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

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https://progearthplanetsci.springeropen.com/counter/pdf/10.1186/s40645-021-00426-7.pdf
https://arxiv.org/ftp/arxiv/papers/2012/2012.06116.pdf **2021**
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CMEs	CDAW	SOHO CME catalog https://cdaw.gsfc.nasa.gov/CME_list/	(S. Yashiro et al. 2004)
CMEs	SEEDS	SOHO and STEREO CME catalogs based on automated method. http://spaceweather.gmu.edu/seeds/	(O. Olmedo et al. 2008)
CMEs	CACTUS	SOHO and STEREO CME catalogs based on automated method http://sidc.oma.be/cactus/	(E. Robbrecht and Berghmans 2004)
CMEs	ARTEMIS	SOHO CME catalog based on automated method http://cesam.lam.fr/lascomission/ARTEMIS/index.html	(Boursier et al. 2005)
CMEs	CORIMP	SOHO CME catalog based on automated method http://alshamess.ifa.hawaii.edu/CORIMP/	(Byrne et al. 2012)
CMEs	--	STEREO COR1 catalog, including CMEs and other events https://cor1.gsfc.nasa.gov/catalog/	--
CMEs	MVCC	STEREO Dual-viewpoint CME catalog http://solar.jhuapl.edu/Data-Products/COR-CME-Catalog.php	(Angelos Vourlidas et al. 2017)
CMEs	KINCAT	STEREO COR2 CMEs (2007-2013) with GCS model results http://www.affects-fp7.eu/cme-database/index.php	(Bosman et al. 2012)
ICMEs-IH	HELCATS	STEREO HI event catalogs including HICAT, HIJoinCAT, HIGeoCAT http://www.helcats-fp7.eu/	(Harrison et al. 2018)
ICMEs-IS	--	ACE ICMEs since 1996 complied by Richardson & Cane http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm	(I. G. Richardson and Cane 2010)
ICMEs-IS	--	WIND ICME catalog (1995-2015) https://wind.nasa.gov/ICME_catalog/ICME_catalog_viewer.php	(T. Nieves-Chinchilla, Vourlidas, et al. 2018)
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CMEs	CORIMP	SOHO CME catalog based on automated method http://alshamess.ifa.hawaii.edu/CORIMP/	(Byrne et al. 2012)
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ICMEs-IS	--	ACE ICMEs since 1996 complied by Richardson & Cane http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm	(I. G. Richardson and Cane 2010)
ICMEs-IS	--	WIND ICME catalog (1995-2015) https://wind.nasa.gov/ICME_catalog/ICME_catalog_viewer.php	(T. Nieves-Chinchilla, Vourlidas, et al. 2018)
ICMEs-IS	--	WIND Magnetic Cloud list (1995-2006) https://wind.nasa.gov/mfi/mag_cloud_pub1.html	(Lepping and Wu 2007)
ICMEs-IS	--	WIND ICME catalog (1995-2015) http://space.ustc.edu.cn/dreams/wind_icmes/	(Chi et al. 2016)
ICMEs-IS	--	ICMEs and other large scale structures in solar wind ftp://www.iki.rssi.ru/pub/omni/	(Yu. I. Yermolaev et al. 2009)

Correlation of the sunspot number and the waiting time distribution of solar flares, coronal mass ejections, and solar wind switchback events observed with the Parker Solar Probe

Markus J. **Aschwanden**, Thierry Dudok de Wit

ApJ **912** 94 **2021**

https://arxiv.org/pdf/2102.02305.pdf

https://doi.org/10.3847/1538-4357/abef69

Waiting time distributions of solar flares and {\sl coronal mass ejections (CMEs)} exhibit power law-like distribution functions with slopes in the range of $\alpha_\tau \approx 1.4-3.2$, as observed in annual data sets during 4 solar cycles (1974-2012). We find a close correlation between the waiting time power law slope α_τ and the {\sl sunspot number (SN)}, i.e., $\alpha_\tau = 1.38 + 0.01 \times SN$. The waiting time distribution can be fitted with a Pareto-type function of the form $N(\tau)=N_0 (\tau_0+\tau)^{-\alpha_\tau}$, where the offset τ_0 depends on the instrumental sensitivity, the detection threshold of events, and pulse pile-up effects. The time-dependent power law slope $\alpha_\tau(t)$ of waiting time distributions depends only on the global solar magnetic flux (quantified by the sunspot number) or flaring rate, independent of other physical parameters of {\sl self-organized criticality (SOC)} or {\sl magneto-hydrodynamic (MHD)} turbulence models. Power law slopes of $\alpha_\tau \approx 1.2-1.6$ were also found in solar wind switchback events, as observed with the {\sl Parker Solar Probe (PSP)}. We conclude that the annual variability of switchback events in the heliospheric solar wind is modulated by flare and CME rates originating in the photosphere and lower corona.

Periodic behaviour of coronal mass ejections, eruptive events, and solar activity proxies during solar cycles 23 and 24

Tatiana **Barlyaeva** JulienWojakabPhilippeLamyabBriceBocletabImreToth

Journal of Atmospheric and Solar-Terrestrial Physics

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sci-hub.ru/10.1016/j.jastp.2018.05.012

https://arxiv.org/pdf/1704.02336.pdf **File**

We report on the parallel analysis of the periodic behaviour of coronal mass ejections (CMEs) based on 21 years [1996–2016] of observations with the SOHO/LASCO–C2 coronagraph, solar flares, prominences, and several proxies of solar activity. We consider values of the rates globally and whenever possible, distinguish solar hemispheres and solar cycles 23 and 24. Periodicities are investigated using both frequency (periodogram) and time-frequency (wavelet) analysis. We find that these different processes, in addition to following the ≈11-year Solar Cycle, exhibit diverse statistically significant oscillations with properties common to all solar, coronal, and heliospheric processes: variable periodicity, intermittence, asymmetric development in the northern and southern solar hemispheres, and largest amplitudes during the maximum phase of solar cycles, being more pronounced during solar cycle 23 than the weaker cycle 24. However, our analysis reveals an extremely complex and diverse situation. For instance, there exists very limited commonality for periods of less than one year. The few exceptions are the periods of 3.1–3.2 months found in the global occurrence rates of CMEs and in the sunspot area (SSA) and those of 5.9–6.1 months found in the northern hemisphere. Mid-range periods of ≈1 and ≈2 years are more wide spread among the studied processes, but exhibit a very distinct behaviour with the first one being present only in the northern hemisphere and the second one only in the southern hemisphere. These periodic behaviours likely results from the complexity of the underlying physical processes, prominently the emergence of magnetic flux.

The State of the Corona During the Weak Solar Cycle 24: the View from LASCO Images

Barlyaeva, T.; Lamy, P.; Llebaria, A.; Boclet, B.

Ground-based Solar Observations in the Space Instrumentation Era

ASP Conference Series, Vol. 504, p. 287, **2016**

http://aspbooks.org/publications/504/287.pdf

The LASCO-C2 coronagraph onboard SOHO continues its white-light imaging of the corona from 1.5 to 6.0 solar radii, thus allowing investigating the consequences of the weak Solar Cycle 24 on the corona and comparing it to the previous cycle (23). Temporal variations of the global radiance of the corona are presented. We pay particular attention to the mid-term variations which are distinctly different between the two cycles and highlight the similarities and differences. Finally, we rely on our ARTEMIS II catalog of coronal mass ejections (CMEs) to compare their global rates during these two cycles.

Solar flares associated coronal mass ejections in case of type II radio bursts

Beena **Bhatt**, Lalan Prasad, Harish Chandra, Suman Garia

Astrophysics and Space Science August **2016**, 361:265

We have statistically studied 220 events from 1996 to 2008 (i.e. solar cycle 23). Two set of flare-CME is examined one with Deca-hectometric (DH) type II and other without DH type II radio burst. Out of 220 events 135 (flare-halo CME) are accompanied with DH type II radio burst and 85 are without DH type II radio burst. Statistical analysis is performed to examine the distribution of solar flare-halo CME around the solar disk and to investigate the relationship between solar flare and halo CME parameters in case of with and without DH type II radio burst. In our analysis we have observed that: (i) 10–20° latitudinal belt is more effective than the other belts for DH type II and without DH type II radio burst. In this belt, the southern region is more effective in case of DH type II radio burst, whereas in case of without DH type II radio burst dominance exits in the northern region. (ii) 0–10° longitudinal belt is more effective than the other belts for DH type II radio burst and without DH type II radio burst. In this belt, the western region is more effective in case of DH type II radio burst, while in case of without DH type II radio burst dominance exits in the eastern region. (iii) Mean speed of halo CMEs (1382 km/s) with DH type II radio burst is more than the mean speed of halo CMEs (775 km/s) without DH type II radio burst. (iv) Maximum number of M-class flares is found in both the cases. (v) Average speed of halo CMEs in each class accompanied with DH type II radio burst is higher than the average speed of halo CMEs in each class without DH type II radio burst. (vi) Average speed of halo CMEs, associated with X-class flares, is greater than the other class of solar flares in both the cases.

Relations between Coronal Mass Ejections and the Photospheric Magnetic Field in Cycles 23 and 24

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2020 ApJ 889 1

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The number of coronal mass ejections (CMEs) and their parameters and cycle variations were investigated and compared to the photospheric magnetic field evolution in cycles 23 and 24. The Coordinated Data Analysis Workshops (CDAW) catalog of white-light CMEs detected by the Solar and Heliospheric Observatory/Large Angle and Spectrometric Coronagraph coronagraphs and the data on the photospheric magnetic fields from the Kitt Peak Vacuum Telescope Spectromagnetograph (KPVT/Spectromagnetograph) and the Synoptic Optical Long-term Investigations of the Sun Vector-Spectromagnetograph (SOLIS/VSM) were used. The results suggest that not only did the number of CMEs increase in cycle 24, but that their parameters, cycle variations, distributions, and dependencies on the photospheric magnetic fields were also different. Various CME categories behave in different ways during solar cycles. The differences in the number and parameters of CMEs and their cycle variations may be related to the differences in the photospheric magnetic fields during the cycles. The strong photospheric magnetic fields maintained approximately the same strength from cycle 23 to cycle 24, whereas the weak fields became weaker and the area they occupied increased. Taking into account that the global magnetic field diminished from cycle 23 to cycle 24, the increase in the number of CMEs in cycle 24 can be understood. A detailed analysis of the similarities and differences in CME parameters and their cycle evolution indicates that, along with the influence of changes in the CME detection mode in 2004 and 2010, the changes in CME rate and parameters were also associated with real differences in the behavior of strong and weak photospheric magnetic fields in cycles 23 and 24.

Influence of the Solar Global Magnetic-Field Structure Evolution on CMEs

Irina A. **Bilenko**

Solar Physics, Volume 289, Issue 11, pp 4209-4237 **2014**

https://arxiv.org/pdf/1804.08354.pdf

We consider the influence of the solar global magnetic-field structure (GMFS) cycle evolution on the occurrence rate and parameters of coronal mass ejections (CMEs) in Solar Cycles 23 – 24. It has been shown that, over solar cycles, CMEs are not distributed randomly, but they are regulated by evolutionary changes in the GMFS. It is proposed that the generation of magnetic Rossby waves in the solar tachocline results in the GMFS cycle changes. Each Rossby wave period favors a particular GMFS. It is proposed that the changes in wave periods result in GMFS reorganization and consequently in CME location, occurrence rate, and parameter changes. The CME rate and parameters depend on the sharpness of the GMFS changes, the strength of the global magnetic field, and the phase of a cycle

Solar flares associated coronal mass ejection accompanied with DH type II radio burst in relation with interplanetary magnetic field, geomagnetic storms and cosmic ray intensity

Harish **Chandra**, Beena Bhatt

New Astronomy Volume 60, April **2018**, Pages 22-32

sci-hub.ru/10.1016/j.newast.2017.10.001

In this paper, we have selected 114 flare-CME events accompanied with Deca-hectometric (DH) type II radio burst chosen from 1996 to 2008 (i.e., solar cycle 23). Statistical analyses are performed to examine the relationship of flare-CME events accompanied with DH type II radio burst with Interplanetary Magnetic field (IMF), Geomagnetic storms (GSs) and Cosmic Ray Intensity (CRI). The collected sample events are divided into two groups. In the first group, we considered 43 events which lie under the CME span and the second group consists of 71 events which are outside the CME span. Our analysis indicates that flare-CME accompanied with DH type II radio burst is inconsistent with CSHKP flare-CME model. We apply the Chree analysis by the superposed epoch method to both set of data to find the geo-effectiveness. We observed different fluctuations in IMF for arising and decay phase of solar cycle in both the cases. Maximum decrease in Dst during arising and decay phase of solar cycle is different for both the cases. It is noted that when flare lie outside the CME span CRI shows comparatively more variation than the flare lie under the CME span. Furthermore, we found that flare lying under the CME span is more geo effective than the flare outside of CME span. We noticed that the time leg between IMF Peak value and GSs, IMF and CRI is on average one day for both the cases. Also, the time leg between CRI and GSs is on average 0 to 1 day for both the cases. In case flare lie under the CME span we observed high correlation (0.64) between CRI and Dst whereas when flare lie outside the CME span a weak correlation (0.47) exists. Thus, flare position with respect to CME span play a key role for geo-effectiveness of CME.

Stationarity and periodicities of linear speed of coronal mass ejection: a statistical signal processing approach

Anirban **Chattopadhyay**, Mofazzal Hossain Khondekar & Anup Kumar Bhattacharjee

Astrophysics and Space Science September **2017**, 362:179

In this paper initiative has been taken to search the periodicities of linear speed of Coronal Mass Ejection in solar cycle 23. Double exponential smoothing and Discrete Wavelet Transform are being used for detrending and filtering of the CME linear speed time series. To choose the appropriate statistical methodology for the said purpose, Smoothed Pseudo Wigner-Ville distribution (SPWVD) has been used beforehand to confirm the non-stationarity of the time series. The Time-Frequency representation tool like Hilbert Huang Transform and Empirical Mode decomposition has been implemented to unearth the underneath periodicities in the non-stationary time series of the linear speed of CME. Of all the periodicities having more than 95% Confidence Level, the relevant periodicities have been segregated out using Integral peak detection algorithm. The periodicities observed are of low scale ranging from 2–159 days with some relevant periods like 4 days, 10 days, 11 days, 12 days, 13.7 days, 14.5 and 21.6 days. These short range periodicities indicate the probable origin of the CME is the active longitude and the magnetic flux network of the sun. The results also insinuate about the probable mutual influence and causality with other solar activities (like solar radio emission, ApAp index, solar wind speed, etc.) owing to the similitude between their periods and CME linear speed periods. The periodicities of 4 days and 10 days indicate the possible existence of the Rossby-type waves or planetary waves in Sun.

Different Periodicities in the Sunspot Area and the Occurrence of Solar Flares and Coronal Mass Ejections in Solar Cycle 23 – 24

D. P. **Choudhary**, J. K. Lawrence, M. Norris, A. C. Cadavid

Solar Physics, February **2014**, Volume 289, Issue 2, pp 649-656

In order to investigate the relationship between magnetic-flux emergence, solar flares, and coronal mass ejections (CMEs), we study the periodicity in the time series of these quantities. It has been known that solar flares, sunspot area, and photospheric magnetic flux have a dominant periodicity of about 155 days, which is confined to a part of the phase of the solar cycle. These periodicities occur at different phases of the solar cycle during successive phases. We present a time-series analysis of sunspot area, flare and CME occurrence during Cycle 23 and the rising phase of Cycle 24 from 1996 to 2011. We find that the flux emergence, represented by sunspot area, has multiple periodicities. Flares and CMEs, however, do not occur with the same period as the flux emergence. Using the results of this study, we discuss the possible activity sources producing emerging flux.

A statistical study of CME properties and of the correlation between flares and CMEs over the solar cycles 23 and 24

A. **Compagnino**, P. Romano, F. Zuccarello

Solar Phys. January **2017**, 292:5

http://arxiv.org/pdf/1609.08943v1.pdf

We investigated some properties of coronal mass ejections (CMEs), such as speed, acceleration, polar angle, angular width and mass, using data acquired by LASCO aboard of SOHO from July 31, 1997, to March 31, 2014, i.e., during the solar cycles 23 and 24. We used two CME catalogs: one provided by the CDAW Data Center and one obtained by the CACTus detection algorithm. For both dataset, we found that the number of CMEs observed during the peak of cycle 24 was higher or comparable to the one during cycle 23, although the photospheric activity during cycle 24 was weaker than during cycle 23. More precisely, using the CMEs detected by CACTus we noted that the number of events N is of the same order of magnitude during the peaks of the two cycles, but the peak of CME distribution during the cycle 24 is more extended in time (N > 1500 during 2012 and 2013). We ascribe the discrepancy between CDAW and CACTus results to the observer bias for CME definition in the CDAW catalog (Robbrecht et al., 2009; Webb and Howard, 2012; Yashiro et al., 2008). We also used a dataset containing 19811 flares of C, M, and X class, observed by GOES during the same period. Using both dataset, we studied the relationship between the mass ejected by the CMEs and the flux emitted during the corresponding flares: we found 11441 flares that were temporally-correlated with CMEs for CDAW and 9120 for CACTus. Moreover, we found a log-linear relationship between the flux of the flares integrated from the start to end in the 0.1-0.8 nm range and the

CME mass: log(CME mass) proportional to 0.23 x log(flare flux). We also found some differences in the mean CMEs velocity and acceleration between the events associated with flares and those that were not. In particular, the CMEs associated with flares are on average 100 km/s faster than the ones not associated with flares.

SOLAR CYCLE VARIATIONS OF CORONAL NULL POINTS: IMPLICATIONS FOR THE MAGNETIC BREAKOUT MODEL OF CORONAL MASS EJECTIONS

G. R. **Cook**1, D. H. Mackay1, and Dibyendu Nandy2

Astrophysical Journal, 704:1021–1035, **2009** October

In this paper, we investigate the solar cycle variation of coronal null points and magnetic breakout configurations in spherical geometry, using a combination of magnetic flux transport and potential field source surface models. Within the simulations, a total of 2843 coronal null points and breakout configurations are found over two solar cycles. It is found that the number of coronal nulls present at any time varies cyclically throughout the solar cycle, in phase with the flux emergence rate. At cycle maximum, peak values of 15–17 coronal nulls per day are found. No significant variation in the number of nulls is found from the rising to the declining phase. This indicates that the magnetic breakout model is applicable throughout both phases of the solar cycle. In addition, it is shown that when the simulations are used to construct synoptic data sets, such as those produced by Kitt Peak, the number of coronal nulls drops by a factor of 1⁄6. The vast majority of the coronal nulls are found to lie above the active latitudes and are the result of the complex nature of the underlying active region fields. Only 8% of the coronal nulls are found to be connected to the global dipole. Another interesting feature is that 18% of coronal nulls are found to lie above the equator due to cross-equatorial interactions between bipoles lying in the northern and southern hemispheres. As the majority of coronal nulls form above active latitudes, their average radial extent is found to be in the lowcorona below
1.25 $R_{\_}$ (175,000 km above the photosphere). Through considering the underlying photospheric flux, it is found that 71% of coronal nulls are produced though quadrupolar flux distributions resulting from bipoles in the same hemisphere interacting. When the number of coronal nulls present in each rotation is compared to the number of bipoles emerging, awide scatter is found. The ratio of coronal nulls to emerging bipoles is found to be approximately 1⁄3. Overall, the spatio-temporal evolution of coronal nulls is found to follow the typical solar butterfly diagram and is in qualitative agreement with the observed time dependence of coronal mass ejection source-region locations.

Coronal mass ejections: Solar cycle aspects

Hebe **Cremades** and O.C. St. Cyr

Advances in Space Research

Volume 40, Issue 7, Pages 1042-1048, **2007, File**

Research in the area of coronal mass ejections (CMEs) is now mature, since their discovery coincided with the first coronagraph that was flown in space in 1971. However, the continuity of space coronagraphs and similar instruments has allowed the detection and measurement of CMEs over almost three consecutive solar cycles. Their importance in the space weather field is well established, and some researchers believe the phenomenon may also be important for the longer-term space climate studies. In this review, we summarize the solar cycle variation of the main properties of CMEs detected by previous and ongoing missions. These include rate of detection, apparent angular width, detected mass, apparent speed, and apparent latitude. Their behavior in time is presented and discussed.

MLSO Mark III K-Coronameter Observations of the CME Rate from 1989 – 1996

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Solar Phys. Volume 290, Issue 10, pp 2951-2962 **2015**

We report here an attempt to fill the 1990 – 1995 gap in the CME rate using the Mauna Loa Solar Observatory's Mark III (Mk3) K-coronameter. The Mk3 instrument observed routinely several hours most days beginning in 1980 until it was upgraded to Mk4 in 1999. We describe the statistical properties of the CMEs detected during 1989 – 1996, and we determine a CME rate for each of those years. Since spaceborne coronagraphs have more complete duty cycles than a ground-based instrument at a single location, we compare the Mk3-derived CME rate from 1989 with the rate from the SMM C/P coronagraph, and from 1996 with the rate from the SOHO LASCO coronagraphs.

Effect of the Heliospheric State on CME Evolution

Fithanegest Kassa **Dagnew**, Nat Gopalswamy, Solomon Belay Tessema, Sachiko Akiyama, Seiji Yashiro

2022 ApJ 936 122

https://arxiv.org/ftp/arxiv/papers/2208/2208.03536.pdf

https://iopscience.iop.org/article/10.3847/1538-4357/ac8744/pdf

The culmination of solar cycle 24 by the end of 2019 has created the opportunity to compare the differing properties of coronal mass ejections (CMEs) between two whole solar cycles: Solar cycle 23 (SC 23) and Solar cycle 24 (SC 24). We report on the width evolution of limb CMEs in SC 23 and 24 in order to test the suggestion by Gopalswamy et al. (2015a) that CME flux ropes attain pressure balance at larger heliocentric distances in SC 24. We measure CME width as a function of heliocentric distance for a significantly large number of limb CMEs (~1000) and determine the distances where the CMEs reach constant width in each cycle. We introduced a new parameter: the transition height (hc) of a CME defined as the critical heliocentric distance beyond which the CME width stabilizes to a quasi-constant value. Cycle and phase-to-phase comparisons are based on this new parameter. We find that the average value of hc in SC 24 is 62% higher than in SC 23. SC 24 CMEs attain their peak width at larger distances from the Sun as compared to SC 23 CMEs. The enhanced transition height in SC 24 is new observational ratification of the anomalous expansion. The anomalous expansion of SC 24 CMEs which is caused by the weak state of the heliosphere, accounts for the larger heliocentric distance where the pressure balance between CME flux rope and the ambient medium is attained. **2014 May 6**

Intercycle and intracycle variation of halo CME rate obtained from SOHO/LASCO observations

Fithanegest Kassa **Dagnew**, Nat Gopalswamy, Solomon Belay Tessema, Sachiko Akiyama, Seiji Yashiro, Tesfay Yemane Tesfu

ApJ **903** 118 **2020**
https://arxiv.org/ftp/arxiv/papers/2009/2009.06033.pdf
https://doi.org/10.3847/1538-4357/abb887

We report on the properties of halo coronal mass ejections (HCMEs) in solar cycles 23 and 24. We compare the HCMEs properties between the corresponding phases (rise, maximum, and declining) in cycles 23 and 24 in addition to comparing those between the whole cycles. Despite the significant decline in the sunspot number (SSN) in cycle 24, which dropped by 46% with respect to cycle 23, the abundance of HCMEs is similar in the two cycles. The HCME rate per SSN is 44% higher in cycle 24. In the maximum phase, cycle-24 rate normalized to SSN increased by 127% while the SSN dropped by 43%. The source longitudes of cycle-24 HCMEs are more uniformly distributed than those in cycle 23. We found that the average sky-plane speed in cycle 23 is ~16% higher than that in cycle 24. The size distributions of the associated flares between the two cycles and the corresponding phases are similar. The average speed at a central meridian distance (CMD) = 600 for cycle 23 is ~28% higher than that of cycle 24. We discuss the unusual bump in HCME activity in the declining phase of cycle 23 as due to exceptional active regions that produced many CMEs during October 2003 to October 2005. The differing HCME properties in the two cycles can be attributed to the anomalous expansion of cycle-24 CMEs. Considering the HCMEs in the rise, maximum and declining phases, we find that the maximum phase shows the highest contrast between the two cycles.

