wave density profile consisting of an enhanced wave component as well as a depleted one. We varied several initial parameters, such as the initial density amplitudes of the incoming wave, the CH density, and the CHB width, which are all based on actual measurements. We analysed the effects of different incident angles on the interaction features and we used the corresponding time-distance plots to detect specific features of the incoming and the reflected waves. We found that the specific combination of a small CH density, a realistic initial density profile, and a sufficiently small incident angle can lead to remarkable interaction features, such as a large density amplitude for the reflected wave and greater phase speed for the reflected wave with respect to the incoming one. The parameter studies in this paper provide a tool for comparing time-distance plots based on observational measurements to those created from simulations. This has enabled us to derive interaction parameters from observed CW–CH interaction events that usually cannot be obtained directly. The simulation results in this study are augmented by analytical expressions for the reflection coefficient of the CW–CH interaction, which allows us to verify the simulations results in an complementary way. This work, with its focus on parameter studies that examine the initial density profile of CWs, is the first of a series of studies aiming to ultimately reconstruct actual observed CW–CH interaction events by means of MHD simulations. These results improve our understanding of the involved interaction parameters in a comprehensive way.

Numerical Simulation of Coronal Waves Interacting with Coronal Holes. II. Dependence on Alfvén Speed Inside the Coronal Hole

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2018 ApJ 857 130
http://sci-hub.tw/10.3847/1538-4357/aab709
We used our newly developed magnetohydrodynamic (MHD) code to perform 2.5D simulations of a fast-mode MHD wave interacting with coronal holes (CHs) of varying Alfvén speed that result from assuming different CH densities. We find that this interaction leads to effects like reflection, transmission, stationary fronts at the CH boundary, and the formation of a density depletion that moves in the opposite direction to the incoming wave. We compare these effects with regard to the different CH densities and present a comprehensive analysis of morphology and kinematics of the associated secondary waves. We find that the density value inside the CH influences the phase speed and the amplitude values of density and magnetic field for all different secondary waves. Moreover, we observe a correlation between the CH density and the peak values of the stationary fronts at the CH boundary. The findings of reflection and transmission on the one hand and the formation of stationary fronts caused by the interaction of MHD waves with CHs on the other hand strongly support the theory that large-scale disturbances in the corona are fast-mode MHD waves.

Solar wind rotation rate and shear at coronal hole boundaries, possible consequences for magnetic field inversions

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https://arxiv.org/pdf/2104.08393.pdf
https://www.aanda.org/articles/aa/pdf/2021/09/aa40180-20.pdf
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In-situ measurements by several spacecraft have revealed that the solar wind is frequently perturbed by transient structures (magnetic folds, jets, waves, flux-ropes) that propagate rapidly away from the Sun over large distances. Parker Solar Probe has detected frequent rotations of the magnetic field vector at small heliocentric distances, accompanied by surprisingly large solar wind rotation rates. The physical origin of such magnetic field bends, the conditions for their survival across the interplanetary space, and their relation to solar wind rotation are yet to be clearly understood. We traced measured solar wind flows from the spacecraft position down to the surface of the Sun to identify their potential source regions and used a global MHD model of the corona and solar wind to relate them to the rotational state of the low solar corona. We identified regions of the solar corona for which solar wind speed and rotational shear are important and long-lived, that can be favourable to the development of magnetic deflections and to their propagation across extended heights in the solar wind. We show that coronal rotation is highly structured and that enhanced flow shear develops near the boundaries between coronal holes and streamers, around and above pseudo-streamers, even when such boundaries are aligned with the direction of solar rotation. A

large fraction of the switchbacks identified by PSP map back to these regions, both in terms of instantaneous magnetic field connectivity and of the trajectories of wind streams that reach the spacecraft. These regions of strong shears are likely to leave an imprint on the solar wind over large distances and to increase the transverse speed variability in the slow solar wind. The simulations and connectivity analysis suggest they can be a source of the switchbacks and spikes observed by Parker Solar Probe.

Uncertainty Estimates of Solar Wind Prediction using HMI Photospheric Vector and Spatial Standard Deviation Synoptic Maps

Bala **Poduval**, Gordon Petrie, Luca Bertello

Solar Phys. **2020**

https://arxiv.org/pdf/2008.06538.pdf

Current solar wind prediction is based on the Wang & Sheeley empirical relationship between the solar wind speed observed at 1 AU and the rate of magnetic flux tube expansion (FTE) between the photosphere and the inner corona, where FTE is computed by coronal models that take the photospheric flux density synoptic maps as their inner boundary conditions to extrapolate the photospheric magnetic fields to deduce the coronal and the heliospheric magnetic field configuration. Since these synoptic maps are among the most widely-used of all solar magnetic data products, the uncertainties in the model predictions that are caused by the uncertainties in the synoptic maps are worthy of study. However, such an estimate related to synoptic map construction was not available until Bertello et al. (Solar Physics, 289, 2014) obtained the spatial standard deviation synoptic maps; 98 Monte-Carlo realizations of the spatial standard deviation maps for each photospheric synoptic maps. In this paper, we present an estimate of uncertainties in the solar wind speed predicted at 1 AU by the CSSS model due to the uncertainties in the photospheric synoptic maps. We also present a comparison of the coronal hole locations predicted by the models with the STEREO/SECCHI EUV synoptic maps. In order to quantify the extent of the uncertainties involved, we compared the predicted speeds with the OMNI solar wind data during the same period (taking the solar wind transit time into account) and obtained the root mean square error between them. To illustrate the significance of the uncertainty estimate in the solar wind prediction, we carried out the analysis for three Carrington rotations, CR 2102, CR 2137 and CR 2160 at different phases of the solar cycle. The uncertainty estimate is critical information necessary for the current and future efforts of improving the solar wind prediction accuracies. **3 – 30 October 2010, 14 May – 11 June, 2013, 1 – 28 February, 2015**

POINT-SPREAD FUNCTIONS FOR THE EXTREME-ULTRAVIOLET CHANNELS OF SDO/AIA TELESCOPES

B. **Poduval**1, C. E. DeForest1, J. T. Schmelz2, and S. Pathak

2013 ApJ 765 144

We present the stray-light point-spread functions (PSFs) and their inverses we characterized for the Atmospheric Imaging Assembly (AIA) EUV telescopes on board the Solar Dynamics Observatory (SDO) spacecraft. The inverse kernels are approximate inverses under convolution. Convolving the original Level 1 images with them produces images with improved stray-light characteristics. We demonstrate the usefulness of these PSFs by applying them to two specific cases: photometry and differential emission measure (DEM) analysis. The PSFs consist of a narrow Gaussian core, a diffraction component, and a diffuse component represented by the sum of a Gaussian-truncated Lorentzian and a shoulder Gaussian. We determined the diffraction term using the measured geometry of the diffraction pattern identified in flare images and the theoretically computed intensities of the principal maxima of the first few diffraction orders. To determine the diffuse component, we fitted its parameterized model using iterative forward-modeling of the lunar interior in the SDO/AIA images from the 2011 March 4 lunar transit. We find that deconvolution significantly improves the contrast in dark features such as miniature coronal holes, though the effect was marginal in bright features. On a percentage-scattering basis, the PSFs for SDO/AIA are better by a factor of two than that of the EUV telescope on board the Transition Region And Coronal Explorer mission. A preliminary analysis suggests that deconvolution alone does not affect DEM analysis of small coronal loop segments with suitable background subtraction. We include the derived PSFs and their inverses as supplementary digital materials.

Observations of ULF wavses in the solar corona and in the solar wind at the Earth's orbit

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JASTP, Volume 102, September 2013, Pages 235–242, **2013**

Signs were looked for that would indicate a possible connection between plasma velocity oscillations observed in the region of solar coronal holes and magnetic field oscillations as recorded in the interplanetary medium. The problem appears to be quite important since the presence of large-scale ULF waves in the solar wind can increase geoeffectiveness of high speed streams in the interplanetary plasma. Observations of solar oscillations in the FeI 6569 Å spectral line in a coronal hole were taken as a basis. The measurements were carried out at the Horizontal Automated Solar Telescope of the Sayan Solar Observatory. High speed solar wind stream ejected from the coronal hole reached the Earth's orbit after approximately 60 hours. The spectra of solar oscillations were compared with those of ultra low frequency (ULF) oscillations of the interplanetary magnetic field (IMF) at libration point L1. The oscillations were recorded with the ACE magnetometer when the leading edge of the high speed stream, bringing increased ULF wave activity, reached the Earth. The spectra of solar oscillations had a sharp peak at about 3.4–3.6 mHz. The spectrum of the solar wind ULF oscillations is much more complex, being formed by different sources. Nevertheless, ULF oscillations of the IMF often had peaks that were close in frequency to those of the solar oscillations. Analysis of the ULF wave spectra observed in the 92 high speed streams confirmed the presence of 3- and 5-min oscillations in the total wave spectrum. It is emphasized that the results cannot be regarded as proving a direct connection between solar oscillations and ULF waves at the Earth's orbit even though they do support such a possibility. Additional research is needed involving IMF wave trajectory calculations.

Recurring coronal holes and their rotation rates during the solar cycles 22–24

K. **Prabhu**, B. Ravindra, Manjunath Hegde & Vijayakumar H. Doddamani

Astrophysics and Space Science   May **2018**, 363:108

http://sci-hub.tw/10.1007/s10509-018-3307-0

Coronal holes (CHs) play a significant role in making the Earth geo-magnetically active during the declining and minimum phases of the solar cycle. In this study, we analysed the evolutionary characteristics of the Recurring CHs from the year 1992 to 2016. The extended minimum of Solar Cycle 23 shows unusual characteristics in the number of persistent coronal holes in the mid- and low-latitude regions of the Sun. Carrington rotation maps of He 10830 Å and EUV 195 Å observations are used to identify the Coronal holes. The latitude distribution of the RCHs shows that most of them are appeared between ±20∘±20∘ latitudes. In this period, more number of recurring coronal holes appeared in and around 100∘100∘ and 200∘200∘ Carrington longitudes. The large sized coronal holes lived for shorter period and they appeared close to the equator. From the area distribution over the latitude considered, it shows that more number of recurring coronal holes with area <1021 cm2<1021 cm2 appeared in the southern latitude close to the equator. The rotation rates calculated from the RCHs appeared between ±60∘±60∘ latitude shows rigid body characteristics. The derived rotational profiles of the coronal holes show that they have anchored to a depth well below the tachocline of the interior, and compares well with the helioseismology results.

The Connection of Solar Wind Parameters with Radio and UV Emission from Coronal Holes

D. V. **Prosovetsky** and I. N. Myagkova

Solar Physics, Volume 273, Number 2, 525-536, **2011, File**

This paper presents the results of a comparison between observations of coronal holes in UV (SOHO EIT) and radio emission (17, 5.7 GHz, 327 and 150.9 MHz, from NoRH, SSRT and Nançay radioheliographs), and solar wind parameters, from ACE spacecraft data over the period **12 March – 31 May 2007**. The increase in the solar wind velocity up to 600 km s−1 was found to correlate with a decrease in the UV flux in the central parts of the solar disk. A connection between the parameters of the radio emission from three different layers of the solar atmosphere and the solar wind velocity near the Earth's orbit was discovered. Such a connection is suggestive of a common mechanism of solar wind acceleration from chromospheric heights to the upper corona.

Evolution of Magnetohydrodynamic Waves in Low Layers of a Coronal Hole

Francesco **Pucci**1, Marco Onofri2, and Francesco Malara

2014 ApJ 796 43

Although a coronal hole is permeated by a magnetic field with a dominant polarity, magnetograms reveal a more complex magnetic structure in the lowest layers, where several regions of opposite polarity of typical size of the order of 104 km are present. This can give rise to magnetic separatrices and neutral lines. MHD fluctuations generated at the base of the coronal hole by motions of the inner layer of the solar atmosphere may interact with such inhomogeneities, leading to the formation of small scales. This phenomenon is studied on a 2D model of a magnetic structure with an X-point, using 2D MHD numerical simulations. This model implements a method of characteristics for boundary conditions in the direction outer-pointing to Sun surface to simulate both wave injection and exit without reflection. Both Alfvénic and magnetosonic perturbations are considered, and they show very different phenomenology. In the former case, an anisotropic power-law spectrum forms with a dominance of perpendicular wavevectors at altitudes ~104 km. Density fluctuations are generated near the X-point by Alfvén wave magnetic pressure and propagate along open fieldlines at a speed comparable to the local Alfvén velocity. An analysis of energy dissipation and heating caused by the formation of small scales for the Alfvénic case is presented. In the magnetosonic case, small scales form only around the X-point, where a phenomenon of oscillating magnetic reconnection is observed to be induced by the periodic deformation of the magnetic structure due to incoming waves.

Birth, Life, and Death of a Solar Coronal Plume

Stefano **Pucci**1, Giannina Poletto2, Alphonse C. Sterling3, and Marco Romoli

2014 ApJ 793 86

We analyze a solar polar-coronal-hole (CH) plume over its entire 40 hr lifetime, using high-resolution Solar Dynamic Observatory Atmospheric Imaging Assembly (AIA) data. We examine (1) the plume's relationship to a bright point (BP) that persists at its base, (2) plume outflows and their possible contribution to the solar wind mass supply, and (3) the physical properties of the plume. We find that the plume started 2 hr after the BP first appeared and became undetectable 1 hr after the BP disappeared. We detected radially moving radiance variations from both the plume and from interplume regions, corresponding to apparent outflow speeds ranging over (30-300) km s–1 with outflow velocities being higher in the "cooler" AIA 171 Å channel than in the "hotter" 193 Å and 211 Å channels, which is inconsistent with wave motions; therefore, we conclude that the observed radiance variations represent material outflows. If they persist into the heliosphere and plumes cover 10% of a typical CH area, these flows could account for 50% of the solar wind mass. From a differential emission measure analysis of the AIA images, we find that the average electron temperature of the plume remained approximately constant over its lifetime, at T e 8.5 × 105 K. Its density, however, decreased with the age of the plume, being about a factor of three lower when the plume faded compared to when it was born. We conclude that the plume died due to a density reduction rather than to a temperature decrease.

SOLAR POLAR X-RAY JETS AND MULTIPLE BRIGHT POINTS: EVIDENCE FOR SYMPATHETIC ACTIVITY

Stefano **Pucci**1, Giannina Poletto2, Alphonse C. Sterling3,4 and Marco Romoli

2012 ApJ 745 L31

We present an analysis of X-ray bright points (BPs) and X-ray jets observed by Hinode/X-Ray Telescope on 2007 November 2-4, within the solar northern polar coronal hole. After selecting small subregions that include several BPs, we followed their brightness evolution over a time interval of a few hours, when several jets were observed. We find that most of the jets occurred in close temporal association with brightness maxima in multiple BPs: more precisely, most jets are closely correlated with the brightening of at least two BPs. We suggest that the jets result from magnetic connectivity changes that also induce the BP variability. We surmise that the jets and implied magnetic connectivity we describe are small-scale versions of the active-region-scale phenomenon, whereby flares and eruptions are triggered by interacting bipoles.

Statistical properties of Hα jets in the polar coronal hole and their implications in coronal activities

Youqian **Qi**, Zhenghua Huang, Lidong Xia, Hui Fu, Mingzhe Guo, Zhenyong Hou, Weixin Liu, Mingzhe Sun, Dayang Liu

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Dynamic features, such as chromospheric jets, transition region network jets, coronal plumes and coronal jets, are abundant in the network regions of the solar polar coronal holes. We investigate the relationship between chromospheric jets and coronal activities (e.g., coronal plumes and jets).We analyze observations of a polar coronal hole including the filtergrams that were taken by the New Vacuum Solar Telescope (NVST) at the H{\alpha}-0.6 Åto study the H{\alpha} jets,and the Atmospheric Imaging Assembly (AIA) 171 Å images to follow the evolution of coronal activities. H{\alpha} jets are persistent in the network regions, only some regions (denoted as R1-R5) are rooted with discernible coronal plumes.With an automated method, we identify and track 1 320 H{\alpha} jets in the network regions. We find that the average lifetime, height and ascending speed of the H{\alpha} jets are 75.38 s, 2.67 Mm, 65.60 km s−1, respectively. The H{\alpha} jets rooted in R1-R5 are higher and faster than those in the others. We also find that propagating disturbances (PDs) in coronal plumes have a close connection with the H{\alpha} jets. The speeds of 28 out of 29 H{\alpha} jets associated with PDs are about 50 km s−1 . In a case of coronal jet, we find that the speeds of both the coronal jet and the H{\alpha} jet are over 150 km s−1, suggesting that both cool and hot jets can be coupled together. Based on our analyses, it is evident that more dynamic H{\alpha} jets could release the energies to the corona, which might be the results of the development of Kelvin-Helmholtz instability (KHi) or small-scaled magnetic activities. We suggest that chromospheric jets, transition region network jets and ray-like features in the corona are coherent phenomena, and they are important tunnels for cycling energy and mass in the solar atmosphere.

Energetics of Solar Coronal Bright Points

Somaye Hosseini **Rad**, Nasibe Alipour, and Hossein Safari

2021 ApJ 906 59

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The several-million-degree, low-density quiet solar corona requires a total energy-loss flux of about 3 × 105 erg cm−2 s−1. Solar coronal bright points (CBPs) are ubiquitous in the quiet Sun. They may release magnetic energy to heat the solar corona, but their contribution to the energy flux has not been determined yet. We used an automatic identification and tracking method for CBPs, which was developed based on the support vector machine classifier and Zernike moments of extreme ultraviolet (EUV) observations from the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory. We applied a spatial synthesis differential emission measure method and a Vertical-Current Approximation Nonlinear Force-Free Field technique to extract the thermal and magnetic energetics of the CBPs, respectively. By analyzing 7.5 yr (within the solar cycle 24) of AIA observations, we show that the average thermal energy and magnetic free energy of 140,000 CBPs are positively correlated with sunspots. However, the number of CBPs and sunspots are highly anti-correlated. We calculate a total energy-loss flux (sum of the radiative and conductive loss flux) of about (4.84 ± 1.60) × 103 erg cm−2 s−1 for the system of CBPs. Therefore, it is about 1.61% ± 0.53% of the total energy-loss flux of quiet corona. By extending the distribution of the magnetic Poynting flux and energy-loss flux for CBPs to nanoflares, the total magnetic Poynting flux and total energy-loss flux are obtained to be in the range of 1.48 × 105 to 1.57 × 106 and 3.86 × 104 to 2.35 × 105 erg cm−2 s−1, respectively.

On the Relative Brightness of Coronal Holes at Low Frequencies

M. M. **Rahman**, Patrick I. McCauley, Iver H. Cairns

Solar Physics   January **2019**, 294:7

https://link.springer.com/content/pdf/10.1007%2Fs11207-019-1396-8.pdf

We present low-frequency (80 – 240 MHz) radio observations of coronal holes (CHs) made with the Murchison Widefield Array (MWA). CHs are expected to be dark structures relative to the background corona across the MWA bandwidth due to their low densities. However, we observe that multiple CHs near disk center transition from being dark structures at higher frequencies to bright structures at lower frequencies (≲145 MHz≲145 MHz). We compare our observations to synthetic images obtained using the software suite FORWARD, in combination with the magnetohydrodynamic algorithm outside a sphere (MAS) model of the global coronal magnetic field, density, and temperature structure. The synthetic images do not exhibit this transition, and we quantify the discrepancy as a function of frequency. We propose that the dark-to-bright transition results from refraction of radio waves into the low-density CH regions, and we develop a qualitative model based on this idea and the relative optical depths inside and outside a CH as a function of frequency. We show that opacity estimates based on the MAS model are qualitatively consistent with our interpretation, and we conclude that propagation and relative absorption effects are a viable explanation for the dark-to-bright transition of CHs from high to low frequencies. **28 August 2014, 31 August 2015, 08 September 2015**

Relative Velocities and Linewidths in a Coronal Hole and Outside

K.P. **Raju**

Solar Phys (**2009**) 255: 119–129, DOI 10.1007/s11207-008-9309-2

Relative Doppler velocities and spectral linewidths in a coronal hole and in the quiet Sun region outside have been obtained from *Solar and Heliospheric Observatory* (SOHO)/Coronal Diagnostic Spectrometer (CDS) observations. Five strong emission lines in the CDS wavelength range (namely, O III 599 Å, O V 630 Å, Ne VI 562.8 Å, He II 304 Å, and Mg IX 368 Å), whose formation temperatures represent different heights in the solar atmosphere from the lower transition region to the inner corona, have been used in the study. As reported earlier, relative velocities in the coronal hole are generally blueshifted with respect to the quiet Sun, and the magnitude of the blueshifts increases with height. It has been found that the polar coronal hole has larger relative velocities than the equatorial extension in the inner corona. Several localized velocity contours have been found mainly on network brightenings and in the vicinity of the coronal hole boundary. The presence of velocity contours on the network may represent network outflows whereas the latter could be due to localized jets probably arising from magnetic reconnection at the boundary. All spectral lines have larger widths in the coronal hole than in the quiet Sun. In O V 630 Å an extended low-linewidth region is seen in the coronal hole – quiet Sun boundary, which may indicate fresh mass transfer across the boundary. Also polar coronal holes have larger linewidths in comparison with the equatorial extension. Together with larger relative velocities, this suggests that the solar wind emanating from polar hole regions is faster than that from equatorial hole regions.

Automated analysis of oscillations in coronal bright points⋆

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https://www.aanda.org/articles/aa/pdf/2023/11/aa46757-23.pdf

Context. Coronal bright points (BPs) are numerous, bright, small-scale dynamical features found in the solar corona. Bright points have been observed to exhibit intensity oscillations across a wide range of periodicities and are likely an important signature of plasma heating and/or transport mechanisms.

Aims. We present a novel and efficient wavelet-based method that automatically detects and tracks the intensity evolution of BPs using images from the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics

Observatory (SDO) in the 193 Å bandpass. Through the study of a large, statistically significant set of BPs, we attempt to place constraints on the underlying physical mechanisms.
Methods. We used a continuous wavelet transform (CWT) in 2D to detect the BPs within images. One-dimensional CWTs were used to analyse the individual BP time series to detect significant periodicities.
Results. We find significant periodicity at 4, 8–10, 17, 28, and 65 min. Bright point lifetimes are shown to follow a power law with exponent −1.13 ± 0.07. The relationship between the BP lifetime and maximum diameter similarly follows a power law with exponent 0.129 ± 0.011.
Conclusions. Our wavelet-based method successfully detects and extracts BPs and analyses their intensity oscillations. Future work will expand upon these methods, using larger datasets and simultaneous multi-instrument observations. **01 January 2020**

INTERCHANGE RECONNECTION IN A TURBULENT CORONA

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2012 ApJ 758 L14

Magnetic reconnection at the interface between coronal holes and loops, the so-called interchange reconnection, can release the hotter, denser plasma from magnetically confined regions into the heliosphere, contributing to the formation of the highly variable slow solar wind. The interchange process is often thought to develop at the apex of streamers or pseudo-streamers, near Y- and X-type neutral points, but slow streams with loop composition have been recently observed along fanlike open field lines adjacent to closed regions, far from the apex. However, coronal heating models, with magnetic field lines shuffled by convective motions, show that reconnection can occur continuously in unipolar magnetic field regions with no neutral points: photospheric motions induce a magnetohydrodynamic turbulent cascade in the coronal field that creates the necessary small scales, where a sheared magnetic field component orthogonal to the strong axial field is created locally and can reconnect. We propose that a similar mechanism operates near and around boundaries between open and closed regions inducing a continual stochastic rearrangement of connectivity. We examine a reduced magnetohydrodynamic model of a simplified interface region between open and closed corona threaded by a strong unipolar magnetic field. This boundary is not stationary, becomes fractal, and field lines change connectivity continuously, becoming alternatively open and closed. This model suggests that slow wind may originate everywhere along loop-coronal-hole boundary regions and can account naturally and simply for outflows at and adjacent to such boundaries and for the observed diffusion of slow wind around the heliospheric current sheet.

The Influence of Polar Coronal Holes on the Polar ENA Flux Observed by IBEX

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2019 ApJ 879 1

sci-hub.se/10.3847/1538-4357/ab22c0

Polar coronal holes (PCHs) fill the high-latitude heliosphere with fast solar wind during the minimum phase of the solar cycle. This leads to a hardening of the energy spectrum of the proton plasma in the inner heliosheath (IHS), observed as energetic neutral atoms (ENAs) by the Interstellar Boundary Explorer (IBEX). In particular, the highest-energy channel of the IBEX-Hi instrument (at 4.3 keV) is a very sensitive indicator of pretermination shock fast wind entering the IHS. We show that the 4.3 keV ENA flux observed from the ecliptic poles is well correlated with the area of the solar surface covered by PCHs throughout the solar cycle, which demonstrates the existence of a direct connection between coronal structure and the dynamic properties of the IHS.

The Observational Uncertainty of Coronal Hole Boundaries in Automated Detection Schemes **Review**

Martin A. **Reiss**, Karin Muglach, Christian Möstl, Charles N. Arge, Rachel Bailey, Veronique Delouille, Tadhg M. Garton, Amr Hamada, Stefan Hofmeister, Egor Illarionov, Robert Jarolim, Michael S.F. Kirk, Alexander Kosovichev, Larisza Krista, Sangwoo Lee, Chris Lowder, Peter J. MacNeice, Astrid Veronig, ISWAT Coronal Hole Boundary Working Team

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Coronal holes are the observational manifestation of the solar magnetic field open to the heliosphere and are of pivotal importance for our understanding of the origin and acceleration of the solar wind. Observations from space missions such as the Solar Dynamics Observatory now allow us to study coronal holes in unprecedented detail. Instrumental effects and other factors, however, pose a challenge to automatically detect coronal holes in solar imagery. The science community addresses these challenges with different detection schemes. Until now, little attention has been paid to assessing the disagreement between these schemes. In this COSPAR ISWAT initiative, we present a comparison of nine automated detection schemes widely-applied in solar and space science. We study, specifically, a prevailing coronal hole observed by the Atmospheric Imaging Assembly instrument on **2018 May 30**. Our results indicate that the choice of detection scheme has a significant effect on the location of the coronal hole boundary. Physical properties in coronal holes such as the area, mean intensity, and mean magnetic field strength vary by a factor of up to 4.5 between the maximum and minimum values. We conclude that our findings are relevant for coronal hole research from the past decade, and are therefore of interest to the solar and space research community. **2018 May 30**

Improvements on coronal hole detection in SDO/AIA images using supervised classification

Martin A. **Reiss**, Stefan J. Hofmeister, Ruben De Visscher, Manuela Temmer, Astrid M. Veronig,Véronique Delouille, Benjamin Mampaey, Helmut Ahammer

J. Space Weather Space Clim., 5, A23 (**2015**)

http://arxiv.org/pdf/1506.06623v1.pdf

http://www.swsc-journal.org/articles/swsc/pdf/2015/01/swsc140061.pdf

We demonstrate the use of machine learning algorithms in combination with segmentation techniques in order to distinguish coronal holes and filaments in SDO/AIA EUV images of the Sun. Based on two coronal hole detection techniques (intensity-based thresholding, SPoCA), we prepared data sets of manually labeled coronal hole and filament channel regions present on the Sun during the time range 2011 - 2013. By mapping the extracted regions from EUV observations onto HMI line-of-sight magnetograms we also include their magnetic characteristics. We computed shape measures from the segmented binary maps as well as first order and second order texture statistics from the segmented regions in the EUV images and magnetograms. These attributes were used for data mining investigations to identify the most performant rule to differentiate between coronal holes and filament channels. We applied several classifiers, namely Support Vector Machine, Linear Support Vector Machine, Decision Tree, and Random Forest and found that all classification rules achieve good results in general, with linear SVM providing the best performances (with a true skill statistic of ~0.90). Additional information from magnetic field data systematically improves the performance across all four classifiers for the SPoCA detection. Since the calculation is inexpensive in computing time, this approach is well suited for applications on real-time data. This study demonstrates how a machine learning approach may help improve upon an unsupervised feature extraction method.
30-Jul-2012

https://github.com/rubendv/ch_filament_classification

Identification of coronal holes and filament channels in SDO/AIA 193Å images via geometrical classification methods

M. **Reiss**, M. Temmer, T. Rotter, S.J. Hofmeister, A.M. Veronig

CEAB, **2014**

http://arxiv.org/pdf/1408.2777v1.pdf

In this study, we describe and evaluate shape measures for distinguishing between coronal holes and filament channels as observed in Extreme Ultraviolet (EUV) images of the Sun. For a set of well-observed coronal hole and filament channel regions extracted from SDO/AIA 193\r{A} images we analyze their intrinsic morphology during the period 2011 to 2013, by using well known shape measures from the literature and newly developed geometrical classification methods. The results suggest an asymmetry in the morphology of filament channels giving support for the sheared arcade or weakly twisted flux rope model for filaments. We find that the proposed shape descriptors have the potential to reduce coronal hole classification errors and are eligible for screening techniques in order to improve the forecasting of solar wind high-speed streams from coronal hole observations in solar EUV images.

The dark side of solar photospheric G-band bright points

T. L. **Riethmüller**, S. K. Solanki

A&A 598, A123 **2017**

https://arxiv.org/pdf/1612.07887v1.pdf

Bright small-scale magnetic elements found mainly in intergranular lanes at the solar surface are named bright points (BPs). They show high contrasts in Fraunhofer G-band observations and are described by nearly vertical slender flux tubes or sheets. A recent comparison between BP observations in the ultraviolet (UV) and visible spectral range recorded with the balloon-borne observatory SUNRISE and state-of-the-art magnetohydrodynamical (MHD) simulations revealed a kiloGauss magnetic field for 98% of the synthetic BPs. Here we address the opposite question, namely which fraction of pixels hosting kiloGauss fields coincides with an enhanced G-band brightness. We carried out 3D radiation MHD simulations for three magnetic activity levels (corresponding to the quiet Sun, weak and strong plage) and performed a full spectral line synthesis in the G-band. Only 7% of the kiloGauss pixels in our quiet-Sun simulation coincide with a brightness lower than the mean quiet-Sun intensity, while 23% of the pixels in the weak-plage simulation and even 49% in the strong-plage simulation are associated with a local darkening. Dark strong-field regions are preferentially found in the cores of larger flux patches that are rare in the quiet Sun, but more common in plage regions, often in the vertices of granulation cells. The significant brightness shortfall in the core of larger flux patches coincide with a slight magnetic field weakening. KiloGauss elements in the quiet Sun are on average brighter than similar features in plage regions. Almost all strong-field pixels display a more or less vertical magnetic field orientation. Hence in the quiet Sun, G-band BPs correspond almost one-to-one with kiloGauss elements. In weak plage the correspondence is still very good, but not perfect.

Comparison of solar photospheric bright points between SUNRISE observations and MHD simulations

T. L. **Riethmüller**, S. K. Solanki, S. V. Berdyugina, M. Schüssler, V. Mart\'\inez Pillet, A. Feller, A. Gandorfer, J. Hirzberger

A&A 568, A13, **2014**

http://arxiv.org/pdf/1406.1387v1.pdf

Bright points (BPs) in the solar photosphere are radiative signatures of magnetic elements described by slender flux tubes located in the darker intergranular lanes. They contribute to the ultraviolet (UV) flux variations over the solar cycle and hence may influence the Earth's climate. Here we combine high-resolution UV and spectro-polarimetric observations of BPs by the SUNRISE observatory with 3D radiation MHD simulations. Full spectral line syntheses are performed with the MHD data and a careful degradation is applied to take into account all relevant instrumental effects of the observations. It is demonstrated that the MHD simulations reproduce the measured distributions of intensity at multiple wavelengths, line-of-sight velocity, spectral line width, and polarization degree rather well. Furthermore, the properties of observed BPs are compared with synthetic ones. These match also relatively well, except that the observations display a tail of large and strongly polarized BPs not found in the simulations. The higher spatial resolution of the simulations has a significant effect, leading to smaller and more numerous BPs. The observation that most BPs are weakly polarized is explained mainly by the spatial degradation, the stray light contamination, and the temperature sensitivity of the Fe I line at 5250.2 \AA{}. The Stokes V asymmetries of the BPs increase with the distance to their center in both observations and simulations, consistent with the classical picture of a production of the asymmetry in the canopy. This is the first time that this has been found also in the internetwork. Almost vertical kilo-Gauss fields are found for 98 % of the synthetic BPs. At the continuum formation height, the simulated BPs are on average 190 K hotter than the mean quiet Sun, their mean BP field strength is 1750 G, supporting the flux-tube paradigm to describe BPs.

On the role played by magnetic expansion factor in the prediction of solar wind speed

Pete **Riley**, Jon A. Linker, C. Nick Arge

Space Weather   Volume 13, Issue 3 March **2015** Pages 154–169

Over the last two decades, the Wang-Sheeley-Arge (WSA) model has evolved significantly. Beginning as a simple observed correlation between the expansion factor of coronal magnetic field lines and the measured speed of the solar wind at 1 AU (the Wang-Sheeley (WS) model), the WSA model now drives NOAA's first operational space weather model, providing real-time predictions of solar wind parameters in the vicinity of Earth. Here we demonstrate that the WSA model has evolved so much that the role played by the expansion factor term is now largely minimal, being supplanted by the distance from the coronal hole boundary (DCHB). We illustrate why and to what extent the three models (WS, DCHB, and WSA) differ. Under some conditions, all approaches are able to reproduce the grossest features of the observed quiet time solar wind. However, we show that, in general, the DCHB- and WSA-driven models tend to produce better estimates of solar parameters at 1 AU than the WS model, particularly when pseudostreamers are present. Additionally, we highlight that these empirical models are sensitive to the type and implementation of the magnetic field model used: In particular, the WS model can only reproduce in situ measurements when coupled with the potential field source surface model. While this clarification is important both in its own right and from an operational/predictive standpoint, because of the underlying physical ideas upon which the WS and DCHB models rest, these results provide support, albeit tentatively, for boundary layer theories for the origin of the slow solar wind.

See **Betz**, E. (**2015**), **Refining solar wind models to better predict space weather,** *Eos*, *96*, doi:10.1029/2015EO034779. Published on 2 September 2015.
https://eos.org/research-spotlights/refining-solar-wind-models-to-better-predict-space-weather

On the relationship between coronal heating, magnetic flux, and the density of the solar wind

Riley, Pete; Mikic, Z.; Lionello, R.; Linker, J. A.; Schwadron, N. A.; McComas, D. J.