A comparison of CME expansion speeds between solar cycles 23 and 24

Fithanegest Kassa **Dagnew**, Nat Gopalswamy, Solomon Belay Tessema

Journal of Physics Conference Series,to appear in the Proc. 19th International Astrophysics Conference held in Santa Fe, New Mexico, March 9 - 13, **2020**
https://arxiv.org/ftp/arxiv/papers/2007/2007.13204.pdf

We report on a comparison of the expansion speeds of limb coronal mass ejections (CMEs) between solar cycles 23 and 24. We selected a large number of limb CME events associated with soft X-ray flare size greater than or equal to M1.0 from both cycles. We used data and measurement tools available at the online CME catalog (this https URL) that consists of the properties of all CMEs detected by the Solar and Heliospheric Observatory's (SOHO) Large Angle and Spectrometric Coronagraph (LASCO). We found that the expansion speeds in cycle 24 are higher than those in cycle 23. We also found that the relation between radial and expansion speeds has different slopes in cycles 23 and 24. The cycle 24 slope is 45% higher than that in cycle 23. The expansion speed is also higher for a given radial speed. The difference increases with speed. For a 2000 km/s radial speed, the expansion speed in cycle 24 is ~48% higher. These results present additional evidence for the anomalous expansion of cycle 24-CMEs, which is due to the reduced total pressure in the heliosphere. **2001 April 02**

Does Nearby Open Flux Affect the Eruptivity of Solar Active Regions?

Marc L. **DeRosa**, Graham Barnes

ApJ **861** 131 **2018** **DOI** 10.3847/1538-4357/aac77a
https://arxiv.org/pdf/1802.01199.pdf

The most energetic solar flares are typically associated with the ejection of a cloud of coronal material into the heliosphere in the form of a coronal mass ejection (CME). However, there exist large flares which are not accompanied by a CME. The existence of these non-eruptive flares raises the question of whether such flares suffer from a lack of access to nearby open fields in the vicinity above the flare (reconnection) site. In this study, we use a sample of 56 flares from Sunspot Cycles 23 and 24 to test whether active regions that produce eruptive X-class

flares are preferentially located near coronal magnetic field domains that are open to the heliosphere, as inferred from a potential field source surface model. The study shows that X-class flares having access to open fields are eruptive at a higher rate than those for which access is lacking. The significance of this result should be moderated due to the small number of non-eruptive X-class flares in the sample, based on the associated Bayes factor. **2001-04-15, 2002-08-21 , 2013-11-10, 2014-12-20, 2017-09-06**
Table 1. Sample of flaring active regions

Variations in the Correlations of Acceleration and Force of Slow and Fast CMEs with Solar Activity during Solar Cycles 23 – 24

Zhanle **Du**
Solar Physics volume 296, Article number: 34 (**2021**)
https://link.springer.com/content/pdf/10.1007/s11207-021-01778-5.pdf

Studying the behavior of coronal mass ejections (CMEs) is important for both solar physics and space weather. The correlations of smoothed monthly mean daily integrated CME acceleration [a], mass [M], and the force [Ma] to drive CMEs with sunspot activity [RI] are analyzed for both slow and fast CMEs and for both Solar Cycles 23 and 24 separately. It is found that aa is inversely related to both RI and M. The correlation between Ma and RI for both slow and fast CMEs is negative at the rising phase of Solar Cycle 23 and positive otherwise. There is a sharp peak in γ=Ma/RI near the solar minimum (December 2008) for both slow and fast CMEs. However, for fast CMEs, there is a sharp negative peak near the previous solar minimum (August 1996) and another positive peak near the current solar minimum (2019). The positive (negative) peak tends to be related to the solar minimum from a stronger (weaker) to a weaker (stronger) solar cycle. These results suggest that the CME acceleration depends more on the strength of solar activity than on the CME’s speed. Stronger magnetic activity may slow down the CMEs that are too massive or too fast and weaker activity may speed up the CMEs that are less massive or too slow. During a few years’ period of magnetic-field polarity reversal around the solar minimum, the force provided by large-scale magnetic-field structures may not be strong enough to constrain CME motions, leading to the “escape” of CMEs with large |γ|.

Correlations Between CME Parameters and Sunspot Activity

Zhanle **Du**
Solar Physics, Volume 278, Number 1 (**2012**), 203-215
http://arxiv.org/abs/1112.5560v1

Smoothed monthly mean coronal mass ejection (CME) parameters (speed, acceleration, central position angle, angular width, mass, and kinetic energy) for Cycle 23 are cross-analyzed, showing that there is a high correlation between most of them. The CME acceleration (a) is highly correlated with the reciprocal of its mass (M), with a correlation coefficient r=0.899. The force (Ma) to drive a CME is found to be well anti-correlated with the sunspot number (R z), r=−0.750. The relationships between CME parameters and R z can be well described by an integral response model with a decay time scale of about 11 months. The correlation coefficients of CME parameters with the reconstructed series based on this model (rf1=0886) are higher than the linear correlation coefficients of the parameters with R z (r0=0830). If a double decay integral response model is used (with two decay time scales of about 6 and 60 months), the correlations between CME parameters and R z improve (rf2=0906). The time delays between CME parameters with respect to R z are also well predicted by this model (19/22=86%); the average time delays are 19 months for the reconstructed and 22 months for the original time series. The model implies that CMEs are related to the accumulation of solar magnetic energy. These relationships can help in understanding the mechanisms at work during the solar cycle.

Relationship between CME Parameters and Large-Scale Structure of Solar Magnetic Fields

V.G. **Fainshtein1,** E.V. Ivanov2
Sun and Geosphere, **2010**; 5(1): 28 – 33, **File**

In this work, we explore how the parameters of coronal mass ejections (CME) associated with eruptive prominences (EP) depend on their position relative to the coronal streamer belt (CSB) and coronal streamer chains (CSCs). We show that the CMEs whose axes are close to CSB propagate at lower mean speed than the CMEs observed in the vicinity of CSCs. The CMEs concentrated at CSCs have larger mean kinetic energy than those associated with CSB. The mean mass is maximum for the events associated with CSB and minimum for events observed near the base of open magnetic field configurations (OMF) - counterparts of coronal holes. The mean angular size is virtually the same for the CMEs of both types. The CME deviation from the radial trajectory has been studied. It is shown that CMEs may deviate noticeably from the radial propagation both on their way from the origin site (prominence eruption site) up to about 2.5 solar radii (Ro) and farther, from ~2.5 up to 20 Ro. In the epoch of solar minimum and at the rise of the cycle, the deviation in the first part of the trajectory (up to 2.5 Ro) is mainly towards the equator. In the other phases, no preferable direction has been revealed. As the EP latitude increases up to ±45o, the CME deviation, on the average, increases, too. It is shown that about 50% of all CMEs change the sense of deviation when passing from the near-solar part of the trajectory to its far part so that, as the CME moves away from the Sun, its propagation becomes more radial. The results obtained show that large-scale solar magnetic fields have a significant effect on the characteristics and propagation of coronal mass ejections.

Phase Relationships Between the CME-Energy Cycle, the Sunspot-Area Cycle and the Flare-Index Cycle

P. X. **Gao**, J. L. Xie, J. Zhong

Solar Phys., Volume 289, Issue 5, pp 1831-1841. **2014**

We study the phase relationships between the coronal-mass-ejection (CME) energy cycle, the sunspot-area cycle, and the flare-index cycle from 1996 to 2010. The results show the following: i) The activity cycle of the flare index significantly leads the activity cycle of the sunspot area. ii) The activity cycle of the CME energy is inferred to be almost in phase with the activity cycle of the sunspot area; the activity cycle of the CME energy at low latitudes slightly leads the activity cycle of the sunspot area; the CME energy at high latitudes is shown to significantly lag behind the sunspot area. iii) The CME energy is shown to significantly lag behind the flare index; the CME energy at low latitudes is shown to slightly lag behind the flare index; the CME energy at high latitudes is shown to significantly lag behind the flare index.

Speed Distributions of CMEs in Cycle 23 at Low and High Latitudes *

Peng-Xin **Gao** and Ke-Jun Li

Chin. J. Astron. Astrophys. Vol. 8 (**2008**), No. 2, 146–152

http://www.chjaa.org

Abstract We analyzed the speed (v) distributions of 11584 coronal mass ejections (CMEs) observed by the Large Angle and Spectrometric Coronagraph Experiment on board the Solar and Heliospheric Observatory (SOHO/LASCO) in cycle 23 from 1996 to 2006.We find that the speed distributions for high-latitude (HL) and low-latitude (LL) CME events are nearly identical and to a good approximation they can be fitted with a lognormal distribution. This finding implies that statistically the same driving mechanism of a nonlinear nature is acting in both HL and LL CME events, and CMEs are intrinsically associated with the source's magnetic structure on large spatial scales. Statistically, the HL CMEs are slightly slower than the LL CMEs. For HL and LL CME events respectively, the speed distributions for accelerating and decelerating events are nearly identical and also to a good approximation they can be both fitted with a lognormal distribution, thus supplementing the results obtained by Yurchyshyn et al.

UVCS/SoHO Catalog of Coronal Mass Ejections from 1996 to 2005: Spectroscopic Proprieties

S. **Giordano**, A. Ciaravella, J. Raymond, Y.-K. Ko and R. Suleiman

E-print, Feb **2013**; JGR, 118, Issue 3, pages 967–981, March **2013**

http://arxiv.org/pdf/1302.1998v2.pdf

Ultraviolet spectra of the extended solar corona have been routinely obtained by SoHO/UVCS since 1996. Sudden variations of spectral parameters are mainly due to the detection of Coronal Mass Ejections (CMEs) crossing the instrumental slit. We present a catalog of CME ultraviolet spectra based upon a systematic search of events in the LASCO CME catalog, and we discuss their statistical properties. Our catalog includes 1059 events through the end of 2005, covering nearly a full solar cycle. It is online available at the URL http://solarweb.oato.inaf.it/UVCS_CME and embedded in the online LASCO CME catalog (http://cdaw.gsfc.nasa.gov/CME_list). The emission lines observed provide diagnostics of CME plasma parameters, such as the light-of-sight velocity, density and temperature and allow to link the CME onset data to the extended corona white-light images. The catalog indicates whether there are clear signatures of features such as shock waves, current sheets, O VI flares, helical motions and which part of the CME structures (front, cavity or prominence material) are detected. The most common detected structure is the cool prominence material (in about 70% of the events). For each event, the catalog also contains movie, images, plots and information relevant to address detailed scientific investigations. The number of events detected in UV is about 1/10 of the LASCO CMEs, and about 1/4 of the halo events. We find that UVCS tends to detect faster, more massive and energetic CME than LASCO and for about 40% of the events events it has been possible to determine the plasma light-of-sight velocity. http://solarweb.oato.inaf.it/UVCS_CME

1999-05-17, 2000-06-28, 2003-11-04

Clustering of fast Coronal Mass Ejections during the solar cycles 23 and 24 and implications for CME-CME interactions

Jenny M. Rodríguez **Gómez**, Tatiana Podladchikova, Astrid Veronig, Alexander Ruzmaikin, Joan Feynman, Anatoly Petrukovich
ApJ **899** 47 **2020**
https://arxiv.org/pdf/2006.10404.pdf
https://doi.org/10.3847/1538-4357/ab9e72
We study the clustering properties of fast Coronal Mass Ejections (CMEs) that occurred during solar cycles 23 and 24. We apply two methods: the Max spectrum method can detect the predominant clusters and the de-clustering threshold time method provides details on the typical clustering properties and time scales. Our analysis shows that during the different phases of solar cycles 23 and 24, CMEs with speed ≥1000 km/s preferentially occur as isolated events and in clusters with on average two members. However, clusters with more members appear particularly during the maximum phases of the solar cycles. Over the total period and in the maximum phases of solar cycles 23 and 24, about 50% are isolated events, 18% (12%) occur in clusters with 2 (3) members, and another 20% in larger clusters ≥4, whereas in solar minimum fast CMEs tend to occur more frequently as isolated events (62%). During different solar cycle phases, the typical de-clustering time scales of fast CMEs are $\tau c=28-32$ hrs, irrespective of the very different occurrence frequencies of CMEs during solar minimum and maximum. These findings suggest that τc for extreme events may reflect the characteristic energy build-up time for large flare and CME-prolific active ARs. Associating statistically the clustering properties of fast CMEs with the Disturbance storm index \textit{Dst} at Earth suggests that fast CMEs occuring in clusters tend to produce larger geomagnetic storms than isolated fast CMEs. This may be related to CME-CME interaction producing a more complex and stronger interaction with the Earth magnetosphere. **2000-11-23-25, 2005-08-22-23, 2017-09-09-10**
5. GEO-EFFECTIVENESS OF CME CLUSTERS

Effect of the Weakened Heliosphere in Solar Cycle 24 on the Properties of Coronal Mass Ejections

N. **Gopalswamy**, S. Akiyama, S. Yashiro, G. Michalek, H. Xie, P. Mäkelä
Proc. 19th International Astrophysics Conference held in Santa Fe, New Mexico, March 9 - 13, **2020**
https://arxiv.org/ftp/arxiv/papers/2007/2007.08291.pdf
Solar cycle (SC) 24 has come to an end by the end of 2019, providing information on two full cycles to understand the manifestations of SC 24, the smallest cycle in the Space Age that has resulted in a weak heliospheric state indicated by the reduced pressure. The backreaction of the heliospheric state is to make the coronal mass ejections (CMEs) appear physically bigger than in SC 23, but their magnetic content has been diluted resulting in a lower geoeffectiveness. The heliospheric magnetic field is also lower in SC 24, leading to the dearth of high-energy solar energetic particle (SEP) events. These space weather events closely follow fast and wide (FW) CMEs. All but FW CMEs are higher in number in SC 24. The CME rate vs. sunspot number (SSN) correlation is high in both cycles but the rate increases faster in SC 24. We revisit the study of limb CMEs (those with source regions within 30 degrees from the limb) previously studied over partial cycles. We find that limb CMEs are slower in SC 24 as in the general population but wider. Limb halo CMEs follow the same trend of slower SC-24 CMEs. However, the SC-24 CMEs become halos at a shorter distance from the Sun. Thus, slower CMEs becoming halos sooner is a clear indication of the backreaction of the weaker heliospheric state on CMEs. We can further pin down the heliospheric state as the reason for the altered CME properties because the associated flares have similar distributions in the two cycles, unaffected by the heliospheric state. **2002-09-06**
Table 3. Halo CMEs originating within 30^0 from the limb in solar cycles 23 and 24

The State of the Heliosphere Revealed by Limb Halo Coronal Mass Ejections in Solar Cycles 23 and 24

Nat **Gopalswamy**, Sachiko Akiyama, Seiji Yashiro
ApJL 897:L1 **2020**
https://arxiv.org/ftp/arxiv/papers/2006/2006.05844.pdf
https://iopscience.iop.org/article/10.3847/2041-8213/ab9b7b/pdf
We compare the properties of halo coronal mass ejections (CMEs) that originate close to the limb (within a central meridian distance range of 60 to 90 deg) during solar cycles 23 and 24 to quantify the effect of the heliospheric state on CME properties. There are 44 and 38 limb halos in the cycles 23 and 24, respectively. Normalized to the cycle-averaged total sunspot number, there are 42 percent more limb halos in cycle 24. Although the limb halos as a population is very fast (average speed 1464 km s-1), cycle-24 halos are slower by 26 percent than the cycle-23 halos. We introduce a new parameter, the heliocentric distance of the CME leading edge at the time a CME becomes a full halo; this height is significantly shorter in cycle 24 (by 20 percent) and has a lower cutoff at 6 Rs. These results show that cycle-24 CMEs become halos sooner and at a lower speed than the cycle-23 ones. On the other hand, the flare sizes are very similar in the two cycles, ruling out the possibility of eruption characteristics contributing to the differing CME properties. In summary, this study reveals the effect of the reduced total pressure in the heliosphere that allows cycle-24 CMEs expand more and become halos sooner than in cycle 23. Our findings have important implications for the space-weather consequences of CMEs in cycle 25 (predicted to be similar to

cycle 24) and for understanding the disparity in halo counts reported by automatic and manual catalogs. **2011 September 22**
Table 1. List of Limb Halo CMEs from Solar Cycles 23 and 24

Coronal mass ejections as a new indicator of the active Sun
Nat Gopalswamy
Proc. IAU Symposium 340 on Long-term datasets for the understanding of solar and stellar magnetic cycles, February 19-24, 2018 Jaipur, India. 2018
https://arxiv.org/pdf/1804.11112.pdf
Coronal mass ejections (CMEs) have become one of the key indicators of solar activity, especially in terms of the consequences of the transient events in the heliosphere. Although CMEs are closely related to the sunspot number (SSN), they are also related to other closed magnetic regions on the Sun such as quiescent filament regions. This makes CMEs a better indicator of solar activity. While sunspots mainly represent the toroidal component of solar magnetism, quiescent filaments (and hence CMEs associated with them) connect the toroidal and poloidal components via the rush-to-the-pole (RTTP) phenomenon. Taking the end of RTTP in each hemisphere as an indicator of solar polarity reversal, it is shown that the north-south reversal asymmetry has a quasi-periodicity of 3-5 solar cycles. Focusing on the geospace consequences of CMEs, it is shown that the maximum CME speeds averaged over Carrington rotation period show good correlation with geomagnetic activity indices such as Dst and aa.

Short-term variability of the Sun-Earth system: an overview of progress made during the CAWSES-II period **Review**
Gopalswamy, Nat; Tsurutani, Bruce; Yan, Yihua
Progress in Earth and Planetary Science, Volume 2, article id. #13, 41 pp., **2015**
http://arxiv.org/pdf/1504.06332v1.pdf **File**
This paper presents an overview of results obtained during the CAWSES-II period on the short-term variability of the Sun and how it affects the near-Earth space environment. CAWSES-II was planned to examine the behavior of the solar-terrestrial system as the solar activity climbed to its maximum phase in solar cycle 24. After a deep minimum following cycle 23, the Sun climbed to a very weak maximum in terms of the sunspot number in cycle 24 (MiniMax24), so many of the results presented here refer to this weak activity in comparison with cycle 23. The short-term variability that has immediate consequence to Earth and geospace manifests as solar eruptions from closed-field regions and high-speed streams from coronal holes. Both electromagnetic (flares) and mass emissions (coronal mass ejections - CMEs) are involved in solar eruptions, while coronal holes result in high-speed streams that collide with slow wind forming the so-called corotating interaction regions (CIRs). Fast CMEs affect Earth via leading shocks accelerating energetic particles and creating large geomagnetic storms. CIRs and their trailing high-speed streams (HSSs), on the other hand, are responsible for recurrent small geomagnetic storms and extended days of auroral zone activity, respectively. The latter leads to the acceleration of relativistic magnetospheric `killer' electrons. One of the major consequences of the weak solar activity is the altered physical state of the heliosphere that has serious implications for the shock-driving and storm-causing properties of CMEs. Finally, a discussion is presented on extreme space weather events prompted by the **23 July 2012** super storm event that occurred on the backside of the Sun. Many of these studies were enabled by the simultaneous availability of remote sensing and in situ observations from multiple vantage points with respect to the Sun-Earth line.
TABLE 2 Major geomagnetic storms of cycle 24 (Dst < -100 nT)

High-energy solar particle events in cycle 24
Nat **Gopalswamy**, Pertti Makela, Seiji Yashiro, Hong Xie, Sachiko Akiyama, Neeharika Thakur
The 14th International Astrophysics Conference held in Tampa, FL during April 24-29, 2015. Accepted for publication in Journal of Physics: Conference Series (JPCS). edited by G. Zank, **2015**
http://arxiv.org/ftp/arxiv/papers/1507/1507.06162.pdf; **File**
The Sun is already in the declining phase of cycle 24, but the paucity of high-energy solar energetic particle (SEP) events continues with only two ground level enhancement (GLE) events as of March 31, 2015. In an attempt to understand this, we considered all the large SEP events of cycle 24 that occurred until the end of 2014. We compared the properties of the associated CMEs with those in cycle 23. We found that the CME speeds in the sky plane were similar, but almost all those cycle-24 CMEs were halos. A significant fraction of (16%) of the frontside SEP events were associated with eruptive prominence events. CMEs associated with filament eruption events accelerate slowly and attain peak speeds beyond the typical GLE release heights. When we considered only western hemispheric events that had good connectivity to the CME nose, there were only 8 events that could be considered

as GLE candidates. One turned out to be the first GLE event of cycle 24 (2012 May 17). In two events, the CMEs were very fast (>2000 km/s) but they were launched into a tenuous medium (high Alfven speed). In the remaining five events, the speeds were well below the typical GLE CME speed (~2000 km/s). Furthermore, the CMEs attained their peak speeds beyond the typical heights where GLE particles are released. We conclude that several factors contribute to the low rate of high-energy SEP events in cycle 24: (i) reduced efficiency of shock acceleration (weak heliospheric magnetic field), (ii) poor latitudinal and longitudinal connectivity), and (iii) variation in local ambient conditions (e.g., high Alfven speed).

Table 1. List of large SEP events from cycle 24

Table 2. List of candidate GLE events

Table 2. List of candidate GLE events

CME Date UT Imp. Flr Loc. FR Loc B0 Final Loc Vsp Max E Ip 4
2011/06/07 06:16 M2.5 S21W54 S08W51 +0.1 S08W51 1680 330-420 72 5
2011/08/04 03:41 M9.3 N19W36 N19W30 +6.0 N13W30 2450 165-500 96 6
2011/08/09 07:48 X6.9 N17W69 N08W68 +6.3 N02W68 2496 330-420 26 8
2011/11/26 06:09 C1.2 N08W49 N10W47 +1.5 N08W47 1187 40-80 80 13
2012/05/17 01:25 M5.1 N11W76 S07W76 -2.4 S05W76 1997 >700 255 23
2012/09/27 23:24 C3.7 N06W34 N16W29 +6.9 N09W29 1479 80-165 28 27
2013/05/22 13:08 M5.0 N15W70 N02W59 -1.8 N04W59 1881 330-420 1660 33
2014/02/20 07:26 M3.0 S15W73 S14W70 -7.0 S07W70 1281 330-420 22
27 January 2012, 2012 May 27, 2014 January 6,

The dynamics of eruptive prominences Review

Nat **Gopalswamy**

Solar Prominences, edited by J.-C. Vial & O. Engvold, Springer, in press (**2014**), Chapter 15, **File** Astrophysics and Space Science Library Volume 415, **2015**, pp 381-410

http://arxiv.org/pdf/1407.2594v1.pdf

http://link.springer.com/chapter/10.1007/978-3-319-10416-4_15

This chapter discusses the dynamical properties of eruptive prominences in relation to coronal mass ejections (CMEs). The fact that eruptive prominences are a part of CMEs is emphasized in terms of their physical association and kinematics. The continued propagation of prominence material into the heliosphere is illustrated using in-situ observations. The solar-cycle variation of eruptive prominence locations is discussed with a particular emphasis on the rush-to-the-pole (RTTP) phenomenon. One of the consequences of the RTTP phenomenon is polar CMEs, which are shown to be similar to the low-latitude CMEs. This similarity is important because it provides important clues to the mechanism by which CMEs erupt. The nonradial motion of CMEs is discussed, including the deflection by coronal holes that have important space weather consequences. Finally, the implications of the presented observations for the modeling CME modeling are outlined. **1998-01-25, 24-11-2000, 2001-12-20, 2003-02-18, 2003-08-16-19, 2009-05-05, 2009-11-08, 2013-09-29-30, 2012-03-12**,

The Peculiar Behavior of Halo Coronal Mass Ejections in Solar Cycle 24

N. **Gopalswamy**, H. Xie, S. Akiyama, P. Mäkelä, S. Yashiro, G. Michalek

ApJL 804 L23 **2015**

http://arxiv.org/ftp/arxiv/papers/1504/1504.01797.pdf

https://iopscience.iop.org/article/10.1088/2041-8205/804/1/L23/pdf

We report on a remarkable finding that the halo coronal mass ejections (CMEs) in cycle 24 are more abundant than in cycle 23, although the sunspot number in cycle 24 has dropped by about 40%. We also find that the distribution of halo-CME source locations is different in cycle 24: the longitude distribution of halos is much flatter with the number of halos originating at central meridian distance >/=60 degrees twice as large as that in cycle 23. On the other hand, the average speed and the associated soft X-ray flare size are the same in the two cycles, suggesting that the ambient medium into which the CMEs are ejected is significantly different. We suggest that both the higher abundance and larger central meridian longitudes of halo CMEs can be explained as a consequence of the diminished total pressure in the heliosphere in cycle 24 (Gopalswamy et al. 2014). The reduced total pressure allows CMEs expand more than usual making them appear as halos.