J. Geophys. Res., Vol. 115, No. A6, A06104, **2010**

The stark differences between the current solar minimum and the previous one offer a unique opportunity to develop new constraints on mechanisms for heating and acceleration of the solar wind. We have used a combination of numerical simulations and analysis of remote solar and in situ observations to infer that the coronal heating rate, H, scales with the average magnetic field strength within a coronal hole, Bch. This was accomplished in three steps. First, we analyzed Ulysses measurements made during its first and third orbit southern and northern polar passes (i.e., during near-solar minimum conditions) to deduce a linear relationship between proton number density (np) and radial magnetic field strength (Br) in the high-speed quiescent solar wind, consistent with the results of McComas et al. (2008) and Ebert et al. (2009). Second, we used Wilcox Solar Observatory measurements of the photospheric magnetic field to show that the magnetic field strength within coronal holes (Bch) is approximately correlated with the strength of the interplanetary field at the location of Ulysses. Third, we used hydrodynamic simulations to show that np in the solar wind scales linearly with H. Taken together, these results imply the chain: H np Br Bch. We also explored ideas that the correlation between np and Br could have resulted from interplanetary processes, or from the superradial expansion of the coronal magnetic field close to the Sun, but find that neither possibility can produce the observed relationship. The derived heating relationship is consistent with (1) empirical heating laws derived for closed-field line regions and (2) theoretical models aimed at understanding both the heating and acceleration of the solar wind.

SOLAR WIND FORECASTING WITH CORONAL HOLES

S. **ROBBINS**, C. J. HENNEY and J. W. HARVEY

Solar Physics (**2006**) 233: 265–276, **File**

An empirical model for forecasting solar wind speed related geomagnetic events is presented here. The model is based on the estimated location and size of solar coronal holes. This method differs from models that are based on photospheric magnetograms (e.g.,Wang–Sheeley model) to estimate the open field line configuration. Rather than requiring the use of a full magnetic synoptic map, the method presented here can be used to forecast solar wind velocities and magnetic polarity from a single coronal hole image, along with a single magnetic full-disk image. The coronal hole parameters used in this study are estimated with Kitt Peak Vacuum Telescope He I 1083 nm spectrograms and photospheric magnetograms. Solar wind and coronal hole data for the period between May 1992 and September 2003 are investigated. The new model is found to be accurate to within 10% of observed solar wind measurements for its best 1-month period, and it has a linear correlation coefficient of **~**0.38 for the full 11 years studied. Using a single estimated coronal hole map, the model can forecast the Earth directed solar wind velocity up to 8.5 days in advance. In addition, this method can be used with any source of coronal hole area and location data.

A Comparative Analysis of Photospheric Bright Points in an Active Region and in the Quiet Sun

P. **Romano**, F. Berrilli, S. Criscuoli, D. Del Moro, I. Ermolli, F. Giorgi, B. Viticchié, F. Zuccarello

Solar Physics, October **2012**, Volume 280, Issue 2, pp 407-416

We present a comparative study of photometric and dynamic properties of photospheric bright points (BPs) observed at the disk centre in the active region (AR) NOAA 10912 and in the quiet Sun. We found that the average concentration of BPs is 54% larger in the AR than in the quiet Sun. We also measure a decrease of the BP concentration and an increase of their size moving away from the AR centre. However, these variations can be ascribed to the variation of the spatial resolution and image quality in the field of view of the AR dataset. We also found that BPs in the quiet Sun are associated with larger downflow motions than those measured within the AR. Finally, from our measurements of contrast and velocity along the line of sight, we deduced that BPs are less bright in high magnetic flux density regions than in quiet regions, due to a lower efficiency of convection in the former regions.

Real-time solar wind prediction based on SDO/AIA coronal hole data

T. **Rotter** (1), A.M. Veronig (1), M. Temmer (1), B. Vrsnak

Solar Phys. May 2015, Volume 290, Issue 5, pp 1355-1370 **2015**

http://arxiv.org/pdf/1501.06697v1.pdf

We present an empirical model based on the visible area covered by coronal holes close to the central meridian in order to predict the solar wind speed at 1 AU with a lead time up to four days in advance with a 1hr time resolution. Linear prediction functions are used to relate coronal hole areas to solar wind speed. The function parameters are automatically adapted by using the information from the previous 3 Carrington Rotations. Thus the algorithm automatically reacts on the changes of the solar wind speed during different phases of the solar cycle. The adaptive algorithm has been applied to and tested on SDO/AIA-193A observations and ACE measurements during the years 2011-2013, covering 41 Carrington Rotations. The solar wind speed arrival time is delayed and needs on average 4.02 +/- 0.5 days to reach Earth. The algorithm produces good predictions for the 156 solar wind high speed streams peak amplitudes with correlation coefficients of cc~0.60. For 80% of the peaks, the predicted arrival matches within a time window of 0.5 days of the ACE in situ measurements. The same algorithm, using linear predictions, was also applied to predict the magnetic field strength from coronal hole areas but did not give reliable predictions (cc~0.2).

28-02-2011, 2011-01-02 - 2011-02-04, 2012-08-05, 2013-07-02

Хорошее Введение, ссылки

Relation Between Coronal Hole Areas on the Sun and the Solar Wind Parameters at 1 AU
T. **Rotter**, A. M. Veronig, M. Temmer and B. Vršnak
Solar Physics, **2012**, December 2012, Volume 281, Issue 2, pp 793-813, **File**
We analyze the relationship between the coronal hole (CH) characteristics on the Sun (area, position, and intensity levels) and the corresponding solar wind parameters (solar wind speed v, proton temperature T, proton density n, and magnetic field strength B) measured in situ at 1 AU with a 6-h time resolution. We developed a histogram-based intensity thresholding method to obtain fractional CH areas from SOHO/EIT 195 Å images. The algorithm was applied to 6-h cadence EIT 195 Å images for the year 2005, which were characterized by a low solar activity. In calculating well-defined peaks of the solar wind parameters corresponding to the peaks in CH area, we found that the solar wind speed v shows a high correlation with correlation coefficient cc=0.78, medium correlation for T and B with cc=0.41 and cc=0.41. No significant correlation was found with the proton density n. Applying an intensity-weighted CH area did not improve the relations, since the size and the mean intensity of the CH areas are not independent parameters but strongly correlated (cc=− 0.72). Comparison of the fractional CH areas derived from GOES/SXI and SOHO/EIT and the related solar wind predictions shows no systematic differences (cc=0.79).

Solar wind flow angle and geo-effectiveness of corotating interaction regions: First results
Diptiranjan **Rout**1,D. Chakrabarty1, P. Janardhan1, R. Sekar1, Vrunda Maniya1, Kuldeep Pandey1
Geophys. Res. Lett., **2017**
http://onlinelibrary.wiley.com.sci-hub.cc/doi/10.1002/2017GL073038/abstract;jsessionid=81CDFA9E47491A9DB3F194AB19EA9F36.f04t01
A total of 43 CIR-induced geomagnetic storms during the unusually deep solar minimum of solar cycle 23 (2006-2010) were identified using a superposed epoch analysis technique. Of these 43 events, a detailed cross spectrum analyses, between the variations in the Z-component of the interplanetary magnetic field (IMF Bz) and the equatorial electrojet (EEJ) strength, were performed for 22 events when the daytime EEJ strengths from Jicamarca were available. The analyses revealed that the ~30 and ~60 min periodic components in IMF Bz were causally related to the EEJ strength subject to the average solar wind ow being radial to within 6_ at L1 during the interval for which EEJ strengths were considered. This investigation elicits the important role of average solar wind azimuthal flow angle in determining the geo-effectiveness of CIR events.
Table 1.

Observational evidence for two-component distributions describing solar magnetic bright points
Gerardine Berrios **Saavedra**1, Dominik Utz2,3,4, Santiago Vargas Domínguez5, José Iván Campos Rozo6, Sergio Javier González Manrique7,8,9, Peter Gömöry9, Christoph Kuckein7,8,10, Horst Balthasar10 and Peter Zelina9
A&A 657, A79 (**2022**)
https://www.aanda.org/articles/aa/pdf/2022/01/aa41231-21.pdf
https://doi.org/10.1051/0004-6361/202141231
Context. High-resolution observations of the solar photosphere reveal the presence of fine structures, in particular the so-called Magnetic Bright Points (MBPs), which are small-scale features associated with strong magnetic field regions of the order of kilogauss (kG). It is especially relevant to study these magnetic elements, which are extensively detected in all moments during the solar cycle, in order to establish their contribution to the behavior of the solar atmosphere, and ultimately a plausible role within the coronal heating problem.
Aims. Characterisation of size and velocity distributions of MBPs in the solar photosphere in two different datasets of quiet Sun images acquired with high-resolution solar instruments i.e. Solar Optical Telescope SOT/Hinode and the High-resolution Fast Imager HiFI/GREGOR, in the G-band (4308 Å).
Methods. In order to detect the MBPs, an automatic segmentation and identification algorithm is used. Next, the identified features were tracked to measure their proper motions. Finally, a statistical analysis of hundreds of MBPs is carried out, generating histograms for areas, diameters and horizontal velocities.
Results. This work establishes that areas and diameters of MBPs display log-normal distributions that are well-fitted by two different components, whereas the velocity vector components follow Gaussians and the vector magnitude a Rayleigh distribution revealing again for all vector elements a two component composition.
Conclusions. The results can be interpreted as due to the presence of two different populations of MBPs in the solar photosphere one likely related to stronger network magnetic flux elements and the other one to weaker intranetwork flux elemens. In particular this work concludes on the effect of the different spatial resolution of GREGOR and Hinode telescopes, affecting detections and average values.

A new approach to kinetic energy flux at the different frequencies above the IRIS Bright Points

Rayhane **Sadeghi**, Ehsan Tavabi

ApJ **938** 74 **2022**

https://arxiv.org/pdf/2210.03583

https://iopscience.iop.org/article/10.3847/1538-4357/ac8ff4/pdf

Various bright structures abound in the chromosphere playing an essential role in the dynamics and evolution therein. Tentatively identifying the wave characteristics in the outer solar atmosphere helps to understand this layer better. One of the most significant aspects of these characteristics is the wave phase speed (PS), which is a dominant contribution to solar coronal heating and Energy distribution in the Sun's atmosphere layers. To obtain energy flux (EF), it is necessary to calculate the filling factor (FF) and the PS. In this study, the FF was determined by tracking the size and intensity of the IRIS bright points (BPs). To estimate an accurate PS and EF, it is necessary to know the chromosphere and transition region (TR) thickness and the phase difference between the two desired levels. chromosphere and TR thickness cannot be measured directly on the disc; This study is performed using spectral data and calibrated based on Doppler velocities. As a result, the PSs in AR and CH, as well as for IRIS BPs have been calculated using the cross-power wavelet transform of Doppler velocities. Consequently, about CH, the PS mean values are from 40 to 180 km/s at network and from 30 to 140 km/s at internetwork; And about AR, are from 80 to 540 km/s at network and 70 to 220 km/s at internetwork. Finally, the EF for the IRIS BPs has been calculated in three different frequencies. The results indicate that the network BPs have an influential role in heating the higher layers while in the internetwork BPs, most of the energy returns to the lower layers.

Characteristics of Chromospheric Oscillation Periods in Magnetic Bright Points (MBPs)

Rayhane **Sadeghi**, Ehsan Tavabi

MNRAS Volume 512, Issue 3, Pages 4164–4170, **2022**

https://arxiv.org/ftp/arxiv/papers/2203/2203.00665.pdf

https://doi.org/10.1093/mnras/stac574

In this investigation oscillation periods in Mg II k line intensity, brightness temperature, and Doppler velocity obtained above Magnetic Bright Points (MBPs) are investigated. For that purpose, data from the Interface Region Imaging Spectrometer (IRIS) observing the higher chromosphere and transition region (TR) were analysed together with imaging and magnetogram data obtained by Solar Dynamics Observatory (SDO). The MBPs were identified in combining Si IV 1403 A Slit Jaw Images (SJIs) with the magnetogram information from the Heliospheric and Magnetic Imager (HMI). A time-slice analysis followed by a wavelet inspection were carried out on the Mg II k (2796 A and 10,000 K) resonance lines for the detection of the oscillation period. Finally, a power spectrum analysis was performed to characterise the oscillations with the result that network points feature a typical intensity, temperature, and velocity oscillation period of about 300 seconds; The internetwork points have a mean intensity oscillation period of about 180 seconds, mean temperature oscillation period of about 202, and mean velocity oscillation period of about 202 seconds. In addition, one BP was analysed in detail, which demonstrates intensity oscillation periods with a value of 500 seconds, obviously not related to the common 3- or 5-minute oscillations found typically elsewhere in chromospheric/photospheric structures. **2014-05-16**

Polarity relevance in flux rope deflections triggered by coronal holes

Abril **Sahade**, Mariana Cécere, Andrea Costa, Hebe Cremades

A&A 652, A111 **2021**

https://arxiv.org/pdf/2104.07127.pdf

https://www.aanda.org/articles/aa/pdf/2021/08/aa41085-21.pdf

https://doi.org/10.1051/0004-6361/202141085

Many observations show that coronal holes (CHs) deviate coronal mass ejections (CMEs) away from them. However, there are some peculiar events reported where the opposite occurs. To contribute to a space weather forecast efforts, in relation to the prediction of CME trajectories, we study the interaction between flux ropes (FRs) and CHs through numerical simulations. We perform 2.5D numerical simulations where FRs and CHs interact with different relative polarity configurations. We also reconstruct the trajectory and magnetic environment of a peculiar event occurred on **30 April 2012**. The numerical simulations indicate that at low coronal levels, depending on the relative magnetic field polarity between the FR and the CH, the deflection will be attractive, i.e. the FR moves towards the CH (for anti-aligned polarities) or repulsive, i.e. the FR moves away to the CH (for aligned polarities). This is likely due to the formation of vanishing magnetic field regions or null points, located between the FR and the CH or, at the other side of the FR, respectively. The analysed observational event shows a double-deflection, first departing from the radial direction by approaching the CH and then moving away from it suggesting that the trajectory could result from a magnetic configuration with an anti-aligned polarity. We numerically reproduce the double deflection of the observed event, providing support to this conjecture.

Influence of coronal holes on CME deflections: numerical study

Abril **Sahade**, Mariana Cécere, Gustavo Krause

ApJ **896** 53 **2020**

https://arxiv.org/pdf/2004.10834.pdf

https://doi.org/10.3847/1538-4357/ab8f25

The understanding of the causes that produce the deflection of coronal mass ejections (CMEs) is essential for the space weather forecast. In this article, we study the effects on CMEs trajectories produced by the different properties of a coronal hole close to the ejection area. For this analysis, we perform numerical simulations of the ideal magnetohydrodynamics equations that emulate the early rising of the CME in presence of a coronal hole. We find that, the stronger the magnetic field and the wider the coronal hole area, the larger the CME deflection. This effect is reduced when the coronal hole moves away from the ejection region. To characterize this behavior, we propose a dimensionless parameter that depends on the coronal hole properties and properly quantifies the deflection. Also, we show that the presence of the coronal hole near a CME magnetic structure produces a minimum magnetic energy region which is responsible for the deflection. Thus, we find a relationship between the coronal hole properties, the location of this region and the CME deflection.

Continuous Plasma Outflows from the Edge of a Solar Active Region as a Possible Source of Solar Wind.

Sakao, T., Kano, R., Narukage, N., Kotoku, J., Bando, T., DeLuca, E.E., Lundquist, L.L., Tsuneta, S., Harra, L.K., Katsukawa, Y., Kubo, M., Hara, H., Matsuzaki, K., Shimojo, M., Bookbinder, J.A., Golub, L., Korreck, K.E., Su, Y., Shibasaki, K., Shimizu, T., Nakatani, I.,

2007. Science 318, 1585–1588.

A STATISTICAL STUDY OF CORONAL ACTIVE EVENTS IN THE NORTH POLAR REGION

Nobuharu **Sako**1,2, Masumi Shimojo1,2, Tetsuya Watanabe1,2, and Takashi Sekii

2013 ApJ 775 22

In order to study the relationship between characteristics of polar coronal active events and the magnetic environment in which such events take place, we analyze 526 X-ray jets and 1256 transient brightenings in the polar regions and in regions around the equatorial limbs. We calculate the occurrence rates of these polar coronal active events as a function of distance from the boundary of coronal holes, and find that most events in the polar quiet regions occur adjacent to and equatorward of the coronal hole boundaries, while events in the polar coronal holes occur uniformly within them. Based primarily on the background intensity, we define three categories of regions that produce activity: polar coronal holes, coronal hole boundary regions, and polar quiet regions. We then investigate the properties of the events produced in these regions. We find no significant differences in their characteristics, for example, length and lifetime, but there are differences in the occurrence rates. The mean occurrence rate of X-ray jets around the boundaries of coronal holes is higher than that in the polar quiet regions, equatorial quiet regions, and polar coronal holes. Furthermore, the mean occurrence rate of transient brightenings is also higher in these regions. We make comparison with the occurrence rates of emerging and canceling magnetic fields in the photosphere reported in previous studies, and find that they do not agree with the occurrence rates of transient brightenings found in this study.

Dynamics of subarcsecond bright dots in the transition region above sunspot and their relation to penumbral micro-jets

Tanmoy **Samanta**, Hui Tian, Dipankar Banerjee, Nicole Schanche

ApJL 835 L19 **2017**

https://arxiv.org/pdf/1701.02531v1.pdf

Recent high-resolution observations reveal that subarcsecond bright dots (BDs) with sub-minute lifetimes appears ubiquitously in the transition region (TR) above sunspot penumbra. The presence of penumbral micro-jets (PMJs) in the chromosphere have also been reported earlier. It was proposed that both the PMJs and BDs are formed due to magnetic reconnection process and may play an important role in heating of the penumbra. Using simultaneous observation of the chromosphere from the Solar Optical Telescope (SOT) aboard Hinode and the TR from the Interface Region Imaging Spectrograph (IRIS), we study the dynamics of BDs and their relation with PMJs. We find two types of BDs, one which is related to PMJs and the others which do not show any visible dynamics in the SOT Ca II H images. From a statistical analysis we show that these two types have different properties. The BDs which are related to PMJs always appear at the top of the PMJs, the vast majority of which show inward motion and originate before the generation of the PMJs. These results may indicate that the reconnection occurs at the lower coronal/TR height and initiates PMJs at the chromosphere. This formation mechanism is in contrast with the currently believed formation of PMJs by reconnection in the (upper) photosphere between differently inclined fields.

19 March 2014

Quasi-Periodic Oscillation of a Coronal Bright Point

Tanmoy **Samanta**, Dipankar Banerjee, Hui Tian

ApJ **806** 172 **2015**

http://arxiv.org/pdf/1505.00587v1.pdf

Coronal bright points (BPs) are small-scale luminous features seen in the solar corona. Quasi-periodic brightenings are frequently observed in the BPs and are generally linked with underneath magnetic flux changes. We study the dynamics of a BP seen in the coronal hole using the Atmospheric Imaging Assembly (AIA) images, the Helioseismic and Magnetic Imager (HMI) magnetogram on board the Solar Dynamics Observatory (SDO) and spectroscopic data from the newly launched Interface Region Imaging Spectrograph (IRIS). The detailed analysis shows that the BP evolves throughout our observing period along with changes in underlying photospheric magnetic flux and shows periodic brightenings in different EUV and FUV images. With highest possible spectral and spatial resolution of IRIS, we attempted to identify the sources of these oscillations. IRIS sit and stare observation provided a unique opportunity to study the time evolution of one foot point of the BP as the slit position crossed it. We noticed enhanced line profile asymmetry, enhanced line width, intensity enhancements and large deviation from the average Doppler shift in the line profiles at specific instances which indicate the presence of sudden flows along the line of sight direction. We propose that transition region explosive events (EEs) originating from small scale reconnections and the reconnection outflows are affecting the line profiles. The correlation between all these parameters is consistent with the repetitive reconnection scenario and could explain the quasi-periodic nature of the brightening. **10-12 May 2014**

Influence of coronal hole morphology on the solar wind speed at Earth

Evangelia **Samara**, Jasmina Magdalenic, Luciano Rodriguez, Stephan G. Heinemann, Manolis K. Georgoulis, Stefan J. Hofmeister, Stefaan Poedts

A&A 662, A68 **2022**

https://arxiv.org/pdf/2204.00368.pdf

https://www.aanda.org/articles/aa/pdf/2022/06/aa42793-21.pdf

It has long been known that the high-speed stream (HSS) peak velocity at Earth directly depends on the area of the coronal hole (CH) on the Sun. Different degrees of association between the two parameters have been shown by many authors. In this study, we revisit this association in greater detail for a sample of 45 nonpolar CHs during the minimum phase of solar cycle 24. The aim is to understand how CHs of different properties influence the HSS peak speeds observed at Earth and draw from this to improve solar wind modeling. The characteristics of the CHs of our sample were extracted based on the Collection of Analysis Tools for Coronal Holes (CATCH) which employs an intensity threshold technique applied to extreme-ultraviolet (EUV) filtergrams. We first examined all the correlations between the geometric characteristics of the CHs and the HSS peak speed and duration at Earth, for the entire sample. The CHs were then categorized in different groups based on morphological criteria, such as the aspect ratio, the orientation angle and the geometric complexity, a parameter which is often neglected when the formation of the fast solar wind at Earth is studied. Our results, confirmed also by the bootstrapping technique, show that all three aforementioned morphological criteria play a major role in determining the HSS peak speed at 1 AU. Therefore, they need to be taken into consideration for empirical models that aim to forecast the fast solar wind at Earth based on the observed CH solar sources.

Differential Emission Measure Plasma Diagnostics of a Long-Lived Coronal Hole

Jonas **Saqri**, Astrid M. Veronig, Stephan G. Heinemann, Stefan J. Hofmeister, Manuela Temmer, Karin Dissauer, Yang Su

Solar Phys. 295:6 **2020**

https://arxiv.org/pdf/2001.02259.pdf

https://doi.org/10.1007/s11207-019-1570-z

We use Solar Dynamics Observatory (SDO)/Atmospheric Imaging Assembly (AIA) data to reconstruct the plasma properties from differential emission measure (DEM) analysis for a previously studied long-lived, low-latitude coronal hole (CH) over its lifetime of ten solar rotations. We initially obtain a non-isothermal DEM distribution with a dominant component centered around 0.9 MK and a secondary smaller component at 1.5 - 2.0 MK. We find that deconvolving the data with the instrument point spread function (PSF) to account for long-range scattered light reduces the secondary hot component. Using the 2012 Venus transit and a 2013 lunar eclipse to test the efficiency of this deconvolution, significant amounts of residual stray light are found for the occulted areas. Accounting for this stray light in the error budget of the different AIA filters further reduces the secondary hot emission, yielding CH DEM distributions that are close to isothermal with the main contribution centered around 0.9 MK. Based on these DEMs, we analyze the evolution of the emission measure (EM), density, and averaged temperature during the CH's lifetime. We find that once the CH is clearly observed in EUV images, the bulk of the CH plasma reveals a quite constant state, i.e. temperature and density reveal no major changes, whereas the total CH area and the photospheric magnetic fine structure inside the CH show a distinct evolutionary pattern. These findings suggest that CH plasma properties are mostly "set" at the CH formation or/and that all CHs have similar plasma properties. **15 February 2012, 14 March 2012, 9 Apr 2012, 6 June 2012, 30 June 2012, 6 Aug 2013**

Solar Cycle 23 in Coronal Bright Points

Sattarov, Isroil; Pevtsov, Alexei A.; Karachik, Nina V.; Sherdanov, Chori T.; Tillaboev, A. M.

Solar Physics, Volume 262, Issue 2, pp.321-335, **2011**

We describe an automatic routine to identify coronal bright points (CBPs) and apply this routine to SOHO/EIT observations taken in the 195 Å spectral range during solar cycle 23. We examine the total number of CBPs and its change in the course of this solar cycle. Unlike some other recent studies, we do find a modest ≈30% decrease in the number of CBPs associated with maximum of sunspot activity. Using the maximum brightness of CBPs as a criterion, we separate them on two categories: dim CBPs, associated with areas of a quiet Sun, and bright CBPs, associated with an active Sun. We find that the number of dim coronal bright points decreases at the maximum of sunspot cycle, while the number of bright CBPs increases. The latitudinal distributions suggest that dim CBPs are distributed uniformly over the solar disk. Active Sun CBPs exhibit a well-defined two-hump latitudinal profile suggestive of enhanced production of this type of CBPs in sunspot activity belts. Finally, we investigate the relative role of two mechanisms in cycle variations of CBP number, and conclude that a change in fraction of solar surface occupied by the quiet Sun's magnetic field is the primary cause, with the visibility effect playing a secondary role

DOES A POLAR CORONAL HOLE'S FLUX EMERGENCE FOLLOW A HALE-LIKE LAW?

A. Savcheva[1], J. W. Cirtain[2], E. E. DeLuca[1] and L. Golub[1]

ApJL 702 L32-L36, **2009** doi: 10.1088/0004-637X/702/1/L32

Recent increases in spatial and temporal resolution for solar telescopes sensitive to EUV and X-ray radiation have revealed the prevalence of transient jet events in polar coronal holes. Using data collected by the X-Ray Telescope on *Hinode*, Savcheva et al. confirmed the observation, made first by the Soft X-ray Telescope on *Yohkoh*, that some jets exhibit a motion transverse to the jet outflow direction. The velocity of this transverse motion is, on average, 10 km s^{-1}. The direction of the transverse motion, in combination with the standard reconnection model for jet production (e.g., Shibata et al.), reflects the magnetic polarity orientation of the ephemeral active region at the base of the jet. From this signature, we find that during the present minimum phase of the solar cycle the jet-base ephemeral active regions in the polar coronal holes had a preferred east-west direction, and that this direction reversed during the cycle's progression through minimum. In late 2006 and early 2007, the preferred direction was that of the active regions of the coming sunspot cycle (cycle 24), but in late 2008 and early 2009 the preferred direction has been that of the active regions of sunspot cycle 25. These findings are consistent with the observations of Wilson et al. suggesting that each cycle of solar activity begins at polar latitudes soon after the onset of the previous cycle.

BRIGHT POINTS: MULTITHERMAL ANALYSIS AS A TEST OF STEADY HEATING MODELS

J. T. **Schmelz**1, A. R. Winebarger2, J. A. Kimble1, S. Pathak1, L. Golub3, B. S. Jenkins1, and B. T. Worley

2013 ApJ 770 160

X-ray bright points are small, million-degree features in the solar atmosphere composed of short coronal loops. They are magnetically driven structures associated with photospheric magnetic bipoles. Their relatively small size and simple structure suggest they are ideal candidates for comparisons with coronal heating models. In this paper, we present the analysis of 12 bright points using data from the EUV Imaging Spectrometer on Hinode and the Michelson Doppler Imager on Solar and Heliospheric Observatory. Using the spectroscopy data, we construct differential emission measure (DEM) curves, calculate the electron density, and find DEM-weighted temperatures. In addition, we determine the most likely ionization balance. Using the magnetic field observations, we complete potential field extrapolations of the magnetograms and estimate the loop lengths. Using this information, we construct models assuming the bright points are formed of hundreds of strands, each heated steadily and uniformly. We formulate the models so that the observed emission measure distribution is matched within a few percent. We then compare the densities determined from the models, (1.4-5.0) × 109, to those calculated from spectral data, (0.6-2.0) × 109. We find the majority of bright points do not agree with steady uniform heating models; instead they are underdense relative to their expected density by a factor of 0.16-0.82.

Atmospheric Imaging Assembly Response Functions: Solving the Fe viii Problems with Hinode EIS Bright Point Data

J. T. **Schmelz**, B. S. Jenkins, J. A. Kimble
Solar Physics, April **2013**, Volume 283, Issue 2, pp 325-340
The Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory is a state-of-the-art imager with the potential to perform an unprecedented time-dependent multi-thermal analysis at every pixel on scales that are short compared to the radiative and conductive cooling times. Recent results, however, have identified missing spectral lines in the CHIANTI atomic physics database, which is used to construct the instrument response functions. This is not surprising since the wavelength range from 90 Å to 140 Å has rarely been observed with solar spectrometers, and atomic data for many of these ions are simply not available in the literature. We have performed a differential emission measure analysis using simultaneous AIA and Hinode/EIS observations of six X-ray bright points. Our results not only support the conclusion that CHIANTI is incomplete near 131 Å, but more importantly, suggest that the peak temperature of the Fe viii emissivity/response is likely to be closer to log T=5.8 than to the current value of log T=5.7. Using a revised emissivity/response calculation for Fe viii, we find that observed AIA 131-Å flux can be underestimated by ≈ 1.25, lower than previous comparisons. With these adjustments, not only the AIA 131-Å data, but also the EIS Fe viii lines, match the remainder of the bright-point data better. In addition, we find that CHIANTI is reasonably complete in the AIA 171- and 193-Å bands. For the AIA 211-, 335-, and 94-Å channels, we recommend that more work be done with AIA–EIS DEM comparisons using observations of active-region cores, i.e. coronal structures with more emission measure at warmer temperatures than our bright points. Then a variety of EIS iron lines could be directly compared with AIA data.

Automatic Detection and Classification of Coronal Holes and Filaments Based on EUV and Magnetogram Observations of the Solar Disk

Isabelle F. **Scholl** · Shadia Rifai Habbal
Solar Phys (**2008**) 248: 425–439; **File**
DOI 10.1007/s11207-007-9075-6
Abstract A new method for the automated detection of coronal holes and filaments on the solar disk is presented. The starting point is coronal images taken by the Extreme Ultraviolet Telescope on the *Solar and Heliospheric Observatory* (SOHO/EIT) in the Fe IX/X 171 Å, Fe XII 195 Å, and He II 304 Å extreme ultraviolet (EUV) lines and the corresponding full-disk magnetograms from the Michelson Doppler Imager (SOHO/MDI) from different phases of the solar cycle. The images are processed to enhance their contrast and to enable the automatic detection of the two candidate features, which are visually indistinguishable in these images. Comparisons are made with existing databases, such as the He I 10830 Å NSO/Kitt Peak coronal-hole maps and the Solar Feature Catalog (SFC) from the European Grid of Solar Observations (EGSO), to discriminate between the two features. By mapping the features onto the corresponding magnetograms, distinct magnetic signatures are then derived. Coronal holes are found to have a skewed distribution of magnetic-field intensities, with values often reaching 100–200 gauss, and a relative magnetic-flux imbalance. Filaments, in contrast, have a symmetric distribution of field intensity values around zero, have smaller magnetic-field intensity than coronal holes, and lie along a magnetic-field reversal line. The identification of candidate features from the processed images and the determination of their distinct magnetic signatures are then combined to achieve the automated detection of coronal holes and filaments from EUV images of the solar disk. Application of this technique to all three wavelengths does not yield identical results. Furthermore, the best agreement among all three wavelengths and NSO/Kitt Peak coronal-hole maps occurs during the declining phase of solar activity. The He II data mostly fail to yield the location of filaments at solar minimum and provide only a subset at the declining phase or peak of the solar cycle. However, the Fe IX/X 171 Å and Fe XII 195 Å data yield a larger number of filaments than the Hα data of the SFC.

Solar Polar Flux Redistribution based on Observed Coronal Holes

Samuel J. **Schonfeld**, Carl J. Henney, Shaela I. Jones, Charles N. Arge
ApJ **932** 115 **2022**
https://arxiv.org/pdf/2204.13676.pdf
https://iopscience.iop.org/article/10.3847/1538-4357/ac6ba1/pdf
We explore the use of observed polar coronal holes (CHs) to constrain the flux distribution within the polar regions of global solar magnetic field maps in the absence of reliable quality polar field observations. Global magnetic maps, generated by the Air Force Data Assimilative Photospheric flux Transport (ADAPT) model, are modified to enforce field unipolarity thresholds both within and outside observed CH boundaries. The polar modified and unmodified maps are used to drive Wang-Sheeley-Arge (WSA) models of the corona and solar wind (SW). The WSA predicted CHs are compared with the observations, and SW predictions at the WIND and Ulysses spacecraft are also used to provide context for the new polar modified maps. We find that modifications of the polar flux never worsen and typically improve both the CH and SW predictions. We also confirm the importance of the choice of the domain over which WSA generates the coronal magnetic field solution but find that solutions optimized for one location in the heliosphere can worsen predictions at other locations. Finally, we investigate the importance of low-

latitude (i.e., active region) magnetic fields in setting the boundary of polar CHs, determining that they have at least as much impact as the polar fields themselves. **1995 October 1**

THE SOLAR WIND POWER FROM MAGNETIC FLUX

N. A. **Schwadron**1,2 and D. J. McComas2

Astrophysical Journal, 686: L33–L36, **2008** October

http://www.journals.uchicago.edu/doi/pdf/10.1086/592877

Observations of the fast, high-latitude solar wind throughout *Ulysses*' three orbits show that solar wind power correlates remarkably well with the Sun's total open magnetic flux. These observations support a recent model of the solar wind energy and particle sources, where magnetic flux emergence naturally leads to an energy flux proportional to the strength of the large-scale magnetic field. This model has also been shown to be consistent with X-ray observations of the Sun and a variety of other stars over 12 decades of magnetic flux. The observations reported here show that the Sun delivers ~600 kW Wb_{-1} to power the solar wind, and that this power to magnetic flux relation has been extremely stable over the last 15 years. Thus, the same law that governs energy released in the corona and from other stars also applies to the total energy in the solar wind.

Small-Scale Upflows in a Coronal Hole – Tracked from the Photosphere to the Corona.

Schwanitz, C., Harra, L., Barczynski, K. et al.

Sol Phys 298, 129 (**2023**).

https://doi.org/10.1007/s11207-023-02216-4

https://link.springer.com/content/pdf/10.1007/s11207-023-02216-4.pdf

Coronal transients are known as sources of coronal upflows. With the commissioning of Solar Orbiter, it became apparent that coronal small-scale features are even more frequent than previously estimated. It was found that even small coronal features seen by Solar Orbiter can produce visible upflows. Therefore, it is important to study the plasma flows on small scales better and understand their atmospheric driving mechanisms.

In this article, we present the results from a two-week coordinated multi-spacecraft observation campaign with Hinode, IRIS, and the GREGOR telescope. We identify a small region of coronal upflows with Doppler velocities of up to 16.5 km s−1. The upflows are located north of a coronal bright point in a coronal hole. We study the corona, the transition region, the chromosphere and the photospheric magnetic field to find evidence of underlying mechanisms for the coronal upflow. We find a complex photospheric magnetic field with several small mixed polarities that are the footpoints of different loops. Flux emergence and cancellation are observed at the constantly changing footpoints of the coronal loops. Reconnection of loops can be identified as the driver of the coronal upflow. Furthermore, the impact of the coronal activity triggers plasma flows in the underlying layers. This work highlights that frequent small coronal features can cause considerable atmospheric response and ubiquitously produce plasma upflows that potentially feed into the solar wind. **10 – 14 May 2021 and 17 – 21 May 2021**

Probing Upflowing Regions in the Quiet Sun and Coronal Holes

Conrad **Schwanitz**, Louise Harra, Nour E. Raouafi, Alphonse C. Sterling, Alejandro Moreno Vacas, Jose Carlos del Toro Iniesta, David Orozco Suárez, Hirohisa Hara

Solar Phys. **296**, Article number: 175 **2021**

https://arxiv.org/pdf/2110.12753.pdf

https://link.springer.com/content/pdf/10.1007/s11207-021-01915-0.pdf

https://doi.org/10.1007/s11207-021-01915-0

Recent observations from Parker Solar Probe have revealed that the solar wind has a highly variable structure. How this complex behaviour is formed in the solar corona is not yet known, since it requires omnipresent fluctuations, which constantly emit material to feed the wind. In this article we analysed 14 upflow regions in the solar corona to find potential sources for plasma flow. The upflow regions were derived from spectroscopic data from the EUV Imaging Spectrometer (EIS) onboard Hinode determining their Doppler velocity and defining regions which have blueshifts stronger than −6kms−1. To identify the sources of this blueshift data from the Atmospheric Imaging Assembly (AIA) and the Helioseismic and Magnetic Imager (HMI), onboard the Solar Dynamics Observatory (SDO), and the X-ray Telescope (XRT), onboard Hinode, were used. The analysis revealed that only 5 out of 14 of the upflows were associated with frequent transients, like obvious jets or bright points. In contrast to that, seven events were associated with small-scale features, which show a large variety of dynamics. Some resemble small bright points, while others show an eruptive nature, all of which are faint and only live for a few minutes; we can not rule out that several of these sources may be fainter and, hence, less obvious jets. Since the complex structure of the solar wind is known, this suggests that new sources have to be considered or better methods used to analyse the known sources. This work shows that small and frequent features, which were previously neglected, can cause strong upflows in the solar corona. These results emphasise the importance of the first observations from the

Extreme-Ultraviolet Imager (EUI) onboard Solar Orbiter, which revealed complex small-scale coronal structures.
11 Feb-7 Mar 2020
Table 2. The blueshifted events are listed in an ascending number

JETS IN POLAR CORONAL HOLES
E. **Scullion**1, M. D. Popescu1, D. Banerjee2, J. G. Doyle1, and R. Erd´elyi3
Astrophysical Journal, 704:1385–1395, **2009** October
Here, we explore the nature of small-scale jet-like structures and their possible relation to explosive events and other known transient features, like spicules and macrospicules, using high-resolution spectroscopy obtained with the *Solar and Heliospheric Observatory/*Solar UltravioletMeasurements of Emitted Radiation instrument.We present a highly resolved spectroscopic analysis and line parameter study of time-series data for jets occurring on-disk and off-limb in both a northern and a southern coronal hole. The analysis reveals many small-scale transients which rapidly propagate between the mid-transition region (Niv 765 Å line formation: 140,000 K) and the lower corona (Ne viii 770 Å line formation: 630,000 K). In one example, a strong jet-like event is associated with a cool feature not present in the Ne viii 770 Å line radiance or Doppler velocity maps. Another similar event is observed, but with a hot component, which could be perceived as a blinker. Our data reveal fast, repetitive plasma outflows with blueshift velocities of ≈145 km s^{-1} in the lower solar atmosphere. The data suggest a strong role for smaller jets (spicules), as a precursor to macrospicule formation, which may have a common origin with explosive events.

STATISTICAL PROPERTIES OF THE DISK COUNTERPARTS OF TYPE II SPICULES FROM SIMULTANEOUS OBSERVATIONS OF RAPID BLUESHIFTED EXCURSIONS IN Ca II 8542 AND Hα
D. H. **Sekse**1, L. Rouppe van der Voort1, and B. De Pontieu
2012 ApJ 752 108
Spicules were recently found to exist as two different types when a new class of so-called type II spicules was discovered at the solar limb with the Solar Optical Telescope on board the Hinode spacecraft. These type II spicules have been linked with on-disk observations of rapid blueshifted excursions (RBEs) in the Hα and Ca II 8542 lines. Here we analyze observations optimized for the detection of RBEs in both Hα and Ca II 8542 lines simultaneously at a high temporal cadence taken with the Crisp Imaging Spectropolarimeter at the Swedish Solar Telescope on La Palma. In this study, we used a high-quality time sequence for RBEs at different blueshifts and employed an automated detection routine to detect a large number of RBEs in order to expand on the statistics of RBEs. We find that the number of detected RBEs is strongly dependent on the associated Doppler velocity of the images on which the search is performed. Automatic detection of RBEs at lower velocities increases the estimated number of RBEs to the same order of magnitude expected from limb spicules. This shows that RBEs and type II spicules are indeed exponents of the same phenomenon. Furthermore, we provide solid evidence that Ca II 8542 RBEs are connected to Hα RBEs and are located closer to the network regions with the Hα RBEs being a continuation of the Ca II 8542 RBEs. Our results show that RBEs have an average lifetime of 83.9 s when observed in both spectral lines and that the Doppler velocities of RBEs range from 10 to 25 km s–1 in Ca II 8542 and 30 to 50 km s–1 in Hα. In addition, we automatically determine the transverse motion of a much larger sample of RBEs than previous studies, and find that, just like type II spicules, RBEs undergo significant transverse motions of the order of 5-10 km s–1. Finally, we find that the intergranular jets discovered at Big Bear Solar Observatory are a subset of RBEs.

Association of radio polar cap brightening with bright patches and coronal holes
Caius L. **Selhorst**, Paulo J. A. Simoes, Alexandre J. Oliveira e Silva, C. G. Gimenez de Castro, Joaquim E. R. Costa, Adriana Valio
ApJ **851** 146 **2017**
https://arxiv.org/pdf/1711.02163.pdf
http://iopscience.iop.org.sci-hub.tw/0004-637X/851/2/146/
Radio-bright regions near the solar poles are frequently observed in Nobeyama Radioheliograph (NoRH) maps at 17 GHz, and often in association with coronal holes. However, the origin of these polar brightening has not been established yet. We propose that small magnetic loops are the source of these bright patches, and present modeling results that reproduce the main observational characteristics of the polar brightening within coronal holes at 17 GHz. The simulations were carried out by calculating the radio emission of the small loops, with several temperature and density profiles, within a 2D coronal hole atmospheric model. If located at high latitudes, the size of the simulated bright patches are much smaller than the beam size and they present the instrument beam size when observed. The larger bright patches can be generated by a great number of small magnetic loops unresolved by the NoRH beam. Loop models that reproduce bright patches contain denser and hotter plasma near the upper chromosphere and lower corona. On the other hand, loops with increased plasma density and temperature only in the corona do not contribute to the emission at 17 GHz. This could explain the absence of a one-to-one association between the 17 GHz bright patches and those observed in extreme ultraviolet. Moreover, the emission arising from small magnetic loops

located close to the limb may merge with the usual limb brightening profile, increasing its brightness temperature and width.

How are the EUV and radio polar limb-brightenings correlated?

C. L. **Selhorst**1,2, C. G. Giménez de Castro2, A. C. Varela Saraiva3 and J. E. R. Costa3
A&A 509, A51 (**2010**)

Aims. We correlate the polar limb brightening time evolution observed with pass-band filters centered at the EUV 17.1 nm (Fe ix,x) and 30.4 nm (He ii) lines with radio continuum images obtained at 17 GHz (~1.76 cm) during solar cycle 23.
Methods. We determine the limb brightening in units of the quiet Sun from daily maps at 17.1 and 30.4 nm obtained by the Extreme Ultraviolet Imager (EIT) aboard the SOHO satellite between 1997 and 2007. The limb brightness at 17 GHz is obtained from daily maps taken by the Nobeyama Radioheliograph (NoRH) since 1992.
Results. The variation in the limb brightening observed at coronal heights (17.1 nm) is correlated positively with the 11 year cycle. However, the observation at chromospheric/transition region heights (17 GHz / 30.4 nm) shows a clear negative correlation with the solar cycle.
Conclusions. The limb brightening measurements at 17.1 nm reproduce the emission measure clearly in the solar corona during a solar cycle in which coronal holes are constantly present at the poles during the minimum. On the other hand, the negative correlation of the polar brightening at 17 GHz and 30.4 nm with the solar cycle are shown to depend upon polar features in the lower atmosphere (chromosphere/transition region). Moreover, the polar brightening variation at these frequencies is similar to that of the photospheric faculae observed at the poles.

An evolutionary computation based algorithm for calculating solar differential rotation by automatic tracking of coronal bright points

Ehsan **Shahamatnia**1,2*, Ivan Dorotovič1,3, Jose M. Fonseca1,2 and Rita A. Ribeiro
J. Space Weather Space Clim., 6, A16 (**2016**)
http://www.swsc-journal.org/articles/swsc/pdf/2016/01/swsc150013.pdf

Developing specialized software tools is essential to support studies of solar activity evolution. With new space missions such as Solar Dynamics Observatory (SDO), solar images are being produced in unprecedented volumes. To capitalize on that huge data availability, the scientific community needs a new generation of software tools for automatic and efficient data processing. In this paper a prototype of a modular framework for solar feature detection, characterization, and tracking is presented. To develop an efficient system capable of automatic solar feature tracking and measuring, a hybrid approach combining specialized image processing, evolutionary optimization, and soft computing algorithms is being followed. The specialized hybrid algorithm for tracking solar features allows automatic feature tracking while gathering characterization details about the tracked features. The hybrid algorithm takes advantages of the snake model, a specialized image processing algorithm widely used in applications such as boundary delineation, image segmentation, and object tracking. Further, it exploits the flexibility and efficiency of Particle Swarm Optimization (PSO), a stochastic population based optimization algorithm. PSO has been used successfully in a wide range of applications including combinatorial optimization, control, clustering, robotics, scheduling, and image processing and video analysis applications. The proposed tool, denoted PSO-Snake model, was already successfully tested in other works for tracking sunspots and coronal bright points. In this work, we discuss the application of the PSO-Snake algorithm for calculating the sidereal rotational angular velocity of the solar corona. To validate the results we compare them with published manual results performed by an expert.

THE FIRST STRAY LIGHT CORRECTED EXTREME-ULTRAVIOLET IMAGES OF SOLAR CORONAL HOLES

Paul **Shearer**1, Richard A. Frazin2, Alfred O. Hero III3 and Anna C. Gilbert
2012 ApJ 749 L8

Coronal holes are the source regions of the fast solar wind, which fills most of the solar system volume near the cycle minimum. Removing stray light from extreme-ultraviolet (EUV) images of the Sun's corona is of high astrophysical importance, as it is required to make meaningful determinations of temperatures and densities of coronal holes. EUV images tend to be dominated by the component of the stray light due to the long-range scatter caused by the microroughness of telescope mirror surfaces, and this component has proven very difficult to measure in pre-flight characterization. In-flight characterization heretofore has proven elusive due to the fact that the detected image is simultaneously nonlinear in two unknown functions: the stray light pattern and the true image that would be seen by an ideal telescope. Using a constrained blind deconvolution technique that takes advantage of known zeros in the true image provided by a fortuitous lunar transit, we have removed the stray light from solar images seen by the EUVI instrument on STEREO-B in all four filter bands (171, 195, 284, and 304 Å). Uncertainty measures of the stray light corrected images, which include the systematic error due to misestimation of the scatter, are provided. It is shown that in EUVI, stray light contributes up to 70% of the emission in coronal holes seen on the solar disk, which has dramatic consequences for diagnostics of temperature and density and therefore estimates of key plasma parameters such as the plasma β and ion-electron collision rates.

CORONAL CELLS

N. R. **Sheeley**, Jr. and H. P. Warren

2012 ApJ 749

We have recently noticed cellular features in Fe XII 193 Å images of the 1.2 MK corona. They occur in regions bounded by a coronal hole and a filament channel, and are centered on flux elements of the photospheric magnetic network. Like their neighboring coronal holes, these regions have minority-polarity flux that is ~0.1-0.3 times their flux of majority polarity. Consequently, the minority-polarity flux is "grabbed" by the majority-polarity flux to form low-lying loops, and the remainder of the network flux escapes to connect with its opposite-polarity counterpart in distant active regions of the Sun. As these regions are carried toward the limb by solar rotation, the cells disappear and are replaced by linear plumes projecting toward the limb. In simultaneous views from the Solar Terrestrial Relations Observatory and Solar Dynamics Observatory spacecraft, these plumes project in opposite directions, extending away from the coronal hole in one view and toward the hole in the other view, suggesting that they are sky-plane projections of the same radial structures. We conclude that these regions are composed of closely spaced radial plumes, extending upward like candles on a birthday cake and visible as cells when seen from above. We suppose that a coronal hole has this same discrete, cellular magnetic structure, but that it is not seen until the encroachment of opposite-polarity flux closes part or all of the hole.

SECCHI OBSERVATIONS OF THE SUN'S GARDEN-HOSE DENSITY SPIRAL

N. R. **Sheeley**, Jr.,1 A. D. Herbst,1,2 C. A. Palatchi,1,3 Y.-M. Wang,1 R. A. Howard,1 J. D. Moses,1 A. Vourlidas,1 J. S. Newmark,1 D. G. Socker,1 S. P. Plunkett,1 C. M. Korendyke,1 L. F. Burlaga,4 J. M. Davila,4 W. T. Thompson,4 O. C. St Cyr,4 R. A. Harrison,5 C. J. Davis,5 C. J. Eyles,5,6 J. P. Halain,7 D. Wang,8 N. B. Rich,8 K. Battams,8 E. Esfandiari,8 and G. Stenborg9

The Astrophysical Journal, 674:L109–L112, 2008 February 20

http://www.journals.uchicago.edu/doi/pdf/10.1086/529020

The SECCHI HI2 white-light imagers on the *STEREO* A and B spacecraft show systematically different proper motions of material moving outward from the Sun in front of high-speed solar wind streams from coronal holes. As a group of ejections enters the eastern (A) field of view, the elements at the rear of the group appear to overrun the elements at the front. (This is a projection effect and does not mean that the different elements actually merge.) The opposite is true in the western (B) field; the elements at the front of the group appear to run away from the elements at the rear. Elongation/time maps show this effect as a characteristic grouping of the tracks of motion into convergent patterns in the east and divergent patterns in the west, consistent with ejections from a single longitude on the rotating Sun. Evidently, we are observing segments of the "garden-hose" spiral made visible when fast wind from a low-latitude coronal hole compresses blobs of streamer material being shed at the leading edge of the hole.

IS THERE ANY EVIDENT EFFECT OF CORONAL HOLES ON GRADUAL SOLAR ENERGETIC PARTICLE EVENTS?

Chenglong **Shen**, Yuming Wang,1 Pinzhong Ye, and S. Wang

The Astrophysical Journal, 639:510–515, **2006; File**

Gradual solar energetic particle (SEP) events are thought to be produced by shocks, which are usually driven by fast coronal mass ejections (CMEs). The strength and magnetic field configuration of the shock are considered the two most important factors for shock acceleration. Theoretically, both of these factors should be unfavorable for producing SEPs in or near coronal holes (CHs). Meanwhile, CMEs and CHs could impact each other. Thus, to answer the question whether CHs have real effects on the intensities of SEP events produced by CMEs, a statistical study is performed. **First, a brightness gradient method is developed to determine CH boundaries. Using this method, CHs can be well identified, eliminating any personal bias.** Then 56 front-side fast halo CMEs originating from the western hemisphere during 1997–2003 are investigated as well as their associated large CHs. It is found that neither CH proximity nor CH relative location manifests any evident effect on the proton peak fluxes of SEP events. The analysis reveals that almost all of the statistical results are significant at no more than one standard deviation, _. Our results are consistent with the previous conclusion suggested by Kahler that SEP events can be produced in fast solar wind regions and there is no requirement for those associated CMEs to be significantly faster.

In this paper, we prefer using EIT 284 A to identify CHs. This consideration is based on the following reasons.

First ALMA Observation of a Plasmoid Ejection from an X-ray Bright Point

M. **Shimojo**, H. S. Hudson, S. M. White, T. S. Bastian, K. Iwai

ApJL 841 L5 **2017**

https://arxiv.org/pdf/1704.04881.pdf

Eruptive phenomena such as plasmoid ejections or jets are an important feature of solar activity with the potential for improving our understanding of the dynamics of the solar atmosphere. Such ejections are often thought to be signatures of the outflows expected in regions of fast magnetic reconnection. The 304 A EUV line of Helium, formed at around 10^5 K, is found to be a reliable tracer of such phenomena, but the determination of physical parameters from such observations is not straightforward. We have observed a plasmoid ejection from an X-ray bright point simultaneously at millimeter wavelengths with ALMA, at EUV wavelengths with AIA, in soft X-rays with Hinode/XRT. This paper reports the physical parameters of the plasmoid obtained by combining the radio, EUV and X-ray data. As a result, we conclude that the plasmoid can consist either of (approximately) isothermal 10^5 K plasma that is optically thin at 100 GHz, or else a 10^4 K core with a hot envelope. The analysis demonstrates the value of the additional temperature and density constraints that ALMA provides, and future science observations with ALMA will be able to match the spatial resolution of space-borne and other high-resolution telescopes. **2015-12-17**

THE RELATION BETWEEN MAGNETIC FIELDS AND CORONAL ACTIVITIES IN THE POLAR CORONAL HOLE

Masumi **Shimojo**[1] and Saku Tsuneta[2]

2009 ApJ 706 L145-L149

We investigated the relation between polar magnetic fields and polar coronal activities based on Stokes maps of photospheric and chromospheric lines, simultaneous X-ray and EUV images. These images are taken with *Hinode* and *Solar and Heliospheric Observatory*. With careful co-alignment between these images, we found that the X-ray jets, the X-ray bright points, and the coronal loops in the polar coronal hole appear around the relatively large magnetic concentrations near the kG-patches with minority polarity. The magnetic concentrations have magnetic polarity opposite to that of kG-patches, and they are clearly identified in the Stokes-*V* maps of the Na I line. We also found that such minority magnetic concentrations emerge from below the photosphere in the polar region. Our results suggest that the coronal activities and structures in the polar coronal hole can be used as a tracer of the appearance of the minority polarities in the polar region.

Synchronization of Small-scale Magnetic Features, Blinkers, and Coronal Bright Points

Zahra **Shokri**, Nasibe Alipour, Hossein Safari, Pradeep Kayshap, Olena Podladchikova, Giuseppina Nigro, Durgesh Tripathi

ApJ 926:42 **2022**

https://arxiv.org/pdf/2201.04459.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/ac4265/pdf

We investigate the relationship between different transients such as blinkers detected in images taken at 304~Å, extreme ultraviolet coronal bright points (ECBPs) at 193~Å, X-ray coronal bright points (XCBPs) at 94~Å on AIA, and magnetic features observed by HMI during ten years of solar cycle 24. An automatic identification method is applied to detect transients, and the YAFTA algorithm is used to extract the magnetic features. Using ten years of data, we detect in total 7,483,827 blinkers, 2,082,162 ECBPs, and 1,188,839 XCBPs, respectively, with their birthrate of about 1.1×10−18 m−2s−1, 3.8×10−19 m−2s−1, and 1.5×10−19 m−2s−1. We find that about 80\% of blinkers are observed at the boundaries of supergranules, and 57\% (34\%) are associated with ECBPs (XCBPs). We further find that about 61{--}80\% of transients are associated with the isolated magnetic poles in the quiet Sun and that \textbf{the normalized maximum intensities of the transients are correlated with photospheric magnetic flux of poles} via a power law. These results conspicuously show that these transients have a magnetic origin and their synchronized behavior provides further clues towards the understanding of the coupling among the different layers of the solar atmosphere. Our study further reveals that the appearance of these transients is strongly anti-correlated with the sunspots cycle. This finding can be relevant for a better understanding of solar dynamo and magnetic structures at different scales during the solar cycle. **2018 August 26, 2019-12-04**

Hierarchical approach to forecasting recurrent solar wind streams

Yu. S**. Shugay**, I. S. Veselovsky, D. B. Seaton and D. Berghmans

Solar System Research, Volume 45, Number 6, 546-556, **2011**

Astronomicheskii Vestnik, **2011**, Vol. 45, No. 6, pp. 560–571.

The hierarchical approach to predicting quasi-stationary, high-speed solar wind (SW) streams is described. This approach integrates various types of data into a single forecasting system by means of an ensemble of experts. The input data included the daily values of the coronal hole areas, which were calculated from the ultraviolet images of the Sun, and the speed of the SW streams during the previous solar rotations. The coronal hole areas were calculated from the images taken by the SWAP instrument aboard the PROBA2 satellite in the spectral interval centered at a wavelength of 17.4 nm and by the AIA instrument aboard the SDO spacecraft in the interval of wavelengths centered at 19.3 and 17.1 nm. The forecast was based on the data for 2010, corresponding to the rising phase of the 24th solar cycle. On the first hierarchical level, a few simple model estimates were obtained for the speed of the SW streams from the input data of each type. On the second level of hierarchy, the final 3 day ahead forecast of the SW velocity was formulated on the basis of the obtained estimates. The proposed hierarchical approach improves the accuracy of forecasting the SW velocity. In addition, in such a method of prediction, the data gaps in the records of one instrument do not crucially affect the final result of forecasting of the system as a whole.

Comparison of solar radio and EUV synoptic limb charts during the present solar maximum

A. J. Oliveirae **Silva**, C. L. Selhorst, P. J. A. Simões, C. G. Giménes de Castro

A&A **2016**

http://arxiv.org/pdf/1606.03406v1.pdf

The present solar cycle is particular in many aspects: it had a delayed rising phase, it is the weakest of the last 100 years, and it presents two peaks separated by more than one year. To understand the impact of these characteristics on the solar chromosphere and coronal dynamics, images from a wide wavelength range are needed. In this work we use the 17~GHz radio continuum, formed in the upper chromosphere and the EUV lines 304 and 171~{\AA}, that come from the transition region (He II) and the corona (Fe IX, X), respectively. We analyze daily images at 304 and 171~{\AA} obtained by the Atmospheric Imaging Assembly (AIA). The 17~GHz maps were obtained by the Nobeyama Radioheliograph (NoRH). To construct synoptic limb charts, we calculated the mean emission of delimited limb areas with 100" wide and angular separation of 5∘. At the equatorial region, the results show an hemispheric asymmetry of the solar activity. The northern hemisphere dominance is coincident with the first sunspot number peak, whereas the second peak occurs concurrently with the increase in the activity at the south. The polar emission reflects the presence of coronal holes at both EUV wavelengths, moreover, the 17~GHz polar brightenings can be associated with the coronal holes. Until 2013, both EUV coronal holes and radio polar brightenings were more predominant at the south pole. Since then they have not been apparent in the north, but thus appear in the beginning of 2015 in the south as observed in the synoptic charts. This work strengthens the association between coronal holes and the 17~GHz polar brightenings as it is evident in the synoptic limb charts, in agreement with previous case study papers. The enhancement of the radio brightness in coronal holes is explained by the presence of bright patches closely associated with the presence of intense unipolar magnetic fields.

Turbulent Diffusion Derived from the Motions of SDO/AIA Coronal Bright Points

I. **Skokić**1, R. Brajša1, D. Sudar1, D. Ruždjak1, and S. H. Saar2

2019 ApJ 877 142

Diffusion of magnetic elements on the Sun has an important role in current solar dynamo models as a part of the mechanism for redistribution of the magnetic field and as an important part for maintaining the solar activity cycle. The main goal is to determine the character of solar magnetic diffusivity and a value of the diffusion coefficient by analyzing the motions of coronal bright points (CBPs) within the frame of the random walk model. We tracked positions of CBPs in Solar Dynamics Observatory/Atmospheric Imaging Assembly images for a period of 5 months and examined their displacement spectrum. We calculated spectral index and diffusion coefficient from the spectrum and investigated their variation with temporal and spatial scale. For the first time, variations of the spectral index with heliographic latitude and time were analyzed. Our results indicate subdiffusion with the spectral index $\gamma = 0.70 \pm 0.01$ and the corresponding diffusion coefficient with a value decreasing from 400 to 100 km2 s−1 for temporal scales of 103–105 s and spatial scales of (1.5–7) × 103 km. Seemingly random variations around the mean value of spectral index were found, with peak-to-peak amplitudes <0.30 with time and <0.10 with latitude. The main conclusion is that CBP motions are consistent with a subdiffusion process.

Identification of coronal sources of the solar wind from solar images in the EUV spectral range

V. A. **Slemzin**, Yu. S. Shugai

Cosmic Research, January **2015**, Volume 53, Issue 1, pp 47-58

Kosmicheskie Issledovaniya, **2015**, Vol. 53, No. 1, pp. 51–62.

Methods of localizing coronal sources of the solar wind (SW), such as coronal holes, quasi-stationary fluxes from active regions, and transient sources associated with small-scale active phenomena are considered based on vacuum-ultraviolet (EUV) images of the corona at low solar activity during the initial period of the 24th solar cycle (2010). It is shown that a SW velocity profile can be calculated from the relative areas of coronal holes (CH) at the central part of the disk based on the images in the ranges of 193 and 171 Å. The images in the 193 Å describe the geometry of large HCs that represent sources of fast SW well. The images in 171 Å are a better visualization of small CHs, based on which the profile of a slow SW component was calculated to a high accuracy (up to 65 km/s). According to Hinode/EIS data of **October 15, 2010**, using the Doppler spectroscopy method at the streamer base over the active region 11112, the source of the outgoing plasma flux with the mean velocity of 17 km/s was localized in the magnetic field region with an intensity of less than 200 Gauss. According to the estimate, the density of the plasma flux from this source is an order of magnitude greater than the value required for explaining the distinction between the calculated and measured profiles of a slow SW velocity. For finding the transient SW component based on small-scale flare activity, SW parameters were analyzed for the periods of flares accompanied by coronal mass ejections (CMEs), and for the periods without flares, according to the data obtained in 2010 from the ACE and GOES satellites and by coronagraphs on the STEREO-A and -B spacecraft. The ion ratios C^{+6}/C^{+5} and O^{+7}/O^{+6} and the mean charge of Fe ions for periods with flares were shown to be shifted toward large values, suggesting the presence of a hot SW component associated with flare activity. A noticeable correlation between the maximum charge of Fe ions and the peak power of a flare, previously observed for flares of a higher class, was confirmed. The mean value of the SW flux density during the periods of flares was 30% higher than that in the periods without flares, which is possibly associated also with the growth of fluxes from other sources with an increasing solar activity level. Based on the example of a series of flares of **October 13–14, 2010**, it was supposed that transient SW fluxes from the weak flares at low solar activity can manifest themselves in the form of interplanetary ICME-transients.

Signatures of Slow Solar Wind Streams from Active Regions in the Inner Corona

V. **Slemzin**, L. Harra, A. Urnov, S. Kuzin, F. Goryaev, D. Berghmans

Solar Physics, August **2013**, Volume 286, Issue 1, pp 157-184

The identification of solar-wind sources is an important question in solar physics. The existing solar-wind models (e.g., the Wang–Sheeley–Arge model) provide the approximate locations of the solar wind sources based on magnetic field extrapolations. It has been suggested recently that plasma outflows observed at the edges of active regions may be a source of the slow solar wind. To explore this we analyze an isolated active region (AR) adjacent to small coronal hole (CH) in **July/August 2009**. On 1 August, Hinode/EUV Imaging Spectrometer observations showed two compact outflow regions in the corona. Coronal rays were observed above the active-region coronal hole (ARCH) region on the eastern limb on 31 July by STEREO-A/EUVI and at the western limb on 7 August by CORONAS-Photon/TESIS telescopes. In both cases the coronal rays were co-aligned with open magnetic-field lines given by the potential field source surface model, which expanded into the streamer. The solar-wind parameters measured by STEREO-B, ACE, Wind, and STEREO-A confirmed the identification of the ARCH as a source region of the slow solar wind. The results of the study support the suggestion that coronal rays can represent signatures of outflows from ARs propagating in the inner corona along open field lines into the heliosphere.

ELECTRON TRANSPORT IN THE FAST SOLAR WIND

H. M. **Smith**1,2, E. Marsch1, and P. Helander

2012 ApJ 753 31

The electron velocity distribution function is studied in the extended solar corona above coronal holes (i.e., the inner part of the fast solar wind) from the highly collisional corona close to the Sun to the weakly collisional regions farther out. The electron kinetic equation is solved with a finite-element method in velocity space using a linearized Fokker-Planck collision operator. The ion density and temperature profiles are assumed to be known and the electric field and electron temperature are determined self-consistently. The results show quantitatively how much lower the electron heat flux and the thermal force are than predicted by high-collisionality theory. The sensitivity of the particle and heat fluxes to the assumed ion temperature profile and the applied boundary condition at the boundary far from the Sun is also studied.

Threaded-field-line Model for the Low Solar Corona Powered by the Alfvén Wave Turbulence

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2021 ApJ 908 172

https://doi.org/10.3847/1538-4357/abc000

https://iopscience.iop.org/article/10.3847/1538-4357/abc000/pdf

We present an updated global model of the solar corona, including the transition region. We simulate the realistic three-dimensional (3D) magnetic field using the data from the photospheric magnetic field measurements and assume the magnetohydrodynamic (MHD) Alfvén wave turbulence and its nonlinear dissipation to be the only source for heating the coronal plasma and driving the solar wind. In closed-field regions, the dissipation efficiency in a balanced turbulence is enhanced. *In the coronal holes, we account for a reflection of the outward-propagating waves, which is accompanied by the generation of weaker counterpropagating waves. The nonlinear cascade rate degrades in strongly imbalanced turbulence, thus resulting in colder coronal holes.* The distinctive feature of the presented model is the description of the low corona as almost-steady-state low-beta plasma motion and heat flux transfer along the magnetic field lines. We trace the magnetic field lines through each grid point of the lower boundary of the global corona model, chosen at some heliocentric distance, $R = R_b \sim 1.1R_\odot$, well above the transition region. One can readily solve the plasma parameters along the magnetic field line from 1D equations for the plasma motion and heat transport together with the Alfvén wave propagation, which adequately describe the physics within the heliocentric distance range R ⊙ < R < R b , in the low solar corona. By interfacing this threaded-field-line model with the full MHD global corona model at r = R b , we find the global solution and achieve a faster-than-real-time performance of the model on ~200 cores.

Investigating the behaviour of neutral hydrogen Lyα spectral line width in polar coronal holes at solar minimum

D. **Spadaro**1, R. Susino2, S. Dolei1, R. Ventura1 and E. Antonucc

A&A 603, A35 (**2017**)

We investigate the behaviour of the H I Lyα spectral line widths measured by UVCS/SOHO in polar coronal holes at minimum of solar magnetic activity. The line widths are reported to significantly increase up to 3 R⊙, while above 3 R⊙ there is observational evidence of either nearly constant or slightly decreasing values. We adopt empirical models of polar coronal holes at solar activity minimum reported in the literature and calculate the characteristic timescales relevant to different processes coupling neutral hydrogen atoms and protons, which are heated and accelerated in the outflowing plasma. This analysis leads us to believe that the progressive decoupling of the two sets of particles below 10 R⊙, caused by the decrease of the plasma density due to the rapid expansion of the wind, cannot explain the behaviour of the Lyα line profile observed in polar coronal holes. We also synthesise the intensity and profile of the Lyα line as a function of heliocentric distance from the coronal hole models, adopting H I densities computed in non-equilibrium ionisation with the aim of satisfactorily reproducing the UVCS Lyα observations reported in the literature. Our analysis shows that the coronal Lyα emission decreases with heliocentric distance, down to values below the interplanetary Lyα emission, owing to the decrease of the plasma density and to non-equilibrium ionisation effects in the expanding plasma. This can lead to the predominance of the interplanetary emission, which is characterised by H I velocity distributions corresponding to temperatures about one order of magnitude lower than the coronal temperatures, and to the narrowing of the resulting coronal profile at higher heliocentric distances. This scenario can be a plausible explanation for the behaviour of the Lyα line profile with height observed in polar coronal holes at solar activity minimum.

Observations of a pulse-driven cool polar jet by SDO/AIA

A. K. **Srivastava**1,2 and K. Murawsk

A&A 534, A62 (**2011**)

Context. We observe a solar jet at north polar coronal hole (NPCH) using SDO AIA 304 Å image data on **3 August 2010**. The jet rises obliquely above the solar limb and then retraces its propagation path to fall back.
Aims. We numerically model this solar jet by implementing a realistic (VAL-C) model of solar temperature.
Methods. We solve two-dimensional ideal magnetohydrodynamic equations numerically to simulate the solar jet. We consider a localized velocity pulse that is essentially parallel to the background magnetic field lines and is initially launched at the top of the solar photosphere. The pulse steepens into a shock at higher altitudes, which triggers plasma perturbations that exhibit the observed features of the jet. The typical direction of the pulse also clearly exhibits the leading front of the moving jet.
Results. Our numerical simulations reveal that a large amplitude initial velocity pulse launched at the top of the solar photosphere in general produces the observed properties of the jet, e.g., upward and backward average velocities, height, width, life-time, and ballistic nature.
Conclusions. The close match between the jet observations and numerical simulations provides a first strong evidence that this jet is formed by a single velocity pulse. The strong velocity pulse is most likely generated by the low-atmospheric reconnection in the polar region, which triggers the jet. The downflowing material of the jet most likely is absorbed in the next upcoming velocity pulses from the lower solar atmosphere, and because of that we only see a single jet moving upward in the solar atmosphere.