Anomalous Expansion of Coronal Mass Ejections during Solar Cycle 24 and its Space Weather Implications

Nat **Gopalswamy**, Sachiko Akiyama, Seiji Yashiro, Hong Xie, and Pertti M?kel?, Grzegorz Michalek

E-print, April **2014**; Geophysical Research Letters, Volume 41, Issue 8, pp. 2673-2680, **2014**

http://arxiv.org/pdf/1404.0252v1.pdf

The familiar correlation between the speed and angular width of coronal mass ejections (CMEs) is also found in solar cycle 24, but the regression line has a larger slope: for a given CME speed, cycle 24 CMEs are significantly wider than those in cycle 23. The slope change indicates a significant change in the physical state of the heliosphere, due to the weak solar activity. The total pressure in the heliosphere (magnetic + plasma) is reduced by ~40%, which leads to the anomalous expansion of CMEs explaining the increased slope. The excess CME expansion contributes to the diminished effectiveness of CMEs in producing magnetic storms during cycle 24, both because the magnetic content of the CMEs is diluted and also because of the weaker ambient fields. The reduced magnetic field in the heliosphere may contribute to the lack of solar energetic particles accelerated to very high energies during this cycle.

Coronal Mass Ejections of Solar Cycle 23

Nat **Gopalswamy**

J. Astrophys. Astr. , **2006, File**

I summarize the statistical, physical, and morphological properties of coronal mass ejections (CMEs) of solar cycle 23, as observed by the Solar and Heliospheric Observatory (SOHO) mission. The SOHO data is by far the most extensive data, which made it possible to fully establish the properties of CMEs as a phenomenon of utmost importance to Sun-Eath connection as well as to the heliosphere. I also discuss various subsets of CMEs that are of primary importance for impact on Earth.

Characterizing Coronal Mass Ejections in Solar Cycle Analysis

Ryan Manuel D. **Guido**

2018

https://arxiv.org/ftp/arxiv/papers/1804/1804.10870.pdf

The Sun is the major source of heat and light in our solar system. The solar cycle is the 11-year cycle of solar activity that can be determined by the rise and fall in the numbers and surface area of sunspots. Solar activity is associated with several factors including radio flux, solar irradiance, magnetic field, solar flares, coronal mass ejections, and solar cycles. This study attempts to determine the Sun's activity specifically for the coronal mass ejection, its trend during solar cycle 23, and its apparent difference. A time series analysis was used to measure the CME data for larger cases and to see the apparent difference and trends of the CMEs. The result shows that a decreasing trend of coronal mass ejection from the year 1996 to 2016. It is therefore concluded that the coronal mass ejection data are normally distributed while coronal mass ejections are distributed and curved normally as fluctuation was found in the intensity of the disturbed storm time index as the number of great geomagnetic storms undeniably increased in the ascending and descending phases of the cycle. This reveals that eventhough the Sun has cycles and trends, it shows its inherent characteristics. The Sun still possess getting more dynamic through time which showcases through the limited parameters involved in this study.

CMEs in the Heliosphere: I. A Statistical Analysis of the Observational Properties of CMEs Detected in the Heliosphere from 2007 to 2017 by STEREO/HI-1

R. A. **Harrison**, J. A. Davies, D. Barnes, J. P. Byrne, C. H. Perry, V. Bothmer, J. P. Eastwood, P. T. Gallagher, E. K. J. Kilpua, C. Möstl, L. Rodriguez, A. P. Rouillard, D. Odstrcil

Solar Phys. 293:77 **2018**

https://arxiv.org/ftp/arxiv/papers/1804/1804.02320.pdf

https://link.springer.com/content/pdf/10.1007%2Fs11207-018-1297-2.pdf

We present a statistical analysis of coronal mass ejections (CMEs) imaged by the Heliospheric Imager (HI) instruments aboard NASAs twin-spacecraft STEREO mission between April 2007 and August 2017 for STEREO-A and between April 2007 and September 2014 for STEREO-B. The analysis exploits a catalogue that was generated within the FP7 HELCATS project. Here, we focus on the observational characteristics of CMEs imaged in the heliosphere by the inner (HI-1) cameras. More specifically, in this paper we present distributions of the basic observational parameters - namely occurrence frequency, central position angle (PA) and PA span - derived from nearly 2000 detections of CMEs in the heliosphere by HI-1 on STEREO-A or STEREO-B from the minimum between Solar Cycles 23 and 24 to the maximum of Cycle 24; STEREO-A analysis includes a further 158 CME detections from the descending phase of Cycle 24, by which time communication with STEREO-B had been lost. We compare heliospheric CME characteristics with properties of CMEs observed at coronal altitudes, and with sunspot number. As expected, heliospheric CME rates correlate with sunspot number, and are not inconsistent with coronal rates once instrumental factors/differences in cataloguing philosophy are considered. As well as being more abundant, heliospheric CMEs, like their coronal counterparts, tend to be wider during solar maximum. Our results confirm previous coronagraph analyses suggesting that CME launch sites don't simply migrate to higher latitudes with increasing solar activity. At solar minimum, CMEs tend to be launched from equatorial latitudes while, at maximum, CMEs appear to be launched over a much wider latitude range; this has implications for understanding the CME/solar source association. Our analysis provides some supporting evidence for the systematic dragging of

CMEs to lower latitude as they propagate outwards. **2008-12-13, 2009-09-01, 2010-06-02, 2011-07-03, 2011-12-01, 2013-12-15**

Comparing Automatic CME Detections in Multiple LASCO and SECCHI Catalogs

Phillip **Hess**1 and Robin C. Colaninno

2017 ApJ 836 134

http://iopscience.iop.org.sci-hub.cc/0004-637X/836/1/134/

With the creation of numerous automatic detection algorithms, a number of different catalogs of coronal mass ejections (CMEs) spanning the entirety of the Solar and Heliospheric Observatory (SOHO) Large Angle Spectrometric Coronagraph (LASCO) mission have been created. Some of these catalogs have been further expanded for use on data from the Solar Terrestrial Earth Observatory (STEREO) Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) as well. We compare the results from different automatic detection catalogs (Solar Eruption Event Detection System (SEEDS), Computer Aided CME Tracking (CACTus), and Coronal Image Processing (CORIMP)) to ensure the consistency of detections in each. Over the entire span of the LASCO catalogs, the automatic catalogs are well correlated with one another, to a level greater than 0.88. Focusing on just periods of higher activity, these correlations remain above 0.7. We establish the difficulty in comparing detections over the course of LASCO observations due to the change in the instrument image cadence in 2010. Without adjusting catalogs for the cadence, CME detection rates show a large spike in cycle 24, despite a notable drop in other indices of solar activity. The output from SEEDS, using a consistent image cadence, shows that the CME rate has not significantly changed relative to sunspot number in cycle 24. These data, and mass calculations from CORIMP, lead us to conclude that any apparent increase in CME rate is a result of the change in cadence. We study detection characteristics of CMEs, discussing potential physical changes in events between cycles 23 and 24. We establish that, for detected CMEs, physical parameters can also be sensitive to the cadence.

Interplanetary Coronal Mass Ejections During Solar Cycles 23 and 24: Sun–Earth Propagation Characteristics and Consequences at the Near-Earth Region

M. Syed **Ibrahim**, Bhuwan Joshi, K.-S. Cho, R.-S. Kim, Y.-J. Moon

Solar Physics May **2019**, 294:54 **File**

sci-hub.se/10.1007/s11207-019-1443-5

In this article, we present a statistical study probing the relation between interplanetary coronal mass ejections (ICMEs) observed at 1 AU and their corresponding coronal mass ejections at the near-Sun region. The work encompasses the ICME activity that occurred during Solar Cycles 23 and 24 (1996 – 2017) while presenting an overall picture of ICME events during the complete Solar Cycle 24 for the first time. The importance of this study further lies in comparing two subsets of ICMEs, i.e. magnetic clouds (MCs) and ejecta (EJ), to explore how the observed structures of ICMEs at 1 AU could be associated with the properties of CMEs during their launch at the Sun. We find that, although Solar Cycle 24 saw a significant reduction in the number of ICME events compared to the previous cycle, the fraction of MCs was much higher during Cycle 24 than Cycle 23 (60% versus 41%). In general, the ICME transit-time decreases with the increase in the CME initial speed, although a broad range of transit times were observed for a given CME speed. We also find that the high-speed ICMEs ($\gtrsim$500 kms−1$\gtrsim$500 kms−1) form a distinct group in terms of the deficit in their transit times when compared with low-speed events ($\lesssim$500 kms−1$\lesssim$500 kms−1), which means that high-speed ICMEs acquire a much higher internal energy from the source active regions during the initiation process that effectively overcomes the aerodynamic drag force while they transit in the interplanetary medium. The CME propagation from the Sun to the near-Earth environment shows both an overall positive and negative acceleration (i.e. deceleration), although the acceleration is limited to only low-speed CMEs that are launched with a speed comparable with or less than the mean solar wind speed (≈400--450 kms−1≈400--450 kms−1). Within a given cycle, the similarities of MC and EJ profiles with respect to the CME–ICME speed relation as well as interplanetary acceleration support the hypothesis that all CMEs have a flux rope structure and that the trajectory of the CMEs essentially determines the observed ICME structure at 1 AU. **13 December 2006, 22 June 2015**

Properties and relationship between solar eruptive flares and Coronal Mass Ejections during rising phase of Solar Cycles 23 and 24

M.Syed **Ibrahim**, A.Shanmugaraju, Y.-J.Moon, B.Vrsnak, S.Umapathy

Advances in Space Research Volume 61, Issue 1, 1 January **2018**, Pages 540-551

https://ac.els-cdn.com/S027311771730666X/1-s2.0-S027311771730666X-main.pdf?_tid=4faa2d64-de43-11e7-8054-00000aab0f01&acdnat=1512976814_f6b3fddde3a016b209ccb968996e7adf

Statistical relationship between major flares and the associated CMEs during rising phases of Solar Cycles 23 and 24 are studied. Totally more than 6000 and 10,000 CMEs were observed by SOHO/LASCO (Solar and Heliospheric Observatory/Large Angle Spectrometric Coronagraph) during 23rd [May 1996–June 2002] and 24th [December 2008–December 2014] solar cycles, respectively. In particular, we studied the relationship between properties of flares and CMEs using the limb events (longitude 70–85°) to avoid projection effects of CMEs and partial occultation of flares that occurred near 90°. After selecting a sample of limb flares, we used certain spatial and temporal constraints to find the flare-CME pairs. Using these constraints, we compiled 129 events in Solar Cycle 23 and 92 events in Solar Cycle 24. We compared the flare-CME relationship in the two solar cycles and no significant differences are found between the two cycles. We only found out that the CME mean width was slightly larger and the CME mean acceleration was slightly higher in cycle 24, and that there was somewhat a better relation between flare flux and CME deceleration in cycle 24 than in cycle 23.

Propagation of Coronal Mass Ejections Observed During the Rising Phase of Solar Cycle 24

M. Syed **Ibrahim**, P. K. Manoharan, A. Shanmugaraju

Solar Physics September **2017**, 292:133 **File**

In this study, we investigate the interplanetary consequences and travel time details of 58 coronal mass ejections (CMEs) in the Sun–Earth distance. The CMEs considered are halo and partial halo events of width >120>120°. These CMEs occurred during 2009 – 2013, in the ascending phase of the Solar Cycle 24. Moreover, they are Earth-directed events that originated close to the centre of the solar disk (within about ±30±30° from the Sun's centre) and propagated approximately along the Sun–Earth line. For each CME, the onset time and the initial speed have been estimated from the white-light images observed by the LASCO coronagraphs onboard the SOHO space mission. These CMEs cover an initial speed range of ∼260--2700 kms−1∼260--2700 kms−1. For these CMEs, the associated interplanetary shocks (IP shocks) and interplanetary CMEs (ICMEs) at the near-Earth environment have been identified from *in-situ* solar wind measurements available at the OMNI data base. Most of these events have been associated with moderate to intense IP shocks. However, these events have caused only weak to moderate geomagnetic storms in the Earth's magnetosphere. The relationship of the travel time with the initial speed of the CME has been compared with the observations made in the previous Cycle 23, during 1996 – 2004. In the present study, for a given initial speed of the CME, the travel time and the speed at 1 AU suggest that the CME was most likely not much affected by the drag caused by the slow-speed dominated heliosphere. Additionally, the weak geomagnetic storms and moderate IP shocks associated with the current set of Earth-directed CMEs indicate magnetically weak CME events of Cycle 24. The magnetic energy that is available to propagate CME and cause geomagnetic storm could be significantly low. **15 March 2013**.
Table 1 Observational parameters of 58 CME events (eight interacting CMEs are marked with asterisk symbols).

Coronal Dynamic Activities in the Declining Phase of a Solar Cycle

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

2016

https://arxiv.org/pdf/1610.02944v1.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**.

COMPARISON BETWEEN 2D AND 3D PARAMETERS OF 306 FRONT-SIDE HALO CMEs FROM 2009 TO 2013

Soojeong **Jang**1,2, Y.-J. Moon1, R.-S. Kim2,3, Harim Lee1, and K.-S. Cho

2016 ApJ 821 95 DOI: 10.3847/0004-637X/821/2/95

We investigate 306 LASCO front-side halo (partial and full) CMEs from 2009 to 2013, which are well-observed by both the Solar and Heliospheric Observatory (SOHO) and the Solar TErrestrial RElations Observatory (STEREO). These CMEs have two-dimensional (2D) parameters, such as speed, angular width, and propagation direction, from a single spacecraft (SOHO), as well as three-dimensional (3D) parameters from a multi-spacecraft (STEREO). These 2D CME parameters, which are based on plane-of-sky observations, are taken from theSOHO LASCO CME catalog and the NGDC flare catalog. We have determined their 3D CME parameters using the Stereoscopic CME analysis tool (StereoCAT) provided by the Community Coordinated Modeling Center at NASA. We compare 2D and 3D CME parameters, making this the most comprehensive statistical study on CME 3D parameters. As a result, we find that 2D speeds underestimate the 3D speed by about 20%. The 3D width ranges from 30° to 158°, values which are much smaller than the 2D widths with a mean value of 225°. We also find that the ratio between the 2D and 3D widths decreases with central meridian distance. The 3D propagation directions are similar to the flare locations, with a mean absolute difference of about 13°. The width-speed relationship in 3D is much stronger than that in 2D.

The visual complexity of coronal mass ejections follows the solar cycle

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Space Weather e2020SW002556 **Volume18, Issue10** **2020**

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https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2020SW002556

The Heliospheric Imagers on board NASA's twin STEREO spacecraft show that coronal mass ejections (CMEs) can be visually complex structures. To explore this complexity, we created a citizen science project with the UK Science Museum, in which participants were shown pairs of CME images and asked to decide which image in each pair appeared the most 'complicated'. A Bradley-Terry model was then applied to these data to rank the CMEs by their 'complicatedness', or 'visual complexity'. This complexity ranking revealed that the annual average visual complexity values follow the solar activity cycle, with a higher level of complexity being observed at the peak of the cycle. The average complexity of CMEs observed by STEREO-A was also found to be significantly higher than those observed by STEREO-B. Visual complexity was found to be associated with CME size and brightness, but our results suggest that complexity may be influenced by the scale-sizes of structure in the CMEs. **15June 2011**

A COMPARISON OF THE INTENSITIES AND ENERGIES OF GRADUAL SOLAR ENERGETIC PARTICLE EVENTS WITH THE DYNAMICAL PROPERTIES OF ASSOCIATED CORONAL MASS EJECTIONS

S. W. **Kahler**1 and A. Vourlidas

2013 ApJ 769 143

Gradual solar energetic particle (SEP) events observed at 1 AU are produced by shocks driven by coronal mass ejections (CMEs). Characterizations of the remotely imaged CMEs and of their associated SEP events observed in situ can be used to increase our ability to forecast SEP events and to understand better the physical connections between the two phenomena. We carry out a statistical comparison of the peak intensities Ip20, of 120 western-hemisphere 20 MeV SEP events with those of their associated CMEs observed by the Solar and Heliospheric Observatory/Large Angle and Spectrometric Coronagraph over the past solar cycle. For a subset of 96 events observed with the EPACT instrument on the Wind spacecraft we also compare the SEP 2 MeV peak intensities Ip2, power-law energy spectral exponents γ, total SEP energies Esep, and 2 MeV nuc–1 H/He ratios with CME properties. New analyses of white-light CME images enable us to improve calculations of the CME masses and potential energies and then to determine two values of their kinetic energies based on frontal V (fr) and center-of-mass V (cm) speeds. Despite considerable scatter in the SEP and CME data, the large dynamical ranges of both the SEP and CME parameters allow us to determine statistical trends in the comparisons of the logs of the parameters. Ip2, Ip20, and Esep are significantly correlated with CME kinetic energies, masses, and speeds, while γ trends lower (harder). Those correlations are higher with V (fr) than with V (cm) parameters, indicating a less significant role for the body of the CME than for the CME front in SEP production. The high ratios (≥10%) of Esep to CME energies found by Mewaldt et al. are confirmed, and the fits are consistent with a linear relationship between the two energies. The 2 MeV nuc–1 H/He ratios decrease with increasing CME speeds, which may be an effect of shock geometry. We discuss several factors that limit the estimates of both the SEP and CME energies.

Observational Properties of Coronal Mass Ejections **Review**

Kahler S.W.

Solar Eruptions and Energetic Particles, ed. N. Gopalswamy, R. Mewaldt, and J. Torsti, Geophysical Monograph 165, p. 21-32, **2006**.

https://sci-hub.ru/10.1029/165GM05

Coronal mass ejections (CMEs) have been known and observed for over 30 years. The total number of observed CMEs is now approaching 10,000, most of them detected with the LASCO coronagraph on the SOHO spacecraft. We review statistical work on CME widths, latitudes, accelerations, speeds, masses, and rates of occurrence. Solar-cycle variations of these parameters are presented. Recent work has focused on CME internal properties and compositions and on CME dynamics, particularly at low (< 3 Ro) altitudes. The challenges to understand the magnetic topology of narrow (< 20 deg width) CMEs, to determine the relationship of coronal holes to CMEs, and to observe magnetic reconnection that effects magnetic disconnections of CMEs from the Sun are discussed.

Kinematic study of radio-loud CMEs associated with solar flares and DH type II radio emissions during solar cycles 23 and 24

P. Pappa **Kalaivani**, O. Prakash, A. Shanmugaraju, G. Michalek, G. Selvarani

Solar Phys. **2022**

https://arxiv.org/pdf/2204.07968.pdf

We have statistically analyzed 379 radio-loud (RL) CMEs and their associated flares during the period 1996 - 2019 covering both solar cycles (SC) 23 and 24. We classified them into two sets of populations based on the observation period: i) 235 events belong to SC 23 (August 1996 - December 2008) and ii) 144 events belong to SC 24 (January 2009 - December 2019). The average residual acceleration of RL CMEs in SC 24 (--17.39 ± 43.51 m s−2) is two times lower than that of the RL CMEs in SC 23 (--8.29 ± 36.23 m s−2), which means that deceleration of RL CMEs in SC 24 is twice as fast as in SC 23. RL CMEs of SC 23 (1443 ± 504 km s−1; 13.82 ± 7.40 \emph{R}⊙) reach their peak speed at higher altitudes than RL CMEs of SC 24 (1920 ± 649 km s−1; 12.51 ± 7.41 \emph{R}⊙).We also observed that the mean apparent widths of RL CMEs in SC 23 are less than in SC 24which is statistically significant. SC 23 has a lower average CME nose height (3.85 \emph{R}⊙) at the start time of DH type II bursts than that of SC 24 (3.46 \emph{R}⊙). The starting frequencies of DH type II bursts associated with RL CMEs for SC 24 are significantly larger (formed at lower heights) than that of SC 23. We found that there is a good correlation between the drift rates and the mid-frequencies of DH type II radio bursts for both the solar cycles (\emph{R} = 0.80, ϵ = 1.53). Most of the RL CMEs kinematics and their associated solar flare properties are found similar for SC 23 and SC 24. We concluded that the reduced total pressure in the heliosphere for SC 24 enables RL CMEs to expand wider and decelerate faster, resulting in DH type II radio emissions at lower heights than SC 23.

Gnevyshev Peaks in the CME Average Speeds in Cycle 23

R. P. **Kane**

Solar Phys., 261(1), Page: 209 – 213, **2010, File**

Sunspots have a major 11-year cycle, but the three to four years near the maximum may show two or more peaks called Gnevyshev peaks. Earlier, it was reported that in Solar Cycle 23, the double peak in sunspot numbers was reflected in the electromagnetic radiations and coronal mass ejection (CME) frequencies in the solar atmosphere, but with phase differences. In this article, it is shown that the average CME speeds also show Gnevyshev peaks but with phase differences.

Fluctuations of Solar Activity during the Declining Phase of the 11-Year Sunspot Cycle

R.P. **Kane**

Solar Phys (**2009**) 255: 163–168, DOI 10.1007/s11207-008-9303-8

Gnevyshev Peaks and Gaps for Coronal Mass Ejections of Different Widths Originating in Different Solar Position Angles

R.P. **Kane**

Solar Phys (**2008**) 249: 369–380

http://springerlink.com/content/h528p165342m2716/fulltext.pdf

The sunspot number series at the peak of sunspot activity often has two or three peaks (Gnevyshev peaks; Gnevyshev, *Solar Phys.* **1**, 107, 1967; *Solar Phys.* **51**, 175, 1977). The sunspot group number (SGN) data were examined for 1997 – 2003 (part of cycle 23) and compared with data for coronal mass ejection (CME) events. It was noticed that they exhibited mostly two Gnevyshev peaks in each of the four latitude belts 0° – 10°, 10° – 20°, 20 ° – 30°, and >30°, in both N (northern) and S (southern) solar hemispheres. The SGN were confined to within latitudes ±50° around the Equator, mostly around ±35°, and seemed to occur later in lower latitudes, indicating possible latitudinal migration as in the Maunder butterfly diagrams. In CMEs, less energetic CMEs (of widths <71°) showed prominent Gnevyshev peaks during sunspot maximum years in almost all latitude belts, including near the poles. The CME activity lasted longer than the SGN activity. However, the CME peaks did not match the SGN peaks and were almost simultaneous at different latitudes, indicating no latitudinal migration. In energetic CMEs including halo CMEs, the Gnevyshev peaks were obscure and ill-defined. The solar polar magnetic fields show polarity reversal during sunspot maximum years, first at the North Pole and, a few months later, at the South Pole. However, the CME peaks and gaps did not match with the magnetic field reversal times, preceding them by several months, rendering any cause – effect relationship doubtful.

Latitude Dependence of the Variations of Sunspot Group Numbers (SGN) and Coronal Mass Ejections (CMEs) in Cycle 23

R.P. **Kane**

Solar Phys (**2008**) 249: 355–367

http://springerlink.com/content/y81lg024vg2826n5/fulltext.pdf

The 12-month running means of the conventional sunspot number *Rz*, the sunspot group numbers (SGN) and the frequency of occurrence of Coronal Mass Ejections (CMEs) were examined for cycle 23 (1996 – 2006). For the whole disc, the SGN and *Rz* plots were almost identical. Hence, SGN could be used as a proxy for *Rz*, for which latitude data are not available. SGN values were used for 5° latitude belts 0° – 5°, 5° – 10°, 10° – 15°, 15° – 20°, 20° – 25°, 25° – 30° and >30°, separately in each hemisphere north and south. Roughly, from latitudes 25° – 30° N to 20° – 25° N, the peaks seem to have occurred *later* for lower latitudes, from latitudes 20° – 25° N to 15° – 20° N, the peaks are stagnant or occur slightly *earlier*, and then from latitudes 15° – 20° N to 0° – 5° N, the peaks seem to have occurred again *later* for lower latitudes. Thus, some latitudinal migration is suggested, clearly in the northern hemisphere, not very clearly in the southern hemisphere, first to the equator in 1998, stagnant or slightly poleward in 1999, and then to the equator again from 2000 onwards, the latter reminiscent of the Maunder butterfly diagrams. Similar plots for CME occurrence frequency also showed multiple peaks (two or three) in almost all latitude belts, but the peaks were almost simultaneous at all latitudes, indicating no latitudinal migration. For similar latitude belts, SGN and CME plots were dissimilar in almost all latitude belts except 10° – 20° S. The CME plots had in general more peaks than the SGN plots, and the peaks of SGN often did not match with those of CME. In the CME data, it was noticed that whereas the values declined from 2002 to 2003, there was no further decline during 2003 – 2006 as one would have expected to occur during the declining phase of sunspots, where 2007 is almost a year of sunspot minimum. An inquiry at GSFC-NASA revealed that the person who creates the preliminary list was changed in 2004 and the new person picks out more weak CMEs. Thus a subjectivity (overestimates after 2002) seems to be involved and hence, values obtained before and during 2002 are not directly comparable to values recorded after 2002, except for CMEs with widths exceeding 60°.

Similarities and Dissimilarities between the Variations of CME and Other Solar Parameters at Different Heliographic Latitudes and Time Scales

R.P. **Kane**

Solar Phys (**2008**) 248: 177–190

From the LASCO CME (CoronalMass Ejection) catalog, the occurrence frequencies of all CMEs (all strong and weak CMEs, irrespective of their widths) were calculated for 3-month intervals and their 12-month running means determined for cycle 23 (1996 –2007) and were compared with those of other solar parameters. The annual values of all-CME frequency were very well correlated (+0.97) with sunspot numbers, but several other parameters also had similarly high correlations. Comparisons of 12-month running means indicated that the sunspot numbers were very well correlated with solar electromagnetic radiations (Lyman-〈, 2800-MHz flux, coronal green line index, solar flare indices, and X-ray background); but for corpuscular radiations [proton fluxes, solar energetic particles (SEP), CMEs, interplanetary CMEs (ICMEs), and stream interaction regions (SIR)] and solar open magnetic fields, the correlations were lower. A notable feature was the appearance of two peaks during 2000 – 2002, and those double peaks in different parameters matched approximately except for proton fluxes and SEP and SIR frequencies. When hemispheric intensities were considered, north – south asymmetries appeared, more in some parameters than in others. When intensities in smaller latitude belts (10°) were compared, sunspot group numbers (SGN) were found to be confined mostly to latitudes within ±30° of the solar equator, showing *two* peaks in all latitude belts, and during the course of the 11-year cycle, the double peaks shifted from middle to equatorial solar latitudes, just as seen in the Maunder butterfly diagrams. In contrast, CME frequency was comparable at all latitude belts (including high, near-polar latitudes), having more than two peaks in almost all latitude belts, and the peaks were almost simultaneous in all latitude belts. Thus, the matching of SGN peaks with those of CME peaks was poor. Incidentally, the CME frequency data for all events (all widths) after 2003 are not comparable to earlier data, owing to inclusion of very weak (narrow) CMEs in later years. The frequencies are comparable with earlier data only for widths exceeding about 70°.

The 12-month running means of the conventional sunspot number *Rz*, the sunspot group numbers (SGN) and the frequency of occurrence of Coronal Mass Ejections (CMEs) were examined for cycle 23 (1996 – 2006). For the whole disc, the SGN and *Rz* plots were almost identical. Hence, SGN could be used as a proxy for *Rz*, for which latitude data are not available. SGN values were used for 5° latitude belts 0° – 5°, 5° – 10°, 10° – 15°, 15° – 20°, 20° – 25°, 25° – 30° and >30°, separately in each hemisphere north and south. Roughly, from latitudes 25° – 30° N to 20° – 25° N, the peaks seem to have occurred *later* for lower latitudes, from latitudes 20° – 25° N to 15° – 20° N, the peaks are stagnant or occur slightly *earlier*, and then from latitudes 15° – 20° N to 0° – 5° N, the peaks seem to have occurred again *later* for lower latitudes. Thus, some latitudinal migration is suggested, clearly in the northern hemisphere, not very clearly in the southern hemisphere, first to the equator in 1998, stagnant or slightly poleward in 1999, and then to the equator again from 2000 onwards, the latter reminiscent of the Maunder butterfly diagrams. Similar plots for CME occurrence frequency also showed multiple peaks (two or three) in almost all latitude belts, but the peaks were almost simultaneous at all latitudes, indicating no latitudinal migration. For similar latitude belts, SGN and CME plots were dissimilar in almost all latitude belts except 10° – 20° S. The CME plots had in general more peaks than the SGN plots, and the peaks of SGN often did not match with those of CME. In the CME data, it was noticed that whereas the values declined from 2002 to 2003, there was no further decline during 2003 – 2006 as one would have expected to occur during the declining phase of sunspots, where 2007 is almost a year of sunspot minimum. An inquiry at GSFC-NASA revealed that the person who creates the preliminary list was changed in 2004 and the new person picks out more weak CMEs. Thus a subjectivity (overestimates after 2002) seems to be involved and hence, values obtained before and during 2002 are not directly comparable to values recorded after 2002, except for CMEs with widths exceeding 60°.

COMPARISON OF THE VARIATIONS OF CMEs AND ICMEs WITH THOSE OF OTHER SOLAR AND INTERPLANETARY PARAMETERS DURING SOLAR CYCLE 23

R. P. **KANE**

Solar Physics (**2006**) 233: 107–115

This paper examines the variations of coronal mass ejections (CMEs) and interplanetary CMEs (ICMEs) during solar cycle 23 and compares these with those of several other indices. During cycle 23, solar and interplanetary parameters had an increase from 1996 (sunspot minimum) to ~2000, but the interval 1998–2002 had short-term fluctuations. Sunspot numbers had peaks in 1998, 1999, 2000 (largest), 2001 (second largest), and 2002. Other solar indices had matching peaks, but the peak in 2000 was larger than the peak in 2001 only for a few indices, and smaller or equal for other solar indices. The solar open magnetic flux had very different characteristics for different solar latitudes. The high solar latitudes (45◦–90◦) in both N and S hemispheres had flux evolutions *anti-parallel* to sunspot activity. Fluxes in low solar latitudes (0◦–45◦) evolved roughly parallel to sunspot activity, but the finer structures (peaks etc. during sunspot maximum years) did not match with sunspot peaks. Also, the low latitude fluxes had considerable N–S asymmetry. For CMEs and ICMEs, there were increases similar to sunspots during 1996–2000, and during 2000–2002, there was good matching of peaks. But the peaks in 2000 and 2001 for CMEs and ICMEs had similar sizes, in contrast to the 2000 peak being greater than the 2001 peak for sunspots. Whereas ICMEs started decreasing from 2001 onwards, CMEs continued to remain high in 2002, probably due to extra contribution from high-latitude prominences, which had no equivalent interplanetary ICMEs or shocks. Cosmic ray intensity had features matching with those of sunspots during 2000–2001, with the 2000 peak (on a reverse scale, actually a cosmic ray decrease or trough) larger than the 2001 peak. However, cosmic ray decreases started with a delay and ended with a delay with respect to sunspot activity.

Using the Coronal Evolution to Successfully Forward Model CMEs' In Situ Magnetic Profiles†

C. **Kay**, N. Gopalswamy

JGR **2017**

Predicting the effects of a coronal mass ejection (CME) impact requires knowing if impact will occur, which part of the CME impacts, and its magnetic properties. We explore the relation between CME deflections and rotations, which change the position and orientation of a CME, and the resulting magnetic profiles at 1 AU. For 45 STEREO-era, Earth-impacting CMEs, we determine the solar source of each CME, reconstruct its coronal position and orientation, and perform a ForeCAT [Kay et al., 2015a] simulation of the coronal deflection and rotation. From the reconstructed and modeled CME deflections and rotations we determine the solar cycle variation and correlations with CME properties. We assume no evolution between the outer corona and 1 AU and use the ForeCAT results to drive the FIDO in situ magnetic field model [Kay et al., 2017a], allowing for comparisons with ACE and Wind observations. We do not attempt to reproduce the arrival time. On average FIDO reproduces the in situ magnetic field for each vector component with an error equivalent to 35% of the average total magnetic field strength when the total modeled magnetic field is scaled to match the average observed value. Random walk best fits distinguish between ForeCAT's ability to determine FIDO's input parameters and the limitations of the simple flux rope model. These best fits reduce the average error to 30%. The FIDO results are sensitive to changes of order a degree in the CME latitude, longitude, and tilt, suggesting that accurate space weather predictions require accurate measurements of a CME's position and orientation.

Using the Coronal Evolution to Successfully Forward Model CMEs' In Situ Magnetic Profiles

C. **Kay**, N. Gopalswamy

JGR Volume 122, Issue 12 December **2017** Pages 11,810–11,834

http://sci-hub.tw/http://onlinelibrary.wiley.com/doi/10.1002/2017JA024541/abstract;jsessionid=2DF604EC239663BA90D09F3C3BE44317.f01t04

Predicting the effects of a coronal mass ejection (CME) impact requires knowing if impact will occur, which part of the CME impacts, and its magnetic properties. We explore the relation between CME deflections and rotations, which change the position and orientation of a CME, and the resulting magnetic profiles at 1 AU. For 45 STEREO-era, Earth-impacting CMEs, we determine the solar source of each CME, reconstruct its coronal position and orientation, and perform a ForeCAT (Forecasting a CME's Altered Trajectory) simulation of the coronal deflection and rotation. From the reconstructed and modeled CME deflections and rotations, we determine the solar cycle variation and correlations with CME properties. We assume no evolution between the outer corona and 1 AU and use the ForeCAT results to drive the ForeCAT In situ Data Observer (FIDO) in situ magnetic field model, allowing for comparisons with ACE and Wind observations. We do not attempt to reproduce the arrival time. On average FIDO reproduces the in situ magnetic field for each vector component with an error equivalent to 35% of the average total magnetic field strength when the total modeled magnetic field is scaled to match the average observed value. Random walk best fits distinguish between ForeCAT's ability to determine FIDO's input parameters and the limitations of the simple flux rope model. These best fits reduce the average error to 30%. The FIDO results are sensitive to changes of order a degree in the CME latitude, longitude, and tilt, suggesting that accurate space weather predictions require accurate measurements of a CME's position and orientation. **24 May 2010.**

Association of solar flares with coronal mass ejections accompanied by Deca-Hectometric type II radio burst for two solar cycles 23 and 24

Hema **Kharayat**, Lalan Prasad & Sumit Pant

Astrophysics and Space Science May **2018**, 363:87

http://sci-hub.tw/10.1007/s10509-018-3309-y

The aim of present study is to find the association of solar flares with coronal mass ejections (CMEs) accompanied by Deca-Hectometric (DH) type II radio burst for the period 1997–2014 (solar cycle 23 and ascending phase of solar cycle 24). We have used a statistical analysis and found that 10–20∘ latitudinal belt of northern region and 80–90∘ longitudinal belts of western region of the sun are more effective for flare-CME accompanied by DH type II radio burst events. M-class flares (52%) are in good association with the CMEs accompanied by DH type II radio burst. Further, we have calculated the flare position and found that most frequent flare site is at the center of the CME span. However, the occurrence probability of all flares is maximum outside the CME span. X-class flare associated CMEs have maximum speed than that of M, C, and B-class flare associated CMEs. We have also found a good correlation between flare position and central position angle of CMEs accompanied by DH type II radio burst.

Statistical Analysis of the Relation between Coronal Mass Ejections and Solar Energetic Particles

Kosuke **Kihara**, Yuwei Huang, Nobuhiko Nishimura, Nariaki V. Nitta, Seiji Yashiro, Kiyoshi Ichimoto, Ayumi Asai

ApJ **2020**

https://arxiv.org/pdf/2007.08062.pdf **File**

To improve the forecasting capability of impactful solar energetic particle (SEP) events, the relation between coronal mass ejections (CMEs) and SEP events needs to be better understood. Here we present a statistical study of SEP occurrences and timescales with respect to the CME source locations and speeds, considering all 257 fast (vCME ≥ 900 km/s) and wide (angular width ≥ 60∘) CMEs that occurred between December 2006 and October 2017. We associate them with SEP events at energies above 10 MeV. Examination of the source region of each CME reveals that CMEs more often accompany a SEP event if they originate from the longitude of E20-W100 relative to the observer. However, a SEP event could still be absent if the CME is < 2000 km/s. For the associated CME-SEP pairs, we compute three timescales for each of the SEP events, following Kahler (2005, 2013); namely the timescale of the onset (TO), the rise time (TR), and the duration (TD). They are correlated with the longitude of the CME source region relative to the footpoint of the Parker spiral (ΔΦ) and vCME. The TO tends to be short for |ΔΦ| < 60∘ . This trend is weaker for TR and TD. The SEP timescales are only weakly correlated with vCME. Positive correlations of both TR and TD with vCME are seen in poorly connected (large |ΔΦ|) events. Additionally, TO appears to be negatively correlated with vCME for events with small |ΔΦ|. **3 Sep 2013**

Table 1. Properties of Fast and Wide CMEs and Associated SEP Events (2006-2017)

Table 2. Timescales of SEP Events

Temporal and Periodic Variation of the MCMESI for the Last Two Solar Cycles; Comparison with the Number of Different Class X-Ray Solar Flares

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Solar Phys. **2020**

https://arxiv.org/ftp/arxiv/papers/2008/2008.11506.pdf

In this study we compared the temporal and periodic variations of the Maximum CME Speed Index (MCMESI) and the number of different class (C, M, and X) solar X-Ray flares for the last two solar cycles (Cycle 23 and 24). To obtain the correlation between the MCMESI and solar flare numbers the cross correlation analysis was applied to monthly data sets. Also to investigate the periodic behavior of all data sets the Multi Taper Method (MTM) and the Morlet wavelet analysis method were performed with daily data from 2009 to 2018. To evaluate our wavelet analysis Cross Wavelet Transform (XWT) and Wavelet Transform Coherence (WTC) methods were performed. Causal relationships between datasets were further examined by Convergence Cross Mapping (CCM) method. In results of our analysis we found followings; 1) The C class X-Ray flare numbers increased about 16 % during the solar cycle 24 compared to cycle 23, while all other data sets decreased; the MCMESI decreased about 16 % and the number of M and X class flares decreased about 32 %. 2) All the X-Ray solar flare classes show remarkable positive correlation with the MCMESI. While the correlation between the MCMESI and C class flares comes from the general solar cycle trend, it mainly results from the fluctuations in the data in case of the X class flares. 3) In general, all class flare numbers and the MCMESI show similar periodic behavior. 4) The 546 days periodicity detected in the MCMESI may not be of solar origin or at least the solar flares are not the source of this periodicity. 5) C and M Class solar flares have a stronger causative effect on the MCMESI compared to X class solar flares. However the only bidirectional causal relationship is obtained between the MCMESI and C class flare numbers.

Maximum CME speed as an indicator of solar and geomagnetic activities

A. **Kilcik**1, V.B. Yurchyshyn1, V. Abramenko1, P.R. Goode1, N. Gopalswamy2, A. Ozguc3, J.P. Rozelot4

BBSO Preprint #1456, 2010**;** Ap. J. 727:44 (6pp), **2011** January, **File**

We investigate the relationship between the monthly averaged maximal speeds of coronal mass ejections (CMEs), international sunspot number (ISSN) and the geomagnetic Dst and Ap indices covering the 1996-2008 time interval (solar cycle 23). Our new findings are as follows. i) There is a noteworthy relationship between monthly averaged maximum CME speeds and sunspot numbers, Ap and Dst indices. Various peculiarities in the monthly Dst index are better correlated with the fine structures in the CME speed profile than that in the ISSN data. ii) Unlike the sunspot numbers, the CME speed index does not exhibit a double peak maximum. Instead, the CME speed profile peaks during the declining phase of solar cycle 23. Similar to the Ap index, both CME speed and the Dst indices lag behind the sunspot numbers by several months. iii) CME number shows a double peak similar to that seen in the sunspot numbers. The CME occurrence rate remained very high even near the minimum of the solar cycle 23, when both sunspot number and the CME average maximum speed were reaching their minimum values. iv) A well defined peak of the Ap index between May 2002 and August 2004 was co-temporal with the excess of the mid-latitude coronal holes during solar cycle 23. The above findings suggest that the CME speed index may be a useful indicator of both solar and geomagnetic activity. It may have advantages over the sunspot numbers, because it better reflects the intensity of Earth directed solar eruptions.

A Statistical Study of the Relationship Between the Sunspot Number, Maximum CME Speed and Geomagnetic Indices

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BBSO Preprint #1424, **2010; File**

We investigated the relationship between the monthly averaged maximal speeds of coronal mass ejections (CMEs), sunspot number (SSN) and the geomagnetic Dst and Ap indices covering the 1996-2008 time interval. The study was carried out using frequency and correlation analyses. Frequency analysis of the maximum speed of CMEs (or CME speed index) shows a cyclic behavior similar to that found for SSN and the Ap index. Our new findings are as follows. 1) Unlike the SSN, the CME speed index does not exhibit a double peak maximum. 2) The CME speed index has a correlative relationship with SSN and Dst and Ap indices (correlation coefficients are 0.76, -0.53, 0.68 respectively). Various peculiarities in the monthly Dst index are better correlated with the fine structures in the CME speed profile than that in the SSN data. 3) Similar to the Ap index, both CME speed and the Dst indices lag behind the sunspot numbers by several months. We thus conclude that CME speed index may be a good parameter to describe the geo-effectiveness of solar activity

Solar Sources of Interplanetary Coronal Mass Ejections During the Solar Cycle 23/24 Minimum

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Solar Phys., 2014

We examine solar sources for 20 interplanetary coronal mass ejections (ICMEs) observed in 2009 in the near-Earth solar wind. We performed a detailed analysis of coronagraph and extreme ultraviolet (EUV) observations from the Solar Terrestrial Relations Observatory (STEREO) and Solar and Heliospheric Observatory (SOHO). Our study shows that the coronagraph observations from viewpoints away from the Sun–Earth line are paramount to locate the solar sources of Earth-bound ICMEs during solar minimum. SOHO/LASCO detected only six CMEs in our sample, and only one of these CMEs was wider than 120∘. This demonstrates that observing a full or partial halo CME is not necessary to observe the ICME arrival. Although the two STEREO spacecraft had the best possible configuration for observing Earth-bound CMEs in 2009, we failed to find the associated CME for four ICMEs, and identifying the correct CME was not straightforward even for some clear ICMEs. Ten out of 16 (63 %) of the associated CMEs in our study were "stealth" CMEs, i.e. no obvious EUV on-disk activity was associated with them. Most of our stealth CMEs also lacked on-limb EUV signatures. We found that stealth CMEs generally lack the leading bright front in coronagraph images. This is in accordance with previous studies that argued that stealth CMEs form more slowly and at higher coronal altitudes than non-stealth CMEs. We suggest that at solar minimum the slow-rising CMEs do not draw enough coronal plasma around them. These CMEs are hence difficult to discern in the coronagraphic data, even when viewed close to the plane of the sky. The weak ICMEs in our study were related to both intrinsically narrow CMEs and the non-central encounters of larger CMEs. We also demonstrate that narrow CMEs (angular widths ≤ 20∘) can arrive at Earth and that an unstructured CME may result in a flux rope-type ICME.

Relation of CME Speed and Magnetic Helicity in CME Source Regions on the Sun during the Early Phase of Solar Cycles 23 and 24

R.-S. **Kim** S.-H. Park S. Jang K.-S. Cho B. S. Lee
Sol Phys (**2017**) 292: 66. doi:10.1007/s11207-017-1079-2
To investigate the relations between coronal mass ejection (CME) speed and magnetic field properties measured in the photospheric surface of CME source regions, we selected 22 disk CMEs in the rising and early maximum phases of the current Solar Cycle 24. For the CME speed, we used two-dimensional (2D) projected speed observed by

the Large Angle and Spectroscopic Coronagraph onboard the Solar and Heliospheric Observatory (SOHO/LASCO), as well as a 3D speed calculated from the triangulation method using multi-point observations. Two magnetic parameters of CME source regions were considered: the average of magnetic helicity injection rate and the total unsigned magnetic flux. We then classified the selected CMEs into two groups, showing: i) a monotonically increasing pattern with one sign of helicity (group A: 16 CMEs) and ii) a pattern of significant helicity injection followed by its sign reversal (group B: 6 CMEs). We found that: 1) 3D speed generally shows better correlations with the magnetic parameters than the 2D speed for 22 CME events in Solar Cycle 24; 2) 2D speed and the magnetic parameters of 22 CME events in this solar cycle have lower values than those of 47 CME events in Solar Cycle 23; 3) all events of group B in Solar Cycle 24 occur only after the beginning of the maximum phase, a trend well consistent with that shown in Solar Cycle 23; 4) the 2D speed and the helicity parameter of group B events continue to increase in the declining phase of Solar Cycle 23, while those of group A events abruptly decrease in the same period. Our results indicate that the two CME groups have a different tendency in the solar cycle variations of CME speed and the helicity parameters. Active regions that show a complex helicity evolution pattern tend to appear in the maximum and declining phases, while active regions with a relatively simple helicity evolution pattern appear throughout the whole solar cycle.

On the occurrence of type IV solar radio bursts in the solar cycle 24 and their association with coronal mass ejections

Anshu **Kumari**, D. E. Morosan, E. K. J. Kilpua

2021 *ApJ* **906** 79

https://arxiv.org/pdf/2011.03509.pdf

https://doi.org/10.3847/1538-4357/abc878

Solar activity, in particular coronal mass ejections (CMEs), are often accompanied by bursts of radiation at metre wavelengths. Some of these bursts have a long duration and extend over a wide frequency band, namely, type IV radio bursts. However, the association of type IV bursts with coronal mass ejections is still not well understood. In this article, we perform the first statistical study of type IV solar radio bursts in the solar cycle 24. Our study includes a total of 446 type IV radio bursts that occurred during this cycle. Our results show that a clear majority, ~81% of type IV bursts, were accompanied by CMEs, based on a temporal association with white-light CME observations. However, we found that only ~2.2% of the CMEs are accompanied by type IV radio bursts. We categorised the type IV bursts as moving or stationary based on their spectral characteristics and found that only ~18% of the total type IV bursts in this study were moving type IV bursts. Our study suggests that type IV bursts can occur with both `Fast' (≥500 km/s) and `Slow' (<500 km/s), and also both `Wide' (≥60∘) and `Narrow' (<60∘) CMEs. However, the moving type IV bursts in our study were mostly associated with `Fast' and `Wide' CMEs (~52%), similar to type II radio bursts. Contrary to type II bursts, stationary type IV bursts have a more uniform association with all CME types. **October 03, 2011, October 18, 2017**

The State of the White-Light Corona over the Minimum and Ascending Phases of Solar Cycle 25 -- Comparison with Past Cycles

Philippe **Lamy** (1), Hugo Gilardy (1)

Solar Phys. **297**, Article number: 140 **2022**

https://arxiv.org/pdf/2205.06462.pdf

https://doi.org/10.1007/s11207-022-02057-7

We report on the state of the corona over the minimum and ascending phases of Solar Cycle (SC) 25 on the basis of the temporal evolutions of its radiance and of the properties of coronal mass ejections (CMEs) as determined from white-light observations performed by the SOHO/LASCO-C2 coronagraph. These evolutions are further compared with those determined during the past two SC. The integrated radiance of the K-corona and the occurrence rate of CMEs closely track the indices/proxies of solar activity, prominently the total magnetic field for the radiance and the radio flux for the CMEs, all undergoing a steep increase during the ascending phase of SC 25. This increase is much steeper than anticipated on the basis of the predicted quasi similarity between SC 25 and 24, and is confirmed by the recent evolution of the sunspot number. The radiance reached the same base level during the minima of SC 24 and 25, but the latitudinal extent of the streamer belt differed, being flatter during the latter minimum and in fact more similar to that of the minimum of SC 23. Phasing the descending branches of SC 23 and 24 led to a duration of SC 24 of 11.0 years, similar to that given by the sunspot number. In contrast, the base level of the occurrence rate of CMEs during the minimum of SC 25 was significantly larger than during the two previous minima. The southern hemisphere is conspicuously more active than the northern one in agreement with several predictions and the current evolution of the hemispheric sunspot numbers. The mean apparent width of CMEs and the number of halo CMEs remains at relatively large, constant levels throughout the early phase of SC 25 implying the persistence of weak total pressure in the heliosphere. These results and the perspective of a corona more active than anticipated are extremely promising for the forthcoming observations by Solar Orbiter and Parker Solar Probe.