Active region contributions to the solar wind over multiple solar cycles

D. **Stansby**, L. M. Green, L. van Driel-Gesztelyi, T. S. Horbury

Solar Phys. **2021**

https://arxiv.org/pdf/2104.04417.pdf

Both coronal holes and active regions are source regions of the solar wind. The distribution of these coronal structures across both space and time is well known, but it is unclear how much each source contributes to the solar wind. In this study we use photospheric magnetic field maps observed over the past four solar cycles to estimate what fraction of magnetic open solar flux is rooted in active regions, a proxy for the fraction of all solar wind originating in active regions. We find that the fractional contribution of active regions to the solar wind varies between 30% to 80% at any one time during solar maximum and is negligible at solar minimum, showing a strong correlation with sunspot number. While active regions are typically confined to latitudes ±30∘ in the corona, the solar wind they produce can reach latitudes up to ±60∘. Their fractional contribution to the solar wind also correlates with coronal mass ejection rate, and is highly variable, changing by ±20% on monthly timescales within individual solar maxima. We speculate that these variations are primarily driven by coronal mass ejections causing global reconfigurations of the coronal magnetic field on sub-monthly timescales.

Sensitivity of solar wind mass flux to coronal temperature

D. **Stansby**, L. Berčič, L. Matteini, C. J. Owen, R. French, D. Baker, S. T. Badman
MNRAS **2020**
https://arxiv.org/pdf/2009.13918.pdf
Solar wind models predict that the mass flux carried away from the Sun in the solar wind should be extremely sensitive to the temperature in the corona, where the solar wind is accelerated. We perform a direct test of this prediction in coronal holes and active regions, using a combination of in-situ and remote sensing observations. For coronal holes, a 50% increase in temperature from 0.8 MK to 1.2 MK is associated with a tripling of the coronal mass flux. At temperatures over 2 MK, within active regions, this trend is maintained, with a four-fold increase in temperature corresponding to a 200-fold increase in coronal mass flux.

Investigating Coronal Holes and CMEs as Sources of Brightness Depletion Detected in PSP/WISPR Images

Guillermo **Stenborg**1, Evangelos Paouris1,2, Russell A. Howard1, Angelos Vourlidas1, and Phillip Hess3
2023 ApJ 949 61
https://iopscience.iop.org/article/10.3847/1538-4357/acd2cf/pdf
The Parker Solar Probe (PSP) mission provides a unique opportunity to observe the solar corona from distances below 20 $R_\odot$. In this work, we utilize white light images from the Wide-field Imager for Solar PRobe aboard the PSP from solar encounters 10 through 13 to examine the causes of brightness depletions of the corona during the rapid transit of PSP through the perihelia of its orbit. We analyze the effect of (1) coronal holes (CHs) and (2) energetic coronal mass ejection (CME) events on the observed brightness of the images. We speculate on the causes of the brightness depletions, ascribing them to the evacuation of (1) free electrons (reduced K-corona) and (2) interplanetary dust (reduced F-corona). In particular, we show that (1) the presence of CHs in all of the orbits is directly correlated with the depletion of the global white light emission recorded, and (2) a huge CME event in encounter 13 caused a very deep depletion in its wake that removed the electron content as well as some of the interplanetary dust. **14-18 Nov 2021; 21 Nov 2021; 18, 24, 25, 27 Feb 2022; 13, 17 May 2022; 1, 2 Jun 2022; 27 Aug 2022; 5, 6, 14 Sep 2022**

Small-scale filament eruptions as the driver of solar coronal hole X-ray jets

Alphonse C. **Sterling**, Ronald L. Moore, David A. Falconer, Mitzi Adams
2015, Nature, 523, 437-440
https://arxiv.org/pdf/1705.03373.pdf
Solar X-ray jets are evidently made by a burst of reconnection of closed magnetic field in a jet's base with ambient "open" field (1,2). In the widely-accepted version of the "emerging-flux" model, that reconnection occurs at a current sheet between the open field and emerging closed field and also makes a compact hot brightening that is usually observed at the edge of the jet's base (1,3). Here we report on high-resolution X-ray and EUV observations of 20 randomly-selected X-ray jets in polar coronal holes. In each jet, contrary to the emerging-flux model, a miniature version of the filament eruptions that initiate coronal mass ejections (CMEs) (4-7) drives the jet-producing reconnection, and the compact hot brightening is made by internal reconnection of the legs of the minifilament-carrying erupting closed field, analogous to solar flares of larger-scale eruptions. Previous observations have found that some jets are driven by base-field eruptions (8-10,12), but only one such study, of only one jet, provisionally questioned the emerging-flux model (13). Our observations support the view that solar filament eruptions are made by a fundamental explosive magnetic process that occurs on a vast range of scales, from the biggest CME/flare eruptions down to X-ray jets, and perhaps down to even smaller jets that are candidates for powering coronal heating (10,14,15). A picture similar to that suggested by our observations was drawn before, inferred from different observations and based on a different origin of the erupting minifilament flux rope (11) (see Methods). **28 Aug 2010, 9 Sept 2010, 17 Sept 2010**
Extended Data **Table 1**: X-Ray Jets of This Study
See http://www.nature.com/nature/journal/v523/n7561/fig_tab/nature14556_SF3.html

FIBRILLAR CHROMOSPHERIC SPICULE-LIKE COUNTERPARTS TO AN EXTREME-ULTRAVIOLET AND SOFT X-RAY BLOWOUT CORONAL JET

Alphonse C. **Sterling**1,3, Louise K. Harra2, and Ronald L. Moore1

Astrophysical Journal, 722:1644–1653, **2010**
We observe an erupting jet feature in a solar polar coronal hole, using data from *Hinode/*Solar Optical Telescope (SOT), Extreme Ultraviolet Imaging Spectrometer (EIS), and X-Ray Telescope (XRT), with supplemental data from *STEREO/*EUVI. From extreme-ultraviolet (EUV) and soft X-ray (SXR) images we identify the erupting feature as a blowout coronal jet: in SXRs it is a jet with a bright base, and in EUV it appears as an eruption of relatively cool (~50,000 K) material of horizontal size scale ~30_ originating from the base of the SXR jet. In SOT Ca ii H images, the most pronounced analog is a pair of thin (~1_) ejections at the locations of either of the two legs of the erupting EUV jet. These Ca ii features eventually rise beyond 45_, leaving the SOT field of view, and have an appearance similar to standard spicules except that they are much taller. They have velocities similar to that of "type II" spicules, ~100 km s^{-1}, and they appear to have spicule-like substructures splitting off from them with horizontal velocity ~50 km s^{-1}, similar to the velocities of splitting spicules measured by Sterling et al. Motions of splitting features and of other substructures suggest that the macroscopic EUV jet is spinning or unwinding as it is ejected. This and earlier work suggest that a subpopulation of Ca ii type II spicules are the Ca ii manifestation of portions of larger scale erupting magnetic jets. A different subpopulation of type II spicules could be blowout jets occurring on a much smaller horizontal size scale than the event we observe here.

What is the true nature of blinkers?

S. **Subramanian**1, M. S. Madjarska1, J. G. Doyle1 and D. Bewsher
A&A 538, A50 (**2012**)
Aims. The aim of this work is to identify the true nature of the transient EUV brightenings, called blinkers.
Methods. Co-spatial and co-temporal multi-instrument data, including imaging (EUVI/STEREO, XRT and SOT/Hinode), spectroscopic (CDS/SoHO and EIS/Hinode) and magnetogram (SOT/Hinode) data, of an isolated equatorial coronal hole were used. An automatic program for identifying transient brightenings in CDS O v 629 Å, EUVI 171 Å and XRT was applied.
Results. We identified 28 blinker groups in the CDS O v 629 Å raster images. All CDS O v 629 Å blinkers showed counterparts in EUVI 171 Å and 304 Å images. We classified these blinkers into two categories, one associated with coronal counterparts and other with no coronal counterparts as seen in XRT images and EIS Fe xii 195.12 Å raster images. Around two-thirds of the blinkers show coronal counterparts and correspond to various events like EUV/X-ray jets, brightenings in coronal bright points or foot-point brightenings of larger loops. These brightenings occur repetitively and have a lifetime of around 40 min at transition region temperatures. The remaining blinker groups with no coronal counterpart in XRT and EIS Fe xii 195.12 Å appear as point-like brightenings and have chromospheric/transition region origin. They take place only once and have a lifetime of around 20 min. In general, lifetimes of blinkers are different at different wavelengths, i.e. different temperatures, decreasing from the chromosphere to the corona.
Conclusions. This work shows that the term blinker covers a range of phenomena. Blinkers are the EUV response of various transient events originating at coronal, transition region and chromospheric heights. Hence, events associated with blinkers contribute to the formation and maintenance of the temperature gradient in the transition region and the corona.

Coronal hole boundaries evolution at small scales: II. XRT view Can small-scale outflows at CHBs be a source of the slow solar wind?

S. **Subramanian**, M. S. Madjarska and J. G. Doyle
A&A, 516, A50 (**2010**), **File**
Aims. We aim to further explore the small-scale evolution of coronal hole boundaries using X-ray high-resolution and high-cadence images. We intend to determine the fine structure and dynamics of the events causing changes of coronal hole boundaries and to explore the possibility that these events are the source of the slow solar wind.
Methods. We developed an automated procedure for the identification of transient brightenings in images from the X-ray telescope on-board Hinode taken with an Al Poly filter in the equatorial coronal holes, polar coronal holes, and the quiet Sun with and without transient coronal holes.
Results. We found that in comparison to the quiet Sun, the boundaries of coronal holes are abundant with brightening events including areas inside the coronal holes where closed magnetic field structures are present. The visual analysis of these brightenings revealed that around 70% of them in equatorial, polar and transient coronal holes and their boundaries show expanding loop structures and/or collimated outflows. In the quiet Sun only 30% of the brightenings show flows with most of them appearing to be contained in the solar corona by closed magnetic field lines. This strongly suggests that magnetic reconnection of co-spatial open and closed magnetic field lines creates the necessary conditions for plasma outflows to large distances. The ejected plasma always originates from preexisting or newly emerging (at X-ray temperatures) bright points.
Conclusions.The present study confirms our findings that the evolution of loop structures known as coronal bright points is associated with the small-scale changes of coronal hole boundaries. The loop structures show an expansion and eruption with the trapped plasma consequently escaping along the "quasi" open magnetic field lines. These ejections appear to be triggered by magnetic reconnection, e.g. the so-called interchange reconnection between the closed magnetic field lines (BPs) and the open

magnetic field lines of the coronal holes. We suggest that these plasma outflows are possibly one of the sources of the slow solar wind.

Rotation Profiles of Coronal Bright Points Inside and Outside of Coronal Holes.

Sudar, D., Brajša, R., Skokić, I. et al.

Sol Phys 299, 50 (**2024**).

https://doi.org/10.1007/s11207-024-02294-y

The rotation of the solar corona is not a fully resolved issue. Coronal holes (CHs) reveal sometimes more rigid, but in other cases more differential rotation profiles. We used two datasets of coronal bright points (CBPs), one within CHs, and one outside of CHs. We analyzed rotation profiles in the two datasets of CBPs and compared them to check if there is any difference between rotation profiles for CBPs within CHs and those outside of CHs. The reported rigidity of the CHs rotational profiles implies that Reynolds stresses, which are considered to be the main drivers of the solar differential profile, should also be different between the two datasets. Therefore, we analyzed the horizontal Reynolds stress for the two datasets as well. We also compared the meridional motion of the two datasets. In all cases the results between the two datasets were the same within the observational error. In both datasets the solar rotation profile is significantly differential and similar to the photospheric profile.

Steps toward a high precision solar rotation profile: Results from SDO/AIA coronal bright point data

Davor **Sudar**, Ivica Skokić, Roman Brajša, Steven H. Saar

2015 A&A 575, A63

http://arxiv.org/pdf/1501.01285v1.pdf

Coronal bright points (CBP) are ubiquitous small brightenings in the solar corona associated with small magnetic bipoles. We derive the solar differential rotation profile by tracing the motions of CBPs detected by the Atmospheric Imaging Assembly (AIA) instrument aboard the Solar Dynamics Observatory (SDO). We also investigate problems related to detection of coronal bright points resulting from instrument and detection algorithm limitations. To determine the positions and identification of coronal bright points we used a segmentation algorithm. A linear fit of their central meridian distance and latitude versus time was utilised to derive velocities. We obtained 906 velocity measurements in a time interval of only 2 days. The differential rotation profile can be expressed as ωrot=(14.47±0.10+(0.6±1.0)sin2(b)+(−4.7±1.7)sin4(b))\degr day−1. Our result is in agreement with other work and it comes with reasonable errors in spite of the very short time interval used. This was made possible by the higher sensitivity and resolution of the AIA instrument compared to similar equipment as well as high cadence. The segmentation algorithm also played a crucial role by detecting so many CBPs, which reduced the errors to a reasonable level. Data and methods presented in this paper show a great potential to obtain very accurate velocity profiles, both for rotation and meridional motion and, consequently, Reynolds stresses. The amount of coronal bright point data that could be obtained from this instrument should also provide a great opportunity to study changes of velocity patterns with a temporal resolution of only a few months. Other possibilities are studies of evolution of CBPs and proper motions of magnetic elements on the Sun. **2011-01-01**

Sympathetic Standard and Blowout Coronal Jets Observed in a Polar Coronal Hole

Zehao **Tang**, Yuandeng Shen, Xinping Zhou, Yadan Duan, Chengrui Zhou, Song Tan, Elmhamdi Abouazza

ApJL **912** L15 **2021**

https://arxiv.org/pdf/2104.04309.pdf

https://doi.org/10.3847/2041-8213/abf73a

We present the sympathetic eruption of a standard and a blowout coronal jets originating from two adjacent coronal bright points (CBP1 and CBP2) in a polar coronal hole, using soft X-ray and extreme ultraviolet observations respectively taken by the Hinode and the Solar Dynamic Observatory. In the event, a collimated jet with obvious westward lateral motion firstly launched from CBP1, during which a small bright point appeared around CBP1's east end, and magnetic flux cancellation was observed within the eruption source region. Based on these characteristics, we interpret the observed jet as a standard jet associated with photosperic magnetic flux cancellation. About 15 minutes later, the westward moving jet spire interacted with CBP2 and resulted in magnetic reconnection between them, which caused the formation of the second jet above CBP2 and the appearance of a bright loop system in-between the two CBPs. In addition, we observed the writhing, kinking, and violent eruption of a small kink structure close to CBP2's west end but inside the jet-base, which made the second jet brighter and broader than the first one. These features suggest that the second jet should be a blowout jet triggered by the magnetic reconnection between CBP2 and the spire of the first jet. We conclude that the two successive jets were physically connected to each other rather than a temporal coincidence, and this observation also suggests that coronal jets can be triggered by external eruptions or disturbances, besides internal magnetic activities or magnetohydrodynamic instabilities. **2019 March 31**

Synchronized Observations of Bright Points from the Solar Photosphere to Corona

Ehsan **Tavabi**

MNRAS **2018**

https://arxiv.org/ftp/arxiv/papers/1801/1801.01307.pdf

One of the most important features in the solar atmosphere is magnetic network and its rela- tionship with the transition region (TR), and coronal brightness. It is important to understand how energy is transported into the corona and how it travels along the magnetic-field lines be- tween deep photosphere and chromosphere through the TR and corona. An excellent proxy for transportation is the Interface Region Imaging Spectrograph (IRIS) raster scans and imaging observations in near-ultraviolet (NUV) and far-ultraviolet (FUV) emission channels with high time-spatial resolutions. In this study, we focus on the quiet Sun as observed with IRIS. The data with high signal to noise ratio in Si IV, C II and Mg II k lines and with strong emission intensities show a high correlation in TR bright network points. The results of the IRIS intensity maps and dopplergrams are compared with those of Atmo- spheric Imaging Assembly (AIA) and Helioseismic and Magnetic Imager (HMI) instruments onboard the Solar Dynamical Observatory (SDO). The average network intensity profiles show a strong correlation with AIA coronal channels. Furthermore, we applied simultaneous observations of magnetic network from HMI and found a strong relationship between the network bright points in all levels of the solar atmosphere. These features in network elements exhibited high doppler velocity regions and large mag- netic signatures. A dominative fraction of corona bright points emission, accompanied by the magnetic origins in photosphere, suggest that magnetic-field concentrations in the network rosettes could help couple between inner and outer solar atmosphere. **2014 July 2**

IRIS Mg II Observations and Non-LTE Modeling of Off-limb Spicules in a Solar Polar Coronal Hole

Akiko **Tei**, Stanislav Gunar, Petr Heinzel, Takenori J. Okamoto, Jiri Stepan, Sonja Jejcic, Kazunari Shibata

ApJ **888** 42 **2020**

https://arxiv.org/pdf/1911.12243.pdf

https://doi.org/10.3847/1538-4357/ab5db1

We investigated the off-limb spicules observed in the Mg II h and k lines by IRIS in a solar polar coronal hole. We analyzed the large dataset of obtained spectra to extract quantitative information about the line intensities, shifts, and widths. The observed Mg II line profiles are broad and double-peaked at lower altitudes, broad but flat-topped at middle altitudes, and narrow and single-peaked with the largest Doppler shifts at higher altitudes. We use 1D non-LTE vertical slab models (i.e. models which consider departures from Local Thermodynamic Equilibrium) in single-slab and multi-slab configurations to interpret the observations and to investigate how a superposition of spicules along the line of sight (LOS) affects the synthetic Mg II line profiles. The used multi-slab models are either static, i.e. without any LOS velocities, or assume randomly assigned LOS velocities of individual slabs, representing the spicule dynamics. We conducted such single-slab and multi-slab modeling for a broad set of model input parameters and showed the dependence of the Mg II line profiles on these parameters. We demonstrated that the observed line widths of the h and k line profiles are strongly affected by the presence of multiple spicules along the LOS. We later showed that the profiles obtained at higher altitudes can be reproduced by single-slab models representing individual spicules. We found that the multi-slab model with a random distribution of the LOS velocities ranging from -25 to 25 km s^{-1} can well reproduce the width and the shape of Mg II profiles observed at middle altitudes. **2016 February 21,**

Possible Evidence for Shear-driven Kelvin–Helmholtz Instability along the Boundary of Fast and Slow Solar Wind in the Corona

Daniele **Telloni**1, Laxman Adhikari2, Gary P. Zank2,3, Lingling Zhao2, Luca Sorriso-Valvo4,5, Ester Antonucci1, Silvio Giordano1, and Salvatore Mancuso1

2022 ApJ 929 98

This paper reports the first possible evidence for the development of the Kelvin–Helmholtz (KH) instability at the border of coronal holes separating the associated fast wind from the slower wind originating from adjacent streamer regions. Based on a statistical data set of spectroscopic measurements of the UV corona acquired with the UltraViolet Coronagraph Spectrometer on board the SOlar and Heliospheric Observatory during the minimum activity of solar cycle 22, high temperature–velocity correlations are found along the fast/slow solar wind interface region and interpreted as manifestations of KH vortices formed by the roll-up of the shear flow, whose dissipation could lead to higher heating and, because of that, higher velocities. These observational results are supported by solving coupled solar wind and turbulence transport equations including a KH-driven source of turbulence along the tangential velocity discontinuity between faster and slower coronal flows: numerical analysis indicates that the correlation between the solar wind speed and temperature is large in the presence of the shear source of turbulence.

These findings suggest that the KH instability may play an important role both in the plasma dynamics and in the energy deposition at the boundaries of coronal holes and equatorial streamers.

On the Fast Solar Wind Heating and Acceleration Processes: A Statistical Study Based on the UVCS Survey Data

Daniele **Telloni**, Silvio Giordano, and Ester Antonucci
2019 ApJL 881 L36
sci-hub.se/10.3847/2041-8213/ab3731
The UltraViolet Coronagraph Spectrometer (UVCS) on board the SOlar and Heliospheric Observatory has almost continuously observed, throughout the whole solar cycle 23, the UV solar corona. This work addresses the first-ever statistical analysis of the daily UVCS observations, performed in the O vi channel, of the northern polar coronal hole, between 1.5 and 3 R ⊙, during the period of low solar activity from 1996 April to 1997 December. The study is based on the investigation, at different heights, of the correlation between the variance of the O vi 1031.92 Å spectral line and the O vi 1031.92, 1037.61 Å doublet intensity ratio, which are proxies of the kinetic temperature of the O5+ ions and of the speed of the oxygen component of the fast solar wind, respectively. This analysis allows the clear identification of the sonic point in polar coronal holes at the distance of 1.9 R ⊙. The results show that heat addition below the sonic point does not lead to an increase of the outflow speed. As a matter of fact, the coronal plasma is heated more efficiently in the subsonic region, while its acceleration occurs more effectively in the region of supersonic flow. So, within the panorama of the Parker Solar Probe and Solar Orbiter missions, the statistical analysis of the historical UVCS data appears to be very promising in providing unique clues to some still unsolved problems, as the coronal heating, in the solar corona.

Coronal hole evolution from multi-viewpoint data as input for a STEREO solar wind speed persistence model

M. **Temmer**, J. Hinterreiter, M.A. Reiss
Journal of Space Weather and Space Climate (SWSC) 2018, 8, A18 **2018**
https://arxiv.org/pdf/1801.10213.pdf
https://www.swsc-journal.org/articles/swsc/pdf/2018/01/swsc170088.pdf
We present a concept study of a solar wind forecasting method for Earth, based on persistence modeling from STEREO in-situ measurements combined with multi-viewpoint EUV observational data. By comparing the fractional areas of coronal holes (CHs) extracted from EUV data of STEREO and SoHO/SDO, we perform an uncertainty assessment derived from changes in the CHs and apply those changes to the predicted solar wind speed profile at 1AU. We evaluate the method for the time period 2008-2012, and compare the results to a persistence model based on ACE in-situ measurements and to the STEREO persistence model without implementing the information on CH evolution. Compared to an ACE based persistence model, the performance of the STEREO persistence model which takes into account the evolution of CHs, is able to increase the number of correctly predicted high-speed streams by about 12%, and to decrease the number of missed streams by about 23%, and the number of false alarms by about 19%. However, the added information on CH evolution is not able to deliver more accurate speed values for the forecast than using the STEREO persistence model without CH information which performs better than an ACE based persistence model. Investigating the CH evolution between STEREO and Earth view for varying separation angles over ~25-140{\deg} East of Earth, we derive some relation between expanding CHs and increasing solar wind speed, but a less clear relation for decaying CHs and decreasing solar wind speed. This fact most likely prevents the method from making more precise forecasts. The obtained results support a future L5 mission and show the importance and valuable contribution using multi-viewpoint data.

Periodic Appearance of Coronal Holes and the Related Variation of SolarWind Parameters

Manuela **Temmer** · Bojan Vršnak · Astrid M. Veronig
Solar Phys (**2007**) 241: 371–383; **File**
http://www.springerlink.com/content/4764048141351573/fulltext.pdf
Abstract We compared the variability of coronal hole (CH) areas (determined from daily GOES/SXI images) with solar wind (daily ACE data) and geomagnetic parameters for the time span 25 January 2005 until 11 September 2005 (late declining phase of solar cycle 23). Applying wavelet spectral analysis, a clear 9-day period is found in the CH time series. The GOES/SXI image sequence suggests that this periodic variation is caused by a mutual triangular distribution of CHs ~120° apart in longitude. From solar wind parameters a 9-day periodicity was obtained as well, simultaneously with the 9-day period in the CH area time series. These findings provide strong evidence that the 9-day period in solar wind parameters, showing up as higher harmonic of the solar rotation frequency, is caused by the “periodic” longitudinal distribution of CHs on the Sun recurring for several solar rotations. The shape of the wavelet spectrum from the *Dst* index matches only weakly with that from the CH areas and is more similar to the wavelet spectrum of the solar wind magnetic

field magnitude. The distinct 9-day period does not show up in sunspot group areas which gives further evidence that the solar wind modulation is strongly related to CH areas but not to active region complexes. The wavelet power spectra for the whole ACE data range (~1998 – 2006) suggest that the 9-day period is not a singular phenomenon occurring only during a specific time range close to solar minimum but is occasionally also present during the maximum and decay phase of solar cycle 23. The main periods correspond to the solar rotation (27_d) as well as to the second (13.5_d) and third (9_d) harmonic.

Construction of coronal hole and active region magnetohydrostatic solutions in two dimensions: Force and energy balance

Terradas J., Soler R., Oliver R., Antolin P., Arregui I., Luna M., Piantschitsch I., Soubrié E., Ballester J. L

A&A 660, A136 **2022**

https://arxiv.org/pdf/2202.06800.pdf

https://doi.org/10.1051/0004-6361/202142975

https://www.aanda.org/articles/aa/pdf/2022/04/aa42975-21.pdf

Coronal holes and active regions are typical magnetic structures found in the solar atmosphere. We propose several magnetohydrostatic equilibrium solutions that are representative of these structures in two dimensions. Our models include the effect of a finite plasma-β and gravity, but the distinctive feature is that we incorporate a thermal structure with properties similar to those reported by observations. We developed a semi-analytical method to compute the equilibrium configuration. Using this method, we obtain cold and under-dense plasma structures in open magnetic fields representing coronal holes, while in closed magnetic configurations, we achieve the characteristic hot and over-dense plasma arrangements of active regions. Although coronal holes and active regions seem to be antagonistic structures, we find that they can be described using a common thermal structure that depends on the flux function. In addition to the force balance, the energy balance is included in the constructed models using an a posteriori approach. From the two-dimensional computation of thermal conduction and radiative losses in our models, we infer the required heating function to achieve energy equilibrium. We find that the temperature dependence on height is an important parameter that may prevent the system from accomplishing thermal balance at certain spatial locations. The implications of these results are discussed in detail.

First direct measurements of transverse waves in solar polar plumes using SDO/AIA

Jonathan **Thurgood**, Richard Morton, James McLaughlin

UKSP Nugget #57, Apr **2015**

http://www.uksolphys.org/?p=9993

Solar plumes are bright, elongated rays rooted in coronal holes, regions of the Sun which are the known sources of the fast solar wind (FSW). Modelling indicates that magnetohydrodynamic (MHD) waves propagating along plumes could play a key role in providing the energy flux needed to accelerate the FSW [2-3]. However, plumes sustain many different modes of oscillation [4], and models of the solar wind are sensitive to which modes are present, because each has distinct transient, energetic and dissipative properties [5].

AIA observations of kink waves in coronal holes suggest they can't accelerate the fast solar wind.

2010 August 6

Observations of Subarcsecond Bright Dots in the Transition Region above Sunspots with the Interface Region Imaging Spectrograph

H. **Tian**, L. Kleint, H. Peter, M. Weber, P. Testa, E. DeLuca, L. Golub, N. Schanche

ApJL, 790 L29, **2014**

http://arxiv.org/pdf/1407.1060v1.pdf

Observations with the Interface Region Imaging Spectrograph (IRIS) have revealed numerous sub-arcsecond bright dots in the transition region above sunspots. These bright dots are seen in the 1400\AA{} and 1330\AA{} slit-jaw images. They are clearly present in all sunspots we investigated, mostly in the penumbrae, but also occasionally in some umbrae and light bridges. The bright dots in the penumbrae typically appear slightly elongated, with the two dimensions being 300--600 km and 250--450 km, respectively. The long sides of these dots are often nearly parallel to the bright filamentary structures in the penumbrae but sometimes clearly deviate from the radial direction. Their lifetimes are mostly less than one minute, although some dots last for a few minutes or even longer. Their intensities are often a few times stronger than the intensities of the surrounding environment in the slit-jaw images. About half of the bright dots show apparent movement with speeds of ∼10--40~km~s−1 in the radial direction. Spectra of a few bright dots were obtained and the Si~{\sc{iv}}~1402.77\AA{} line profiles in these dots are significantly broadened. The line intensity can be enhanced by one to two orders of magnitude. Some relatively bright and long-lasting dots are also observed in several passbands of the Atmospheric Imaging Assembly onboard the Solar

Dynamics Observatory, and they appear to be located at the bases of loop-like structures. Many of these bright dots are likely associated with small-scale energy release events at the transition region footpoints of magnetic loops.
2014 January 9.

OBSERVATION OF HIGH-SPEED OUTFLOW ON PLUME-LIKE STRUCTURES OF THE QUIET SUN AND CORONAL HOLES WITH SOLAR DYNAMICS OSERVATORY/ATMOSPHERIC IMAGING ASSEMBLY

Hui **Tian**1, Scott W. McIntosh1, Shadia Rifal Habbal2 and Jiansen He

2011 ApJ 736 130

Observations from the Atmospheric Imaging Assembly onboard the Solar Dynamics Observatory reveal ubiquitous episodic outflows (jets) with an average speed around 120 km s–1 at temperatures often exceeding a million degree in plume-like structures, rooted in magnetized regions of the quiet solar atmosphere. These outflows are not restricted to the well-known plumes visible in polar coronal holes, but are also present in plume-like structures originating from equatorial coronal holes and quiet-Sun (QS) regions. Outflows are also visible in the "inter-plume" regions throughout the atmosphere. Furthermore, the structures traced out by these flows in both plume and inter-plume regions continually exhibit transverse (Alfvénic) motion. Our finding suggests that high-speed outflows originate mainly from the magnetic network of the QS and coronal holes (CHs), and that the plume flows observed are highlighted by the denser plasma contained therein. These outflows might be an efficient means to provide heated mass into the corona and serve as an important source of mass supply to the solar wind. We demonstrate that the QS plume flows can sometimes significantly contaminate the spectroscopic observations of the adjacent CHs—greatly affecting the Doppler shifts observed, thus potentially impacting significant investigations of such regions

Sizes of transition-region structures in coronal holes and in the quiet Sun

H. **Tian**[1, 2], E. Marsch[1], C.-Y. Tu[1, 2], L.-D. Xia[3], and J.-S. He[2]

A&A 482, 267-272 (**2008**)

http://www.aanda.org/index.php?option=article&access=doi&doi=10.1051/0004-6361:20079235

MAGNETIC TOPOLOGY OF CORONAL HOLE LINKAGES

V. S. **Titov**1, Z. Mikić1, J. A. Linker1, R. Lionello1 and S. K. Antiochos

2011 ApJ 731 111

In recent work, Antiochos and coworkers argued that the boundary between the open and closed field regions on the Sun can be extremely complex with narrow corridors of open flux connecting seemingly disconnected coronal holes from the main polar holes and that these corridors may be the sources of the slow solar wind. We examine, in detail, the topology of such magnetic configurations using an analytical source surface model that allows for analysis of the field with arbitrary resolution. Our analysis reveals three new important results. First, a coronal hole boundary can join stably to the separatrix boundary of a parasitic polarity region. Second, a single parasitic polarity region can produce multiple null points in the corona and, more important, separator lines connecting these points. It is known that such topologies are extremely favorable for magnetic reconnection, because they allow this process to occur over the entire length of the separators rather than being confined to a small region around the nulls. Finally, the coronal holes are not connected by an open-field corridor of finite width, but instead are linked by a singular line that coincides with the separatrix footprint of the parasitic polarity. We investigate how the topological features described above evolve in response to the motion of the parasitic polarity region. The implications of our results for the sources of the slow solar wind and for coronal and heliospheric observations are discussed.

SolO/EUI Observations of Ubiquitous Fine-scale Bright Dots in an Emerging Flux Region: Comparison with a Bifrost MHD Simulation

Sanjiv K. **Tiwari**, Viggo H. Hansteen, Bart De Pontieu, Navdeep K. Panesar, David Berghmans

ApJ **929** 103 **2022**

https://arxiv.org/pdf/2203.06161.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/ac5d46/pdf

We report on the presence of numerous tiny bright dots in and around an emerging flux region (an X-ray/coronal bright point) observed with SolO's EUI/\hri\ in 174 Å. These dots are roundish, have a diameter of 675±300 km, a lifetime of 50±35 seconds, and an intensity enhancement of 30\% ±10\% above their immediate surroundings. About half of the dots remain isolated during their evolution and move randomly and slowly (<10 \kms). The other half show extensions, appearing as a small loop or surge/jet, with intensity propagations below 30\,\kms. Many of the bigger and brighter \hri\ dots are discernible in SDO/AIA 171 Å channel, have significant emissivity in the temperature range of 1--2 MK, and are often located at polarity inversion lines observed in HMI LOS magnetograms. Although not as pervasive as in observations, Bifrost MHD simulation of an emerging flux region do show dots in synthetic \fe\ images. These dots in simulation show distinct Doppler signatures -- blueshifts and redshifts coexist, or a redshift of the order of 10 \kms\ is followed by a blueshift of similar or higher magnitude. The synthetic images of \oxy\ and \siiv\ lines, which represent transition region radiation, also show the dots that are observed in \fe\ images, often expanded in size, or extended as a loop, and always with stronger Doppler velocities (up to 100 \kms) than that in \fe\ lines. Our observation and simulation results, together with the field geometry of dots in the simulation, suggest that most dots in emerging flux regions form in the lower solar atmosphere (at ≈1 Mm) by magnetic reconnection between emerging and pre-existing/emerged magnetic field. Some dots might be manifestations of magneto-acoustic shocks through the line formation region of \fe\ emission. **May 20, 2020**

Coronal Holes in Solar Cycles 21 to 23

A. **Tlatov**, K. Tavastsherna, V. Vasil'eva

Solar Physics, April **2014**, Volume 289, Issue 4, pp 1349-1358

We present identifications of coronal holes (CHs) from observations in the He i 10 830 Å line made at Kitt Peak Observatory (from 1975 to 2003) and in the EUV 195 Å wavelength with SOHO/EIT (from 1996 to 2012). To determine whether a feature is a CH we have developed semi-automatic techniques for delineating CH borders on synoptic charts and for subsequent mapping of these borders on magnetic-field charts. Using these techniques, we superimposed CH borders on magnetic-field charts over the time interval from 1975 to 2012. A major contribution to the total area was made by high-latitude CHs, but in the declining phase of solar cycle 23, the contribution from low-latitude CHs increased substantially. Variations in the flux of Galactic cosmic rays and those in the inclination angle of the heliospheric current sheet followed the cyclic variations of CH areas. High-latitude CHs affect the properties of the solar wind in the ecliptic plane.

Relation Between Coronal Hole Areas and Solar Wind Speeds Derived from Interplanetary Scintillation Measurements

Munetoshi **Tokumaru**, Daiki Satonaka, Ken'ichi Fujiki, Keiji Hayashi, Kazuyuki Hakamada

Solar Physics March **2017**, 292:41

http://link.springer.com/article/10.1007/s11207-017-1066-7

We investigate the relation between coronal hole (CH) areas and solar wind speeds during 1995 – 2011 using the potential field (PF) model analysis of magnetograph observations and interplanetary scintillation (IPS) observations by the Institute for Space-Earth Environmental Research (formerly Solar-Terrestrial Environment Laboratory) of Nagoya University. We obtained a significant positive correlation between the CH areas (AA) derived from the PF model calculations and solar wind speeds (VV) derived from the IPS observations. The correlation coefficients between them are usually high, but they drop significantly in solar maxima. The slopes of the AA – VV relation are roughly constant except for the period around solar maximum, when flatter or steeper slopes are observed. The excursion of the correlation coefficients and slopes at solar maxima is ascribed partly to the effect of rapid structural changes in the coronal magnetic field and solar wind, and partly to the predominance of small CHs. It is also demonstrated that VV is inversely related to the flux expansion factor (ff) and that ff is closely related to A−1/2A−1/2; hence, V∝A1/2V∝A1/2. A better correlation coefficient is obtained from the A1/2A1/2 – VV relation, and this fact is useful for improving space weather predictions. We compare the CH areas derived from the PF model calculations with He i 1083 nm observations and show that the PF model calculations provide reliable estimates of the CH area, particularly for large AA.

Various Local Heating Events in the Earliest Phase of Flux Emergence

Shin **Toriumi**, Yukio Katsukawa, Mark C.M. Cheung

ApJ 836 63 **2017**

https://arxiv.org/pdf/1701.01446v1.pdf

Emerging flux regions (EFRs) are known to exhibit various sporadic local heating events in the lower atmosphere. To investigate the characteristics of these events, especially to link the photospheric magnetic fields and atmospheric dynamics, we analyze Hinode, IRIS, and SDO data of a new EFR in NOAA AR 12401. Out of 151 bright points (BPs) identified in Hinode/SOT Ca images, 29 are overlapped by an SOT/SP scan. Seven BPs in the EFR center possess mixed-polarity magnetic backgrounds in the photosphere. Their IRIS UV spectra (e.g., Si IV 1402.8 A) are strongly enhanced and red- or blue-shifted with tails reaching +/- 150 km/s, which is highly suggestive of bi-directional jets, and each brightening lasts for 10 - 15 minutes leaving flare-like light curves. Most of this group show bald patches, the U-shaped photospheric magnetic loops. Another 10 BPs are found in unipolar regions at the EFR edges. They are generally weaker in UV intensities and exhibit systematic redshifts with Doppler speeds up to 40 km/s, which could exceed the local sound speed in the transition region. Both types of BPs show signs of strong temperature increase in the low chromosphere. These observational results support the physical picture that heating events in the EFR center are due to magnetic reconnection within cancelling undular fields like Ellerman bombs, while the peripheral heating events are due to shocks or strong compressions caused by fast downflows along the overlying arch filament system. **2015 August 19**

Coronal heating and solar wind formation in quiet Sun and coronal holes: a unified scenario

Durgesh **Tripathi**, V. N. Nived, Sami K Solanki

ApJ **908** 28 **2021**

https://arxiv.org/pdf/2011.09803.pdf

https://doi.org/10.3847/1538-4357/abcc6b

Coronal holes (CHs) are darker than quiet Sun (QS) when observed in coronal channels. This study aims to understand the similarities and differences between CHs and QS in the transition region using the \ion{Si}{4}~1394~Å line recorded by the Interface Region Imaging Spectrograph (IRIS) by considering the distribution of magnetic field measured by the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO). We find that \ion{Si}{4} intensities obtained in CHs are lower than those obtained in QS for regions with identical magnetic flux densities. Moreover, the difference in intensities between CHs and QS increases with increasing magnetic flux. For the regions with equal magnetic flux density, QS line profiles are more redshifted than those measured in CHs. Moreover, the blue shifts measured in CHs show an increase with increasing magnetic flux density unlike in the QS. The non-thermal velocities in QS, as well as in CHs, show an increase with increasing magnetic flux. However, no significant difference was observed in QS and CHs, albeit a small deviation at small flux densities. Using these results, we propose a unified model for the heating of the corona in the QS and in CHs and the formation of the solar wind. **2014/07/24, 2014/07/26, 2015/10/14**

The Magnetic Landscape of the Sun's Polar Region

S. **Tsuneta**, K. Ichimoto, Y. Katsukawa, B. W. Lites, K. Matsuzaki, S., Nagata, D. Orozco Suarez, T. Shimizu, M. Shimojo, R. A. Shine, Y. Suematsu, T. K. Suzuki, T. D. Tarbell, and A. M. Title

The Astrophysical Journal, Vol. 688, No. 2: 1374-1381.

http://www.journals.uchicago.edu/doi/abs/10.1086/592226

We present observations of the magnetic landscape of the polar region of the Sun that are unprecedented in terms of spatial resolution, field of view, and polarimetric precision. They were carried out with the Solar Optical Telescope aboard Hinode. Using a Milne-Eddington inversion, we find many vertically oriented magnetic flux tubes with field strengths as strong as 1 kG scattered in latitude between 70_ and 90_. They all have the same polarity, consistent with the global polarity of the polar region. The field vectors are observed to diverge from the centers of the flux elements, consistent with a view of magnetic fields that are expanding and fanning out with height. The polar region is also found to have ubiquitous horizontal fields. The polar regions are the source of the fast solar wind, which is channeled along unipolar coronal magnetic fields whose photospheric source is evidently rooted in the strong-field, vertical patches of flux.We conjecture that vertical flux tubes with large expansion around the photospheric-coronal boundary serve as efficient chimneys for Alfve´n waves that accelerate the solar wind.

Oscillations in the lower solar atmosphere at the base of coronal holes<<<

I. P. **Turova**

Astronomy Letters, February **2014**, Volume 40, Issue 2-3, pp 145-160

The oscillatory processes in the relatively quiet solar atmosphere, at the base of an extensive coronal hole, have been investigated. The properties of the oscillations in a number of parameters related mainly to the Ca II line intensity have been analyzed in areas belonging to various chromospheric network structures (cells, networks, flocculi, etc.). The goal of this study was to reveal peculiarities of the oscillatory process in the spatial areas located (in projection) at the center of a coronal hole, near its boundary, and at a bright coronal point at various heights of the solar atmosphere (from the photosphere to the middle chromosphere). In most structural elements, the low- and high-frequency components of the spectrum have been found to increase and decrease, respectively, with height. The oscillatory power of the low-frequency oscillations is at a maximum in the areas bordering the bright magnetic network elements. The power of the three-minute, five-minute, and low-frequency oscillations decreases at the centers of the bright chromospheric network. The phase relations point to the propagation of waves mainly at the boundaries of the bright chromospheric network and intermediate (in brightness) network elements. In two of the three investigated regions, the power of the five-minute oscillations (2.4–4.0 mHz) in cells is higher than that of the three-minute ones (5.2–6.8 mHz) at the investigated levels of the quiet solar atmosphere

On the formation of solar wind & switchbacks, and quiet Sun heating

Vishal **Upendran** (1), Durgesh Tripathi (1)

ApJ **2021**

https://arxiv.org/pdf/2111.11668.pdf

The solar coronal heating in quiet Sun (QS) and coronal holes (CH), including solar wind formation, are intimately tied by magnetic field dynamics. Thus, a detailed comparative study of these regions is needed to understand the underlying physical processes. CHs are known to have subdued intensity and larger blueshifts in the corona. This work investigates the similarities and differences between CHs and QS in the chromosphere using the Mg II h & k, C II lines, and transition region using Si IV line, for regions with identical absolute magnetic flux density (|B|). We find CHs to have subdued intensity in all the ines, with the difference increasing with line formation height and |B|. The chromospheric lines show excess upflows and downflows in CH, while Si IV shows excess upflows (downflows) in CHs (QS), where the flows increase with |B|. We further demonstrate that the upflows (downflows) in Si IV are correlated with both upflows and downflows (only downflows) in the chromospheric lines. CHs (QS) show larger Si IV upflows (downflows) for similar flows in the chromosphere, suggesting a common origin to these flows. These observations may be explained due to impulsive heating via interchange (closed-loop) reconnection in CHs (QS), resulting in bidirectional flows at different heights, due to differences in magnetic field topologies. Finally, the kinked field lines from interchange reconnection may be carried away as magnetic field rotations and observed as switchbacks. Thus, our results suggest a unified picture of solar wind emergence, coronal heating, and near-Sun switchback formation.

Properties of the C II 1334 Å line in Coronal Hole and Quiet Sun as observed by IRIS

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ApJ **922** 112 **2021**

https://arxiv.org/pdf/2109.04287

https://doi.org/10.3847/1538-4357/ac2575

Coronal Holes (CHs) have subdued intensity and net blueshifts when compared to Quiet Sun (QS) at coronal temperatures. At transition region temperatures, such differences are obtained for regions with identical photospheric absolute magnetic flux density (|B|). In this work, we use spectroscopic measurements of the \car 1334~Å line from Interface Region Imaging Spectrograph (IRIS), formed at chromospheric temperatures, to investigate the intensity, Doppler shift, line width, skew, and excess kurtosis variations with |B|. We find the intensity, Doppler shift, and line widths to increase with |B| for CHs and QS. The CHs show deficit in intensity and excess total widths over QS for regions with identical |B|. For pixels with only upflows, CHs show excess upflows over QS, while for pixels with only downflows, CHs show excess downflows over QS that cease to exist at |B| ≤ 40. Finally, the spectral profiles are found to be more skewed and flatter than a Gaussian, with no difference between CH and QS. These results are important in understanding the heating of the atmosphere in CH and QS, including solar wind formation, and provide further constraints on the modeling of the solar atmosphere.

Self-Similar Outflows at the Source of the Fast Solar Wind: A Smoking Gun of Multiscale Impulsive Reconnection?

Vadim M. **Uritsky**, Judith T. Karpen, Nour E. Raouafi, Pankaj Kumar, C. Richard DeVore, Craig E. Deforest

ApJL **955** L38 **2023**

https://arxiv.org/pdf/2309.06407.pdf

https://iopscience.iop.org/article/10.3847/2041-8213/acf85c/pdf

We present results of a quantitative analysis of structured plasma outflows above a polar coronal hole observed by the Atmospheric Imaging Assembly onboard the Solar Dynamics Observatory spacecraft. In a 6-hour interval of continuous high-cadence SDO/AIA images, we identified more than 2300 episodes of small-scale plasma flows in the polar corona. The mean upward flow speed measured by the surfing transform technique (Uritsky et al., 2013) is estimated to be 122 ± 34 \kms, which is comparable to the local sound speed. The typical recurrence period of the flow episodes is 10 to 30 minutes, and the mean duration and transverse size of each episode are about 3-5 min and 3-4 Mm, respectively. The largest identifiable episodes last for tens of minutes and reach widths up to 40 Mm. For the first time, we demonstrate that the polar coronal-hole outflows obey a family of power-law probability distributions characteristic of impulsive interchange magnetic reconnection. Turbulent photospheric driving may play a crucial role in releasing magnetically confined plasma onto open field. The estimated occurrence rate of the detected self-similar coronal outflows is sufficient for them to make a dominant contribution to the fast-wind mass and energy fluxes and to account for the wind's small-scale structure. **2021-04-28**

Reconnection-Driven Magnetohydrodynamic Turbulence in a Simulated Coronal-Hole Jet

Vadim M. **Uritsky**, Merrill A. Roberts, C. Richard DeVore, Judith T. Karpen

2017 ApJ 837 123

http://arxiv.org/pdf/1607.03843v1.pdf

Extreme-ultraviolet and X-ray jets occur frequently in magnetically open coronal holes on the Sun, especially at high solar latitudes. Some of these jets are observed by white-light coronagraphs as they propagate through the outer corona toward the inner heliosphere, and it has been proposed that they give rise to microstreams and torsional Alfv\'{e}n waves detected in situ in the solar wind. To predict and understand the signatures of coronal-hole jets, we have performed a detailed statistical analysis of such a jet simulated with an adaptively refined magnetohydrodynamics model. The results confirm the generation and persistence of three-dimensional, reconnectiondriven magnetic turbulence in the simulation. We calculate the spatial correlations of magnetic fluctuations within the jet and find that they agree best with the M\"{u}ller - Biskamp scaling model including intermittent current sheets of various sizes coupled via hydrodynamic turbulent cascade. The anisotropy of the magnetic fluctuations and the spatial orientation of the current sheets are consistent with an ensemble of nonlinear Alfv\'{e}n waves. These properties also reflect the overall collimated jet structure imposed by the geometry of the reconnecting magnetic field. A comparison with Ulysses observations shows that turbulence in the jet wake is in quantitative agreement with that in the fast solar wind.

Temporal relations between magnetic bright points and the solar sunspot cycle

D. **Utz**, R. Muller, T. Van Doorsselaere

proceeding/paper of the 10-years anniversary Hinode conference **2017**

Publ. Astron. Soc. Japan Volume 69, Issue 6, 1 December **2017**, 98,

https://doi.org/10.1093/pasj/psx115

https://arxiv.org/pdf/1710.01678.pdf

The Sun shows a global magnetic field cycle traditionally best visible in the photosphere as a changing sunspot cycle featuring roughly an 11 year period. In addition we know that our host star also harbours small-scale magnetic fields often seen as strong concentrations of magnetic flux reaching kG field strengths. These features are situated in inter-granular lanes where they show up bright as so-called magnetic bright points (MBPs). In this short paper we wish to analyse a homogenous nearly 10 year long synoptic Hinode image data set recorded from November 2006 up to February 2016 in the G-band to inspect the relationship between the number of MBPs at the solar disc centre and the relative sunspot number.

Our findings suggest that indeed the number of MBPs at the solar disc centre is correlated to the relative sunspot number, but with the particular feature of showing two different temporal shifts between the decreasing phase of cycle 23 including the minimum and the increasing phase of cycle 24 including the maximum. While the former is shifted by about 22 months the later is only shifted by less than 12 months. Moreover, we introduce and discuss an analytical model to predict the number of MBPs at the solar disc centre purely depending on the evolution of the relative sunspot number as well as the temporal change of the relative sunspot number and two background parameters describing a possibly acting surface dynamo as well as the strength of the magnetic field diffusion. Finally, we are able to confirm the plausibility of the temporal shifts by a simplistic random walk model.

The main conclusion to be drawn from this work is that the injection of magnetic flux, coming from active regions as represented by sunspots, happens on faster time scales than the removal of small-scale magnetic flux elements later on.

The formation and disintegration of magnetic bright points observed by Sunrise/IMaX

D. **Utz**, J. C. del Toro Iniesta, L. R. Bellot Rubio, J. Jurčák, V. Martínez Pillet, S. K. Solanki, W. Schmidt

ApJ, 796(2) 79 **2014**

http://arxiv.org/pdf/1411.3240v1.pdf

The evolution of the physical parameters of magnetic bright points (MBPs) located in the quiet Sun (mainly in the interwork) during their lifetime is studied. First we concentrate on the detailed description of the magnetic field evolution of three MBPs. This reveals that individual features follow different, generally complex, and rather dynamic scenarios of evolution. Next we apply statistical methods on roughly 200 observed MBP evolutionary tracks. MBPs are found to be formed by the strengthening of an equipartition field patch, which initially exhibits a moderate downflow. During the evolution, strong downdrafts with an average velocity of 2.4 km/s set in. These flows, taken together with the concurrent strengthening of the field, suggest that we are witnessing the occurrence of convective collapses in these features, although only 30% of them reach kG field strengths. This fraction might turn out to be larger when the new 4 m class solar telescopes are operational as observations of MBPs with current state of the art instrumentation could still be suffering from resolution limitations. Finally, when the bright point disappears (although the magnetic field often continues to exist) the magnetic field strength has dropped to the equipartition level and is generally somewhat weaker than at the beginning of the MBP's evolution. Noteworthy is that in about 10% of the cases we observe in the vicinity of the downflows small-scale strong (exceeding 2 km/s) intergranular upflows related spatially and temporally to these downflows.

Variations of Magnetic Bright Point Properties with Longitude and Latitude as Observed by Hinode/SOT G-band Data

D. **Utz**, A. Hanslmeier, A. Veronig, O. Kühner, R. Muller, J. Jurčák, B. Lemmerer

Solar Physics, June **2013**, Volume 284, Issue 2, pp 363-378

Small-scale magnetic fields can be observed on the Sun in high-resolution G-band filtergrams as magnetic bright points (MBPs). We study Hinode/Solar Optical Telescope (SOT) longitude and latitude scans of the quiet solar surface taken in the G-band in order to characterise the centre-to-limb dependence of MBP properties (size and intensity). We find that the MBP's sizes increase and their intensities decrease from the solar centre towards the limb. The size distribution can be fitted using a log–normal function. The natural logarithm of the mean (μ parameter) of this function follows a second-order polynomial and the generalised standard deviation (σ parameter) follows a fourth-order polynomial or equally well (within statistical errors) a sine function. The brightness decrease of the features is smaller than one would expect from the normal solar centre-to-limb variation; that is to say, the ratio of a MBP's brightness to the mean intensity of the image increases towards the limb. The centre-to-limb variations of the intensities of the MBPs and the quiet-Sun field can be fitted by a second-order polynomial. The detailed physical process that results in an increase of a MBP's brightness and size from Sun centre to the limb is not yet understood and has to be studied in more detail in the future.

Dynamics of isolated magnetic bright points derived from Hinode/SOT G-band observations

D. **Utz**, A. Hanslmeier, R. Muller, A. Veronig, J. Rybák and H. Muthsam

A&A 511, A39 (**2010**)

http://www.aanda.org/10.1051/0004-6361/200913085

Context. Small-scale magnetic fields in the solar photosphere can be identified in high-resolution magnetograms or in the G-band as magnetic bright points (MBPs). Rapid motions of these fields can cause magneto-hydrodynamical waves and can also lead to nanoflares by magnetic field braiding and twisting. The MBP velocity distribution is a crucial parameter for estimating the amplitudes of those waves and the amount of energy they can contribute to coronal heating.

Aims. The velocity and lifetime distributions of MBPs are derived from solar G-band images of a quiet sun region acquired by the Hinode/SOT instrument with different temporal and spatial sampling rates.

Methods. We developed an automatic segmentation, identification and tracking algorithm to analyse G-Band image sequences to obtain the lifetime and velocity distributions of MBPs. The influence of temporal/spatial sampling rates on these distributions is studied and used to correct the obtained lifetimes and velocity distributions for these digitalisation effects.

Results. After the correction of algorithm effects, we obtained a mean MBP lifetime of (2.50 ± 0.05)min and mean MBP velocities, depending on smoothing processes, in the range of (1–2) $\mathrm{km\ s^{-1}}$. Corrected for temporal sampling effects, we obtained for the effective velocity distribution a Rayleigh function with a coefficient of $(1.62 \pm 0.05)\mathrm{km\ s^{-1}}$. The *x*- and *y*-components of the velocity distributions are Gaussians. The lifetime distribution can be fitted by an exponential function.

Heating and Acceleration of the Fast Solar Wind by Alfvén Wave Turbulence

A. A. **van Ballegooijen**, M. Asgari-Targhi

2016

http://arxiv.org/pdf/1602.06883v1.pdf

We present numerical simulations of reduced magnetohydrodynamic (RMHD) turbulence in a magnetic flux tube at the center of a polar coronal hole. The model for the background atmosphere is a solution of the momentum equation, and includes the effects of wave pressure on the solar wind outflow. Alfv\'{e}n waves are launched at the coronal base, and reflect at various heights due to variations in Alfv\'{e}n speed and outflow velocity. The turbulence is driven by nonlinear interactions between the counter-propagating Alfv\'{e}n waves. Results are presented for two models of the background atmosphere. In the first model the plasma density and Alfv\'{e}n speed vary smoothly with height, resulting in minimal wave reflections and low energy dissipation rates. We find that the dissipation rate is insufficient to maintain the temperature of the background atmosphere. The standard phenomenological formula for the dissipation rate significantly overestimates the rate derived from our RMHD simulations, and a revised formula is proposed. In the second model we introduce additional density variations along the flux tube with a correlation length of 0.04 R⊙ and with relative amplitude of 10%. These density variations simulate the effects of compressive MHD waves on the Alfv\'{e}n waves. We find that such variations significantly enhance the wave reflection and thereby the turbulent dissipation rates, producing enough heat to maintain the background atmosphere. We conclude that interactions between Alfv\'{e}n- and compressive waves may play an important role in the turbulent heating of the fast solar wind.

Magnetic topology of Active Regions and Coronal Holes: Implications for Coronal Outflows and the Solar Wind

L. **van Driel-Gesztelyi**, J. L. Culhane, D. Baker, P. D?moulin, C.H. Mandrini, M.L. DeRosa, A. P. Rouillard, A. Opitz, G. Stenborg, A. Vourlidas, D. H. Brooks

E-print, July, **2012**; Solar Phys., **2012**, Volume 281, Issue 1, pp 237-262, **File**

During **2-18 January 2008** a pair of low-latitude opposite-polarity coronal holes (CHs) were observed on the Sun with two active regions (ARs) and the heliospheric plasma sheet located between them. We use the Hinode/EUV Imaging Spectrometer (EIS) to locate AR-related outflows and measure their velocities. Solar-Terrestrial Relations Observatory (STEREO) imaging is also employed as are the Advanced Composition Explorer (ACE) in-situ observations, to assess the resulting impacts on the interplanetary solar wind (SW) properties. Magnetic field extrapolations of the two ARs confirm that AR plasma outflows observed with EIS are co-spatial with quasi-separatrix layer locations, including the separatrix of a null point. Global potential field source-surface modeling indicates that field lines in the vicinity of the null point extend up to the source surface, enabling a part of the EIS plasma upflows access to the SW. We find that similar upflow properties are also observed within closed-field regions that do not reach the source surface. We conclude that some of plasma upflows observed with EIS remain confined along closed coronal loops, but that a fraction of the plasma may be released in the slow SW. This suggests that ARs bordering coronal holes can contribute to the slow SW. Analyzing the in-situ data, we propose that the type of slow SW present depends on whether the AR is fully or partially enclosed by an overlying streamer.

Characterizing the Motion of Solar Magnetic Bright Points at High Resolution

Samuel J. **Van Kooten**, Steven R. Cranmer

ApJ **850** 64 **2017**

https://arxiv.org/pdf/1710.04738.pdf

Magnetic bright points in the solar photosphere, visible in both continuum and G-band images, indicate footpoints of kilogauss magnetic flux tubes extending to the corona. The power spectrum of bright-point motion is thus also the power spectrum of Alfven wave excitation, transporting energy up flux tubes into the corona. This spectrum is a key input in coronal and heliospheric models. We produce a power spectrum of bright-point motion using radiative magnetohydrodynamic simulations, exploiting spatial resolution higher than can be obtained in present-day observations, while using automated tracking to produce large data quantities. We find slightly higher amounts of power at all frequencies compared to observation-based spectra, while confirming the spectrum shape of recent observations. This also provides a prediction for observations of bright points with DKIST, which will achieve similar resolution and high sensitivity. We also find a granule size distribution in support of an observed two-population distribution, and we present results from tracking passive tracers which show a similar power spectrum to that of bright points. Finally, we introduce a simplified, laminar model of granulation, with which we explore the roles of turbulence and of the properties of the granulation pattern in determining bright-point motion.

CORONAL PLUMES IN THE FAST SOLAR WIND

Marco **Velli**1, Roberto Lionello2, Jon A. Linker2 and Zoran Mikić

2011 ApJ 736 32

The expansion of a coronal hole filled with a discrete number of higher density coronal plumes is simulated using a time-dependent two-dimensional code. A solar wind model including an exponential coronal heating function and a flux of Alfvén waves propagating both inside and outside the structures is taken as a basic state. Different plasma plume profiles are obtained by using different scale heights for the heating rates. Remote sensing and solar wind in situ observations are used to constrain the parameter range of the study. Time dependence due to plume ignition and disappearance is also discussed. Velocity differences of the order of ~50 km s–1, such as those found in microstreams in the high-speed solar wind, may be easily explained by slightly different heat deposition profiles in different plumes. Statistical pressure balance in the fast wind data may be masked by the large variety of body and surface waves which the higher density filaments may carry, so the absence of pressure balance in the microstreams should not rule out their interpretation as the extension of coronal plumes into interplanetary space. Mixing of plume-interplume material via the Kelvin-Helmholtz instability seems to be possible within the parameter ranges of the models defined here, only at large distances from the Sun, beyond 0.2-0.3 AU. Plasma and composition measurements in the inner heliosphere, such as those which will become available with Solar Orbiter and Solar Probe Plus, should therefore definitely be able to identify plume remnants in the solar wind.

Solar wind high-speed streams and related geomagnetic activity in the declining phase of solar cycle 23

G. **Verbanac**1, B. Vršnak2, S. Živkovıć1, T. Hojsak1, A. M. Veronig3 and M. Temmer

A&A 533, A49 (**2011**) **File**

Context. Coronal holes (CHs) are the source of high-speed streams (HSSs) in the solar wind, whose interaction with the slow solar wind creates corotating interaction regions (CIRs) in the heliosphere.

Aims. We investigate the magnetospheric activity caused by CIR/HSS structures, focusing on the declining phase of the solar cycle 23 (years 2005 and 2006), when the occurrence rate of coronal mass ejections (CMEs) was low. We aim to (i) perform a systematic analysis of the relationship between the CH characteristics, basic parameters of

HSS/CIRs, and the geomagnetic indices Dst, Ap and AE; (ii) study how the magnetospheric/ionospheric current systems behave when influenced by HSS/CIR; (iii) investigate if and how the evolution of the background solar wind from 2005 to 2006 affected the correlations between CH, CIR, and geomagnetic parameters.
Methods. The cross-correlation analysis was applied to the fractional CH area (CH) measured in the central meridian distance interval ± 10°, the solar wind velocity (V), the interplanetary magnetic field (B), and the geomagnetic indices Dst, Ap, and AE.
Results. The performed analysis shows that Ap and AE are better correlated with CH and solar wind parameters than Dst, and quantitatively demonstrates that the combination of solar wind parameters BV2 and BV plays the central role in the process of energy transfer from the solar wind to the magnetosphere.
Conclusions. We provide reliable relationships between CH properties, HSS/CIR parameters, and geomagnetic indices, which can be used in forecasting the geomagnetic activity in periods of low CME activity.

Equatorial coronal holes, solar wind high-speed streams, and their geoeffectiveness_

G. **Verbanac**1, B. Vršnak2, A. Veronig3, and M. Temmer3

A&A 526, A20 (**2011**), **File**

Context.Solar wind high-speed streams (HSSs), originating in equatorial coronal holes (CHs), are the main driver of the geomagnetic activity in the late-declining phase of the solar cycle.
Aims.We analyze correlations between CH characteristics, HSSs parameters, and the geomagnetic activity indices, to establish empirical relationships that would provide forecasting of the solar wind characteristics, as well as the effect of HSSs on the geomagnetic activity in periods when the effect of coronal mass ejections is low.
Methods.We apply the cross-correlation analysis to the fractional CH area (*CH*) measured between central meridian distances ±10◦, solar wind parameters (flow velocity *V*, proton density *n*, temperature *T*, and the magnetic field *B*), and the geomagnetic indices *Dst* and *Ap*.
Results. The cross-correlation analysis reveals a high degree of correlation between all studied parameters. In particular, we show that the *Ap* index is considerably more sensitive to HSS and CH characteristics than *Dst*. The *Ap* and *Dst* indices are most tightly correlated with the solar wind parameter *BV*2.
Conclusions.From the point of view of space weather, the most important result is that the established empirical relationships provide a few-days-in-advance forecasting of the HSS characteristics and the related geomagnetic activity at the six-hour resolution.

A TURBULENCE-DRIVEN MODEL FOR HEATING AND ACCELERATION OF THE FAST WIND IN CORONAL HOLES

A. Verdini[1], M. Velli[2,3], W. H. Matthaeus[4], S. Oughton[5] and P. Dmitruk[6]

ApJ **708** L116-L120, **2010**

A model is presented for generation of fast solar wind in coronal holes, relying on heating that is dominated by turbulent dissipation of MHD fluctuations transported upward in the solar atmosphere. Scale-separated transport equations include large-scale fields, transverse Alfvénic fluctuations, and a small compressive dissipation due to parallel shears near the transition region. The model accounts for proton temperature, density, wind speed, and fluctuation amplitude as observed in remote sensing and in situ satellite data.

One-Parameter Representation of the Daily Averaged Solar-Wind Velocity

I. S. **Veselovsky**, I. G. Persiantsev, A. Yu. Ryazanov, and Yu. S. Shugai

Solar System Research, **2006**, Vol. 40, No. 5, pp. 427–431.**File**
Original Russian Text: Astronomicheskii Vestnik, 2006, Vol. 40, No. 5, pp. 465–469.

An empirical formula was found to describe the dependence *V*(*S*)of the daily average solar-wind velocity *V* on the coronal-hole area *S* on the visible side of the Sun in the form of first- and second-order Taylor expansions. The results can be used for approximate evaluation of the solar-wind velocity at the Earth's orbit from coronal-hole observations.
We analyzed daily solar images obtained in 1997–2004 with the Extreme Ultraviolet Imaging Telescope (EIT) onboard the *Solar and Heliospheric Observatory* (*SOHO*) at a wavelength of 284 Å.

SOLAR METALLICITY DERIVED FROM IN SITU SOLAR WIND COMPOSITION

2016 ApJ 816 13

R. **von Steiger**1,2 and T. H. Zurbuchen

We use recently released solar wind compositional data to determine the metallicity of the Sun—the fraction per unit mass that is composed of elements heavier than He. We focus on a present-day solar sample available to us, which is the least fractionated solar wind from coronal holes near the poles of the Sun. Using these data, we derive a

metallicity of Z = 0.0196 ± 0.0014, which is significantly larger than recent published values based on photospheric spectroscopy, but consistent with results from helioseismology.

Polar coronal holes during the past solar cycle: Ulysses observations

von Steiger, Rudolf; Zurbuchen, Thomas H.

J. Geophys. Res., Vol. 116, No. A1, A01105, **2011**

During its nearly 19-year mission, Ulysses pioneered novel measurements of the three-dimensional heliosphere and particularly in situ observations of high-latitude solar wind from polar coronal holes (PCHs). Winds from PCHs exhibit constant elemental abundances to within the limits of the measurements, indicative of the fact that such winds truly provide a ground state of solar wind composition. However, these solar wind streams show long-term variability in the composition of ionic charge states frozen into the low corona. The C and O freeze-in temperatures measured in high-latitude solar wind have decreased ~10% as compared to the previous solar minimum and are now around 0.87 and 1.01 MK, respectively. The ionization states of Si and Fe also exhibit a substantial cooling with a reduction of 0.4 and 0.5 charge states, respectively. We show that these observations are indicative of an overall decrease of coronal temperature, forming a trend toward cooler PCH temperature persisting for over 14 years. We support these observations with a detailed and comprehensive description of the data analysis processes relevant for Ulysses SWICS and similar instruments.

Geomagnetic Effects of Corotating Interaction Regions

Bojan **Vršnak**, Mateja Dumbović, Jaša Čalogović, Giuliana Verbanac, Ivana Poljanĭć–Beljan

Solar Physics September **2017**, 292:140

We present an analysis of the geoeffectiveness of corotating interaction regions (CIRs), employing the data recorded from 25 January to 5 May 2005 and throughout 2008. These two intervals in the declining phase of Solar Cycle 23 are characterised by a particularly low number of interplanetary coronal mass ejections (ICMEs). We study in detail how four geomagnetic-activity parameters (the Dst, Ap, and AE indices, as well as the Dst time derivative, dDst/dtdDst/dt) are related to three CIR-related solar wind parameters (flow speed, VV, magnetic field, BB, and the convective electric field based on the southward Geocentric solar magnetospheric (GSM) magnetic field component, VBsVBs) on a three-hour time resolution. In addition, we quantify statistical relationships between the mentioned geomagnetic indices. It is found that Dst is correlated best to VV, with a correlation coefficient of cc≈0.6cc≈0.6, whereas there is no correlation between dDst/dtdDst/dt and VV. The Ap and AE indices attain peaks about half a day before the maximum of VV, with correlation coefficients ranging from cc≈0.6cc≈0.6 to cc≈0.7cc≈0.7, depending on the sample used. The best correlations of Ap and AE are found with VBsVBs with a delay of 3 h, being characterised by cc≳0.6cc≳0.6. The Dst derivative dDst/dtdDst/dt is also correlated with VBsVBs, but the correlation is significantly weaker cc≈0.4cc≈0.4 – 0.5, with a delay of 0 – 3 h, depending on the employed sample. Such low values of correlation coefficients indicate that there are other significant effects that influence the relationship between the considered parameters. The correlation of all studied geomagnetic parameters with BB are characterised by considerably lower correlation coefficients, ranging from cc=0.3cc=0.3 in the case of dDst/dtdDst/dt up to cc=0.56cc=0.56 in the case of Ap. It is also shown that peak values of geomagnetic indices depend on the duration of the CIR-related structures. The Dst is closely correlated with Ap and AE (cc=0.7cc=0.7), Dst being delayed for about 3 h. On the other hand, dDst/dtdDst/dtpeaks simultaneously with Ap and AE, with correlation coefficients of 0.48 and 0.56, respectively. The highest correlation (cc=0.81cc=0.81) is found for the relationship between Ap and AE.

Coronal Holes and SolarWind High-Speed Streams: I. Forecasting the SolarWind Parameters

Bojan **Vršnak** · Manuela Temmer · Astrid M. Veronig

Solar Phys (**2007**) 240: 315–330

http://www.springerlink.com/content/4134764l20612q44/fulltext.pdf

Abstract We analyze the relationship between the coronal hole (CH) area/position and physical characteristics of the associated corotating high-speed stream (HSS) in the solar wind at 1 AU. For the analysis we utilize the data in the period DOY 25 – 125 of 2005, characterized by a very low coronal mass ejection (CME) activity. Distinct correlations between the daily averaged CH parameters and the solar wind characteristics are found, which allows us to forecast the solar wind velocity v, proton temperature T, proton density n, and magnetic field strength B, several days in advance in periods of low CME activity. The forecast is based on monitoring fractional areas A, covered by CHs in the meridional slices embracing the central meridian distance ranges [−40°,−20°], [−10°, 10°], and [20°, 40°]. On average, the peaks in the daily values of n, B, T, and v appear delayed by 1, 2, 3, and 4 days, respectively, after the area A attains its maximum in the central-meridian slice. The peak values of the solar wind parameters are correlated to the peak values of A, which provides

also forecasting of the peak values of *n*, *B*, *T* , and *v*. The most accurate prediction can be obtained for the solar wind velocity, for which the average relative difference between the calculated and the observed peak values amounts to $|\delta| \approx$ 10%. The forecast reliability is somewhat lower in the case of *T* , *B*, and *n* ($|\delta| \approx$ 20, 30, and 40%, respectively). The space weather implications are discussed, including the perspectives for advancing the realtime calculation of the Sun – Earth transit times of coronal mass ejections and interplanetary shocks, by including more realistic real-time estimates of the solar wind characteristics.