Coronal Mass Ejections over Solar Cycles 23 and 24 **Review**

P. L. **Lamy**, O. Floyd, B. Boclet, J. Wojak, H. Gilardy…
Space Science Reviews August **2019**, 215:39
https://link.springer.com/content/pdf/10.1007%2Fs11214-019-0605-y.pdf
We present a statistical analysis of solar coronal mass ejections (CMEs) based on 23 years of quasi-continuous observations with the LASCO coronagraph, thus covering two complete Solar Cycles (23 and 24). We make use of five catalogs, one manual (CDAW) and four automated (ARTEMIS, CACTus, SEEDS, and CORIMP), to characterize the temporal evolutions and distributions of their properties: occurrence and mass rates, waiting times, periodicities, angular width, latitude, speed, acceleration and kinetic energy. Our analysis points to inevitable discrepancies between catalogs due to the complex nature of CMEs and to the different techniques implemented to detect them, but also to large areas of convergence that are critically important to ascertain the reliability of the results. The temporal variations of these properties are compared to four indices/proxies of solar activity: the radio flux at 10.7 cm (F10.7), the international sunspot number (SSN), the sunspot area (SSA), and the total magnetic field (TMF), either globally or separately in the northern and southern hemispheres in the case of the last three. We investigate the association of CMEs with flares, erupting prominences, active regions and streamers. We find that the CME occurrence and mass rates globally track the indices/proxies of solar activity with no time lag, prominently the radio flux F10.7, but the linear relationships were different during the two solar cycles, implying that the CME rates were relatively larger during SC 24 than during SC 23. However, there exists a pronounced divergence of the CME rates in the northern hemisphere during SC 24 as these rates were substantially larger than predicted by the temporal variation of the sunspot number. The distribution of kinetic energy follows a log-normal law and that of angular width follows an exponential law implying that they are random and independent. The distribution of waiting time (WTD) has a long power-law tail extending from 3 to 100 hr with a power-law index which varies with the solar cycle, thus reflecting the temporal variability of the process of CME formation. There is very limited evidence for periodicities in the occurrence and mass rates of CMEs, a striking feature being the dichotomy between the two hemispheres. Rather weak correlations are present among the various CME parameters and particularly none between speed and acceleration. The association of CMEs with flares and erupting prominences involves only a few percents of the overall population of CMEs but the associated CMEs have distinctly larger mass, speed, kinetic energy and angular width. A more pronounced association is found with active regions but the overwhelming one is with streamers further confirmed by the similarity between the heliolatitudinal distribution of CMEs and that of the electron density reconstructed from time-dependent tomographic inversion. We find no evidence of bimodality in the distributions of physical parameters that would support the existence of two classes, particularly that based on speed and acceleration, the distributions thus favoring a continuum of properties. There exists an excess of narrows CMEs which however does not define a special class. These narrow CMEs are likely associated with the ubiquitous mini-filaments eruptions and with mini flux ropes originating from small magnetic bipoles, the disruption mechanisms being similar to those launching larger CMEs. This supports the concept that CMEs at large arise from closed-field coronal regions at both large and small scales.

Space, time and velocity association of successive coronal mass ejections
Alejandro **Lara**. Nat Gopalswamy, Tatiana Niembro, Román Pérez-Enríquez, Seiji Yashiro
A&A 635, A112 **2020**
https://arxiv.org/pdf/2002.03998.pdf
https://doi.org/10.1051/0004-6361/201936016
Our aim is to investigate the possible physical association between consecutive coronal mass ejections (CMEs). Through a statistical study of the main characteristics of 27761 CMEs observed by SOHO/LASCO during the past 20 years. We found the waiting time (WT) or time elapsed between two consecutive CMEs is <5 hrs for 59\% and <25 hrs for 97\% of the events, and the CME WTs follow a Pareto Type IV statistical distribution. The difference of the position-angle of a considerable population of consecutive CME pairs is less than 30∘, indicating the possibility that their source locations are in the same region. The difference between the speed of trailing and leading consecutive CMEs follows a generalized Student t-distribution. The fact that the WT and the speed difference have heavy-tailed distributions along with a detrended fluctuation analysis shows that the CME process has a long-range dependence. As a consequence of the long-range dependence, we found a small but significative difference between the speed of consecutive CMEs, with the speed of the trailing CME being higher than the speed of the leading CME. The difference is largest for WTs < 2 hrs and tends to be zero for WTs > 10 hrs, and it is more evident during the ascending and descending phases of the solar cycle. We suggest that this difference may be caused by a drag force acting over CMEs closely related in space and time.

The Source Region of Coronal Mass Ejections
Alejandro **Lara**
The Astrophysical Journal, Vol. 688, No. 1: 647-655, **2008**.
http://www.journals.uchicago.edu/doi/abs/10.1086/591725
We use the large database of coronal mass ejections (CMEs) observed by SOHO LASCO during solar cycle 23 to statistically obtain information about the source regions of CMEs. By determining the functional form of the

position angle (P.A.) distribution, we are able to construct a random set of CME direction vectors (DVCME) under the following conditions: (1) assume a radial movement of the CME center of mass and (2) propose a latitude and longitude (λ, ϕ) photospheric position for the DVCME in such a way that (3) the distribution of the projected (on the plane of the sky) DVCME must be equal to the observed distribution of position angles. We iteratively adjust the proposed positions (λ, ϕ) until both distributions are equal, based on the Kolmogorov-Smirnov statistics. In this way, we obtain a set of DVCME that we use to study the relation between the CME source region and the overall coronal and photospheric magnetic field structures. We found that the CME activity has a small "preference" for the northern hemisphere during the first part of solar cycle, and for the southern hemisphere during the second part. This P.A. asymmetry is related to the overall magnetic field north-south asymmetry. We found also that most CME source regions are situated between high magnetic field regions, and are not necessarily associated to any one such region. For instance, during the minimum and ascending phase of the cycle, ~85% and ~60%, respectively, of the CME source regions are confined to the equatorial plane ($\lambda = 0°$), between the two active region belts ($\lambda = \pm 40°$). We conclude from this study that CME sources are in general high-altitude magnetic loops, or more precisely, transequatorial loops, occurring during the minimum and ascending phases of the cycle.

Short-Period Fluctuations in Coronal Mass Ejection Activity during Solar Cycle 23

Alejandro **Lara** · Andrea Borgazzi · Odim Mendes Jr. · Reinaldo R. Rosa · Margarete Oliveira Domingues

Solar Phys (2008) 248: 155–166
http://www.springerlink.com/content/44k0w353n6445633/fulltext.pdf

We have constructed a time series of the number of coronal mass ejections (CMEs) observed by SOHO/LASCO during solar cycle 23. Using spectral analysis techniques (the maximum entropy method and wavelet analysis) we found short-period (<one year) semiperiodic activity. Among others, we found interesting periodicities at 193, 36, 28, and 25 days. We discuss the implications of such short-period activity in terms of the emergence and escape of magnetic flux from the convection zone, through the low solar atmosphere (where these periodicities have been found for numerous activity parameters), toward interplanetary space. This analysis shows that CMEs remove the magnetic flux in a quasiperiodic process in a way similar to that of magnetic flux emergence and other solar eruptive activity.

Solar cycle evolution of ICME sheath regions at 1 AU

C. **Larrodera**1★, M. Temmer2 and M. Owens3

A&A, 705, A21 (**2026**)
https://www.aanda.org/articles/aa/pdf/2026/01/aa57295-25.pdf

Aims. We investigate the evolution of interplanetary coronal mass ejection (ICME) sheath regions at 1 AU across solar cycles 23, 24, and the rising phase of 25, focusing on their variability and turbulence in relation to upstream solar wind conditions and the global heliospheric state.
Methods. Using a dataset of over 900 ICME sheath events, we applied statistical metrics such as the interquartile range (IQR) and the turbulence index (TI) to quantify variability and turbulence. The analysis compares full and rising phases of solar cycles and examines both local ICME parameters (e.g., sheath total pressure, non-radial flows) and global interplanetary indicators such as open solar flux (OSF).
Results. From solar cycle 23 to solar cycle 24, the sheath total pressure and magnetic field strength decreased by over 40% and 25%, respectively, accompanied by reduced turbulence and variability. In contrast, the rising phase of solar cycle 25 shows increased magnetic complexity, particularly in non-radial field components, despite stable bulk parameters. Non-radial flow patterns also shift from tangentially dominated in solar cycle 23 and solar cycle 24 to normal-dominated in solar cycle 25, suggesting changes in ICME orientation and sheath formation mechanisms. No significant correlation is found between OSF and sheath properties, indicating that local solar wind and ICME-specific factors are the primary drivers of sheath evolution.
Conclusions. The study reinforces the importance of upstream solar wind dynamics in relation to variations in plasma and magnetic field measured components of ICME sheaths. The derived trends in turbulence, magnetic orientation, and flow geometry suggest that sheath regions are sensitive indicators of solar cycle phase and should be considered as distinct, structured components in ICME modeling.

DEPENDENCE OF OCCURRENCE RATES OF SOLAR FLARES AND CORONAL MASS EJECTIONS ON THE SOLAR CYCLE PHASE AND THE IMPORTANCE OF LARGE-SCALE CONNECTIVITY

Kangjin **Lee**1, Y.-J. Moon1, and V. M. Nakariakov1,2

2016 ApJ 831 131 DOI 10.3847/0004-637X/831/2/131

We investigate the dependence of the occurrence rates of major solar flares (M- and X-class) and front-side halo coronal mass ejections (FHCMEs), observed from 1996 to 2013, on the solar cycle (SC) phase for six active McIntosh sunspot group classes: Fkc, Ekc, Dkc, Fki, Eki, and Dki. We classify SC phases as follows: (1) ascending

phase of SC 23 (1996–1999), (2) maximum phase of SC 23 (2000–2002), (3) descending phase of SC 23 (2003–2008), and (4) ascending phase of SC 24 (2009–2013). We find that the occurrence rates of major flares and FHCMEs during the descending phase are noticeably higher than those during the other phases for most sunspot group classes. For the most active sunspot group class, Fkc, the occurrence rate of FHCMEs during the descending phase of SC 23 is three times as high as that during the ascending phase of SC 23. The potential of each McIntosh sunspot group class to produce major flares or FHCMEs is found to depend on the SC phase. The occurrence rates (R) of major flares and FHCMEs are strongly anti-correlated with the annual average latitude of the sunspot groups (L): for major flares and for FHCMEs. This finding indicates the possible role of large-scale coronal connectivity, e.g., trans-equatorial loops, in powerful energy releases. Interestingly, this relationship is very similar to that between the volumetric coronal heating rate and X-ray loop lengths, indicating common energy release mechanisms.

Magnetic Flux of Active Regions Determining the Eruptive Character of Large Solar Flares

Ting **Li**, Yijun Hou, Shuhong Yang, Jun Zhang, Lijuan Liu, Astrid M. Veronig

ApJ **900** 128 **2020**

https://arxiv.org/pdf/2007.08127.pdf

https://doi.org/10.3847/1538-4357/aba6ef

We establish the largest eruptive/confined flare database to date and analyze 322 flares of \emph{GOES} class M1.0 and larger that occurred during 2010−2019, i.e., almost spanning the entire solar cycle 24. We find that the total unsigned magnetic flux (ΦAR) of active regions (ARs) is a key parameter in governing the eruptive character of large flares, with the proportion of eruptive flares exhibiting a strong anti-correlation with ΦAR. This means that an AR containing a large magnetic flux has a lower probability for the large flares it produces to be associated with a coronal mass ejection (CME). This finding is supported by the high positive correlation we obtained between the critical decay index height and ΦAR, implying that ARs with a larger ΦAR have a stronger magnetic confinement. Moreover, the confined flares originating from ARs larger than 1.0×1023 Mx have several characteristics in common: stable filament, slipping magnetic reconnection and strongly sheared post-flare loops. Our findings reveal new relations between the magnetic flux of ARs and the occurrence of CMEs in association with large flares. These relations obtained here provide quantitative criteria for forecasting CMEs and adverse space weather, and have also important implications for "superflares" on solar-type stars and stellar CMEs. **2011-10-02, 06 March 2012, 2012-07-10, 2014-10-22, 2014-10-24, 2014-12-19**

HMI Naggets # 162 **2021** http://hmi.stanford.edu/hminuggets/?p=3624

A Twin-CME Scenario for Ground Level Enhancement Events

G. **Li** · R. Moore · R.A. Mewaldt · L. Zhao · A.W. Labrador

Space Sci Rev, 171, Numbers 1-4, 141-160, **2012, File**

Ground Level Enhancement (GLEs) events are extreme Solar Energetic Particle (SEP) events. Protons in these events often reach ~GeV/nucleon. Understanding the underlying particle acceleration mechanism in these events is a major goal for Space Weather studies. In Solar Cycle 23, a total of 16 GLEs have been identified. Most of them have preceding CMEs and in-situ energetic particle observations show some of them are enhanced in ICME or flare-like material. Motivated by this observation, we discuss here a scenario in which two CMEs erupt in sequence during a short period of time from the same Active Region (AR) with a pseudo-streamer-like pre-eruption magnetic field configuration. The first CME is narrower and slower and the second CME is wider and faster. We show that the magnetic field configuration in our proposed scenario can lead to magnetic reconnection between the open and closed field lines that drape and enclose the first CME and its driven shock. The combined effect of the presence of the first shock and the existence of the open close reconnection is that when the second CME erupts and drives a second shock, one finds both an excess of seed population and an enhanced turbulence level at the front of the second shock than the case of a single CME-driven shock. Therefore, a more efficient particle acceleration will occur. The implications of our proposed scenario are discussed.

Cyclical Behavior of Coronal Mass Ejections

K.J. **Li** · P.X. Gao · Q.X. Li · J. Mu · T.W. Su

Solar Phys., **2009,** 257(1), 149 – 154, DOI: 10.1007/s11207-009-9333-x, **File**

With the use of coronal mass ejections (CMEs) observed by the Large Angle and Spectrometric Coronagraph (LASCO) onboard the *Solar and Heliospheric Observatory* (SOHO) from January 1996 through December 2005, it is found that, for the cyclical activity of CMEs, there is surprisingly no equatorward drift at low latitudes (thus, no “butterfly diagram”) and no poleward drift at high latitudes, and no antiphase relationship between CME activity at low and high latitudes. The cyclical behaviors of CMEs differ in a significant way from that of the small-scale solar photospherical and chromospherical phenomena. Thus, our analysis leads to results that are inconsistent with a close, physical relationship with small-scale aspects of solar activity, and it is suggested that there is possibly a single so-called large-scale activity cycle in CMEs.

The Temporal and Spatial Behaviors of CME Occurrence Rate at Different Latitudes

Jiaqi **Lin**, Feng Wang, Linhua Deng, Hui Deng, Ying Mei, Yangfan Xie
ApJ **932** 62 **2022**
https://arxiv.org/pdf/2205.05908
https://iopscience.iop.org/article/10.3847/1538-4357/ac6f54/pdf
The statistical study of the Coronal Mass Ejections (CMEs) is a hot topic in solar physics. To further reveal the temporal and spatial behaviors of the CMEs at different latitudes and heights, we analyzed the correlation and phase relationships between the occurrence rate of CMEs, the Coronal Brightness Index (CBI), and the 10.7-cm solar radio flux (F10.7). We found that the occurrence rate of the CMEs correlates with CBI relatively stronger at high latitudes (>=60) than at low latitudes (<=50). At low latitudes, the occurrence rate of the CMEs correlates relatively weaker with CBI than F10.7. There is a relatively stronger correlation relationship between CMEs, F10.7, and CBI during Solar Cycle 24(SC24) than Solar Cycle 23 (SC23). During SC23, the high-latitude CME occurrence rate lags behind F10.7 by three months, and during SC24, the low-latitude CME occurrence rate leads to the low-latitude CBI by one month. The correlation coefficient values turn out to be larger when the very faint CMEsare removed from the samples of the CDAW catalog. Based on our results, we may speculate that the source regions of the high/low-latitude CMEs may vary in height, and the process of magnetic energy accumulation and dissipation is from the lower to the upper atmosphere of the Sun. The temporal offsets between different indicators could help us better understand the physical processes responsible for the solar-terrestrial interactions.

Importance of CME Radial Expansion on the Ability of Slow CMEs to Drive Shocks

Noé **Lugaz**1,2, Charles J. Farrugia1,2, Reka M. Winslow1, Colin R. Small2, Thomas Manion2, and Neel P. Savani3
2017 ApJ 848 75
http://sci-hub.cc/http://iopscience.iop.org/0004-637X/848/2/75/
Coronal mass ejections (CMEs) may disturb the solar wind by overtaking it or expanding into it, or both. CMEs whose front moves faster in the solar wind frame than the fast magnetosonic speed drive shocks. Such shocks are important contributors to space weather, by triggering substorms, compressing the magnetosphere, and accelerating particles. In general, near 1 au, CMEs with speed greater than about 500 km s^{-1} drive shocks, whereas slower CMEs do not. However, CMEs as slow as 350 km s^{-1} may sometimes, although rarely, drive shocks. Here we study these slow CMEs with shocks and investigate the importance of CME expansion in contributing to their ability to drive shocks and in enhancing shock strength. Our focus is on CMEs with average speeds under 375 km s^{-1}. From Wind measurements from 1996 to 2016, we find 22 cases of such shock-driving slow CMEs, and for about half of them (11 out of the 22), the existence of the shock appears to be strongly related to CME expansion. We also investigate the proportion of all CMEs with speeds under 500 km s^{-1} with and without shocks in solar cycles 23 and 24, depending on their speed. We find no systematic difference, as might have been expected on the basis of the lower solar wind and Alfvén speeds reported for solar cycle 24 versus 23. The slower expansion speed of CMEs in solar cycle 24 might be an explanation for this lack of increased frequency of shocks, but further studies are required. **1997 July 15, 2001 April 21, 2001 October 31,**
Table 1 List of 22 CMEs with Average Speed Less or Equal to 375 km s^{-1} That Drove a Shock

CME–flare association during the 23rd solar cycle

A. **Mahrous**, M. Shaltout, M.M. Beheary, R. Mawad, and M. Youssef
Advances in Space Research, Volume 43, Issue 7, 1 April **2009**, Pages 1032-1035
The relation between coronal mass ejections (CMEs) and solar flares are statistically studied. More than 10,000 CME events observed by SOHO/LASCO durifg the period 1996–2005 have been analyzed. The soft X-ray flux measurements provided by the Geostationary Operational Environmental Satellite (GOES), recorded more than 20,000 flares in the same time period. The data is filtered under certain temporal and spatial conditions to select the CME–flare associated events. The results show that CME–flare associated events are triggered with a lift-off time within the range 0.4–1.0 h. We list a set of(41 CME–flare associated events satisfying the temporal and spatial conditions. The listed events show a good correlation between the CME energy and the X-ray flux of the CME–flare associated events with correlation coefficient of 0.76.

Estimating the Height of CMEs Associated with a Major SEP Event at the Onset of the Metric Type II Radio Burst during Solar Cycles 23 and 24

P. **Mäkelä**, N. Gopalswamy, S. Akiyama, H. Xie, and S. Yashiro
ApJ **2015**
http://cdaw.gsfc.nasa.gov/publications/makela/makela2015ApJ.pdf
We studied the coronal mass ejection (CME) height at the onset of 59 metric type II radio bursts associated with major solar energetic particle (SEP) events, excluding ground level enhancements (GLEs), during solar cycles 23 and 24. We calculated CME heights using a simple flare-onset method used by Gopalswamy et al. (2012b) to estimate CME heights at the metric type II onset for cycle-23 GLEs. We found the mean CME height for non-GLE

events (1.72 R⊙) to be ∼12% greater than that (1.53 R⊙) for cycle-23 GLEs. The difference could be caused by more impulsive acceleration of the GLE-associated CMEs. For cycle-24 non-GLE events, we compared the CME heights obtained using the flare-onset method and the 3-D spherical-shock fitting method and found the correlation to be good (CC=0.68). We found the mean CME height for cycle 23 non-GLE events (1.79 R⊙) to be greater than for cycle 24 non-GLE events (1.58 R⊙), but statistical tests do not definitely reject the possibility of coincidence. We suggest that the lower formation height of the shocks during cycle 24 indicates a change in the Alfvén speed profile because solar magnetic fields are weaker and e plasma density levels are closer to the surface than usual during cycle 24. We also found that complex type III bursts showing diminution of type III emission in the 7-14 MHz frequency range are more likely associated with events with the CME height at the type II onset above 2 R⊙ , supporting suggestions that the CME/shock structure causes the feature. **Table. Event Data**

Long-Term Cosmic Ray Variability and the CME-Index

Helen **Mavromichalaki** and Evangelos Paouris

Advances in Astronomy, Volume 2012 (**2012**), Article ID 607172, 8 pages

http://www.hindawi.com/journals/aa/2012/607172/

The cosmic ray modulation in relation to solar activity indices and heliospheric parameters during the period January 1996–October 2011, covering the solar cycle 23 and the ascending phase of solar cycle 24, is studied. The new perspective of this contribution is that the CME-index, obtained from only the CMEs with angular width greater than 30 degrees, gives much better results than in previous works. The proposed model for the calculation of the modulated cosmic ray intensity obtained from the combination of solar indices and heliospheric parameters gives a very satisfactory value of the standard deviation. The best reproduction of the cosmic ray intensity is obtained by taking into account solar and interplanetary indices such as sunspot number, interplanetary magnetic field, CME-index, and heliospheric current sheet tilt. The standard deviation between the observed and calculated values is about 6.63% for the solar cycle 23 and 4.13% for the ascending part of solar cycle 24.

A statistical study of CME-Preflare associated events

Ramy **Mawad**, M.Youssef Advances in Space Research

Volume 62, Issue 2, 15 July **2018**, Pages 417-425

http://sci-hub.tw/http://linkinghub.elsevier.com/retrieve/pii/S0273117718303727

We investigated the relationship of associated CME-Preflare during the solar period 1996–2010. We found 292 CME-Preflare associated events (∼2%). Those associated events have 0–1 h interval time, popular events occur within half an hour before flare starting time. Post-flares–CME associated events are wider than CME-Preflare associated events. CME-Preflare associated events are ejected from the northern hemisphere during the solar cycle 23rd, while the non-associated CMEs are ejected from the southern hemisphere. Polar CME-Preflare associated events are more energetic than the equatorial events. This means that post-flare–CME associated events are more decelerated than CME-Preflare associated events, CME-Flare associated simultaneously events and other CMEs. The CME-Preflare associated events are slower than the post-flare–CME associated events, and slightly faster than non-associated CME events. Post-flare–CME associated events are in average more massive than Preflare CME associated events and all other CMEs ejected from the Sun. CME-Preflare associated has a mean average speed which is equivalent to the mean average solar wind speed approximately.

Filaments disappearance in relation to coronal mass ejections during the solar cycle 23

R. **Mawad**, Mosalam Shaltout, M. Yousef, S. Yousef, M. Ewaida

Advances in Space Research, Volume 55, Issue 2, 15 January **2015**, Pages 688–695

http://www.sciencedirect.com/science/article/pii/S0273117714006929

We have studied the relationship between filament disappearances with CMEs during solar period 1996–2010. We used the observed disappearing filaments in Hα data from Meudon given in NOAA, and coronal mass ejections data (CMEs) from SOHO/LASCO. We obtained 278 CME events (14%) contemporary filament disappearances and CME ejections (from a total of 2018 filament disappearance events and 15,874 CME events during 1996–2010). We found that the number of associated CME–filament disappearance events increased with the increase of the solar activity and significantly decreased with quiet sun. The longer filament disappearances have activity and ability to contemporary association with CMEs more than shorter filament disappearances. The filament disappearance powers the associated CMEs. CMEs which are associated with filament disappearance are ejected with higher speeds, massive, more energetic, and smaller angular width compared to non-associated CME events. In addition, the associated filament disappearance CMEs have two types depending on their duration; short-lived (<9 h), and long-lived (>9 h).