Coronal Holes and SolarWind High-Speed Streams: II. Forecasting the Geomagnetic Effects

Bojan **Vršnak** · Manuela Temmer · Astrid M. Veronig
Solar Phys (**2007**) 240: 331–346
http://www.springerlink.com/content/b22516x128250075/fulltext.pdf

Abstract We present a simple method of forecasting the geomagnetic storms caused by high-speed streams (HSSs) in the solar wind. The method is based on the empirical correlation between the coronal hole area/position and the value of the *Dst* index, which is established in a period of low interplanetary coronal mass ejection (ICME) activity. On average, the highest geomagnetic activity, *i.e.*, the minimum in *Dst*, occurs four days after a low-latitude coronal hole (CH) crosses the central meridian. The amplitude of the *Dst* dip is correlated with the CH area and depends on the magnetic polarity of the CH due to the Russell –McPherron effect. The *Dst* variation may be predicted by employing the expression $Dst(t) = (-65 \pm 25$Ч$\cos\lambda)[A(t_*)]^{0.5}$, where $A(t_*)$ is the fractional CH area measured in the central-meridian slice [−10°, 10°] of the solar disc, λ is the ecliptic longitude of the Earth, ± stands for positive/negative CH polarity, and $t - t_* = 4$ days. In periods of low ICME activity, the proposed expression provides forecasting of the amplitude of the HSS-associated *Dst* dip to an accuracy of ≈30%. However, the time of occurrence of the *Dst* minimum cannot be predicted to better than ±2 days, and consequently, the overall mean relative difference between the observed and calculated daily values of *Dst* ranges around 50%.

Estimating Total Open Heliospheric Magnetic Flux

S. **Wallace**, C. N. Arge, M. Pattichis, R. A. Hock-Mysliwiec, C. J. Henney
Solar Physics February **2019**, 294:19
sci-hub.tw/10.1007/s11207-019-1402-1
https://arxiv.org/pdf/1903.12613.pdf

Over the solar-activity cycle, there are extended periods where significant discrepancies occur between the spacecraft-observed total (unsigned) open magnetic flux and that determined from coronal models. In this article, the total open heliospheric magnetic flux is computed using two different methods and then compared with results obtained from in-situinterplanetary magnetic-field observations. The first method uses two different types of photospheric magnetic-field maps as input to the Wang–Sheeley–Arge (WSA) model: i) traditional Carrington or diachronic maps, and ii) Air Force Data Assimilative Photospheric Flux Transport model synchronic maps. The second method uses observationally derived helium and extreme-ultraviolet coronal-hole maps overlaid on the same magnetic-field maps in order to compute total open magnetic flux. The diachronic and synchronic maps are both constructed using magnetograms from the same source, namely the National Solar Observatory Kitt Peak Vacuum Telescope and Vector Spectromagnetograph. The results of this work show that the total open flux obtained from observationally derived coronal holes agrees remarkably well with that derived from WSA, especially near solar minimum. This suggests that, on average, coronal models capture well the observed large-scale coronal-hole structure over most of the solar cycle. Both methods show considerable deviations from total open flux deduced from spacecraft data, especially near solar maximum, pointing to something other than poorly determined coronal-hole area specification as the source of these discrepancies.

Global Effect of New Active Regions on Coronal Holes and Their Wind Streams

Y.-M. **Wang**1, K. J. Knizhnik1, I. Ugarte-Urra1, and M. J. Weberg1
2024 ApJ 972 107
https://iopscience.iop.org/article/10.3847/1538-4357/ad5f87/pdf

Solar wind prediction algorithms and simulations of coronal events often employ photospheric field maps that are assembled over a 27 day solar rotation. This has stimulated efforts to update and better synchronize the maps by applying flux transport and including observations of the back side of the Sun. Here, using potential-field source-surface extrapolations, we address the question of how the emergence of a large active region (AR) on the Sun's farside affects the coronal field and configuration of coronal holes on the Earth-facing side. We find that, if the new AR is located ∼135°–180° in longitude from Earth, the effect on the coronal field and solar wind near the central meridian will be almost negligible. This is because, when sunspot activity is relatively low, the outermost AR loops will become connected to the nearby polar fields; when sunspot activity is high, the newly emerged flux will connect to neighboring ARs. However, large ARs that emerge near the solar limb may sometimes have a significant effect on the field near the central meridian. In particular, a coronal hole having opposite polarity to that of the nearest sector of the AR may partially close down, resulting in slower wind; conversely, if the coronal hole has the same polarity as the facing AR sector, it will tend to increase in areal size, resulting in faster wind. In most cases, the main effect of a new AR will be to redistribute open flux between itself and neighboring coronal holes (including the polar holes) through interchange reconnection. **2021 January 22-February 18 , 2012 April 28-May 25**

Coronal Holes, Footpoint Reconnection, and the Origin of the Slow (and Fast) Solar Wind.

Wang, YM.

Sol Phys 299, 54 (**2024**).

https://doi.org/10.1007/s11207-024-02300-3

https://link.springer.com/content/pdf/10.1007/s11207-024-02300-3.pdf

The tendency for low-speed solar wind to show greater spatiotemporal variability and different compositional properties from high-speed wind has led to the prevailing idea of a bimodal solar wind, in which fast wind comes from coronal holes and slow wind comes from coronal streamers. We present observational evidence that most of the slow wind originates from small coronal holes or from just inside the boundaries of large holes, with the rest leaking out from coronal streamers and confined to the immediate vicinity of the heliospheric current and plasma sheets. Although this conclusion was suggested earlier by extrapolations of photospheric field maps, additional support comes from (1) observations of slow wind at Earth following the central-meridian passage of small equatorial holes; (2) observations of slow wind with high Alfvénicity at 1 au by Wind, and more recently near the Sun by Parker Solar Probe and Solar Orbiter; and (3) the finding that 80% of the solar wind observed by Helios at 0.3 – 0.4 au during 1974 – 1978 was Alfvénic. We show that compositional properties such as charge-state ratios vary over the solar cycle and may depend on parameters such as the footpoint field strength B0, and thus cannot be used alone to distinguish between coronal hole and noncoronal-hole wind. Finally, we note that magnetograms greatly underestimate the amount of small-scale flux emerging inside coronal holes and other unipolar regions. If this rate is taken to be the same as in the quiet Sun, the energy flux density resulting from interchange reconnection with open field lines is on the order of 3×105 erg cm−2 s−1 (B0/10 G), sufficient to drive the solar wind. The wind speed depends on the rate of flux-tube expansion, with slower expansion leading to more energy deposition at greater heights and faster wind.

Cosmic Ray Variation Lags behind Sunspot Number due to the Late Opening of Solar Magnetic Field

Yuming **Wang**, Jingnan Guo, Gang Li, Elias Roussos, Junwei Zhao

ApJ **2022**

https://arxiv.org/pdf/2201.01908.pdf

Galactic cosmic rays (GCRs), the highly energetic particles that may raise critical health issues of astronauts in space, are modulated by solar activity with their intensity lagging behind the sunspot number (SSN) variation by about one year. Previously, this lag has been attributed to result of outward convecting solar wind and inward propagating GCRs. However, the lag's amplitude and its solar-cycle dependence are still not fully understood (e.g., Ross & Chaplin 2019). By investigating the solar surface magnetic field, we find that the source of heliospheric magnetic field, i.e., the open magnetic flux on the Sun, already lags behind SSN before it convects into heliosphere along with the solar wind, and the delay during odd cycles is longer than that during sequential even cycles. Thus, we propose that the GCR lag is primarily due to the greatly late opening of the solar magnetic field with respect to SSN, though solar wind convection and particle transport in the heliosphere also matters. We further investigate the origin of the open flux from different latitudes of the Sun and found that the total open flux is significantly contributed by that from low latitudes where coronal mass ejections frequently occur and also show an odd-even cyclic pattern. Our findings challenge existing theories, and may serve as the physical basis of long-term forecasts radiation dose estimates for manned deep-space exploration missions.

Figure 6. The solar cycle variations of the CME numbers

Small-scale Flux Emergence, Coronal Hole Heating, and Flux-tube Expansion: A Hybrid Solar Wind Model

Y.-M. **Wang**

2020 ApJ 904 199

https://doi.org/10.3847/1538-4357/abbda6

https://arxiv.org/ftp/arxiv/papers/2104/2104.04016.pdf

Extreme-ultraviolet images from the Solar Dynamics Observatory often show loop-like fine structure to be present where no minority-polarity flux is visible in magnetograms, suggesting that the rate of ephemeral region (ER) emergence inside "unipolar" regions has been underestimated. Assuming that this rate is the same inside coronal holes as in the quiet Sun, we show that interchange reconnection between ERs and open field lines gives rise to a solar wind energy flux that exceeds 105 erg cm−2 s−1 and that scales as the field strength at the coronal base, consistent with observations. In addition to providing ohmic heating in the low corona, these reconnection events may be a source of Alfvén waves with periods ranging from the granular timescale of ~10 minutes to the supergranular/plume timescale of many hours, with some of the longer-period waves being reflected and dissipated in the outer corona. The asymptotic wind speed depends on the radial distribution of the heating, which is largely controlled by the rate of flux-tube expansion. Along the rapidly diverging flux tubes associated with slow wind, heating is concentrated well inside the sonic point (1) because the outward conductive heat-flux density and thus the outer coronal temperatures are reduced, and (2) because the net wave energy flux is dissipated at a rate proportional to the local Alfvén speed. In this "hybrid" solar wind model, reconnection heats the lower corona and drives the mass flux, whereas waves impart energy and momentum to the outflow at greater distances. **29 Jun 2012, 12 Dec 2014**

Observations of Slow Solar Wind from Equatorial Coronal Holes

Y.-M. **Wang** and Y.-K. Ko

2019 ApJ 880 146

sci-hub.se/10.3847/1538-4357/ab2add

https://arxiv.org/ftp/arxiv/papers/2104/2104.06626.pdf

Because of its distinctive compositional properties and variability, low-speed ($\lesssim$450 km s−1) solar wind is widely believed to originate from coronal streamers, unlike high-speed wind, which comes from coronal holes. An alternative scenario is that the bulk of the slow wind (excluding that in the immediate vicinity of the heliospheric current sheet) originates from rapidly diverging flux tubes rooted inside small coronal holes or just within the boundaries of large holes. This viewpoint is based largely on photospheric field extrapolations, which are subject to considerable uncertainties and do not include dynamical effects, making it difficult to be certain whether a source is located just inside or outside a hole boundary, or whether a high-latitude hole will be connected to Earth. To minimize the dependence on field-line extrapolations, we have searched for cases where equatorial coronal holes at central meridian are followed by low-speed streams at Earth. We describe 14 examples from the period 2014–2017, involving Fe xiv 21.1 nm coronal holes located near active regions and having equatorial widths of ~3°–10°. The associated in situ wind was characterized by speeds v ~ 300–450 km s−1 and by O7+/O6+ ratios of ~0.05–0.15, with v showing the usual correlation with proton temperature. In addition, consistent with other recent studies, this slow wind had remarkably high Alfvénicity, similar to that in high-speed streams. We conclude that small coronal holes are a major contributor to the slow solar wind during the maximum and early post-maximum phases of the solar cycle. **2014 Feb 11-Mar 11, 2014 Feb 26-28, 2014 Mar 11_Apr 7, 2014 May 4-31, 2014 June 28-July 25, 2014 Aug 21-Sep 17, 2015 May 21-June 17, 2015 July 14_Aug 11, 2016 Feb 18-Apr 16, 2016 June 6-July 3, 2017 Sep 12 –Oct 10**

Small Coronal Holes Near Active Regions as Sources of Slow Solar Wind

Y.-M. **Wang**

2017 ApJ 841 94

http://sci-hub.cc/10.3847/1538-4357/aa706e **File**

We discuss the nature of the small areas of rapidly diverging, open magnetic flux that form in the strong unipolar fields at the peripheries of active regions (ARs), according to coronal extrapolations of photospheric field measurements. Because such regions usually have dark counterparts in extreme-ultraviolet (EUV) images, we refer to them as coronal holes, even when they appear as narrow lanes or contain sunspots. Revisiting previously identified "AR sources" of slow solar wind from 1998 and 1999, we find that they are all associated with EUV coronal holes; the absence of well-defined He i 1083.0 nm counterparts to some of these holes is attributed to the large flux of photoionizing radiation from neighboring AR loops. Examining a number of AR-associated EUV holes during the 2014 activity maximum, we confirm that they are characterized by wind speeds of ~300–450 km s−1, O7+/O6+ ratios of ~0.05–0.4, and footpoint field strengths typically of order 30 G. The close spacing between ARs at sunspot maximum limits the widths of unipolar regions and their embedded holes, while the continual emergence of new flux leads to rapid changes in the hole boundaries. Because of the highly nonradial nature of AR fields, the smaller EUV holes are often masked by the overlying canopy of loops, and may be more visible toward one solar limb than at central meridian. As sunspot activity declines, the AR remnants merge to form much larger, weaker, and longer-lived unipolar regions, which harbor the "classical" coronal holes that produce recurrent high-speed streams.

CONVERGING SUPERGRANULAR FLOWS AND THE FORMATION OF CORONAL PLUMES

Y.-M. **Wang**1, H. P. Warren1, and K. Muglach

2016 ApJ 818 203

Earlier studies have suggested that coronal plumes are energized by magnetic reconnection between unipolar flux concentrations and nearby bipoles, even though magnetograms sometimes show very little minority-polarity flux

near the footpoints of plumes. Here we use high-resolution extreme-ultraviolet (EUV) images and magnetograms from the Solar Dynamics Observatory (SDO) to clarify the relationship between plume emission and the underlying photospheric field. We find that plumes form where unipolar network elements inside coronal holes converge to form dense clumps, and fade as the clumps disperse again. The converging flows also carry internetwork fields of both polarities. Although the minority-polarity flux is sometimes barely visible in the magnetograms, the corresponding EUV images almost invariably show loop-like features in the core of the plumes, with the fine structure changing on timescales of minutes or less. We conclude that the SDO observations are consistent with a model in which plume emission originates from interchange reconnection in converging flows, with the plume lifetime being determined by the ~1 day evolutionary timescale of the supergranular network. Furthermore, the presence of large EUV bright points and/or ephemeral regions is not a necessary precondition for the formation of plumes, which can be energized even by the weak, mixed-polarity internetwork fields swept up by converging flows.

Coronal Mass Ejections and the Solar Cycle Variation of the Sun's Open Flux

Y.-M. **Wang** and N. R. Sheeley, Jr.

2015 ApJ 809 L24

The strength of the radial component of the interplanetary magnetic field (IMF), which is a measure of the Sun's total open flux, is observed to vary by roughly a factor of two over the 11 year solar cycle. Several recent studies have proposed that the Sun's open flux consists of a constant or "floor" component that dominates at sunspot minimum, and a time-varying component due to coronal mass ejections (CMEs). Here, we point out that CMEs cannot account for the large peaks in the IMF strength which occurred in 2003 and late 2014, and which coincided with peaks in the Sun's equatorial dipole moment. We also show that near-Earth interplanetary CMEs, as identified in the catalog of Richardson and Cane, contribute at most ~30% of the average radial IMF strength even during sunspot maximum. We conclude that the long-term variation of the radial IMF strength is determined mainly by the Sun's total dipole moment, with the quadrupole moment and CMEs providing an additional boost near sunspot maximum. Most of the open flux is rooted in coronal holes, whose solar cycle evolution in turn reflects that of the Sun's lowest-order multipoles.

Semiempirical Models of the Slow and Fast Solar Wind

Y.-M. **Wang**

Space Science Reviews, November **2012**, Volume 172, Issue 1-4, pp 123-143

Coronal holes can produce several types of solar wind with a variety of compositional properties, depending on the location and strength of the heating along their open magnetic field lines. High-speed wind is associated with (relatively) slowly diverging flux tubes rooted in the interiors of large holes with weak, uniform footpoint fields; heating is spread over a large radial distance, so that most of the energy is conducted outward and goes into accelerating the wind rather than increasing the mass flux. In the rapidly diverging open fields present at coronal hole boundaries and around active regions, the heating is concentrated at low heights and the temperature maximum is located near the coronal base, resulting in high oxygen freezing-in temperatures and low asymptotic wind speeds. Polar plumes have a strong additional source of heating at their bases, which generates a large downward conductive flux, raising the densities and enhancing the radiative losses. The relative constancy of the solar wind mass flux at Earth reflects the tendency for the heating rate in coronal holes to increase monotonically with the footpoint field strength, with very high mass fluxes at the Sun offsetting the enormous flux-tube expansion in active region holes. Although coronal holes are its main source, slow wind is also released continually from helmet streamer loops by reconnection processes, giving rise to plasma blobs (small flux ropes) and the heliospheric plasma sheet.

ON THE NATURE OF THE SOLAR WIND FROM CORONAL PSEUDOSTREAMERS

Y.-M. **Wang**1, R. Grappin2,3, E. Robbrecht4 and N. R. Sheeley, Jr.

2012 ApJ 749 182

Coronal pseudostreamers, which separate like-polarity coronal holes, do not have current sheet extensions, unlike the familiar helmet streamers that separate opposite-polarity holes. Both types of streamers taper into narrow plasma sheets that are maintained by continual interchange reconnection with the adjacent open magnetic field lines. White-light observations show that pseudostreamers do not emit plasma blobs; this important difference from helmet streamers is due to the convergence of like-polarity field lines above the X-point, which prevents the underlying loops from expanding outward and pinching off. The main component of the pseudostreamer wind has the form of steady outflow along the open field lines rooted just inside the boundaries of the adjacent coronal holes. These flux tubes are characterized by very rapid expansion below the X-point, followed by reconvergence at greater heights. Analysis of an idealized pseudostreamer configuration shows that, as the separation between the underlying holes increases, the X-point rises and the expansion factor f ss at the source surface increases. In situ observations of pseudostreamer crossings indicate wind speeds v ranging from ~350 to ~550 km s–1, with O7 +/O6 + ratios that are enhanced compared with those in high-speed streams but substantially lower than in the slow solar wind. Hydrodynamic energy-balance models show that the empirical v-f ss relation overestimates the wind speeds from

nonmonotonically expanding flux tubes, particularly when the X-point is located at low heights and f ss is small. We conclude that pseudostreamers produce a "hybrid" type of outflow that is intermediate between classical slow and fast solar wind.

FORMATION AND EVOLUTION OF CORONAL HOLES FOLLOWING THE EMERGENCE OF ACTIVE REGIONS

Y.-M. **Wang**, E. Robbrecht1, A. P. Rouillard1, N. R. Sheeley, Jr., and A. F. R. Thernisien2

Astrophysical Journal, 715:39–50, **2010** May

The low level of solar activity over the past four years has provided unusually favorable conditions for tracking the formation and evolution of individual coronal holes and their wind streams. Employing extreme-ultraviolet images recorded with the *Solar Terrestrial Relations Observatory* during 2007–2009, we analyze three cases in which small coronal holes first appear at the edges of newly emerged active regions and then expand via flux transport processes, eventually becoming attached to the polar holes. The holes form gradually over timescales comparable to or greater than that for the active regions to emerge, without any obvious association with coronal mass ejections. The evolving hole areas coincide approximately with the footpoints of open field lines derived from potential-field source-surface extrapolations of the photospheric field. One of these coronal-hole systems, centered at the equator and maintained by a succession of old-cycle active regions emerging in the same longitude range, persists in one form or another for up to two years. The other two holes, located at midlatitudes and originating from new-cycle active regions, become strongly sheared and decay away after a few rotations. The hole boundaries and the small active-region holes, both of which are sources of slow wind, are observed to undergo continual short-term (_1 day) fluctuations on spatial scales comparable to that of the supergranulation. From in situ measurements, we identify a number of plasma sheets associated with pseudostreamers separating holes of the same polarity.

Coronal waves, shocks, and associated radio signatures **Review**

Alexander **Warmuth**∗

CESRA **2016** p.37

http://cesra2016.sciencesconf.org/conference/cesra2016/pages/CESRA2016_prog_abs_book_v3.pdf

For over half a century there has been indirect evidence for large-scale waves and shocks propagating through the solar corona. High-cadence space-based observations, available for nearly decade now, have indeed revealed globally propagating wave-like perturbations in the solar corona. These observations have revealed a wealth of information about these phenomena, but have also sparked major controversies about their physical nature and their cause. I will review how the different observational characteristics have both constrained existing models and have led to the development of new models. In the discussion, I will emphasize two issues: the currently growing consensus on the physical nature of coronal waves, and the question of how type II radio bursts fit into the picture.

Areas of Polar Coronal Holes from 1996 Through 2010

S. A. Hess **Webber**, N. Karna, W. D. Pesnell, M. S. Kirk

Solar Phys., Volume 289, Issue 11, pp 4047-4067, **2014**

Polar coronal holes (PCHs) trace the magnetic variability of the Sun throughout the solar cycle. Their size and evolution have been studied as proxies for the global magnetic field. We present measurements of the PCH areas from 1996 through 2010, derived from an updated perimeter-tracing method and two synoptic-map methods. The perimeter-tracing method detects PCH boundaries along the solar limb, using full-disk images from the SOlar and Heliospheric Observatory/Extreme ultraviolet Imaging Telescope (SOHO/EIT). One synoptic-map method uses the line-of-sight magnetic field from the SOHO/Michelson Doppler Imager (MDI) to determine the unipolarity boundaries near the poles. The other method applies thresholding techniques to synoptic maps created from EUV image data from EIT. The results from all three methods suggest that the solar maxima and minima of the two hemispheres are out of phase. The maximum PCH area, averaged over the methods in each hemisphere, is approximately 6 % during both solar minima spanned by the data (between Solar Cycles 22/23 and 23/24). The northern PCH area began a declining trend in 2010, suggesting a downturn toward the maximum of Solar Cycle 24 in that hemisphere, while the southern hole remained large throughout 2010.

Using Transverse Waves to Probe the Plasma Conditions at the Base of the Solar Wind

Micah J. **Weberg**1,2, Richard J. Morton1, and James A. McLaughlin1

2020 ApJ 894 79

https://doi.org/10.3847/1538-4357/ab7c59

It has long been suggested that magnetohydrodynamic (MHD) waves may supply a significant proportion of the energy required to heat the corona and accelerate the solar wind. Depending on the properties of the local plasma, MHD wave modes may exhibit themselves as a variety of incompressible, transverse waves. The local magnetic field and particle density influence the properties of these waves (e.g., amplitude), thus direct measurements of transverse waves provide a mechanism to indirectly probe the local plasma conditions. We present the first statistical approach to magnetoseismology of a localized region of the solar corona, analyzing transverse waves above the south polar coronal hole on 2011 May 23. Automated methods are utilized to examine 4 hr of EUV imaging data to study how the waves evolve as a function of height (i.e., altitude) through the low corona. Between heights of 15 and 35 Mm, we find that the measured wave periods are approximately constant, and that observed displacement and velocity amplitudes increase at rates that are consistent with undamped waves. This enables us to derive a relative density profile for the coronal hole environment in question, without the use of spectroscopic data. Furthermore, our results indicate that between 5 and 15 Mm above the limb, the relative density is larger than that expected from 1D hydrostatic models, and signals a more extended transition region with a gradual change in density. This has implications for self-consistent models of wave propagation from the photosphere to the corona and beyond.

EUV Emission and Scattered Light Diagnostics of Equatorial Coronal Holes as Seen by Hinode/EIS

Carolyn **Wendeln**, Enrico Landi

ApJ **856** 28 **2018**

https://arxiv.org/pdf/1712.03042.pdf

Spectroscopic diagnostics of solar coronal plasmas critically depends on the uncertainty in the measured line intensities. One of the main sources of uncertainty is instrumental scattered light, which is potentially most important in low-brightness areas. In the solar corona, such areas include polar and equatorial coronal holes, which are the source regions of the solar wind; instrument-scattered light must thus pose a significant obstacle to studies of the source regions of the solar wind. In this paper we investigate the importance of instrument-scattered light on observations of equatorial coronal holes made by the Hinode/EIS spectrometer in two different phases of the solar cycle. We find that the instrument-scattered light is significant at all temperatures, and in both regions it amounts to approximately 10% of the average intensity of the neighboring quiet Sun regions. Such contribution dominates the measured intensity for spectral lines formed at temperatures larger than Log T = 6.15 K, and has deep implications for spectroscopic diagnostics of equatorial coronal hole plasmas and studies of the source regions of a large portion of the solar wind which reaches Earth. Our results suggest that the high temperature tail of in the coronal hole plasma distribution with temperature, however small, is an artifact due to the presence of scattered light.

2007 March 31, 2013 October 12

SUMER Observations of Coronal-Hole Temperatures

Klaus **Wilhelm**

Space Science Reviews, November **2012**, Volume 172, Issue 1-4, pp 57-68

Observations of emission lines in the vacuum-ultraviolet spectral range with calibrated instrumentation provide crucial information on the prevailing plasma temperatures in the solar atmosphere. Coronal-hole temperatures measured by the SUMER spectrometer on SOHO will be presented in this contribution. Electron temperatures can be estimated from the formation temperatures of the observed emission lines. Line-ratio and emission-measure analyses, however, offer higher accuracies. Typical electron temperatures at altitudes of H<200 Mm in coronal holes are below 1 MK in bright structures—the coronal plumes—with higher values in darker areas—the inter-plume regions. Line-width measurements yield effective ion temperatures, which are much higher than the electron temperatures. Observations of line profiles emitted from species with different masses allow a separation of the effective temperatures into ion temperatures and unresolved non-thermal motions along the line of sight.

Morphology, dynamics and plasma parameters of plumes and inter-plume regions in solar coronal holes

K. **Wilhelm**, L. Abbo, F. Auchère, N. Barbey, L. Feng, A. H. Gabriel, S. Giordano, S. Imada, A. Llebaria, W. H. Matthaeus, G. Poletto, N.-E. Raouafi, S. T. Suess, L. Teriaca & Y.-M. Wang

Astronomy and Astrophysics Review, Volume 19, Number 1, 35, **2011**

Coronal plumes, which extend from solar coronal holes (CH) into the high corona and—possibly—into the solar wind (SW), can now continuously be studied with modern telescopes and spectrometers on spacecraft, in addition to investigations from the ground, in particular, during total eclipses. Despite the large amount of data available on these prominent features and related phenomena, many questions remained unanswered as to their generation and relative contributions to the high-speed streams emanating from CHs. An understanding of the processes of plume formation and evolution requires a better knowledge of the physical conditions at the base of CHs, in plumes and in the surrounding inter-plume regions. More specifically, information is needed on the magnetic field configuration, the electron densities and temperatures, effective ion temperatures, non-thermal motions, plume cross sections relative to the size of a CH, the plasma bulk speeds, as well as any plume signatures in the SW. In spring 2007, the authors proposed a study on ‘Structure and dynamics of coronal plumes and inter-plume regions in solar coronal holes’ to the International Space Science Institute (ISSI) in Bern to clarify some of these aspects by considering relevant observations and the extensive literature. This **review** summarizes the results and conclusions of the study. Stereoscopic observations allowed us to include three-dimensional reconstructions of plumes. Multi-instrument investigations carried out during several campaigns led to progress in some areas, such as plasma densities, temperatures, plume structure and the relation to other solar phenomena, but not all questions could be answered concerning the details of plume generation process(es) and interaction with the SW.

Time-Dependent Turbulent Heating of Open Flux Tubes in the Chromosphere, Corona, and Solar Wind

Lauren N. **Woolsey**, Steven R. Cranmer

ApJ **2015**

http://arxiv.org/pdf/1509.00377v1.pdf

We investigate several key questions of plasma heating in open-field regions of the corona that connect to the solar wind. We present results for a model of Alfven-wave-driven turbulence for three typical open magnetic field structures: a polar coronal hole, an open flux tube neighboring an equatorial streamer, and an open flux tube near a strong-field active region. We compare time-steady, one-dimensional turbulent heating models (Cranmer et al., 2007) against fully time-dependent three-dimensional reduced-magnetohydrodynamics modeling of BRAID (van Ballegooijen et al., 2011). We find that the time-steady results agree well with time-averaged results from BRAID. The time-dependence allows us to investigate the variability of the magnetic fluctuations and of the heating in the corona. The high-frequency tail of the power spectrum of fluctuations forms a power law whose exponent varies with height, and we discuss the possible physical explanation for this behavior. The variability in the heating rate is bursty and nanoflare-like in nature, and we analyze the amount of energy lost via dissipative heating in transient events throughout the simulation. The average energy in these events is 10^21.91 erg, within the "picoflare" range, and many events reach classical "nanoflare" energies. We also estimated the multithermal distribution of temperatures that would result from the heating-rate variability, and found good agreement with observed widths of coronal differential emission measure (DEM) distributions. The results of the modeling presented in this paper provide compelling evidence that turbulent heating in the solar atmosphere by Alfven waves accelerates the solar wind in open flux tubes.

A Model for Coronal Hole Bright Points and Jets due to Moving Magnetic Elements

Peter F. **Wyper**, C. Richard DeVore, Judy T. Karpen, Spiro K. Antiochos, Anthony R. Yeates

ApJ **864** 165 **2018**

https://arxiv.org/pdf/1808.03688.pdf

http://sci-hub.tw/http://iopscience.iop.org/article/10.3847/1538-4357/aad9f7/meta

Coronal jets and bright points occur prolifically in predominantly unipolar magnetic regions, such as coronal holes, where they appear above minority-polarity intrusions. Intermittent low-level reconnection and explosive, high-energy-release reconnection above these intrusions are thought to generate bright points and jets, respectively. The magnetic field above the intrusions possesses a spine-fan topology with a coronal null point. The movement of magnetic flux by surface convection adds free energy to this field, forming current sheets and inducing reconnection. We conducted three-dimensional magnetohydrodynamic simulations of moving magnetic elements as a model for coronal jets and bright points. A single minority-polarity concentration was subjected to three different experiments: a large-scale surface flow that sheared part of the separatrix surface only, a large-scale surface flow that also sheared part of the polarity inversion line surrounding the minority flux, and the latter flow setup plus a "fly-by" of a majority-polarity concentration past the moving minority-polarity element. We found that different bright-point morphologies, from simple loops to sigmoids, were created. When only the field near the separatrix was sheared, steady interchange reconnection modulated by quasi-periodic, low-intensity bursts of reconnection occurred, suggestive of a bright point with periodically varying intensity. When the field near the PIL was strongly sheared, on the other hand, filament channels repeatedly formed and erupted via the breakout mechanism, explosively increasing the interchange reconnection and generating non-helical jets. The fly-by produced even more energetic and explosive jets. Our results explain several key aspects of coronal-hole bright points and jets, and the relationships between them.

Solar Atmosphere Observed by Hinode/SOT in the G band and in Ca ii H Bright Points

Jianping **Xiong**1, Yunfei Yang1,2,4, Chunlan Jin2, Kaifan Ji3, Song Feng1,2, Feng Wang1,3, Hui Deng1, andYu Hu1

2017 ApJ 851 42

Photospheric bright points (PBPs) and chromospheric bright points (CBPs) reflect the cross sections of magnetic flux tubes at different heights of the lower solar atmosphere. We aim to study the fine 3D structures and transportation dynamics of the magnetic flux tubes using G-band and simultaneous Ca ii H image-series from the Solar Optical Telescope (SOT) on board Hinode. A 3D track-while-detect method is proposed to detect and track PBPs and CBPs. The mean values of equivalent diameters, maximum intensity contrasts, transverse velocities, motion ranges, motion types, and diffusion indices of PBPs and CBPs are 180 ± 20 and 210 ± 30 km, $1.0 \pm 0.1 \langle I_{QS\_G} \rangle$ and $1.2 \pm 0.1 \langle I_{QS\_Ca} \rangle$, 1.6 ± 0.8 and 2.7 ± 1.4 km s−1, 1.5 ± 0.6 and 1.7 ± 0.8, 0.8 ± 0.2 and 0.6 ± 0.2, and 1.7 ± 0.7 and 1.3 ± 0.7, respectively. Moreover, the ratios of each CBP characteristics to its corresponding PBP are derived to explore the change rates of the flux tubes. The corresponding ratios are 1.2 ± 0.2, 1.2 ± 0.1, 1.9 ± 0.1, 1.4 ± 0.3, 0.7 ± 0.2, and 0.9 ± 0.4, respectively. The statistical results imply that the majority magnetic flux tubes expand slightly with increasing solar height, look brighter than their surroundings, show a higher transverse velocity, a wider motion range, and a more erratic path, but the majority of the flux tubes diffuse slightly slower. The phenomenon might be explained by the conservation of momentum combined with a decrease in density. The more erratic path leads to a swing or twist of the flux tubes and therefore guides magnetohydrodynamic

Research on Multiwavelength Isolated Bright Points Based on Deep Learning

Li **Xu**1, Yunfei Yang5,1,2, Yihua Yan2,3, Yin Zhang2, Xianyong Bai2, Bo Liang1, Wei Dai1, Song Feng1, and Wenda Cao4

2021 ApJ 911 32

https://doi.org/10.3847/1538-4357/abe705

Multiwavelength bright points (BPs) are taken to be cross sections of magnetic flux tubes extending from the surface of the photosphere upward to the higher photosphere. We aim to study the characteristics of isolated multiwavelength BPs using the cotemporal and cospatial TiO band and Hα line wings from the Goode Solar Telescope at Big Bear Solar Observatory. A deep-learning method, based on Track Region-based Convolutional Neural Networks, is proposed to detect, segment, and match the BPs across multiple wavelength observations, including the TiO, Hα + 1 Å, Hα − 1 Å, Hα + 0.8 Å, and Hα − 0.8 Å line wings. Based on the efficient detection and matching result with a precision of 0.98, 1283 groups of BPs matched in all five wavelengths are selected for statistics analysis. The characteristic values of the BPs observed at the same red and blue line wings are averaged. For the BPs of the TiO, averaged Hα ± 1 Å, and averaged Hα ± 0.8 Å line wings, the mean equivalent diameters are 162 ± 32, 254 ± 33, and 284 ± 28 km, respectively. The maximum intensity contrasts are 1.11 ± 0.09, 1.05 ± 0.03, and 1.05 ± 0.02$\langle I_{QS} \rangle$, respectively. The mean eccentricities are 0.65 ± 0.14, 0.63 ± 0.11, and 0.65 ± 0.11, respectively. Moreover, the characteristic ratios of each Hα ± 1 Å and Hα ± 0.8 Å BP to its corresponding TiO BP are derived. Hα ± 1 Å and Hα ± 0.8 Å line wings BPs show 60% and 80% increases compared to TiO BPs, respectively. With increasing height, most BPs almost keep their shapes. This work is helpful for modeling the three-dimensional structure of flux tubes.

A Complete Catalogue of High-Speed Solar Wind Streams during Solar Cycle 23

G. **Xystouris**, E. Sigala, H. Mavromichalaki

Solar Physics, March **2014**, Volume 289, Issue 3, pp 995-1012

High-speed solar wind streams (HSSWSs) are ejected from the Sun and travel into the interplanetary space. Because of their high speed, they carry out energetic particles such as protons and heavy ions, which leads to an increase in the mean interplanetary magnetic field (IMF). Since the Earth is in the path of those streams, Earth's magnetosphere interacts with the disturbed magnetic field, leading to a significant radiation-induced degradation of technological systems. These interactions provide an enhanced energy transfer from the solar wind/IMF system into the Earth's magnetosphere and initiate geomagnetic disturbances that may have a possible impact on human health. Solar cycle 23 was a particularly unusual cycle with many energetic phenomena during its descending phase and also had an extended minimum. We have identified and catalogued the HSSWSs of this cycle and determined their characteristics, such as their maximum velocity, beginning and ending time, duration, and possible sources. We identified 710 HSSWSs and compared them with the corresponding characteristics of the streams of previous solar cycles. For first time, we used the CME data to study the stream sources, which led to useful results for the monitoring and forecasting of space weather effects.

(See **HIGH - SPEED STREAMS CATALOGUE (1996 – 2008)**
O. Maris and G. Maris
http://www.spacescience.ro/new1/HSS_Catalogue.html)

Similarity measurement tracking and properties evolution of photospheric bright point groups in the quiet Sun and active region

Peng **Yang**, Haicheng Bai, Limin Zhao, Xiaoying Gong, Libo Zhong, Yang Yang, Changhui Rao

Monthly Notices of the Royal Astronomical Society, Volume 525, Issue 4, **2023**, Pages 4887–4903,

https://doi.org/10.1093/mnras/stad2468

Photospheric bright points (BPs) fast movement is more effective than the slow movement that occurs most of the time in transmitting energy to the corona. The splitting and merging BPs tend to produce relatively large velocities. Therefore, our aim is to detect and track BP groups. After that, the attribute distribution of BP groups and the attribute evolution under possible high-speed movement are studied and analysed. We use a new BPs detection model (HBD-model) that can effectively detect weak BPs and layered BPs and then use similarity measures to judge the splitting and merging of BPs for tracking. The average accuracy of the BPs detection algorithm is 0.74, and the average accuracy of tracking is more than 85 per cent. For the BPs in the quiet Sun (QS) and active region (AR), a total of 62 388 evolutionary BPs were identified and tracked. The average velocities are more than 2 km s^{-1} in the QS and ARs. For the QS and ARs, the evolution process of splitting or merging BPs is basically the same. The results show that for the merged BPs, the area and velocity of the BPs are tiny in the initial stage, reach a peak in the middle stage, and then become smaller and disappear. The area, intensity contrast, and velocity of the BPs with splitting are relatively tiny at the beginning, become larger at the middle stage, reach the peak after splitting, and then become smaller and disappear rapidly.

On the relationship between G-band bright point dynamics and their magnetic field strengths

Yunfei **Yang**, Qiang Li, Kaifan Ji, Song Feng, Hui Deng, Feng Wang, Jiaben Lin
Solar Phys. Volume 291, Issue 4, pp 1089-1105 **2016**
http://arxiv.org/pdf/1604.00152v1.pdf

G-band bright points (GBPs) are regarded as good manifestations of magnetic flux concentrations. We aim to investigate the relationship between the dynamic properties of GBPs and their longitudinal magnetic field strengths. High spatial and temporal resolution observations were recorded simultaneously with G-band filtergrams and Narrow-band Filter Imager (NFI) Stokes I and V images with Hinode /Solar Optical Telescope. The GBPs are identified and tracked in the G-band images automatically, and the corresponding longitudinal magnetic field strength of each GBP is extracted from the calibrated NFI magnetograms by a point-to-point method. After categorizing the GBPs into five groups by their longitudinal magnetic field strengths, we analyze the dynamics of GBPs of each group. The results suggest that with increasing longitudinal magnetic field strengths of GBPs correspond to a decrease in their horizontal velocities and motion ranges as well as by showing more complicated motion paths. This suggests that magnetic elements showing weaker magnetic field strengths prefer to move faster and farther along straighter paths, while stronger ones move more slowly in more erratic paths within a smaller region. The dynamic behaviors of GBPs with different longitudinal magnetic field strengths can be explained by that the stronger flux concentrations withstand the convective flows much better than weaker ones.

Dispersal of G-band bright points at different longitudinal magnetic field strengths

Yunfei **Yang**1,2,3, Kaifai Ji1, Song Feng1,2,3, Hui Deng1, Feng Wang1,4, and Jiaben Lin
2015 ApJ 810 88
http://arxiv.org/pdf/1509.01426v1.pdf

G-band bright points (GBPs) are thought to be the foot-points of magnetic flux tubes. The aim of this paper is to investigate the relation between the diffusion regimes of GBPs and the associated longitudinal magnetic field strengths. Two high resolution observations of different magnetized environments were acquired with the Hinode/Solar Optical Telescope. Each observation was recorded simultaneously with G-band filtergrams and Narrow-band Filter Imager (NFI) Stokes I and V images. GBPs are identified and tracked automatically, and then categorized into several groups by their longitudinal magnetic field strengths, which are extracted from the calibrated NFI magnetograms using a point-by-point method. The Lagrangian approach and the distribution of diffusion indices approach are adopted separately to explore the diffusion regime of GBPs for each group. It is found that the values of diffusion index and diffusion coefficient both decrease exponentially with the increasing longitudinal magnetic field strengths whichever approach is used. The empirical formulas deduced from the fitting equations are proposed to describe these relations. Stronger elements tend to diffuse more slowly than weak elements, independently of the magnetic flux of the surrounding medium. This may be because the magnetic energy of stronger elements is not negligible compared with the kinetic energy of the gas, and therefore the flows cannot perturb them so easily. **2007 July 1.**

Characterising motion types of G-band bright points in the quiet Sun

Yun-Fei **Yang**, Hui-Xue Qu, Kai-Fan Ji, Song Feng, Hui Deng, Jia-Ben Lin, Feng Wang
Research in Astron. Astrophys., **2014**
http://arxiv.org/pdf/1407.7958v1.pdf

We study the motions of G band bright points (GBPs) in the quiet Sun to obtain the characteristics of different motion types. A high resolution image sequence taken with the Hinode/Solar Optical Telescope (SOT) is used, and GBPs are automatically tracked by segmenting 3D evolutional structures in a space time cube. After putting the

GBPs that do not move during their lifetimes aside, the non stationary GBPs are categorized into three types based on an index of motion type. Most GBPs that move in straight or nearly straight lines are categorized into a straight motion type, a few moving in rotary paths into a rotary motion, and the others fall into a motion type we called erratic. The mean horizontal velocity is 2.18 km/s, 1.63 km/s and 1.33 km/s for straight, erratic and rotary motion type, respectively. We find that a GBP drifts at a higher and constant velocity during its whole life if it moves in a straight line. However, it has a lower and variational velocity if it moves in a rotary path. The diffusive process is ballistic, super and sub diffusion for straight, erratic and rotary motion type, respectively. The corresponding diffusion index and coefficients are 2.13 and 850 km2/s, 1.82 and 331 km2/s, 0.73 and 13 km2/s. In terms of direction of motion, it is homogeneous and isotropical, and usually persists between neighbouring frames, no matter what motion type a GBP belongs to. **2007 February 19**

SELF-CANCELLATION OF EPHEMERAL REGIONS IN THE QUIET SUN

Shuhong **Yang**1, Jun Zhang1, Ting Li1, and Yang Liu

2012 ApJ 752 L24

With the observations from the Helioseismic and Magnetic Imager aboard the Solar Dynamics Observatory, we statistically investigate the ephemeral regions (ERs) in the quiet Sun. We find that there are two types of ERs: normal ERs (NERs) and self-canceled ERs (SERs). Each NER emerges and grows with separation of its opposite polarity patches which will cancel or coalesce with other surrounding magnetic flux. Each SER also emerges and grows and its dipolar patches separate at first, but a part of the magnetic flux of the SER will move together and cancel gradually, which is described with the term "self-cancellation" by us. We identify 2988 ERs, among which there are 190 SERs, about 6.4% of the ERs. The mean value of self-cancellation fraction of SERs is 62.5%, and the total self-canceled flux of SERs is 9.8% of the total ER flux. Our results also reveal that the higher the ER magnetic flux is, (1) the easier the performance of ER self-cancellation is, (2) the smaller the self-cancellation fraction is, and (3) the more the self-canceled flux is. We think that the self-cancellation of SERs is caused by the submergence of magnetic loops connecting the dipolar patches, without magnetic energy release.

SDO OBSERVATIONS OF MAGNETIC RECONNECTION AT CORONAL HOLE BOUNDARIES

Shuhong **Yang**1,2, Jun Zhang1, Ting Li1,2 and Yang Liu

2011 ApJ 732 L7

With the observations from the Atmospheric Imaging Assembly and the Helioseismic and Magnetic Imager on board the Solar Dynamics Observatory, we investigate the coronal hole boundaries (CHBs) of an equatorial extension of the polar coronal hole. At the CHBs, many extreme-ultraviolet jets, which appear to be the signatures of magnetic reconnection, are observed in the 193 Å images, and some jets occur repetitively at the same sites. The evolution of the jets is associated with the emergence and cancellation of magnetic fields. We note that both the east and west CHBs shift westward, and the shift velocities are close to the velocities of rigid rotation compared with those of the photospheric differential rotation. This indicates that magnetic reconnection at CHBs results in the evolution of CHBs and maintains the rigid rotation of coronal holes

VECTOR MAGNETIC FIELDS AND CURRENT HELICITIES IN CORONAL HOLES AND QUIET REGIONS

Shuhong **Yang**1, Jun Zhang1, Ting Li1, and Mingde Ding2,3

Astrophysical Journal, 726:49 (9pp), **2011**

In the solar photosphere, many properties of coronal holes (CHs) are not known, especially vector magnetic fields. Using observations from *Hinode*, we investigate vector magnetic fields, current densities, and current helicities in two CHs, and compare them with two normal quiet regions (QRs) for the first time. We find that the areas where large current helicities are located are mainly co-spatial with strong vertical and horizontal field elements both in shape and in location. In the CHs, horizontal magnetic fields, inclination angles, current densities, and current helicities are larger than those in the QRs. The mean vertical current density and current helicity in the CHs and QRs, averaged over all the observed areas including the CHs and QRs, are approximately 0.008 A m^{-2} and 0.005 G^2 m^{-1}, respectively. The mean current density in magnetic flux concentrations where the vertical fields are stronger than 100 G is as large as 0.012 ± 0.001 A m^{-2}, consistent with that in the flare productive active regions. Our results imply that the magnetic fields, especially the strong fields, both in the CHs and in the QRs are nonpotential.

The formation of an equatorial coronal hole

Liheng **Yang**[1], Yunchun Jiang[1] and Jun Zhang[2]

Solar and Stellar Variability: Impact on Earth and Planets, Proceedings IAU Symposium No. 264, **2009**, p. 295-297, A.G. Kosovichev, A.H. Andrei & J.-P. Rozelot, eds.

Y:\obridko\otchet09

The formation of an equatorial coronal hole (CH) from **2006 January 9 to 12** was simultaneously observed by GOES-12/SXI, SOHO/EIT and SOHO/MDI instruments. The varieties of soft X-ray and EUV brightness, coronal temperature, and total magnetic flux in the CH were examined and compared with that of a quiet-sun (QS) region nearby. The following results are obtained. (1) A preexisting dark lane appeared on the location of the followed CH and was reinforced by three enhanced networks. (2) The CH gradually formed in about 81 hours and was predominated by positive magnetic flux. (3) During the formation, the soft X-ray and EUV brightness, coronal temperature, and total magnetic flux obviously decreased in the CH, but were almost no change in the QS region. The decrease of the total magnetic flux may be the result of magnetic reconnection between the open and closed magnetic lines, probably indicating the physical mechanism for the birth of the CH.

Dipolar Evolution in a Coronal Hole Region

Shuhong **Yang**, Jun Zhang, and Juan Manuel Borrero

E-print, Aug **2009**; ApJ, 703:1012–1020, 2009 September 20

Using observations from the SOHO, STEREO and Hinode, we investigate magnetic field evolution in an equatorial coronal hole region. Two dipoles emerge one by one. The negative element of the first dipole disappears due to the interaction with the positive element of the second dipole. During this process, a jet and a plasma eruption are observed. The opposite polarities of the second dipole separate at first, and then cancel with each other, which is first reported in a coronal hole. With the reduction of unsigned magnetic flux of the second dipole from 9.8?10^20 Mx to 3.0?10^20 Mx in two days, 171 ? brightness decreases by 75% and coronal loops shrink obviously. At the cancellation sites, the transverse fields are strong and point directly from the positive elements to the negative ones, meanwhile Doppler red-shifts with an average velocity of 0.9 km s-1 are observed, comparable to the horizontal velocity (1.0 km s-1) derived from the cancelling island motion. Several days later, the northeastern part of the coronal hole, where the dipoles are located, appears as a quiet region. These observations support the idea that the interaction between the two dipoles is caused by flux reconnection, while the cancellation between the opposite polarities of the second dipole is due to the submergence of original loops. These results will help us to understand coronal hole evolution.

Response of the solar atmosphere to magnetic field evolution in a coronal hole region

S. H. **Yang**[1], J. Zhang[1], C. L. Jin[1], L. P. Li[1], and H. Y. Duan[2]

E-print, Apr **2009;** A&A 501, 745-753 (**2009**)

Context. Coronal holes (CHs) are deemed to be the sources of the fast solar wind streams that lead to recurrent geomagnetic storms and have been intensively investigated, but not all the properties of them are well known.

Aims.We study the response of the solar atmosphere to the magnetic field evolution in a CH region, such as magnetic flux emergence and cancellation for both network (NT) and intranetwork (IN) regions.

Methods.We study an equatorial CH observed simultaneously by *HINODE* and *STEREO* on July 27, 2007. The *HINODE*=SP maps are adopted to derive the physical parameters of the photosphere and to investigate the magnetic field evolution and distribution. The G band and Ca ii H images with high tempo-spatial resolution from *HINODE*=BFI and the multi-wavelength data from *STEREO*=EUVI are utilized to study the corresponding atmospheric response of di_erent overlying layers.

Results.We explore an emerging dipole located at the CH boundary. Mini-scale arch filaments (AFs) accompanying the emerging dipole were observed with the Ca ii H line. During the separation of the dipolar footpoints, three AFs appeared and expanded in turn. The first AF divided into two segments in its late stage, while the second and third AFs erupted in their late stages. The lifetimes of these three AFs are 4, 6, 10 minutes, and the two intervals between the three divisions or eruptions are 18 and 12 minutes, respectively. We display an example of mixed-polarity flux emergence of IN fields within the CH and present the corresponding chromospheric response. With the increase of the integrated magnetic flux, the brightness of the Ca ii H images exhibits an increasing trend. We also study magnetic flux cancellations of NT fields located at the CH boundary and present the chromospheric and coronal response. We notice that the brighter regions seen in the 171 Å images are relevant to the interacting magnetic elements. By examining the magnetic NT and IN elements and the response of di_erent atmospheric layers, we obtain close positive linear correlations between the NT magnetic flux densities and the brightness of both G band (correlation coe_cient 0.85) and Ca ii H (correlation coe_cient 0.58).

Corotating Solar Wind Structures and Recurrent Trains of Enhanced Diurnal Variation in Galactic Cosmic Rays

T. **Yeeram**1,2, D. Ruffolo1,2, A. Sáiz1,2, N. Kamyan1,2, and T. Nutaro

2014 ApJ 784 136

Data from the Princess Sirindhorn Neutron Monitor at Doi Inthanon, Thailand, with a vertical cutoff rigidity of 16.8 GV, were utilized to determine the diurnal anisotropy (DA) of Galactic cosmic rays (GCRs) near Earth during solar minimum conditions between 2007 November and 2010 November. We identified trains of enhanced DA over several days, which often recur after a solar rotation period (~27 days). By investigating solar coronal holes as identified from synoptic maps and solar wind parameters, we found that the intensity and anisotropy of cosmic rays are associated with the high-speed streams (HSSs) in the solar wind, which are in turn related to the structure and evolution of coronal holes. An enhanced DA was observed after the onset of some, but not all, HSSs. During time periods of recurrent trains, the DA was often enhanced or suppressed according to the sign of the interplanetary magnetic field B, which suggests a contribution from a mechanism involving a southward gradient in the GCR density, n, and a gradient anisotropy along B × ∇n. In one non-recurrent and one recurrent sequence, an HSS from an equatorial coronal hole was merged with that from a trailing mid-latitude extension of a polar coronal hole, and the slanted HSS structure in space with suppressed GCR density can account for the southward GCR gradient. We conclude that the gradient anisotropy is a source of temporary changes in the GCR DA under solar minimum conditions, and that the latitudinal GCR gradient can sometimes be explained by the coronal hole morphology.

Trans-Equatorial Loop System Arising from Coronal Hole Boundaries through Interactions between Active Regions and Coronal Holes

Masaki **Yokoyama** · Satoshi Masuda

Solar Phys (**2010**) 263: 135–152, DOI 10.1007/s11207-010-9525-4; **File**

It is not clear how trans-equatorial loop systems (TLSs) are formed, although they have been observed often with *Yohkoh*/SXT. We focus here on a TLS that appeared on **27 May 1998**. Yokoyama and Masuda (*Solar Phys.* **254**, 285, 2009) proposed a new scenario for the formation mechanism of the TLS. In this scenario, they pointed out the importance of magnetic interaction between an active region and a coronal hole to make "strong-seed magnetic fields" before a transient (bright and short-lived) trans-equatorial loop was created. The main aims of this study are to verify the scenario and to make the TLS formation mechanism clear, based on observational data. *Yohkoh*/SXT images, SOHO/MDI magnetograph data, and Kitt Peak coronal-hole maps were mainly used for our analyses. We investigated the TLS in detail from the time that there were no signatures of the TLS to its clear appearance. The following results are obtained: *i*) an active region emerged in the vicinity of a coronal-hole boundary, *ii*) the coronal-hole boundary retreated during the period when the active region was developing, *iii*) temporal variations of soft X-ray intensities were roughly synchronized between the coronal-hole boundary and a trans-equatorial region, and *iv*) new closed loops were observed in soft X-rays clearly at the coronal-hole boundary. Since *i*), *ii*), *iii*), and *iv*) are just what we expect in the scenario of YM2009, the scenario found support. We conclude that the TLS was originating with large-scale magnetic fields of the coronal-hole boundary through magnetic reconnection between the active region and a coronal hole.

An Analysis of Spikes in *Atmospheric Imaging Assembly* (AIA) Data

Peter R. **Young**, Nicholeen M. Viall, Michael S. Kirk, Emily I. Mason & Lakshmi Pradeep Chitta

Solar Physics volume 296, Article number: 181 (**2021**

https://link.springer.com/content/pdf/10.1007/s11207-021-01929-8.pdf

https://doi.org/10.1007/s11207-021-01929-8

https://arxiv.org/pdf/2108.02624.pdf

The Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO) returns high-resolution images of the solar atmosphere in seven extreme ultraviolet (EUV) wavelength channels. The images are processed on the ground to remove intensity spikes arising from energetic particles hitting the instrument, and the despiked images are provided to the community. In this article, a three-hour series of images from the 171 Å channel obtained on **28 February 2017** was studied to investigate how often the despiking algorithm gave false positives caused by compact brightenings in the solar atmosphere. The latter were identified through spikes appearing in the same detector pixel for three consecutive frames. 1096 examples were found from the 900 image frames. These "three-spikes" were assigned to 126 dynamic solar features, and it is estimated that the three-spike method identifies 19% of the total number of features affected by despiking. For any ten-minute sequence of AIA 171 Å images there are around 37 solar features that have their intensity modified by despiking. The features are found in active regions, quiet Sun, and coronal holes and, in relation to solar surface area, there is a greater proportion within coronal holes. In 96% of the cases, the despiked structure is a compact brightening with a size of two arcsec or less, and the remaining 4% have narrow, elongated structures. By applying an EUV burst detection algorithm, we found that 96% of the events could be classified as EUV bursts. None of the spike events are rendered invisible by the AIA processing pipeline, but the total intensity over an event's lifetime can be reduced by up to 67%. Users are recommended to always restore the original intensities in AIA data when studying short-lived or rapidly evolving features that exhibit fine-scale structure.

Dark Jets in Solar Coronal Holes

Peter R. **Young**

2015 ApJ 801 124

http://arxiv.org/pdf/1501.02751v1.pdf

A new solar feature termed a dark jet is identified from observations of an extended solar coronal hole that was continuously monitored for over 44 hr by the Extreme Ultraviolet Imaging Spectrometer on board the Hinode spacecraft in **2011 February 8–10** as part of Hinode Operation Plan No. 177 (HOP 177). Line of sight (LOS) velocity maps derived from the coronal Fe xii λ195.12 emission line, formed at 1.5 MK, revealed a number of large-scale, jet-like structures that showed significant blueshifts. The structures had either weak or no intensity signal in 193 Å filter images from the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory, suggesting that the jets are essentially invisible to imaging instruments. The dark jets are rooted in bright points and occur both within the coronal hole and at the quiet Sun–coronal hole boundary. They exhibit a wide range of shapes, from narrow columns to fan-shaped structures, and sometimes multiple jets are seen close together. A detailed study of one dark jet showed LOS speeds increasing along the jet axis from 52 to 107 km s−1 and a temperature of 1.2–1.3 MK. The low intensity of the jet was due either to a small filling factor of 2% or to a curtain-like morphology. From the HOP 177 sample, dark jets are as common as regular coronal hole jets, but their low intensity suggests a mass flux around two orders of magnitude lower.

A coronal hole jet observed with Hinode and the Solar Dynamics Observatory

Peter R. **YOUNG**1,∗ and Karin MUGLACH2,3

Publ. Astron. Soc. Japan (**2014**) 66 (SP1), S12 (1–9)

http://pasj.oxfordjournals.org/content/66/SP1/S12.full.pdf+html

A small blowout jet was observed at the boundary of the south polar coronal hole on **2011 February 8** at around 21:00UT. Images from the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO) revealed an expanding loop rising from one footpoint of a compact, bipolar bright point. Magnetograms from the Helioseismic Magnetic Imager (HMI) on board SDO showed that the jet was triggered by the cancelation of a parasitic positive polarity feature near the negative pole of the bright point. The jet emission was present for 25 min and it extended 30Mmfrom the bright point. Spectra from the Extreme Ultraviolet Imaging Spectrometer on board Hinode yielded a temperature and density of 1.6MK and 0.9–1.7×108 cm−3 for the ejected plasma. Line-of-sight velocities reached up to 250 kms−1 and were found to increase with height, suggesting plasma acceleration within the body of the jet. Evidence was found for twisting motions within the jet based on variations of the line-of-sight velocities across the jet width. The derived angular speed was in the range (9–12)×10−3 rad s−1, consistent with previous measurements from jets. The density of the bright point was 7.6×108 cm−3, and the peak of the bright point's emission measure occurred at 1.3MK, with no plasma above 3 MK.

Solar Dynamics Observatory and Hinode Observations of a Blowout Jet in a Coronal Hole

P. R. **Young**, K. Muglach

Solar Phys., Volume 289, Issue 9, pp 3313-3329, **2014**

A blowout jet occurred within the south coronal hole on **9 February 2011** at 09:00 UT and was observed by the Atmospheric Imaging Assembly (AIA) and Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory, and by the EUV Imaging Spectrometer (EIS) and X-Ray Telescope (XRT) onboard the Hinode spacecraft during coronal-hole monitoring performed as part of Hinode Operations Program No. 177. Images from AIA show expanding hot and cold loops from a small bright point with plasma ejected in a curtain up to 30 Mm wide. The initial intensity front of the jet had a projected velocity of 200 km s−1, and the line-of-sight (LOS) velocities measured by EIS are between 100 and 250 km s−1. The LOS velocities increased along the jet, implying that an acceleration mechanism operates within the body of the jet. The jet plasma had a density of 2.7×108 cm−3 and a temperature of 1.4 MK. During the event a number of bright kernels were seen at the base of the bright point. The kernels have sizes of ≈ 1000 km, are variable in brightness, and have lifetimes of 1 – 15 minutes. An XRT filter ratio yields temperatures of 1.5 – 3.0 MK for the kernels. The bright point existed for at least ten hours, but disappeared within two hours after the jet, which lasted for 30 minutes. HMI data reveal converging photospheric flows at the location of the bright point, and the mixed-polarity magnetic flux canceled over a period of four hours on either side of the jet.

Motion and Magnetic Flux Changes of Coronal Bright Points Relative to Supergranular Cell Boundaries

M. **Yousefzadeh**, H. Safari , R. Attie, N. Alipour

Solar Phys. January **2016**, Volume 291, Issue 1, pp 29-39

To calculate the magnetic flux and the horizontal movement of coronal bright points (CBPs) in relation to supergranular cell boundaries, the time series of the SDO/HMI visible-light continuum images and SDO/AIA EUV images for **13 February 2011** have been studied. The supergranular lanes were detected in HMI continuum images using the automatic supergranular cell recognition method. The automatic identification and tracking method was applied for detecting the CBPs in AIA 193 Å images. By applying the ball-tracking method on HMI continuum images, the underlying flow fields were determined. By using the velocity fields and the automatic supergranular cell recognition method, the lanes and boundaries were detected. The locations of CBPs were projected on the photospheric co-spatial and co-temporal images. We found that about 90 % of the locations of CBPs correspond to the lane of the supergranular cell boundaries (network CBPs or NCBPs) of which about 40 % of them appeared at junctions. The remaining 10 % appeared within the supergranular regions (internetwork CBPs or INCBPs). The horizontal velocities for NCBPs and INCBPs were about 1.6±0.1 kms^{-1} and 1.7±0.1 kms^{-1}, respectively. Using the magnetic field extrapolation, we were able to detect the bipoles underlying CBPs, and we studied their magnetic evolution. The orientation of CBPs observed in the 171, 193, and 211 Å images and the orientation of their magnetic bipoles are positively correlated. For out of 50 INCBPs, 54 % showed cancellation, 32 % emergence, and 12 % complex flux changes. Out of 90 NCBPs, 60 % presented cancellation, 20 % showed emergence, and 20 % showed complex flux changes.

Analysis and Predictive Modeling of Solar Coronal Holes Using Computer Vision and LSTM Networks

Juyoung **Yun**, Jungmin Shin

SPAICE Conference **2024**

https://arxiv.org/pdf/2405.09802

In the era of space exploration, coronal holes on the sun play a significant role due to their impact on satellites and aircraft through their open magnetic fields and increased solar wind emissions. This study employs computer vision techniques to detect coronal hole regions and estimate their sizes using imagery from the Solar Dynamics Observatory (SDO). Additionally, we utilize deep learning methods, specifically Long Short-Term Memory (LSTM) networks, to analyze trends in the area of coronal holes and predict their areas across various solar regions over a span of seven days. By examining time series data, we aim to identify patterns in coronal hole behavior and understand their potential effects on space weather. This research enhances our ability to anticipate and prepare for space weather events that could affect Earth's technological systems. **23-25 Dec 2022**

Coronal Hole Analysis and Prediction using Computer Vision and LSTM Neural Network

Juyoung **Yun**

2023

https://arxiv.org/pdf/2301.06732.pdf

As humanity has begun to explore space, the significance of space weather has become apparent. It has been established that coronal holes, a type of space weather phenomenon, can impact the operation of aircraft and satellites. The coronal hole is an area on the sun characterized by open magnetic field lines and relatively low temperatures, which result in the emission of the solar wind at higher than average rates. In this study, To prepare for the impact of coronal holes on the Earth, we use computer vision to detect the coronal hole region and calculate its size based on images from the Solar Dynamics Observatory (SDO). We then implement deep learning techniques, specifically the Long Short-Term Memory (LSTM) method, to analyze trends in the coronal hole area data and predict its size for different sun regions over 7 days. By analyzing time series data on the coronal hole area, this study aims to identify patterns and trends in coronal hole behavior and understand how they may impact space weather events. This research represents an important step towards improving our ability to predict and prepare for space weather events that can affect Earth and technological systems. 23-26 Dec 2022

Equatorial Magnetohydrodynamic Shallow Water Waves in the Solar Tachocline

Teimuraz **Zaqarashvili**

2018 ApJ 856 32

http://iopscience.iop.org/article/10.3847/1538-4357/aab26f/pdf

The influence of a toroidal magnetic field on the dynamics of shallow water waves in the solar tachocline is studied. A sub-adiabatic temperature gradient in the upper overshoot layer of the tachocline causes significant reduction of surface gravity speed, which leads to trapping of the waves near the equator and to an increase of the Rossby wave period up to the timescale of solar cycles. Dispersion relations of all equatorial magnetohydrodynamic (MHD) shallow water waves are obtained in the upper tachocline conditions and solved analytically and numerically. It is found that the toroidal magnetic field splits equatorial Rossby and Rossby-gravity waves into fast and slow modes. For a reasonable value of reduced gravity, global equatorial fast magneto-Rossby waves (with the spatial scale of equatorial extent) have a periodicity of 11 years, matching the timescale of activity cycles. The solutions are confined around the equator between latitudes ±20°–40°, coinciding with sunspot activity belts. Equatorial slow magneto-Rossby waves have a periodicity of 90–100 yr, resembling the observed long-term modulation of cycle strength, i.e., the Gleissberg cycle. Equatorial magneto-Kelvin and slow magneto-Rossby-gravity waves have the periodicity of 1–2 years and may correspond to observed annual and quasi-biennial oscillations. Equatorial fast magneto-Rossby-gravity and magneto-inertia-gravity waves have periods of hundreds of days and might be responsible for observed Rieger-type periodicity. Consequently, the equatorial MHD shallow water waves in the upper overshoot tachocline may capture all timescales of observed variations in solar activity, but detailed analytical and numerical studies are necessary to make a firm conclusion toward the connection of the waves to the solar dynamo.

Earth-affecting Solar Transients: A Review of Progresses in Solar Cycle 24

Jie **Zhang**, Manuela Temmer, Nat Gopalswamy, Olga Malandraki, Nariaki V. Nitta, Spiros Patsourakos, Fang Shen, Bojan Vršnak, Yuming Wang, David Webb, Mihir I. Desai, Karin Dissauer, Nina Dresing, Mateja Dumbović, Xueshang Feng, Stephan G. Heinemann, Monica Laurenza, Noé Lugaz, Bin Zhuang

https://arxiv.org/ftp/arxiv/papers/2012/2012.06116.pdf **File 2021**

2020 https://arxiv.org/abs/2012.06116

https://arxiv.org/ftp/arxiv/papers/2012/2012.06116.pdf

This review article summarizes the advancement in the studies of Earth-affecting solar transients in the last decade that encompasses most of solar cycle 24. The Sun Earth is an integrated physical system in which the space environment of the Earth sustains continuous influence from mass, magnetic field and radiation energy output of the Sun in varying time scales from minutes to millennium. This article addresses short time scale events, from minutes to days that directly cause transient disturbances in the Earth space environment and generate intense adverse effects on advanced technological systems of human society. Such transient events largely fall into the following four types: (1) solar flares, (2) coronal mass ejections (CMEs) including their interplanetary counterparts ICMEs, (3) solar energetic particle (SEP) events, and (4) stream interaction regions (SIRs) including corotating interaction regions (CIRs). In the last decade, the unprecedented multi viewpoint observations of the Sun from space, enabled by STEREO Ahead/Behind spacecraft in combination with a suite of observatories along the Sun-Earth lines, have provided much more accurate and global measurements of the size, speed, propagation direction and morphology of CMEs in both 3-D and over a large volume in the heliosphere. Several advanced MHD models have been developed to simulate realistic CME events from the initiation on the Sun until their arrival at 1 AU. Much progress has been made on detailed kinematic and dynamic behaviors of CMEs, including non-radial motion, rotation and deformation of CMEs, CME-CME interaction, and stealth CMEs and problematic ICMEs. The knowledge about SEPs has also been significantly improved**. 2008-11-03, 7 March 2011 , June 30, 2012, 12-14 July 2012, 2012.10.04-05, 8-10 October 2012, 29 May 2013, 2014-06-24**

Observations of multiple blobs in homologous solar coronal jets in closed loops

Q. M. **Zhang**, H. S. Ji, Y. N. Su

Solar Phys. **2016**

http://arxiv.org/pdf/1601.04390v1.pdf

Coronal bright points (CBPs) and jets are ubiquitous small-scale brightenings that are often associated with each other. In this paper, we report our multiwavelength observations of two groups of homologous jets. The first group was observed by the EUVI aboard the behind STEREO spacecraft in 171 {\AA} and 304 {\AA} on **2014 September 10**, from a location where data from the SDO could not observe. The jets (J1−J6) recurred for six times with intervals of 5−15 minutes. They originated from the same primary CBP (BP1) and propagated in the northeast direction along large-scale, closed coronal loops. Two of the jets (J3 and J6) produced sympathetic CBPs (BP2 and BP3) after reaching the remote footpoints of the loops. The time delays between the peak times of BP1 and BP2 (BP3) are 240±75 s (300±75 s). The jets were not coherent. Instead, they were composed of bright and compact blobs. The sizes and apparent velocities of the blobs are 4.5−9 Mm and 140−380 km/s, respectively. The arrival times of the multiple blobs in the jets at the far-end of the loops indicate that the sympathetic CBPs are caused by jet flows rather than thermal conduction fronts. The second group was observed by the AIA aboard SDO in various wavelengths on **2010 August 3**. Similar to the first group, the jets originated from a short-lived bright point (BP) at the boundary of AR 11092 and propagated along a small-scale, closed loop before flowing into the active region. Several tiny blobs with sizes of ∼1.7 Mm and apparent velocity of ~238 km/s were identified in the jets. We carried out the DEM inversions to investigate the temperatures of the blobs, finding that the blobs were multithermal with average temperature of 1.8−3.1 MK.