Periodic Oscillations in LASCO Coronal Mass Ejection Speeds: Space Seismology

Grzegorz **Michalek**1, Nat Gopalswamy2, and Seiji Yashiro2,3

2022 ApJL 927 L16

https://iopscience.iop.org/article/10.3847/2041-8213/ac54b0/pdf
Coronal mass ejections (CMEs) are energetic eruptions of organized magnetic structures from the Sun. Therefore, the reconnection of the magnetic field during ejection can excite periodic speed oscillations of CMEs. A previous study showed that speed oscillations are frequently associated with CME propagation. The Solar and Heliospheric Observatory mission's white-light coronagraphs have observed about 30,000 CMEs from 1996 January to the end of 2019 December. This period of time covers two solar cycles (23 and 24). In the present study, the basic attributes of speed oscillations during this period of time were analyzed. We showed that the oscillation parameters (period and amplitude) significantly depend not only on the phase of a given solar cycle but also on the intensity of individual cycles as well. This reveals that the basic attributes of speed oscillation are closely related to the physical conditions prevailing inside the CMEs as well as in the interplanetary medium in which they propagate. Using this approximation, we estimated that, on average, the CME internal magnetic field varies from 18 up to 25 mG between minimum and maximum solar activity. The obtained results show that a detailed analysis of speed oscillations can be a very efficient tool for studying not only the physical properties of the ejections themselves but also the condition of the interplanetary medium in which they expand. This creates completely new perspectives for studying the physical parameters of CMEs shortly after their eruption in the Sun's environment (space seismology). **2004 February 8, 2004 February 11**

On the Coronal Mass Ejection Detection Rate during Solar Cycles 23 and 24

Grzegorz **Michalek**1, Nat Gopalswamy2, and Seiji Yashiro2,3
2019 ApJ 880 51
sci-hub.se/10.3847/1538-4357/ab26a7
The Solar and Heliospheric Observatory (SOHO) mission's white light coronagraphs have observed more than 25,000 coronal mass ejections (CMEs) from 1996 January to the end of 2015 July. This period of time covers almost two solar cycles (23 and 24). The basic attributes of CMEs, reported in the SOHO/Large Angle and Spectrometric Coronagraph (LASCO) catalog, during these solar cycles were statistically analyzed. The question of the CME detection rate and its connection to the solar cycles was considered in detail. Based on the properties and detection rate, CMEs can be divided into two categories: regular and specific events. The regular events are pronounced and follow the pattern of sunspot number. On the other hand, the special events are poorer and more correlated with the general conditions of heliosphere and corona. Nevertheless, both groups of CMEs are the result of the same physical phenomenon, viz. release of magnetic energy from closed field regions. It was demonstrated that the enhanced CME rate, since the solar cycle 23 polar-field reversal, is due to a significant decrease of total (magnetic and plasma) heliospheric pressure as well as the changed magnetic pattern of solar corona. CMEs expel free magnetic energy and helicity from the Sun; therefore, they are related to complex solar magnetic field structure. It is also worth emphasizing that the CMEs listed in the SOHO/LASCO catalog are real ejections (not false identification). Their detection rate reflects the global evolution of the magnetic field on the Sun, and not only changes in the magnetic structures associated with sunspots.

Statistical Analysis of Periodic Oscillations in LASCO Coronal Mass Ejection Speeds

G. **Michalek**, A. Shanmugaraju, N. Gopalswamy, S. Yashiro, S. Akiyama
Solar Phys. Volume 291, Issue 12, pp 3751–3764 **2016**
http://link.springer.com/article/10.1007/s11207-016-1000-4
A large set of coronal mass ejections (CMEs, 3463) has been selected to study their periodic oscillations in speed in the Solar and Heliospheric Observatory (SOHO) mission's Large Angle and Spectrometric Coronagraph (LASCO) field of view. These events, reported in the SOHO/LASCO catalog in the period of time 1996 – 2004, were selected based on having at least 11 height–time measurements. This selection criterion allows us to construct at least ten-point speed–distance profiles and evaluate kinematic properties of CMEs with a reasonable accuracy. To identify quasi-periodic oscillations in the speed of the CMEs a sinusoidal function was fitted to speed–distance profiles and the speed–time profiles. Of the considered events 22 % revealed periodic velocity fluctuations. These speed oscillations have on average amplitude equal to \(87~\mbox{km}\,\mbox{s}^{-1}\) and period \(7.8 R _{\odot}/241~\mbox{min}\) (in distance/time). The study shows that speed oscillations are a common phenomenon associated with CME propagation implying that all the CMEs have a similar magnetic flux-rope structure. The nature of oscillations can be explained in terms of magnetohydrodynamic (MHD) waves excited during the eruption process. More accurate detection of these modes could, in the future, enable us to characterize magnetic structures in space (space seismology). **19/12/1996, 03/07/2000**

Coronal Mass Ejections, Magnetic Fields, and the Green Corona in Cycle 23

M. **Minarovjech** · V. Rušin · M. Saniga
Solar Phys (**2008**) 248: 167–176
http://www.springerlink.com/content/k6727801mt5r58x1/fulltext.pdf
We study a time – latitudinal distribution of CMEs observed by the SOHO spacecraft, their projected speeds and associated magnetic fields, as well as the north – south (N – S) asymmetry of solar surface magnetic fields, and the coronal green line intensities. We have found that (a) there exists an intricate relation between the average projected velocity of

CMEs and the mean value of large-scale magnetic fields; (b) there exists a pronounced N– S asymmetry in both the distribution and the number of CMEs; (c) this asymmetry is in favor of the northern hemisphere at the beginning of the cycle, and of the southern hemisphere from 2001 onward, being, in fact, (d) closely related with the N– S asymmetry in the distribution of large-scale magnetic fields and the coronal green line intensities.

Solar cycle variation of coronal mass ejections contribution to solar wind mass flux

Wageesh **Mishra**, Nandita Srivastava, Zavkiddin Mirtoshev, Yuming Wang

Proceedings IAU Symposium No. 340, **2018**

https://arxiv.org/pdf/1805.07593.pdf

Coronal Mass Ejections (CMEs) contributes to the perturbation of solar wind in the heliosphere. Thus, depending on the different phases of the solar cycle and the rate of CME occurrence, contribution of CMEs to solar wind parameters near the Earth changes. In the present study, we examine the long term occurrence rate of CMEs, their speeds, angular widths and masses. We attempt to find correlation between near sun parameters, determined using white light images from coronagraphs, with solar wind measurements near the Earth from in-situ instruments. Importantly, we attempt to find what fraction of the averaged solar wind mass near the Earth is provided by the CMEs during different phases of the solar cycles.

On some properties of coronal mass ejections in solar cycle 23

Mittal, N., & Narain, U.

2009, New Astronomy, 14, 341

We have investigated some properties such as speed, apparent width, acceleration, latitude, mass and kinetic energy, etc. of all types of coronal mass ejections (CMEs) observed during the period 1996 2007 by SOHO/LASCO covering the solar cycle 23. The results are in satisfactory agreement with previous investigations.

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.

Moving solar radio bursts and their association with coronal mass ejections

D. E. **Morosan**, A. Kumari, E. K. J. Kilpua, A. Hamini

A&A **2021**

https://arxiv.org/pdf/2103.05942.pdf

Context: Solar eruptions, such as coronal mass ejections (CMEs), are often accompanied by accelerated electrons that can in turn emit radiation at radio wavelengths. This radiation is observed as solar radio bursts. The main types of bursts associated with CMEs are type II and type IV bursts that can sometimes show movement in the direction of the CME expansion, either radially or laterally. However, the propagation of radio bursts with respect to CMEs has only been studied for individual events.
Aims: Here, we perform a statistical study of 64 moving bursts with the aim to determine how often CMEs are accompanied by moving radio bursts. This is done in order to ascertain the usefulness of using radio images in estimating the early CME expansion.
Methods: Using radio imaging from the Naçay Radioheliograph (NRH), we constructed a list of moving radio bursts, defined as bursts that move across the plane of sky at a single frequency. We define their association with CMEs and the properties of associated CMEs using white-light coronagraph observations. We also determine their connection to classical type II and type IV radio burst categorisation.
Results: We find that just over a quarter of type II and half of type IV bursts that occurred during the NRH observing windows in Solar Cycle 24 are accompanied by moving radio emission. All but one of the moving radio

bursts are associated with white--light CMEs and the majority of moving bursts (90%) are associated with wide CMEs (>60 degrees in width). In particular, all but one of the moving bursts corresponding to type IIs are associated with wide CMEs; however, and unexpectedly, the majority of type II moving bursts are associated with slow white-light CMEs (<500 km/s). On the other hand, the majority of moving type IV bursts are associated with fast CMEs (>500 km/s). **14 June 2012**

Investigating the Coronal Mass Ejections associated with DH type-II radio bursts and solar flares during the ascending phase of the solar cycle 24

Mohamed **Nedal** M.Youssef AymanMahrous RababHelal

Advances in Space Research Volume 63, Issue 5, 1 March **2019**, Pages 1824-1836

sci-hub.tw/10.1016/j.asr.2018.11.001

We studied a set of 74 CMEs, with shedding the light on the halo-CMEs (HCMEs), that are associated with decametric – hectometric (DH) type-II radio bursts (1–16 MHz) and solar flaresduring the period 2008–2014. The events were classified into 3 groups (disk, intermediate, and limb events) based on their longitudinal distribution. We found that the events are mostly distributed around 15.32° and 15.97° at the northern and southern solar hemispheres, respectively. We found that there is a clear dependence between the longitude and the CME's width, speed, acceleration, mass, and kinetic energy. For the CMEs' widths, most of the events were HCMEs (∼62%), while the partial HCMEs comprised ∼35% and the rest of events were CMEs with widths less than 120°. For the CMEs' speeds, masses, and kinetic energies, the mean values showed a direct proportionality with the longitude, in which the limb events had the highest speeds, the largest masses, and the highest kinetic energies. The mean peak flux of the solar flares for different longitudes was comparable, but the disk flares were more energetic. The intermediate flares were considered as gradual flares since they tended to last longer, while the limb flares were considered as impulsive flares since they tended to last shorter.
A weak correlation (R = 0.32) between the kinetic energy of the CMEs and the duration of the associated flares has been noticed, while there was a good correlation (R = 0.76) between the kinetic energy of the CMEs and the peak flux of the associated flares. We found a fair correlation (R = 0.58) between the kinetic energy of the CMEs and the duration of the associated DH type-II radio bursts.

Coronal Mass Ejections and the Index of Effective Solar Multipole

V. N. **Obridko**, E. V. Ivanov, A. Özgüç, A. Kilcik and V. B. Yurchyshyn

Solar Physics, **2012**, 281(2), 779-792, **File**

The paper considers the relationship between the cyclic variations in the velocity of coronal mass ejections (CME) and the large-scale magnetic field structure (LSMF) in cycles 21 – 23. To characterize a typical size of the LSMF structure, we have used the index of the effective solar multipole (ESMI). The cyclic behavior of the CME occurrence rate and velocity proved to be similar to that of ESMI. The hysteresis observed in variations of the CME maximum velocity is interpreted as a manifestation of different contributions from the two field structures (local and global magnetic fields) in different phases of the 11-year activity cycle. It is suggested that cyclic variations in the maximum velocity of coronal mass ejections are due to different conditions for the formation of the complexes of active regions connected by coronal arch systems, which are the main source of high-velocity CMEs.

QUANTITATIVE MEASUREMENTS OF CORONAL MASS EJECTION-DRIVEN SHOCKS FROM LASCO OBSERVATIONS

Veronica **Ontiveros**[1,3] and Angelos Vourlidas

Astrophysical Journal, 693:267–275, **2009** March 1; **File**

In this paper, we demonstrate that coronal mass ejection (CME)-driven shocks can be detected in white light coronagraph images and in which properties such as the density compression ratio and shock direction can be measured. Also, their propagation direction can be deduced via simple modeling. We focused on CMEs during the ascending phase of solar cycle 23 when the large-scale morphology of the corona was simple. We selected events which were good candidates to drive a shock due to their high speeds ($V > 1500$ km s^{-1}). The final list includes 15 CMEs. For each event, we calibrated the LASCO data, constructed excess mass images, and searched for indications of faint and relatively sharp fronts ahead of the bright CME front. We found such signatures in 86% (13/15) of the events and measured the upstream/downstream densities to estimate the shock strength. Our values are in agreement with theoretical expectations and show good correlations with the CME kinetic energy and momentum. Finally, we used a simple forward modeling technique to estimate the threedimensional shape and orientation of the white light shock features.We found excellent agreement with the observed density profiles and the locations of the CME source regions. Our results strongly suggest that the observed brightness enhancements result from density enhancements due to a bow-shock structure driven by the CME.

Effects of Hysteresis Between Maximum CME Speed Index and Typical Solar Activity Indicators During Cycle 23

A. **Özgüç**, A. Kilcik, J. P. Rozelot

Solar Physics, December **2012**, Volume 281, Issue 2, pp 839-846

Using the smoothed time series of maximum CME speed index for solar cycle 23, it is found that this index, analyzed jointly with six other solar activity indicators, shows a hysteresis phenomenon. The total solar irradiance, coronal index, solar radio flux (10.7 cm), Mg ii core-to-wing ratio, sunspot area, and Hα flare index follow different paths for the ascending and the descending phases of solar cycle 23, while a saturation effect exists at the maximum phase of the cycle. However, the separations between the paths are not the same for the different solar activity indicators used: the Hα flare index and total solar irradiance depict broad loops, while the Mg ii core-to-wing ratio and sunspot area depict narrow hysteresis loops. The lag times of these indices with respect to the maximum CME speed index are discussed, confirming that the hysteresis represents a clue in the search for physical processes responsible for changing solar emission.

Dependence of Coronal Mass Ejection Properties on Their Solar Source Active Region Characteristics and Associated Flare Reconnection Flux

Sanchita **Pal**1, Dibyendu Nandy1,2, Nandita Srivastava1,3, Nat Gopalswamy4, and Suman Panda

2018 ApJ 865 4

https://arxiv.org/pdf/1808.04144.pdf **File**
http://sci-hub.tw/10.3847/1538-4357/aada10
https://iopscience.iop.org/article/10.3847/1538-4357/aada10/pdf

The near-Sun kinematics of coronal mass ejections (CMEs) determine the severity and arrival time of associated geomagnetic storms. We investigate the relationship between the deprojected speed and kinetic energy of CMEs and magnetic measures of their solar sources, reconnection flux of associated eruptive events, and intrinsic flux-rope characteristics. Our data covers the period 2010–2014 in solar cycle 24. Using vector magnetograms of source active regions, we estimate the size and nonpotentiality. We compute the total magnetic reconnection flux at the source regions of CMEs using the post-eruption arcade method. By forward modeling the CMEs, we find their deprojected geometric parameters and constrain their kinematics and magnetic properties. Based on an analysis of this database, we report that the correlation between CME speed and their source active region size and global nonpotentiality is weak, but not negligible. We find the near-Sun velocity and kinetic energy of CMEs to be well correlated with the associated magnetic reconnection flux. We establish a statistically significant empirical relationship between the CME speed and reconnection flux that may be utilized for prediction purposes. Furthermore, we find CME kinematics to be related with the axial magnetic field intensity and relative magnetic helicity of their intrinsic flux ropes. The amount of coronal magnetic helicity shed by CMEs is found to be well correlated with their near-Sun speeds. The kinetic energy of CMEs is well correlated with their intrinsic magnetic energy density. Our results constrain processes related to the origin and propagation of CMEs and may lead to better empirical forecasting of their arrival and geoeffectiveness. **2012 June 14**

Table 1 Properties of Selected CMEs and Associated Source Region Information (2010-2014)

Investigating width distribution of slow and fast CMEs in solar cycles 23 and 24

V. **Pant**, R. Majumdar, R. Patel, A. Chauhan, D. Banerjee, N. Gopalswamy

Frontiers in Astronomy and Space Sciences Volume 8, id.73 8:634358 **2021**

https://arxiv.org/pdf/2104.12850.pdf
https://www.frontiersin.org/articles/10.3389/fspas.2021.634358/full
https://doi.org/10.3389/fspas.2021.634358

Coronal Mass Ejections (CMEs) are highly dynamic events originating in the solar atmosphere, that show a wide range of kinematic properties and are the major drivers of the space weather. The angular width of the CMEs is a crucial parameter in the study of their kinematics. The fact that whether slow and fast CMEs (as based on their relative speed to the average solar wind speed) are associated with different processes at the location of their ejection is still debatable. Thus, in this study, we investigate their angular width to understand the differences between the slow and fast CMEs. We study the width distribution of slow and fast CMEs and find that they follow different power law distributions, with a power law indices (α) of -1.1 and -3.7 for fast and slow CMEs respectively. To reduce the projection effects, we further restrict our analysis to only limb events as derived from manual catalog and we find similar results. We then associate the slow and fast CMEs to their source regions, and classified the sources as Active Regions (ARs) and Prominence Eruptions (PEs). We find that slow and fast CMEs coming from ARs and PEs, also follow different power laws in their width distributions. This clearly hints towards a possibility that different mechanisms might be involved in the width expansion of slow and fast CMEs coming from different sources.These results are also crucial from the space weather perspective since the width of the CME is an important factor in that aspect. **May 03, 2012**

DH Type II Radio Bursts During Solar Cycles 23 and 24: Frequency-dependent Classification and their Flare-CME Associations

Binal D. **Patel** (USO/PRL), Bhuwan Joshi (USO/PRL), Kyung-Suk Cho (SSD/KASI), Rok-Soon Kim (DASS/UST)

Solar Phys. **2021**

https://arxiv.org/pdf/2108.12990.pdf

We present the characteristics of DH type II bursts for the Solar Cycles 23 and 24. The bursts are classified according to their end frequencies into three categories, i.e. Low Frequency Group (LFG; 20 kHz ≤ f ≤ 200 kHz), Medium Frequency Group (MFG; 200 kHz < f ≤ 1 MHz), and High Frequency Group (HFG; 1 MHz < f ≤ 16 MHz). We find that the sources for LFG, MFG, and HFG events are homogeneously distributed over the active region belt. Our analysis shows a drastic reduction of the DH type II events during Solar Cycle 24 which includes only 35% of the total events (i.e. 179 out of 514). Despite having smaller number of DH type II events in the Solar Cycle 24, it contains a significantly higher fraction of LFG events compared to the previous cycle (32% versus 24%). However, within the LFG group the cycle 23 exhibits significant dominance of type II bursts that extend below 50 kHz, suggesting rich population of powerful CMEs travelling beyond half of the Sun-Earth distance. The events of LFG group display strongest association with faster and wider (more than 82% events are halo) CMEs while at the source location they predominantly trigger large M/X class flares (in more than 83% cases). Our analysis also indicates that CME initial speed or flare energetics are partly related with the duration of type II burst and that survival of CME associated shock is determined by multiple factors/parameters related to CMEs, flares, and state of coronal and interplanetary medium. The profiles relating CME heights with respect to the end frequencies of DH type II bursts suggest that for HFG and MFG categories, the location for majority of CMEs (≈65%-70%) is in well compliance with ten-fold Leblanc coronal density model, while for LFG events a lower value of density multiplier (≈3) seems to be compatible. **2011 November 26, 2013 May 22**

On the enhanced coronal mass ejection detection rate since the solar cycle 23 polar field reversal

Gordon **Petrie**

ApJ 812 74 **2015**

http://arxiv.org/pdf/1508.06729v1.pdf

Coronal mass ejections (CMEs) with angular width >30∘ have been observed to occur at a higher rate during solar cycle 24 compared to cycle 23, per sunspot number. This result is supported by data from three independent databases constructed using Large Angle and Spectrometric Coronagraph Experiment (LASCO) coronagraph images, two employing automated detection techniques and one compiled manually by human observers. According to the two databases that cover a larger field of view, the enhanced CME rate actually began shortly after the cycle 23 polar field reversal, in 2004, when the polar fields returned with a 40\% reduction in strength and interplanetary radial magnetic field became ≈30% weaker. This result is consistent with the link between anomalous CME expansion and heliospheric total pressure decrease recently reported by Gopalswamy et al.

CORONAL MASS EJECTIONS AND SUNSPOTS—SOLAR CYCLE PERSPECTIVE

K. B. **Ramesh**

Astrophysical Journal Letters, 712:L77–L80, **2010** March, **File**

Recent studies have indicated that the occurrence of the maxima of coronal mass ejection (CME) rate and sunspot number (SSN) were nearly two years apart.We find that the two-year lag of CME rate manifests only when the SSN index is considered and the lag is minimal (two–three months) when the sunspot area is considered. CMEs with speeds greater than the average speed follow the sunspot cycle much better than the entire population of CMEs. Analysis of the linear speeds of CMEs further indicates that during the descending phase of the solar cycle the loss of magnetic flux is through more frequent and less energetic CMEs.We emphasize that the magnetic field attaining the nonpotentiality that represents the free energy content, rather than the flux content as measured by the area of the active region, plays an important role in producing CMEs.

Kinematics of coronal mass ejections in the LASCO field of view

Anitha **Ravishankar**1, Grzegorz Michałek1 and Seiji Yashiro2

A&A 639, A68 (**2020**)

https://www.aanda.org/articles/aa/pdf/2020/07/aa37834-20.pdf

In this paper we present a statistical study of the kinematics of 28894 coronal mass ejections (CMEs) recorded by the Large Angle and Spectrometric Coronagraph (LASCO) on board the Solar and Heliospheric Observatory spacecraft from 1996 until mid-2017. The initial acceleration phase is characterized by a rapid increase in CME velocity just after eruption in the inner corona. This phase is followed by a non-significant residual acceleration (deceleration) characterized by an almost constant speed of CMEs. We demonstrate that the initial acceleration is in the range 0.24–2616 m s−2 with median (average) value of 57 m s−2 (34 m s−2) and it takes place up to a distance of about 28 RSUN with median (average) value of 7.8 RSUN (6 RSUN). Additionally, the initial acceleration is significant in the case of fast CMEs (V > 900 km s−1), where the median (average) values are about 295 m s−2 (251 m s−2), respectively, and much weaker in the case of slow CMEs (V < 250 km s−1), where the median (average) values are about 18 m s−2 (17 m s−2), respectively. We note that the significant driving force (Lorentz force) can operate up to a distance of 6 RSUN from the Sun during the first 2 hours of propagation. We found a significant anti-correlation between the initial acceleration magnitude and the acceleration duration, whereas the residual acceleration covers a range from −1224 to 0 m s−2 with a median (average) value of −34 m s−2 (−17 m s−2). One intriguing finding is that the residual acceleration is much smaller during the 24th cycle in comparison to the 23rd cycle of solar activity. Our study has also revealed that the considered parameters, initial acceleration (ACCINI), residual acceleration (ACCRES), maximum velocity (VMAX), and time at maximum velocity (TimeMAX) mostly follow solar cycles and the intensities of the individual cycle.