Reciprocatory magnetic reconnection in a coronal bright point

Q. M. **Zhang**, P. F. Chen, M. D. Ding, and H. S. Ji

E-print, June **2014**; A&A, 568, A30 (**2014**)

http://arxiv.org/pdf/1406.5328v1.pdf

Coronal bright points (CBPs) are small-scale and long-duration brightenings in the lower solar corona. They are often explained in terms of magnetic reconnection. We aim to study the sub-structures of a CBP and clarify the relationship among the brightenings of different patches inside the CBP. The event was observed by the X-ray Telescope (XRT) aboard the Hinode spacecraft on **2009 August 22-23**. The CBP showed repetitive brightenings (or CBP flashes). During each of the two successive CBP flashes, i.e., weak and strong flashes which are separated by ~2 hr, the XRT images revealed that the CBP was composed of two chambers, i.e., patches A and B. During the weak flash, patch A brightened first, and patch B brightened ~2 min later. During the transition, the right leg of a large-scale coronal loop drifted from the right side of the CBP to the left side. During the strong flash, patch B brightened first, and patch A brightened ~2 min later. During the transition, the right leg of the large-scale coronal loop drifted from the left side of the CBP to the right side. In each flash, the rapid change of the connectivity of the large-scale coronal loop is strongly suggestive of the interchange reconnection. For the first time we found reciprocatory reconnection in the CBP, i.e., reconnected loops in the outflow region of the first reconnection process serve as the inflow of the second reconnection process.

TWO TYPES OF MAGNETIC RECONNECTION IN CORONAL BRIGHT POINTS AND THE CORRESPONDING MAGNETIC CONFIGURATION

Q. M. **Zhang**, P. F. Chen1,2, Y. Guo1, C. Fang1,2 and M. D. Ding

2012 ApJ 746 19

Coronal bright points (CBPs) are long-lived small-scale brightenings in the solar corona. They are generally explained by magnetic reconnection. However, the corresponding magnetic configurations are not well understood. We carry out a detailed multi-wavelength analysis of two neighboring CBPs on **2007 March 16**, observed in soft X-ray (SXR) and EUV channels. It is seen that the SXR light curves present quasi-periodic flashes with an interval of ~1 hr superposed over the long-lived mild brightenings, suggesting that the SXR brightenings of this type of CBPs might consist of two components: one is the gentle brightenings and the other is the CBP flashes. It is found that the strong flashes of the bigger CBP are always accompanied by SXR jets. The potential field extrapolation indicates that both CBPs are covered by a dome-like separatrix surface, with a magnetic null point above. We propose that the repetitive CBP flashes, as well as the recurrent SXR jets, result from the impulsive null-point reconnection, while the long-lived brightenings are due to the interchange reconnection along the separatrix surface. Although the EUV images at high-temperature lines resemble the SXR appearance, the 171 Å and 195 Å channels reveal that the blurry CBP in SXR consists of a cusp-shaped loop and several separate bright patches, which are explained to be due to the null-point reconnection and the separatrix reconnection, respectively.

Magnetic Evolution and Temperature Variation in a Coronal Hole

Jun **Zhang**,[1] Guiping Zhou,[1] Jingxiu Wang,[1] and Haimin Wang[2]

The Astrophysical Journal, 655:L113-L116, **2007**

2005 October 10-14.

http://www.journals.uchicago.edu/cgi-bin/resolve?ApJL21217

Comparison of Magnetic Flux Distribution between a Coronal Hole and a Quiet Region

Jun **Zhang**, Jun Ma, and Haimin Wang

APJ,649, 464, **2006**

Statistical Properties of Magnetic Bright Points at Different Latitudes and Longitudes of the Sun.

Zhao, L., Yang, P., Bai, H. et al.

Sol Phys 299, 1 (**2024**).

https://doi.org/10.1007/s11207-023-02242-2

Magnetic bright points (MBPs) are located in intergranular channels on the solar surface. Studying the properties and evolution process of MBPs can help us to better understand solar activity and predict solar events that have a significant impact on Earth. In this study, we performed a statistical analysis of MBPs at different latitudes and longitudes. Data from the quiet-Sun (QS) in the eastward-equator (**8 June 2021**) and in the southern hemisphere (**31 July 2020**), as well as data from the QS near the disk center (**30 July 2020**), are analyzed. We studied the properties of MBPs, including lifetime, intensity contrast, and velocity. Moreover, we analyzed the intensity contrast of isolated MBPs at the moments of their birth and disappearance at different latitudes and longitudes, as well as the variation in the number of MBPs that appeared and disappeared in each frame. The results show that non-isolated MBPs have longer lifetimes than isolated MBPs, and the average lifetime of non-isolated MBPs located in the southern hemisphere (SH) is significantly shorter than that of MBPs near the disk center (DC) in the eastward-equator (EE). We find that the lifetime of non-isolated MBPs in the SH is negatively correlated with the intensity contrast, with higher intensity contrast associated with a shorter lifetime. The velocities of isolated MBPs at different latitudes and longitudes follow a Rayleigh distribution, while the velocities of non-isolated MBPs follow a log-normal distribution. Non-isolated MBPs exhibit higher horizontal velocities, with the maximum horizontal velocity reaching 8 km s−1. Finally, we find that the number of isolated MBPs per square Mm at different latitudes and longitudes remains stable during consecutive periods, and the intensity contrast of isolated MBPs is similar at the moment of their birth and disappearance.

Observational Evidence of Magnetic Reconnection for Brightenings and Transition Region Arcades in IRIS observations

Jie **Zhao**, Brigitte Schmieder, Hui Li, Etienne Pariat, Xiaoshuai Zhu, Li Feng, Michalina Grubecka
ApJ 836 52 **2017**
https://arxiv.org/pdf/1701.08356v1.pdf
By using a new method of forced-field extrapolation, we study the emerging flux region AR 11850 observed by the Interface Region Imaging Spectrograph (IRIS) and Solar Dynamical Observatory (SDO). Our results suggest that the bright points (BPs) in this emerging region have responses in lines formed from the upper photosphere to the transition region, with a relatively similar morphology. They have an oscillation of several minutes according to the Atmospheric Imaging Assembly (AIA) data at 1600 and 1700 Å . The ratio between the BP intensities measured in 1600 Å and 1700 Å filtergrams reveals that these BPs are heated differently. Our analysis of the Helioseismic and Magnetic Imager (HMI) vector magnetic field and the corresponding topology in AR11850 indicates that the BPs are located at the polarity inversion line (PIL) and most of them related with magnetic reconnection or cancelation. The heating of the BPs might be different due to different magnetic topology. We find that the heating due to the magnetic cancelation would be stronger than the case of bald patch reconnection. The plasma density rather than the magnetic field strength could play a dominant role in this process. Based on physical conditions in the lower atmosphere, our forced-field extrapolation shows consistent results between the bright arcades visible in slit-jaw image (SJI) 1400 Å and the extrapolated field lines that pass through the bald patches. It provides a reliable observational evidence for testing the mechanism of magnetic reconnection for the BPs and arcades in emerging flux region, as proposed in simulation works. **September 24, 2013**

Polar and Equatorial Coronal Hole Winds at Solar Minima: From the Heliosphere to the Inner Corona

L. **Zhao** and E. Landi
2014 ApJ 781 110
Fast solar wind can be accelerated from at least two different sources: polar coronal holes and equatorial coronal holes. Little is known about the relationship between the wind coming from these two different latitudes and whether these two subcategories of fast wind evolve in the same way during the solar cycle. Nineteen years of Ulysses observations, from 1990 to 2009, combined with ACE observations from 1998 to the present provide us with in situ measurements of solar wind properties that span two entire solar cycles. These missions provide an ideal data set to study the properties and evolution of the fast solar wind originating from equatorial and polar holes. In this work, we focus on these two types of fast solar wind during the minima between solar cycles 22 and 23 and 23 and 24. We use data from SWICS, SWOOPS, and VHM/FGM on board Ulysses and SWICS, SWEPAM, and MAG on board ACE to analyze the proton kinetic, thermal, and dynamic characteristics, heavy ion composition, and magnetic field properties of these two fast winds. The comparison shows that: (1) their kinetic, thermal, compositional, and magnetic properties are significantly different at any time during the two minima and (2) they respond differently to the changes in solar activity from cycle 23 to 24. These results indicate that equatorial and polar fast solar wind are two separate subcategories of fast wind. We discuss the implications of these results and relate them to remote-sensing measurements of the properties of polar and equatorial coronal holes carried out in the inner corona during these two solar minima.

KINETIC ALFVÉN WAVES EXCITED BY OBLIQUE MAGNETOHYDRODYNAMIC ALFVÉN WAVES IN CORONAL HOLES

J. S. **Zhao**1,2, D. J. Wu1,4 and J. Y. Lu

2011 ApJ 735 114

Kinetic Alfvén waves (KAWs) are small-scale dispersive AWs that can play an important role in particle heating and acceleration of space and solar plasmas. An excitation mechanism for KAWs created by the coupling between large-scale oblique AWs and small-scale KAWs is presented in this paper. Taking into account both the collisional and Landau damping dissipations, the results show that the net growth rate of the excited KAWs increases with their perpendicular wavenumber k and reaches maximum at λ e k ~ 0.3, where λ e is the electron inertial length. However, for KAWs with shorter perpendicular wavelengths, the net growth rate decreases rapidly due to dissipative effects. The evaluation of the threshold amplitude of the AW implies that for KAWs with λ e k < 0.3, the relative threshold amplitude is well below 10%, which is easy to satisfy. In particular, when applying this mechanism to the case of a solar coronal hole containing a dense plume structure, our results show that KAWs with λ e k < 0.3 can be not only efficiently excited in the interplume region but also strongly dissipated in the dense plume due to the Landau damping.

Total reflection of a flare-driven quasi-periodic EUV wave train at a coronal hole boundary

Xinping **Zhou**, Yuandeng Shen, Zehao Tang, Chengrui Zhou, Yadan Duan, Song Tang

A&A **2022**

https://arxiv.org/pdf/2112.15098.pdf

The reflection, refraction, and transmission of large-scale extreme ultraviolet (EUV) waves (collectively, secondary waves) have been observed during their interactions with coronal structures such as active regions (ARs) and coronal holes (CHs). However, the effect of the total reflection of EUV waves has not been reported in the literature. Here, we present the first unambiguous observational evidence of the total reflection of a quasi-periodic EUV wave train during its interaction with a polar CH. The event occurred in NOAA AR 12473, located close to the southeast limb of the solar disk, and was characterized by a jet-like CME. In this study, we focus in particular on the driving mechanism s of the quasi-periodic wave train and the total reflection effect at the CH boundary. We find that the periods of the incident and the reflected wave trains are both about 100 seconds. The excitation of the quasi-periodic wave train was possibly due to the intermittent energy release in the associated flare since its period is similar to that of the quasi-periodic pulsations in the associated flare. Our observational results showed that the reflection of the wave train at the boundary of the CH was a total reflection because the measured incidence and critical angles satisfy the theory of total reflection, i.e., the incidence angle is less than the critical angle. **2015 December 22**

Estimating Ion Temperatures at the Polar Coronal Hole Boundary

Yingjie **Zhu**, Judit Szente, Enrico Landi

ApJ **2022**

https://arxiv.org/pdf/2209.10686

Physical quantities, such as ion temperature and nonthermal velocity, provide critical information about the heating mechanism of the million-degree solar corona. We determined the possible ion temperature Ti intervals using extreme ultraviolet (EUV) line widths, only assuming that the plasma nonthermal velocity is the same for all ions. We measured ion temperatures at the polar coronal hole boundary simultaneously observed in 2007 by the EUV Imaging Spectrometer (EIS) on board the Hinode satellite and the Solar Ultraviolet Measurements of Emitted Radiation (SUMER) on board the Solar and Heliospheric Observatory (SOHO). The temperatures of ions with the charge-to-mass ratio (Z/A) less than 0.20 or greater than 0.33 are much higher than the local electron temperature. The measured ion temperature decreases with the Z/A to 0.25 and then increases with the charge-to-mass ratio. We ran the Alfvén Wave Solar Model-realtime (AWSoM-R) and the SPECTRUM module to validate the ion temperature diagnostic technique and to help interpret the results. We suggest that the widths of hot lines in the coronal hole (e.g., Fe XII, Fe XIII) are also affected by the solar wind bulk motions along the line of sight. We discussed the factors that might affect the line width fitting, including the instrumental width and non-Gaussian wings in some bright SUMER lines that can be fitted by a double-Gaussian or a κ distribution. Our study confirms the presence of preferential heating of heavy ions in coronal holes and provides new constraints to coronal heating models.

Fe XII and Fe XIII Line Widths in a Southern Coronal Hole up to 1.5 Solar Radii

Yingjie **Zhu**, Judit Szente, Enrico Landi

ApJ **2020**

https://arxiv.org/pdf/2009.14640.pdf

The non-thermal broadening of spectral lines formed in the solar corona is often used to seek the evidence of Alfvén waves propagating in the corona. To have a better understanding of the variation of line widths at different altitudes, we measured the line widths of the strong Fe \textsc{xii} 192.4 \mboxÅ, 193.5 \mboxÅ, 195.1 \mboxÅ and Fe

\textsc{xiii} 202.0 \mboxÅ in an off-limb southern coronal hole up to 1.5 R⊙ observed by the \textit{Extreme Ultraviolet Spectrometer} (EIS) on board the \textit{Hinode} satellite. We compared our measurements to the predictions from the Alfvén Wave Solar Model (AWSoM) and the SPECTRUM module. We found the Fe \textsc{xii} and Fe \textsc{xiii} line widths first increase monotonically below 1.1 R⊙, then keep fluctuating between 1.1 - 1.5 R⊙. The synthetic line widths of Fe \textsc{xii} and Fe \textsc{xiii} below 1.3 R⊙ are notably lower than the observed ones. We discuss several possible sources of this discrepancy and suggest that some other heating mechanisms besides the dissipation of the Alfvén waves are required to understand the coronal heating and solar wind acceleration from coronal holes below 1.3 R⊙

Periodic variations of the Hα profile width in the chromosphere of coronal holes as a possible indicator of Alfvén waves

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Astronomy Letters, April **2014**, Volume 40, Issue 4, pp 222-229

Pis'ma v Astronomicheskiı Zhurnal, **2014**, Vol. 40, No. 4, pp. 251–259.

We analyze the oscillations of the Hα profile width based on our observations of the chromosphere at the base of solar coronal holes. The maximum oscillation amplitude averaged over ten time series is 64 m 0 A. Direct calculations show that this value cannot be reached through temperature oscillations, because the periodic intensity fluctuations observed during our experiment did not exceed 5%, corresponding to Hα profile broadening only by 1.5–2 m Å. We hypothesize that the observed variations can result from the propagation of torsional Alfvén waves in the chromosphere of coronal holes.

Sources of Solar Wind at Solar Minimum: Constraints from Composition Data

Thomas H. **Zurbuchen**, Rudolf von Steiger, Jacob Gruesbeck, Enrico Landi, Susan T. Lepri, Liang Zhao, Viggo Hansteen

Space Science Reviews, November **2012**, Volume 172, Issue 1-4, pp 41-55

In this discussion of observational constraints on the source regions and acceleration processes of solar wind, we will focus on the ionic composition of the solar wind and the distribution of charge states of heavy elements such as oxygen and iron. We first focus on the now well-known bi-modal nature of solar wind, which dominates the heliosphere at solar minimum: Compositionally cool solar wind from polar coronal holes over-expands, filling a much larger solid angle than the coronal holes on the Sun. We use a series of remote and in-situ characteristics to derive a global geometric expansion factor of ~5. Slower, streamer-associated wind is located near the heliospheric current sheet with a width of 10–20°, but in a well-defined band with a geometrically small transition width. We then compute charge states under the assumption of thermal electron distributions and temperature, velocity, and density profiles predicted by a recent solar wind model, and conclude that the solar wind originates from a hot source at around 1 million K, characteristic of the closed corona.

Magnetic Field of Coronal Holes During the Polarity Reversal

V. I. **Abramenko** & R. A. Biktimirova

Geomagnetism and Aeronomy volume 62, pages 869–872 (**2022**)

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Polar coronal holes are large-scale configurations with open magnetic fields on the surface of the Sun. They are most active during the period of minimum solar activity and almost disappear during the period of maximum solar activity. We present the evolution of two coronal holes that were observed during the polarity reversal of cycle 23. Data were taken from SOHO/MDI/fd and SOHO/EIT/284 Å. These coronal holes had the polarity of the next, 24th, cycle. Instead of localization at the pole, in both cases, the propagation of coronal holes to the opposite hemisphere was observed. Thus, the open magnetic fields actively interacted with the toroidal magnetic field of the active regions during the polarity reversal period.

НАБЛЮДЕНИЯ КОРОНАЛЬНЫХ ДЫР НА СИБИРСКОМ РАДИОГЕЛИОГРАФЕ

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СОЛНЕЧНО-ЗЕМНАЯ ФИЗИКА Том: 10 Номер: 3 Год: 2024 Страницы: 5-12

Впервые выполнены многоволновые наблюдения корональной дыры (КД) с двумерным пространственным разрешением в диапазоне частот от 2.8 до 12 ГГц. На частотах ниже 6 ГГц средняя яркость по дыре в 1.5 раза меньше яркости спокойного Солнца. Распределение радиояркости по дыре неоднородно: отношение максимальных к минимальным яркостным температурам падает от нескольких раз на низких частотах до десятых долей на верхних принимаемым частотах. На частотах выше 6 ГГц контраст температур между КД и участками спокойного Солнца мал. Внутри КД наблюдаются яркие относительно спокойного Солнца компактные источники. В целом наблюдения КД с помощью СРГ перспективны как для исследования природы КД, так и как средство регулярного мониторинга в прикладных задачах прогнозирования характеристик солнечного ветра.

ЦИКЛИЧЕСКИЕ ВАРИАЦИИ ПЛОЩАДЕЙ КОРОНАЛЬНЫХ ДЫР И СОЛНЕЧНЫХ ПЯТЕН В 2010-2021 ГГ

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Изв. КрАО Том: 118Номер: 2 Год: 2022 Страницы: 20-27
https://www.elibrary.ru/download/elibrary_48749026_91711861.pdf

В работе исследуется циклическая связь корональных дыр с индексами солнечной активности (solar activity – SA). На основе наблюдательных данных, полученных инструментом AIA/SDO в линии железа Fe XII 19.3 нм в период с 13.05.2010 по 13.05.2021, изучены свойства полярных и неполярных корональных дыр (coronal holes – CHs). Подробно рассмотрены особенности каждой группы, установлена связь площадей корональных дыр с фазой солнечного цикла. В исследуемый период обнаружена северо-южная (N – S) асимметрия полушарий как по индексам солнечной активности, так и по локализации максимальных площадей полярных и неполярных CHs. На протяжении всего цикла выявлена определяющая роль полярных CHs южного и неполярных CHs северного полушария, которая проявилась как в динамике SA полушарий, так и всего диска Солнца в целом.

ВРАЩЕНИЕ ДОЛГОЖИВУЩЕЙ КОРОНАЛЬНОЙ ДЫРЫ В 24-М ЦИКЛЕ СОЛНЕЧНОЙ АКТИВНОСТИ

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ГиА Том: 63Номер: 4 Год: 2023 Страницы: 496-502

В работе обсуждаются результаты статистического исследования характеристик вращения долгоживущей гигантской корональной дыры. Исследование основано на данных наблюдений, полученных прибором Atmospheric Imaging Assembly в линии Fe XII 19.3 нм на борту космического аппарата Solar Dynamics Observatory в период с июня 2015 г. по март 2017 г. – 24 кэррингтоновских оборота. Рассмотрены отдельно четыре этапа развития корональной дыры: формирование, две фазы развитой корональной дыры и завершающая фаза. Установлено, что средняя скорость вращения на широте 40° близка к стандартной скорости в начале (12.75°/сут) и в первой фазе максимального развития (13°/сут); меньше – во второй фазе максимального развития (11.7°/сут) и в конце ее существования (12.5°/сут). Небольшое увеличение скорости на завершающем этапе связано с перестройкой корональной дыры. Согласно современным теориям, вращение солнечной короны отражает вращение подфотосферных слоев. Более высокие слои короны отражают вращение более глубоких слоев Солнца. Результаты, полученные в нашей работе, показывают, что скорость вращения гигантской корональной дыры, в максимальной фазе ее развития, больше скорости вращения диска Солнца. Возможно, это свидетельствует о том, что корональные дыры могут быть связаны с глубокими солнечными слоями через конфигурацию глобального магнитного поля и что источник образования корональных дыр находится более глубоко, чем источник фонового поля.

КОРОНАЛЬНЫЕ ДЫРЫ 24-ГО ЦИКЛА ПО НАБЛЮДЕНИЯМ КОСМИЧЕСКОГО АППАРАТА SDO

АНДРЕЕВА О.А.*, **АБРАМЕНКО В.И.***[1], **МАЛАЩУК В.М.***

ГиА Том: 62Номер: 1 Год: 2022 Страницы: 3-10

Исследовалась динамика площадей корональных дыр и их локализация на Солнце в 24-м и минимуме 24–25-го циклов солнечной активности. Исследование базируется на данных наблюдений, полученных инструментом Atmospheric Imaging Assembly в линии железа Fe XII 19.3 нм на борту космического аппарата Solar Dynamics Observatory в период 13.05.2010–31.12.2020 гг. Разделение всех корональных дыр рассматриваемого периода на полярные и неполярные показало: ежедневная суммарная площадь полярных корональных дыр увеличивается в минимумах солнечной активности и снижается в максимуме цикла. Это согласуется с общим представлением о полярных корональных дырах, как основном источнике дипольного магнитного поля Солнца. Наблюдается асимметрия площадей полярных корональных дыр в северной и южной полусферах, которая требует дальнейших объяснений. Показано, что площади неполярных корональных дыр меняются квази-синхронно с пятенной активностью Солнца, что позволяет предположить наличие физической связи этих двух явлений. По-видимому, природа магнитных полей полярных и неполярных корональных дыр разная. Магнитные силовые линии неполярных корональных дыр, возможно, представляют собой очень высокие петли, замыкающиеся через корону на других областях Солнца, в то время как магнитные силовые линии полярных корональных дыр уходят далеко в гелиосферу.

О ЗАВИСИМОСТИ МАГНИТНОГО ПОЛЯ НИЗКОШИРОТНОЙ КОРОНАЛЬНОЙ ДЫРЫ ОТ ЕЕ ПЛОЩАДИ

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ПАЖ Том: 47Номер: 2 Год: **2021** Страницы: 138-144

На основе данных, полученных с помощью алгоритма CHIMERA, рассмотрена эволюция долгоживущей низкоширотной корональной дыры при прохождении центрального меридиана за период с 15.02.2012 по 14.10.2012 г. Коэффициент корреляции между напряженностью фотосферного магнитного поля корональной дыры и ее площадью за девять кэррингтоновских оборотов составил R=−0.55. Он заметно отличается от соответствующего значения R=−0.82, приведенного в работе Хейнеманна и др. Результаты свидетельствуют о существенной зависимости площади корональных дыр от метода определения их границ, что может оказать заметное влияние как на прогноз геомагнитной активности, так и на понимание природы солнечных явлений, связанных с этими образованиями.

ФОРМИРОВАНИЕ И ЭВОЛЮЦИОННЫЕ ИЗМЕНЕНИЯ КОРОНАЛЬНЫХ ДЫР НА ФАЗЕ РОСТА 23-ГО ЦИКЛА

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Г и А   Том: 60 Номер: 4 Год: **2020** Страницы: 436-447

Исследованы закономерности формирования корональных дыр на фазе роста 23-го цикла. Детально рассмотрен период с 01.01.1997 г. по 01.03.2000 г. (Кэррингтоновские обороты 1918–2059). Проанализирована эволюция глобального магнитного поля Солнца от зональной структуры распределения магнитных полей к секторной. Показано, что зональная структура является квазистабильной. Сумма зональных гармоник доминирует до 1941-го Кэррингтоновского оборота, хотя с оборота 1932-го формируется устойчивая четырехсекторная структура глобального магнитного поля. В 1941–1950-м Кэррингтоновских оборотах вклад зональных и секторных компонент становится приблизительно одинаков, а начиная с Кэррингтоновского оборота 1950 доминирует секторная структура глобального магнитного поля. Секторная структура претерпевает резкие изменения от четырехсекторной в начале роста секторных гармоник (с Кэррингтоновского оборота 1926) к двухсекторной, затем снова к четырехсекторной и далее опять к двухсекторной. Корональные дыры однозначно трассируют все эволюционные изменения глобального магнитного поля. Структура полярности глобального магнитного поля однозначно определяет зоны фотосферных магнитных полей, где формируются корональные дыры.

МАГНИТНЫЕ ПОЛЯ НА ФОТОСФЕРЕ И В КОРОНЕ В ОБЛАСТЯХ КОРОНАЛЬНЫХ ДЫР

Биленко И.А.

Астрономия-**2018** Том 2 Солнечно-земная физика – современное состояние и перспективы Стр. 31

http://www.izmiran.ru/library/eaas2018/eaas-2018-2.pdf

СРАВНИТЕЛЬНЫЙ АНАЛИЗ СВОЙСТВ КОРОНАЛЬНЫХ ДЫР В 24-м ЦИКЛЕ АКТИВНОСТИ

Васильева В.В., Тлатов А.Г.

Пулково *«Солнечная и солнечно-земная физика – **2015**», с. 39*

The analysis of the properties of coronal holes (CH) in the 21–24's activity cycle.
To select the CH in the 24th cycle, we reconstructed the synoptic charts of the observational data SDO/AIA-193A. In order to determine magnetic characteristics of a CH of their position were combined with observations Magnetograph WSO. It was established that during the minimum of the 24th activity cycle intensity and flux of the magnetic field were minimal over the entire observation period.

АНАЛИЗ РЕЗУЛЬТАТОВ ИССЛЕДОВАНИЯ НАБЛЮДЕНИЙ ПОЛЯРНОЙ КОРОНАЛЬНОЙ ДЫРЫ НА СОЛНЦЕ В МИКРОВОЛНОВОМ ДИАПАЗОНЕ ДЛИН ВОЛН

ГОЛУБЧИНА О. А.

АЖ   Том: 98Номер: 4 Год: **2021**   Страницы: 332-341

Представлен обзор основных результатов исследования полярной корональной дыры (КД) над Северным полюсом Солнца на основе наблюдений солнечного затмения **29 марта 2006** г. с помощью радиотелескопа РАТАН-600 в широком диапазоне сантиметровых длин волн: 1.03, 1.38, 2.7, 6.2, 13.0, 30.7 см – с привлечением наблюдательных и теоретических данных работ о свойствах корональных дыр на Солнце, опубликованных различными авторами. Обсуждаются полученные результаты: распределение яркостных температур полярной корональной дыры над Северным полюсом Солнца на расстояниях 1.005–2.0 радиуса оптического диска Солнца от центра солнечного диска; усиление микроволнового излучения полярной корональной дыры, зарегистрированное на коротких длинах волн; идентичность температурных свойств полярной КД и низкоширотных корональных дыр на Солнце в период минимальной солнечной активности. Сравнение полученных яркостных температур полярной корональной дыры с яркостными температурами крупных низкоширотных корональных дыр, наблюдавшихся ранее (1973–1976, 1984–1987 гг.) на близких длинах волн, свидетельствует об идентичности температурных свойств корональных дыр независимо от их расположения на Солнце и организации корональных дыр в период минимума солнечной активности.

ФИЗИЧЕСКИЕ ХАРАКТЕРИСТИКИ РАДИОИЗЛУЧЕНИЯ НАД ПОЛЯРНЫМИ ОБЛАСТЯМИ СОЛНЦА

Голубчина О.А.

Пулково *«Солнечная и солнечно-земная физика – **2015**», с.81*

In this paper the brief review of polar coronal holes observations in different wave lengths is given. Comparison of physical characteristics of coronal hole cm-radio emission above the North Pole of the Sun with characteristics of coronal holes, located outside of polar areas on a background of the quiet Sun which were received on RATAN-600 earlier is resulted. Results of comparisons have shown that properties of the polar coronal hole above the North Pole of the Sun are identical to properties of coronal holes located outside of polar areas on a background of the quiet Sun.

ОСНОВНЫЕ СВОЙСТВА ФОРБУШ-ЭФФЕКТОВ, СВЯЗАННЫХ С ВЫСОКОСКОРОСТНЫМИ ПОТОКАМИ ИЗ КОРОНАЛЬНЫХ ДЫР

МЕЛКУМЯН А.А.1, БЕЛОВ А.В.2, АБУНИНА М.А.2, АБУНИН А.А.2, ЕРОШЕНКО Е.А.2, ОЛЕНЕВА В.А.2, ЯНКЕ В.Г.2

Геомагн. и Аэрон. Том: 58Номер: 2 Год: **2018** Страницы: 163-176

Для того чтобы изучить особенности воздействия высокоскоростных потоков солнечного ветра из корональных дыр на космические лучи, была использована база данных Форбуш-эффектов и межпланетных возмущений, созданная в ИЗМИРАН. Были выделены 350 Форбуш-эффектов, созданных корональными дырами без других воздействий. Для различных характеристик событий этой группы найдены средние значения и распределения и проведено их сравнение со всеми Форбуш-эффектами и Форбуш-эффектами, обусловленными корональными выбросами. Несмотря на большие различия высокоскоростных потоков из корональных дыр, эта группа оказалась более компактной и однородной по сравнению с событиями, связанными с корональными выбросами. Получены регрессионные зависимости и корреляционные связи между различными параметрами событий для исследуемых групп. Показано, что Форбуш-эффекты, обусловленные корональными выбросами, значительно сильнее зависят от характеристик межпланетных возмущений по сравнению с Форбуш-эффектами, связанными с корональными дырами. Это говорит о существенном различии модуляционных механизмов Форбуш-эффектов разных типов и подтверждает выводы, сделанные ранее по косвенным данным.

ОТКРЫТЫЕ МАГНИТНЫЕ ПОЛЯ НА СОЛНЦЕ И ХАРАКТЕРИСТИКИ СОЛНЕЧНОГО ВЕТРА У ЗЕМЛИ

ОБРИДКО В.Н.1, ШЕЛЬТИНГ Б.Д.1, ЛИВШИЦ И.М.1

АЖ Том: 88Номер: 3 Год: **2011** Страницы: 313-320
https://www.elibrary.ru/download/elibrary_15638861_27044961.pdf

Показано, что характеристики магнитного поля в солнечном ветре определяются областью в корональной дыре на уровне 1.1–1.4 радиуса Солнца, где силовые линии являются радиальными уже на малых высотах. Расширяясь далее в узком “сопле” или “воронке” (funnel), силовые линии к высоте 2.5 радиусов Солнца становятся радиальными всюду в униполярной области. Таким образом, традиционная схема сопоставления характеристик межпланетного магнитного поля у Земли с точкой гелиопроекции на Солнце не совсем корректна. Она дает хорошие результаты при сопоставлении знака поля и секторной структуры. Однако абсолютные значения поля формируются в более широкой зоне. Учет этого эффекта позволяет согласовать значения полей на Солнце и в межпланетном магнитном поле и объяснить эффект отсутствия слабых полей вблизи нейтральной линии межпланетного магнитного поля (двухвершинность распределения).

О ВОЗМОЖНЫХ ПРИЧИНАХ НЕСООТВЕТСТВИЯ МЕЖДУ ПРОГНОЗИРУЕМЫМИ И НАБЛЮДАЕМЫМИ ПАРАМЕТРАМИ ВЫСОКОСКОРОСТНЫХ ПОТОКОВ СОЛНЕЧНОГО ВЕТРА

ШУГАЙ Ю.С.1, ВЕСЕЛОВСКИЙ И.С.1,2, СЛЕМЗИН В.А.3, ЕРМОЛАЕВ Ю.И.2, РОДЬКИН Д.Г.

Косм. Исслед. Том: 55Номер: 1 Год: **2017** Страницы: 22-31 DOI: 10.7868/S0023420617010083

Рассмотрены возможные причины несоответствий между прогнозируемыми и наблюдаемыми на 1 а. е. параметрами рекуррентных потоков солнечного ветра (СВ) в максимуме 24-го солнечного цикла. Такие

несоответствия наблюдаются как в профиле (значениях скорости), так и во времени прихода потока СВ, а также в отсутствии ожидаемого высокоскоростного потока СВ. Степень несоответствия зависит от модели, используемой для прогнозирования СВ, но в ряде случаев разные методы прогнозирования дают похожее расхождение с наблюдаемыми параметрами СВ на 1 а. е. На примерах нескольких случаев показано, что причиной расхождений может быть отклонение высокоскоростного потока СВ от радиального направления из-за взаимодействия с транзиентными потоками СВ при определенной конфигурации магнитных полей источников высокоскоростных и транзиентных потоков СВ в солнечной короне.

КОМПЛЕКСЫ АКТИВНОСТИ И КОРОНАЛЬНЫЕ ДЫРЫ НА СОЛНЦЕ: ФЕНОМЕНОЛОГИЯ СВЯЗИ

Язев С.А., Томозов В.М., Исаева Е.С.

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Проанализирована связь комплексов активности (КА) и корональных дыр (КД) по данным 24 цикла солнечной активности. Получены следующие выводы. 1. Первые низкоширотные КД проявляются в виде выступов (“хоботов”) полярных КД, вытягивающихся в сторону активной области (АО) в составе комплексов активности. 2. Изолированные (не связанные с полярными КД) низкоширотные КД возникают в результате эволюции “хоботов” полярных КД. 3. Эффект замещения, когда на месте распавшихся АО КА, возникает КД, проявляется не в появлении новой КД вместо АО, а в распространении (расширении или удлинении) уже существующей близлежащей КД на место распавшейся АО. КД рождаются от КД, а не от КА, но КА влияют на их локализацию и форму. 4. Высокоширотные КД подчиняются дифференциальному вращению. Низкоширотные изолированные КД, взаимодействующие с КА, вращаются с кэррингтоновской скоростью. Низкоширотные КД, не связанные с КА, подчиняются дифференциальному вращению. 5. Возникновение “хоботов” полярных КД связано с влиянием АО (прежде всего, АО в составе КА). 6. Подтвержден сделанный ранее предварительный вывод о том, что все КА на определенном этапе своего развития связаны с близлежащими КД. Это проявляется в изменениях формы границ КД и в особенностях скорости вращения КД.