Relationship between solar energetic particle intensities and coronal mass ejection kinematics using STEREO/SECCHI field of view

Anitha **Ravishankar** and Grzegorz Michalek

A&A 646, A142 (**2021**)

https://www.aanda.org/articles/aa/pdf/2021/02/aa39537-20.pdf

https://doi.org/10.1051/0004-6361/202039537

https://arxiv.org/pdf/2102.12640.pdf

Solar energetic particles (SEPs) accelerated from shocks driven by coronal mass ejections (CMEs) are one of the major causes of geomagnetic storms on Earth. Therefore, it is necessary to predict the occurrence and intensity of such disturbances. For this purpose we analyzed in detail 38 non-interacting halo and partial halo CMEs, as seen by the Solar and Heliospheric Observatory/Large Angle and Spectrometric Coronagraph, generating SEPs (in > 10 MeV, > 50 MeV, and > 100 MeV energy channels) during the quadrature configuration of the Solar TErrestrial RElations Observatory (STEREO) twin spacecrafts with respect to the Earth, which marks the ascending phase of solar cycle 24 (i.e., 2009–2013). The main criteria for this selection period is to obtain height–time measurements of the CMEs without significant projection effects and in a very large field of view. Using the data from STEREO/Sun Earth Connection Coronal and Heliospheric Investigation (STEREO/SECCHI) images we determined several kinematic parameters and instantaneous speeds of the CMEs. First, we compare instantaneous CME speed and Mach number versus SEP fluxes for events originating at the western and eastern limb; we observe high correlation for the western events and anticorrelation for the eastern events. Of the two parameters, the Mach number offers higher correlation. Next we investigated instantaneous CME kinematic parameters such as maximum speed, maximum Mach number, and the CME speed and Mach number at SEP peak flux versus SEP peak fluxes. Highly positive correlation is observed for Mach number at SEP peak flux for all events. The obtained instantaneous Mach number parameters from the emperical models was verified with the start and end time of type II radio bursts, which are signatures of CME-driven shock in the interplanetary medium. Furthermore, we conducted estimates of delay in time and distance between CME, SEP, and shock parameters. We observe an increase in the delay in time and distance when SEPs reach peak flux with respect to CME onset as we move from the western to the eastern limb. Western limb events (longitude 60°) have the best connectivity and this decreases as we move towards the eastern limb. This variation is due to the magnetic connectivity from the Sun to the Earth, called the Parker spiral interplanetary magnetic field. Comparative studies of the considered energy channels of the SEPs also throw light on the reacceleration of suprathermal seed ions by CME-driven shocks that are pre-accelerated in the magnetic reconnection. **22 September 2011, 13 March 2012, 12 July 2012**

See Comment on "Non-interacting coronal mass ejections and solar energetic particles near the quadrature configuration of solar terrestrial relations observatory": CME shocks are fast magnetosonic shocks and not intermediate Alfvén shocks

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A&A 656, A152 (**2021**)

https://www.aanda.org/articles/aa/pdf/2021/12/aa41029-21.pdf

https://doi.org/10.1051/0004-6361/202141029

Kinematics of coronal mass ejections in the LASCO field of view

Anitha **Ravishankar**, Grzegorz Michalek, Seiji Yashiro

Astronomy & Astrophysics, Volume 639, id.A68, 12 pp, July **2020**

https://arxiv.org/pdf/2010.02682.pdf

In this paper we present a statistical study of the kinematics of 28894 coronal mass ejections (CMEs) recorded by the Large Angle and Spectrometric Coronagraph (LASCO) on board the Solar and Heliospheric Observatory spacecraft from 1996 until mid-2017. The initial acceleration phase is characterized by a rapid increase in CME velocity just after eruption in the inner corona. This phase is followed by a non-significant residual acceleration (deceleration) characterized by an almost constant speed of CMEs. We demonstrate that the initial acceleration is in the range 0.24-2616 ms-2 with median (average) value of 57 ms-2 (34 ms-2) and it takes place up to a distance of about 28 solar radius with median (average) value of 7.8 solar radius (6 solar radius). Additionally, the initial acceleration is significant in the case of fast CMEs (V > 900 kms-1), where the median (average) values are about 295 ms-2 (251 ms-2), respectively, and much weaker in the case of slow CMEs (V < 250 kms-1), where the median (average) values are about 18 ms-2 (17 ms-2), respectively. We note that the significant driving force (Lorentz force) can operate up to a distance of 6 solar radius from the Sun during the first 2 hours of propagation. We found a significant anti-correlation between the initial acceleration magnitude and the acceleration duration, whereas the residual acceleration covers a range from -1224 to 0 ms-2 with a median (average) value of -34 ms-2 (-17 ms-2). One intriguing finding is that the residual acceleration is much smaller during the 24th cycle in comparison to the 23rd cycle of solar activity. Our study has also revealed that the considered parameters, initial acceleration (ACC INI), residual acceleration (ACC RES), maximum velocity (V MAX), and time at maximum velocity (Time MAX) mostly follow solar cycles and the intensities of the individual cycle.

AUTOMATED LASCO CME CATALOG FOR SOLAR CYCLE 23: ARE CMEs SCALE INVARIANT?

E. **Robbrecht** et al **2009** ApJ 691 1222-1234

In this paper, we present the first automatically constructed LASCO coronal mass ejection (CME) catalog, a result of the application of the Computer Aided CME Tracking software (CACTus) on the LASCO archive during the interval 1997 September-2007 January. We have studied the CME characteristics and have compared them with similar results obtained by manual detection (CDAW CME catalog). On average, CACTus detects less than two events per day during solar minimum, up to eight events during maximum, nearly half of them being narrow (<20°). Assuming a correction factor, we find that the CACTus CME rate is surprisingly consistent with CME rates found during the past 30 years. The CACTus statistics show that small-scale outflow is ubiquitously observed in the outer corona. The majority of CACTus-only events are narrow transients related to previous CME activity or to intensity variations in the slow solar wind, reflecting its turbulent nature. A significant fraction (about 15%) of CACTus-only events were identified as independent events, thus not related to other CME activity. **The CACTus CME width distribution is essentially scale invariant in angular span over a range of scales from 20° to 120° while previous catalogs present a broad maximum around 30°**. The possibility that the size of coronal mass outflows follow a power-law distribution could indicate that no typical CME size exists, i.e., that the narrow transients are not different from the larger well defined CMEs.

A Comparative Study of the Eruptive and Non-Eruptive Flares Produced by the Largest Active Region of Solar Cycle 24

Ranadeep **Sarkar**, Nandita Srivastava

Solar Phys. 293:16 **2018**

https://arxiv.org/pdf/1801.00473.pdf

https://link.springer.com/content/pdf/10.1007%2Fs11207-017-1235-8.pdf

We investigate the morphological and magnetic characteristics of solar active region (AR) NOAA 12192. AR 12192 was the largest region of Solar Cycle 24; it underwent noticeable growth and produced 6 X-class flares, 22 M-class flares, and 53 C-class flares in the course of its disc passage. However, the most peculiar fact of this AR is that it was associated with only one CME in spite of producing several X-class flares. In this work, we carry out a comparative study between the eruptive and non-eruptive flares produced by AR 12192. We find that the magnitude of abrupt and permanent changes in the horizontal magnetic field and Lorentz force are significantly smaller in the case of the confined flares compared to the eruptive one. We present the areal evolution of AR 12192 during its disc passage. We find the flare-related morphological changes to be weaker during the confined flares, whereas the eruptive flare exhibits a rapid and permanent disappearance of penumbral area away from the magnetic neutral line after the flare. Furthermore, from the extrapolated nonlinear force-free magnetic field, we examine the overlying coronal magnetic environment over the eruptive and non-eruptive zones of the AR. We find that the critical decay index for the onset of torus instability was achieved at a lower height over the eruptive flaring region, than for the non-eruptive core area. These results suggest that the decay rate of the gradient of overlying magnetic field strength may play a decisive role to determine the CME productivity of the AR. In addition, the magnitude of changes in the flare-related magnetic characteristics are found to be well correlated with the nature of solar eruptions. **2014.10.22-25**

HMI Science Nuggets, **#90** March **2018** http://hmi.stanford.edu/hminuggets/?p=2333

Solar filament eruptions and their physical role in triggering Coronal Mass Ejections

Schmieder B., Demoulin P., Aulanier G. **Review**

E-print, Dec **2012**; Advances in Space Research, v. 51, No. 11, p. 1967-1980, **2013, File**

http://www.sciencedirect.com/science/article/pii/S027311771300032X

Solar filament eruptions play a crucial role in triggering coronal mass ejections (CMEs). More than 80 % of eruptions lead to a CME. This correlation has been studied extensively during the past solar cycles and the last long solar minimum. The statistics made on events occurring during the rising phase of the new solar cycle 24 is in

agreement with this finding. Both filaments and CMEs have been related to twisted magnetic fields. Therefore, nearly all the MHD CME models include a twisted flux tube, called a flux rope. Either the flux rope is present long before the eruption, or it is built up by reconnection of a sheared arcade from the beginning of the eruption. In order to initiate eruptions, different mechanisms have been proposed: new emergence of flux, and/or dispersion of the external magnetic field, and/or reconnection of field lines below or above the flux rope. These mechanisms reduce the downward magnetic tension and favor the rise of the flux rope. Another mechanism is the kink instability when the configuration is twisted too much. In this paper we open a forum of discussions revisiting observational and theoretical papers to understand which mechanisms trigger the eruption. We conclude that all the above quoted mechanisms could bring the flux rope to an unstable state. However, the most efficient mechanism for CMEs is the loss-of-equilibrium or torus instability, when the flux rope has reached an unstable threshold determined by a decay index of the external magnetic field.
27 May 2005, 4-7 Dec 2007, 17 September 2010, 3 November 2010, 23 January 2012,
See http://inspirehep.net/record/1207540/plots

Halo Coronal Mass Ejections during Solar Cycle 24: reconstruction of the global scenario and geoeffectiveness

Camilla **Scolini**, Mauro Messerotti, Stefaan Poedts, Luciano Rodriguez
Journal of Space Weather and Space Climate **2018**, 8, A09
https://arxiv.org/pdf/1712.05847.pdf
https://www.swsc-journal.org/articles/swsc/pdf/2018/01/swsc170032.pdf **File**
Coronal mass ejections (CMEs), in particular Earth-directed ones, are regarded as the main drivers of geomagnetic activity. In this study, we present a statistical analysis of a set of 53 fast ($V \geq 1000\,km \cdot s^{-1}$) Earth-directed halo CMEs observed by the SOHO/LASCO instrument during the period Jan. 2009–Sep. 2015, and we then use this CME sample to test the forecasting capabilities of a new Sun-to-Earth prediction scheme for the geoeffectiveness of Earth-directed halo CMEs. First, we investigate the CME association with other solar activity features such as solar flares, active regions, and others, by means of multi-instrument observations of the solar magnetic and plasma properties, with the final aim of identifying recurrent peculiar features that can be used as precursors of CME-driven geomagnetic storms. Second, using coronagraphic images to derive the CME kinematical properties at 0.1 AU, we propagate the events to 1 AU by means of 3D global MHD simulations. In particular, we use the WSA-ENLIL+Cone model to reconstruct the propagation and global evolution of each event up to their arrival at Earth, where simulation results are compared with interplanetary CME (ICME) in-situ signatures. We then use simulation outputs upstream of Earth to predict their impact on geospace. By applying the pressure balance condition at the magnetopause and the coupling function proposed by Newell et al. [J Geophys Res: Space Phys 113 (2008)] to link upstream solar wind properties to the global Kp index, we estimate the expected magnetospheric compression and geomagnetic activity level, and compare our predictions with global data records. The analysis indicates that 82% of the fast Earth-directed halo CMEs arrived at Earth within the next 4 days. Almost the totality of them compressed the magnetopause below geosynchronous orbits and triggered a minor or major geomagnetic storm afterwards. Among them, complex sunspot-rich active regions associated with X- and M-class flares are the most favourable configurations from which geoeffective CMEs originate. The analysis of related Solar Energetic Particle (SEP) events shows that 74% of the CMEs associated with major SEPs were geoeffective, i.e. they triggered a minor to intense geomagnetic storm ($Kp \geq 5$). Moreover, the SEP production is enhanced in the case of fast and interacting CMEs. In this work we present a first attempt at applying a Sun-to-Earth geoeffectiveness prediction scheme − based on 3D simulations and solar wind-geomagnetic activity coupling functions − to a statistical set of fast Earth-directed, potentially geoeffective halo CMEs. The results of the prediction scheme are promising and in good agreement with the actual data records for geomagnetic activity. However, we point out the need for future studies performing a fine-tuning of the prediction scheme, in particular in terms of the evaluation of the CME input parameters and the modelling of their internal magnetic structure. **5-13 March 2012, 18-27 June 2015**,
Table 1. Complete list of the selected CME events.

On the reduced geoeffectiveness of solar cycle 24: a moderate storm perspective

R. **Selvakumaran**, B. Veenadhari, S. Akiyama, Megha Pandya, N. Gopalswamy, S. Yashiro, Sandeep Kumar, P. Mäkelä, H. Xie
JGR **2016** **DOI:** 10.1002/2016JA022885
The moderate and intense geomagnetic storms are identified for the first 77 months of solar cycle 23 and 24. The solar sources responsible for the moderate geomagnetic storms are indentified during the same epoch for both the cycles. Solar cycle 24 has shown nearly 80 % reduction in the occurrence of intense storms where as it is only 40 % in case of moderate storms when compared to previous cycle. The solar and interplanetary characteristics of the moderate storms driven by CME are compared for solar cycle 23 and 24 in order to see reduction in geoeffectiveness has anything to do with the occurrence of moderate storm. Though there is reduction in the occurrence of moderate storms, the Dst distribution does not show much difference. Similarly the solar source parameters like CME speed, mass and width did not show any significant variation in the average values as well as

the distribution. The correlation between VBz and Dst is determined and it is found to be moderate with value of 0.68 for cycle 23 and 0.61 for cycle 24. The magnetospheric energy flux parameter epsilon (Ɛ) is estimated during the main phase of all moderate storms during solar cycles 23 and 24. The energy transfer decreased in solar cycle 24 when compared to cycle 23. These results are significantly different when all geomagnetic storms are taken in to consideration for both the solar cycles.

A statistical study of CME-associated flare during the solar cycle 24

AMK **Shaltout**; Eid A Amin; M.M. Beheary; R. H. Hamid

Advances in Space Research Volume 63, Issue 7, 1 April **2019**, Pages 2300-2311

https://www.sciencedirect.com/science/article/pii/S0273117718309359?dgcid=raven_sd_via_email

We investigate on the relationship between flares and coronal mass ejections (CMEs) in which a flare started before and after the CME events which differ in their physical properties, indicating potentially different initiation mechanisms. The physical properties of two types flare-correlated CME remain an interesting and important question in space weather. We study the relationship between flares and CMEs using a different approach requiring both temporal and spatial constraints during the period from December 1, 2008 to April 30, 2017 in which the CMEs data were acquired by SOHO/LASCO (Solar and Heliospheric Observatory/Large Angle Spectrometric Coronagraph) over the solar cycle 24. The soft X-ray flare flux data, such as flare class, location, onset time and integrated flux, are collected from Geostationary Environmental satellite (GOES) \textbf{and XRT Flare catalogs}. We selected 301 CMEs-flares pairs applying simultaneously temporal and spatial constraints in all events for the distinguish between two associated CME-flare types. We study the correlated properties of coincident flares and CMEs during this period, specifically separating the sample into two types: flares that precede a CME and flares that follow a CME. We found an opposite correlation relationship between the acceleration and velocity of CMEs in the After- and Before-CMEs events. We found a log-log relation between the width and mass of CMEs in the two associated types. The CMEs and flares properties show that there were significant differences in all physical parameters such as (mass, angular width, kinetic energy, speed and acceleration) between two flare-associated CME types.

Occurrence Rate of Radio-Loud and Halo CMEs in Solar Cycle 25: Prediction Using their Correlation with the Sunspot Number

A. **Shanmugaraju**, P. Pappa Kalaivani, Y.-J. Moon & O. Prakash

Solar Physics volume 296, Article number: 75 (**2021**)

https://arxiv.org/pdf/2103.13699.pdf

https://link.springer.com/content/pdf/10.1007/s11207-021-01818-0.pdf

https://doi.org/10.1007/s11207-021-01818-0

Solar coronal mass ejections (CMEs) are known for their space-weather and geomagnetic consequences. Among all CMEs, the so-called radio-loud (RL) and halo CMEs are considered the most energetic in the sense that they are usually faster and wider than the general population of CMEs. Hence the study of RL and halo CMEs has become important and the prediction of their occurrence rate in a future cycle will help their forecasting. In this article we predict the occurrence rates of RL and halo CMEs in Solar Cycle (SC) 25, obtaining good correlations between the numbers of RL and halo CMEs in each year and the yearly mean sunspot number in the previous two cycles. The values of the sunspot number predicted by NOAA/NASA for SC 25 are considered to be representative and the corresponding numbers of RL and halo CMEs are determined using linear relations. Our results show that the maximum number of RL and halo CMEs will be around 39±3 and 45±4, respectively. Removing backside events, a set of front-side events is also considered separately and front-side events in SC 25 are also predicted. The peak values of front-side RL and halo events have been estimated to be around 31±3 and 29±3, respectively. These results are discussed in comparison with the predicted sunspot number values by different authors.

Empirical Relationship Between CME Parameters and Geo-effectiveness of Halo CMEs in the Rising Phase of Solar Cycle 24 (2011 – 2013)

A. **Shanmugaraju**, M. Syed Ibrahim, Y.-J. Moon, A. Mujiber Rahman, S. Umapathy

Solar Phys. Volume 290, Issue 5, pp.1417-1427 **2015**

We analyzed the physical characteristics of 40 halo coronal mass ejections (CMEs) and their geo-effective parameters observed during the period 2011 to 2013 in the rising phase of Solar Cycle 24. Out of all halo CMEs observed by SOHO/LASCO, we selected 40 halo CMEs and investigated their geomagnetic effects. In particular, we estimated the CME direction parameter (DP) from coronagraph observations, and we obtained the geomagnetic storm disturbance index (Dst) value corresponding to each event by following certain criteria. We studied the correlation between near-Sun parameters of CMEs such as speed and DP with Dst. For this new set of events in the current solar cycle, the relations are found to be consistent with those of previous studies. When the direction parameter increases, the Dst value also increases for symmetrical halo CME ejections. IfDP>0.6, these events produce high Dst values. In addition, the intensity of geomagnetic storm calculated using an empirical model with the near-Sun parameters is nearly equal to the observed values. More importantly, we find that the geo-effectiveness in the rising phase of Solar Cycle 24 is much weaker than that in Cycle 23.

Analysis of large deflections of prominence-CME events during the rising phase of solar cycle 24

M.V. **Sieyra**, M. Cécere, H. Cremades, F.A. Iglesias, A. Sahade, M. Mierla, G. Stenborg, A. Costa, M. West, E. D'Huys

2020 *Solar Physics* **volume 295**, Article number: 126
https://arxiv.org/pdf/2007.14317.pdf
https://link.springer.com/content/pdf/10.1007/s11207-020-01694-0.pdf

The analysis of the deflection of coronal mass ejection (CME) events plays an important role in the improvement of the forecasting of their geo-effectiveness. Motivated by the scarcity of comprehensive studies of CME events with focus on the governing conditions that drive deflections during their early stages, we performed an extensive analysis of 13 CME events that exhibited large deflections during their early development in the low corona. The study was carried out by exploiting solar corona imaging observations at different heights and wavelengths from instruments onboard several space and ground solar observatories, namely the Project for Onboard Autonomy 2 (PROBA2), Solar Dynamics Observatory (SDO), Solar TErrestrial RElations Observatory (STEREO), Solar and Heliospheric Observatory (SOHO) spacecraft, and from National Solar Observatory (NSO). The selected events were observed between October 2010 and September 2011, to take advantage of the location in near quadrature of the STEREO spacecraft and Earth in this time period. In particular, we determined the 3D trajectory of the front envelope of the CMEs and their associated prominences with respect to their solar sources by means of a forward modeling and tie-pointing tool, respectively. By using a potential field source surface model, we estimated the coronal magnetic fields of the ambient medium through which the events propagate to investigate the role of the magnetic energy distribution in the non-radial propagation of both structures (front envelope and prominence) and in their kinematic properties. The ambient magnetic environment during the eruption and early stages of the events is found to be crucial in determining the trajectory of the CME events, in agreement with previous reports. **2011-01-30, 2011-03-27, 29 March 2011, 2011-05-13, 2011-08-11**

Table 1: The 13 selected events that satisfy |ΔCPA| & 20◦ and ΔΨ & 20◦ between October 2010 and September 2011.

A Study of the Observational Properties of Coronal Mass Ejection Flux Ropes near the Sun*

G. **Sindhuja**1 and N. Gopalswamy2

2020 ApJ 889 104
https://doi.org/10.3847/1538-4357/ab620f

We present the observational properties of coronal mass ejection (CME) flux ropes (FRs) near the Sun based on a set of 35 events from solar cycle 24 (2010–2017). We derived the CME FR properties using the Flux Rope from Eruption Data technique. According to this technique, the geometrical properties are obtained from a flux-rope fit to CMEs and the magnetic properties from the reconnected flux in the source region. In addition, we use the magnetic flux in the dimming region at the eruption site. Geometric properties like radius of the FR and the aspect ratio are derived from the FR fitting. The reconnected flux exhibits a positive correlation with flare fluence in soft X-rays (SXRs), peak flare intensity in SXRs, CME speed, and kinetic energy, with correlation coefficients (cc) 0.78, 0.6, 0.48, and 0.55, respectively. We found a moderate positive correlation between magnetic flux in the core dimming regions and the toroidal flux obtained from the Lundquist solution for a force-free FR (cc = 0.43). Furthermore, we correlate the core dimming flux and CME mass (cc = 0.34). The area of the core dimming region shows a moderate correlation with the radius of the FR (cc = 0.4). Thus, we infer that greater magnetic content (poloidal and toroidal fluxes) indicates a more energetic eruption in terms of flare size, CME speed, kinetic energy, mass, and radius of the FR, suggesting important implications for space weather predictions.

A STUDY OF FAST FLARELESS CORONAL MASS EJECTIONS

H. Q. **Song**1,2, Y. Chen1, D. D. Ye1, G. Q. Han1, G. H. Du1, G. Li1,3, J. Zhang2, and Q. Hu

2013 ApJ 773 129, **File**

Two major processes have been proposed to convert coronal magnetic energy into the kinetic energy of a coronal mass ejection (CME): resistive magnetic reconnection and the ideal macroscopic magnetohydrodynamic instability of a magnetic flux rope. However, it remains elusive whether both processes play a comparable role or one of them prevails during a particular eruption. To shed light on this issue, we carefully studied energetic but flareless CMEs, i.e., fast CMEs not accompanied by any flares. Through searching the Coordinated Data Analysis Workshops database of CMEs observed in Solar Cycle 23, we found 13 such events with speeds larger than 1000 km s–1. Other common observational features of these events are: (1) none of them originated in active regions, they were associated with eruptions of well-developed long filaments in quiet-Sun regions; (2) no apparent enhancement of

flare emissions was present in soft X-ray, EUV, and microwave data. Further studies of two events reveal that (1) the reconnection electric fields, as inferred from the product of the separation speed of post-eruption ribbons and the photospheric magnetic field measurement, were generally weak; (2) the period with a measurable reconnection electric field is considerably shorter than the total filament-CME acceleration time. These observations indicate that for these fast CMEs, the magnetic energy was released mainly via the ideal flux-rope instability through the work done by the large-scale Lorentz force acting on the rope currents rather than via magnetic reconnections. We also suggest that reconnections play a less important role in accelerating CMEs in quiet-Sun regions of weak magnetic field than those in active regions of strong magnetic field. **98/01/03, 98/06/05, 99/09/16, 99/09/23, 00/07/24, 02/03/02, 02/05/11, 02/07/13, 02/08/06, 02/12/21, 02/12/26, 03/01/05, 05/01/04**

Investigation on Radio-Quiet and Radio-Loud Fast CMEs and Their Associated Flares During Solar Cycles 23 and 24

K. **Suresh**, A. Shanmugaraju

Solar Phys. Volume 290, Issue 3, pp 875-889 **2015**

We present the results of a detailed analysis on the differences between radio-loud (RL) and radio-quiet (RQ) fast coronal mass ejections (CMEs) ($V \geq 900$ km s−1) observed during the period 1996 – 2012. The analysis consists of three different steps in which we examined the properties of (i) RL and RQ CMEs, (ii) accelerating (class-A) and decelerating (class-D) CMEs among RL and RQ CMEs, and (iii) associated flares. The last two steps and events from a longer period are the extensions of the earlier work on RL and RQ CMEs that mainly aimed to determine the reason for the radio-quietness of some fast CMEs. During this period, we found that 38 % of fast CMEs are RL and 62 % of fast CMEs are RQ. Moreover, fewer RQ CMEs occur around the disc centre. The average speeds of RL and RQ CMEs are 1358 km s−1 and 1092 km s−1. Around 10 % of the RQ events are halo CMEs, but ≈ 66 % of RL events are halo CMEs. The mean acceleration or deceleration value of RL-CMEs is slightly greater than that of RQ-CMEs. When we divide these events based on their acceleration behaviour into class A and class D, there are no considerable differences between classes A and D of RL-CMEs or between classes A and D of RQ CMEs, except for their initial acceleration values. But there are significant differences among their associated flare properties. According to our study here, the RQ CMEs are less energetic than RL CMEs, and they are not associated with flares as strong as those associated with RL CMEs. This confirms the previous results that RQ CMEs do not often exceed the critical Alfvén speed of 1000 km s−1 in the outer corona that is needed to produce type II radio bursts.

Correlations between the CME acceleration, other CME parameters and flare energy

G.S. **Suryanarayana**

Journal of Atmospheric and Solar-Terrestrial Physics Volume 185, April **2019**, Pages 1-6

https://reader.elsevier.com/reader/sd/pii/S1364682618303936?token=CB263260630F0BB5166EA1A495BF4EA0DB39552277C6C7C0722457BB500255FA3C2D97018F71DF80EB4E1FEEB8B05F00

sci-hub.tw/10.1016/j.jastp.2019.01.014

While the Coronal Mass Ejections (CMEs) without associated flares are known to accelerate and decelerate being moderated by the Lorentz force, gravity and the drag force due to solar wind, the flare association is known to prolong the acceleration. However, with or without the flare association, a significant proportion of slow CMEs decelerate and a similar proportion of fast CMEs accelerate. In the case of accelerating CMEs, various parameters of CMEs such as the mass, angular width etc. show good correlation and this improves with flare association. When the flares and CMEs are associated, there is apparently a division of energy between the flares and the CMEs. It is also known that the magnetic flux spanned by the flare arcade and ribbons after flare maximum, roughly equals the magnetic flux content of the CME and their ratio could be between one and two. The magnetic flux content of the CME can be estimated from the final angular width of the CME. Hence, we suggest that the CMEs experience net acceleration when the different parameters of CMEs such as angular width, mass etc. are correlated and when the CME parameters are correlated with flare duration and peak flux. The absence of the same may lead to CMEs experience net deceleration.

Nature of helicity injection in non-erupting solar active regions

P **Vemareddy**

MNRAS, Volume 516, Issue 1, **2022**, Pages 158–166,

https://doi.org/10.1093/mnras/stac2253

Using time-sequence vector magnetic field and coronal observations from Solar Dynamics Observatory, we report the observations of the magnetic field evolution and coronal activity in four emerging active regions (ARs). The ARs emerge with leading polarity being the same as for the majority of ARs in a hemisphere of solar cycle 24. After emergence, the magnetic polarities separate each other without building a sheared polarity inversion line. In all four ARs, the magnetic fields are driven by foot point motions such that the sign of the helicity injection (dH/dt) in the first half of the evolution is changed to the opposite sign in the later part of the observation time. This successive injection of opposite helicity is also consistent with the sign of mean force–free twist parameter (α_{av}). Further, the EUV light curves off the ARs in 94 Å and GOES X-ray flux reveal flaring activity below C-class magnitude.

Importantly, the white-light coronagraph images in conjunction with the AR images in Atmospheric Imaging Assembly (AIA) 94 Å delineate the absence of associated Coronal Mass ejections (CMEs) with the studied ARs. These observations imply that the ARs with successive injection of opposite sign magnetic helicity are not favourable to twisted flux rope formation with excess coronal helicity, and therefore are unable to launch CMEs, according to recent reports. This study provides the characteristics of helicity flux evolution in the ARs referring to the conservative property of magnetic helicity and more such studies would help to quantify the eruptive capability of a given AR.

Streamer Blowout Coronal Mass Ejections: Their Properties and Relation to the Coronal Magnetic Field Structure

Angelos **Vourlidas**, David F. Webb

ApJ **861** 103 **2018**

https://arxiv.org/ftp/arxiv/papers/1806/1806.00644.pdf

http://sci-hub.tw/http://iopscience.iop.org/0004-637X/861/2/103/

We present a comprehensive analysis of a particular class of coronal mass ejection (CME) event, called streamer-blowout CME (SBOs). The events are characterized by a gradual swelling of the overlying streamer, lasting hours to days, followed by a slow, wide CME, generally exhibiting a 3-part structure, which leaves the streamer significantly depleted in its wake. We identify 909 SBO events in the LASCO/C2 observations between 1996 and 2015. The average blowout lasts for 40.5 hours but the evacuation can take days for some events. SBO-CMEs are wider and more massive than the average CME. Their properties generally vary during and between solar cycles. Their minimum (maximum) monthly occurrence rate of one (six) events in cycle 23 has doubled in cycle 24---a probable manifestation of the weaker global fields in the current cycle. The locations of SBOs follow the tilt of the global dipole (but not from 2014 onwards), do not correlate with sunspot numbers and exhibit flux rope morphology at a much higher rate (61%) than regular CMEs (40%). We propose that these characteristics are consistent with SBOs arising from extended polarity inversion lines outside active regions (e.g. quiet sun and polar crown filaments) through the release, via reconnection, of magnetic energy, likely accumulated via differential rotation. **March 22-25, 2000, 2003/10/30, 2008/11/27**

Multi-viewpoint Coronal Mass Ejection Catalog Based on STEREO COR2 Observations

Angelos **Vourlidas**1,4, Laura A. Balmaceda2,5,6, Guillermo Stenborg3, and Alisson Dal Lago2

2017 ApJ 838 141 **File**

http://sci-hub.cc/10.3847/1538-4357/aa67f0

We present the first multi-viewpoint coronal mass ejection (CME) catalog. The events are identified visually in simultaneous total brightness observations from the twin SECCHI/COR2 coronagraphs on board the Solar Terrestrial Relations Observatory mission. The Multi-View CME Catalog differs from past catalogs in three key aspects: (1) all events between the two viewpoints are cross-linked, (2) each event is assigned a physics-motivated morphological classification (e.g., jet, wave, and flux rope), and (3) kinematic and geometric information is extracted semi-automatically via a supervised image segmentation algorithm. The database extends from the beginning of the COR2 synoptic program (2007 March) to the end of dual-viewpoint observations (2014 September). It contains 4473 unique events with 3358 events identified in both COR2s. Kinematic properties exist currently for 1747 events (26% of COR2-A events and 17% of COR2-B events). We examine several issues, made possible by this cross-linked CME database, including the role of projection on the perceived morphology of events, the missing CME rate, the existence of cool material in CMEs, the solar cycle dependence on CME rate, speeds and width, and the existence of flux rope within CMEs. We discuss the implications for past single-viewpoint studies and for Space Weather research. The database is publicly available on the web including all available measurements. We hope that it will become a useful resource for the community. **2009-01-18, 2009-01-22, 2010-04-03, 2011-02-26, 2012-01-26, 2012-10-14, 2013-05-12, 2013-06-08, 2013-10-11, 2013-10-23**

See http://solar.jhuapl.edu/Data-Products/**COR-CME-Catalog**.php

ERRATUM: "COMPREHENSIVE ANALYSIS OF CORONAL MASS EJECTION MASS AND ENERGY PROPERTIES OVER A FULL SOLAR CYCLE" (2010, ApJ, 722, 1522)

A. **Vourlidas**1, R. A. Howard1, E. Esfandiari2, S. Patsourakos3, S. Yashiro4 and G. Michalek5

2011 ApJ 730 59

In our recent paper (Vourlidas et al. 2010, Paper I hereafter), we reported various statistics regarding the masses and energies of coronal mass ejections (CMEs) including the detection of a 6 month CME mass variability. Since then, we have uncovered a processing error in the routines that create the mass images. They failed to take into account the image rotation during the 180◦ rolls of the *SOHO* spacecraft (see http://soho.nascom.nasa.gov/hotshots/2004_01_04 for more information). Therefore, the mass and energy measurements for those periods did not correspond to the actual CME location. This error affected about half of the events since 2003 June when the spacecraft began rolling for 3 months at a time. We corrected the software error, reprocessed all images and measurements since 2003, and redid the analysis exactly as it was reported in Paper I.

The final sample includes slightly more events (7820 CMEs) compared to the 7668 events used in Paper I.We found that the correction affected mostly our discussion on the solar cycle effects (Section 3.5 in Paper I). We describe these changes in detail below and provide updated figures where necessary.

COMPREHENSIVE ANALYSIS OF CORONAL MASS EJECTION MASS AND ENERGY PROPERTIES OVER A FULL SOLAR CYCLE

A. **Vourlidas**1,, R. A. Howard1, E. Esfandiari2, S. Patsourakos3, S. Yashiro4, and G. Michalek5

Astrophysical Journal, 722:1522–1538, **2010, File**

See ERRATUM, 2011

The LASCO coronagraphs, in continuous operation since 1995, have observed the evolution of the solar corona and coronal mass ejections (CMEs) over a full solar cycle with high-quality images and regular cadence. This is the first time that such a data set becomes available and constitutes a unique resource for the study of CMEs. In this paper, we present a comprehensive investigation of the solar cycle dependence on the CME mass and energy over a full solar cycle (1996–2009) including the first in-depth discussion of the mass and energy analysis methods and their associated errors. Our analysis provides several results worthy of further studies. It demonstrates the possible existence of two event classes: "normal" CMEs reaching constant mass for >10 *R*_ and "pseudo"-CMEs which disappear in the C3 field of view. It shows that the mass and energy properties of CME reach constant levels and therefore should be measured only above ~10*R*_. The mass density (*g/R*2_) of CMEs varies relatively little (<order of magnitude) suggesting that the majority of the mass originates from a small range in coronal heights. We find a sudden reduction in the CME mass in mid-2003 which may be related to a change in the electron content of the large-scale corona and we uncover the presence of a 6 month periodicity in the ejected mass from 2003 onward.

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

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

https://arxiv.org/ftp/arxiv/papers/2104/2104.07238.pdf

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.

Coronal Mass Ejections and the Solar Cycle Variation of the Sun's Open Flux

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Correlation Between CME Occurrence Rate and Current Helicity in the Global Magnetic Field of Solar Cycle 23

Chuanyu **Wang**, Mei Zhang

Solar Phys. Volume 290, Issue 3, pp 811-818 **2015**

We investigate the correlation between the occurrence rate of the monthly coronal mass ejection (CME) and the magnitude of the current helicity in global magnetic field on the photosphere of solar cycle 23. We used the technique introduced by Pevtsov and Latushko (Astrophys. J. 528, 999,2000) to retrieve the vector magnetic field from longitudinal full-disk magnetograms, but applied a different method to calculate the current helicity and focused on the evolution of the magnitude of current helicity over a full solar cycle. We found that there is a close relationship between the variation of the current helicity in the global magnetic field and that of the monthly CME occurrence rate. This provides further evidence to support that helicity is an important ingredient for solar eruptions.

Is Solar Cycle 24 Producing More Coronal Mass Ejections Than Cycle 23?

Y.-M. **Wang** and R. Colaninno

2014 ApJ 784 L27

Although sunspot numbers are roughly a factor of two lower in the current cycle than in cycle 23, the rate of coronal mass ejections (CMEs) appears to be at least as high in 2011-2013 as during the corresponding phase of the previous cycle, according to three catalogs that list events observed with the Large Angle and Spectrometric Coronagraph (LASCO). However, the number of CMEs detected is sensitive to such factors as the image cadence and the tendency (especially by human observers) to under-/overcount small or faint ejections during periods of high/low activity. In contrast to the total number, the total mass of CMEs is determined mainly by larger events. Using the mass measurements of 11,000 CMEs given in the manual CDAW catalog, we find that the mass loss rate remains well correlated with the sunspot number during cycle 24. In the case of the automated CACTus and SEEDS catalogs, the large increase in the number of CMEs during cycle 24 is almost certainly an artifact caused by the near-doubling of the LASCO image cadence after mid-2010. We confirm that fast CMEs undergo a much stronger solar-cycle variation than slow ones, and that the relative frequency of slow and less massive CMEs increases with decreasing sunspot number. We conclude that cycle 24 is not only producing fewer CMEs than cycle 23, but that these ejections also tend to be slower and less massive than those observed one cycle earlier.

WAITING TIMES OF QUASI-HOMOLOGOUS CORONAL MASS EJECTIONS FROM SUPER ACTIVE REGIONS

Yuming **Wang**, Lijuan Liu, Chenglong Shen, Rui Liu, Pinzhong Ye, and S. Wang

2013 ApJ 763 L43

Why and how do some active regions (ARs) frequently produce coronal mass ejections (CMEs)? These are key questions for deepening our understanding of the mechanisms and processes of energy accumulation and sudden release in ARs and for improving our space weather prediction capability. Although some case studies have been performed, these questions are still far from fully answered. These issues are now being addressed statistically through an investigation of the waiting times of quasi-homologous CMEs from super ARs in solar cycle 23. It is found that the waiting times of quasi-homologous CMEs have a two-component distribution with a separation at about 18 hr. The first component is a Gaussian-like distribution with a peak at about 7 hr, which indicates a tight physical connection between these quasi-homologous CMEs. The likelihood of two or more occurrences of CMEs faster than 1200 km s–1 from the same AR within 18 hr is about 20%. Furthermore, the correlation analysis among CME waiting times, CME speeds, and CME occurrence rates reveals that these quantities are independent of each other, suggesting that the perturbation by preceding CMEs rather than free energy input is the direct cause of quasi-homologous CMEs. The peak waiting time of 7 hr probably characterizes the timescale of the growth of the instabilities triggered by preceding CMEs. This study uncovers some clues from a statistical perspective for us to understand quasi-homologous CMEs as well as CME-rich ARs.

Is There a CME Rate Floor? CME and Magnetic Flux Values for the Last Four Solar Cycle Minima

D. F. **Webb**1, R. A. Howard2, O. C. St. Cyr3, and A. Vourlidas4

2017 ApJ 851 142

http://sci-hub.tw/10.3847/1538-4357/aa9b81

The recent prolonged activity minimum has led to the question of whether there is a base level of the solar magnetic field evolution that yields a "floor" in activity levels and also in the solar wind magnetic field strength. Recently, a flux transport model coupled with magneto-frictional simulations has been used to simulate the continuous magnetic field evolution in the global solar corona for over 15 years, from 1996 to 2012. Flux rope eruptions in the simulations are estimated (Yeates), and the results are in remarkable agreement with the shape of the SOlar Heliospheric Observatory/Large Angle and Spectrometric Coronagraph Experiment coronal mass ejection (CME) rate distribution. The eruption rates at the two recent minima approximate the observed-corrected CME rates, supporting the idea of a base level of solar magnetic activity. In this paper, we address this issue by comparing annual averages of the CME occurrence rates during the last four solar cycle minima with several tracers of the global solar magnetic field. We conclude that CME activity never ceases during a cycle, but maintains a base level of 1 CME every 1.5 to ~3 days during minima. We discuss the sources of these CMEs. **1996 May-July, 2008 December - 2009 February**

Coronal Mass Ejections: Observations   A Review

David F. **Webb** and Timothy A. Howard

Living Rev. Solar Phys., 9, (**2012**), 3, **File**

http://www.livingreviews.org/lrsp-2012-3

Solar eruptive phenomena embrace a variety of eruptions, including flares, solar energetic particles, and radio bursts. Since the vast majority of these are associated with the eruption, development, and evolution of coronal mass ejections (CMEs), we focus on CME observations in this review. CMEs are a key aspect of coronal and interplanetary dynamics. They inject large quantities of mass and magnetic flux into the heliosphere, causing major transient disturbances. CMEs can drive interplanetary shocks, a key source of solar energetic particles and are known to be the major contributor to severe space weather at the Earth. Studies over the past decade using the data sets from (among others) the SOHO, TRACE, Wind, ACE, STEREO, and SDO spacecraft, along with ground-based instruments, have improved our knowledge of the origins and development of CMEs at the Sun and how they contribute to space weather at Earth. SOHO, launched in 1995, has provided us with almost continuous coverage of the solar corona over more than a complete solar cycle, and the heliospheric imagers SMEI (2003–2011) and the HIs (operating since early 2007) have provided us with the capability to image and track CMEs continually across the inner heliosphere. We review some key coronal properties of CMEs, their source regions and their propagation through the solar wind. The LASCO coronagraphs routinely observe CMEs launched along the Sun-Earth line as halo-like brightenings. STEREO also permits observing Earth-directed CMEs from three different viewpoints of increasing azimuthal separation, thereby enabling the estimation of their three-dimensional properties. These are important not only for space weather prediction purposes, but also for understanding the development and internal structure of CMEs since we view their source regions on the solar disk and can measure their in-situ characteristics along their axes. Included in our discussion of the recent developments in CME-related phenomena are the latest developments from the STEREO and LASCO coronagraphs and the SMEI and HI heliospheric imagers.

Comparing SSN Index to X-ray Flare and Coronal Mass Ejection Rates from Solar Cycles 22-24

Lisa M. **Winter**, Rick Pernak, K.S. Balasubramaniam

Solar Phys.   **2016**

http://arxiv.org/pdf/1605.00503v1.pdf

The newly revised sunspot number series allows for placing historical geoeffective storms in the context of several hundred years of solar activity. Using statistical analyses of the Geostationary Operational Environmental Satellites (GOES) X-ray observations from the past ~30 years and the Solar and Heliospheric Observatory (SOHO) Large Angle and Spectrometric Coronagraph (LASCO) Coronal Mass Ejection (CME) catalog (1996-present), we present sunspot-number-dependent flare and CME rates. In particular, we present X-ray flare rates as a function of sunspot number for the past three cycles. We also show that the 1-8 AA X-ray background flux is strongly correlated with sunspot number across solar cycles. Similarly, we show that the CME properties (e.g., proxies related to the CME linear speed and width) are also correlated with sunspot number for SC 23 and 24. These updated rates will enable future predictions for geoeffective events and place historical storms in the context of present solar activity.

A Catalog of Prominence Eruptions Detected Automatically in the SDO/AIA 304 Å Images
S. **Yashiro** (1 and 2), N. Gopalswamy (2), S. Akiyama (1 and 2), P.A. Mäkelä
2020
See https://cdaw.gsfc.nasa.gov/CME_list/autope/
https://arxiv.org/ftp/arxiv/papers/2005/2005.11363.pdf
We report on a statistical study of prominence eruptions (PEs) using a catalog of these events routinely imaged by the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO) in the 304 Å pass band. Using an algorithm developed as part of an LWS project, we have detected PEs in 304 Å synoptic images with 2-min cadence since May 2010. **A catalog of these PEs is made available online (this https URL).** The 304 Å images are polar-transformed and divided by a background map (pixels with minimum intensity during one day) to get the ratio maps above the limb. The prominence regions are defined as pixels with a ratio ≥2. Two prominence regions with more than 50% of pixels overlapping are considered the same prominence. If the height of a prominence increases monotonically in 5 successive images, it is considered eruptive. All the PEs seen above the limb are detected by the routine, but only PEs with width ≥15° are included in the catalog to eliminate polar jets and other small-scale mass motions. The identifications are also cross-checked with the PEs identified in Nobeyama Radioheliograph images (this http URL). The catalog gives the date, time, central position angle, latitude, and width of the eruptive prominence. The catalog also provides links to JavaScript movies that combine SDO/AIA images with GOES soft X-ray data to identify the associated flares, and with SOHO/LASCO C2 images to identify the associated coronal mass ejections. We examined the statistical properties of the PEs and found that the high-latitude PE speed decreased with the decreasing of the average polar magnetic field strength of the previous cycle. **2011.05.30**

A Catalog of White Light Coronal Mass Ejections Observed by the SOHO Spacecraft
S. **Yashiro**, N. Gopalswamy, G. Michalek, O. C. St.Cyr, S. P. Plunkett, N. B. Rich, and R. A. Howard
Journal of Geophysical Research, 109, A07105, doi:10.1029/2003JA010282 , **(2004**)
The Solar and Heliospheric Observatory (SOHO) mission's white light coronagraphs have observed nearly 7000 coronal mass ejections (CMEs) between 1996 and 2002. We have documented the measured properties of all these CMEs in an online catalog. We describe this catalog and present a summary of the statistical properties of the CMEs. The primary measurements made on each CME are the apparent central position angle, the angular width in the sky plane, and the height (heliocentric distance) as a function of time. The height-time measurements are then fitted to first and second order polynomials to derive the average apparent speed and acceleration of the CMEs. The statistical properties of CMEs are: (1) the average width of normal CMEs (20 < width < 120) increased from 47 deg (1996; solar minimum) to 61 deg (1999; early phase of solar maximum) and then decreased to 53 deg (2002; late phase of solar maximum), (2) CMEs were detected around the equatorial region during solar minimum, while during solar maximum CMEs appear at all latitudes, (3) the average apparent speed of CMEs increases from 300 km/s (solar minimum) to 500 km/s (solar maximum), (4) the average apparent speed of halo CMEs (957 km/s) is twice of that of normal CMEs (428 km/s), and (5) most of the slow CMEs (V < 250 km/s) show acceleration while most of the fast CMEs (V>900 km/s) show deceleration. Solar cycle variation and statistical properties of CMEs are revealed with greater clarity in this study as compared to previous studies. Implications of our findings for CME models are discussed.

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
Progress in Earth and Planetary Science, Volume 8, Issue 1, article id.56, **2021 File**
https://progearthplanetsci.springeropen.com/counter/pdf/10.1186/s40645-021-00426-7.pdf
https://arxiv.org/ftp/arxiv/papers/2012/2012.06116.pdf **2021**
2020 https://arxiv.org/abs/2012.06116
https://arxiv.org/ftp/arxiv/papers/2012/2012.06116.pdf
https://doi.org/10.1186/s40645-021-00426-7
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**

Quantifying the Propagation of Fast Coronal Mass Ejections from the Sun to Interplanetary Space Combining Remote Sensing and Multi-Point in-situ Observations

Xiaowei **Zhao**, Ying D. Liu, Huidong Hu, Rui Wang

ApJ **882** 122 **2019**

https://arxiv.org/pdf/1908.04450.pdf

sci-hub.se/10.3847/1538-4357/ab379b

In order to have a comprehensive view of the propagation and evolution of coronal mass ejections (CMEs) from the Sun to deep interplanetary space beyond 1 au, we carry out a kinematic analysis of 7 CMEs in solar cycle 23. The events are required to have coordinated coronagraph observations, interplanetary type II radio bursts, and multi-point in-situ measurements at the Earth and Ulysses. A graduated cylindrical shell model, an analytical model without free parameters and a magnetohydrodynamic model are used to derive CME kinematics near the Sun, to quantify the CME/shock propagation in the Sun-Earth space, and to connect in-situ signatures at the Earth and Ulysses, respectively. We find that each of the 7 CME-driven shocks experienced a major deceleration before reaching 1 au and thereafter propagated with a gradual deceleration from the Earth to larger distances. The resulting CME/shock propagation profile for each case is roughly consistent with all the data, which verifies the usefulness of the simple analytical model for CME/shock propagation in the heliosphere. The statistical analysis of CME kinematics indicates a tendency that the faster the CME, the larger the deceleration, and the shorter the deceleration time period within 1 au. For several of these events, the associated geomagnetic storms were mainly caused by the southward magnetic fields in the sheath region. In particular, the interaction between a CME-driven shock and a preceding ejecta significantly enhanced the preexisting southward magnetic fields and gave rise to a severe complex geomagnetic storm. **1997 November 4, 2000 June 6, 2001 April 2, 2001 November 4, 2001 November 22, 2005 May 13, 2006 December 13**

Table 1. Solar source information, CME propagation direction, shock arrival time and Ulysses position relative to the Earth for the 7 CMEs.

Successive Coronal Mass Ejections Associated with Weak Solar Energetic Particle Events

Bin **Zhuang**, Noé Lugaz, Tingyu Gou, Liuguan Ding

ApJ **2021**

https://arxiv.org/pdf/2109.02225.pdf

The scenario of twin coronal mass ejections (CMEs), i.e., a fast and wide primary CME (priCME) preceded by previous CMEs (preCMEs), has been found to be favorable to a more efficient particle acceleration in large solar energetic particle (SEP) events. Here, we study 19 events during 2007--2014 associated with twin-CME eruptions but without large SEP observations at L1 point. We combine remote-sensing and in situ observations from multiple spacecraft to investigate the role of magnetic connectivity in SEP detection and the CME information in 3-dimensional (3D) space. We study one-on-one correlations of the priCME 3D speed, flare intensity, suprathermal backgrounds, and height of CME-CME interaction with the SEP intensity. Among these, the priCME speed is found to correlate with the SEP peak intensity at the highest level. We use the projection correlation method to analyze the correlations between combinations of these multiple independent factors and the SEP peak intensity. We find that the only combination of two or more parameters that has higher correlation with the SEP peak intensity than the CME speed is the CME speed combined with the propagation direction. This further supports the dominant role of the priCME in controlling the SEP enhancements, and emphasizes the consideration of the latitudinal effect. Overall, the magnetic connectivity in longitude as well as latitude and the relatively lower priCME speed may explain the existence of the twin-CME SEP-poor events. The role of the barrier effect of preCME(s) is discussed for an event on **2013 October 28.**

Table 1:: Twin-CME (L1-point) SEP-poor events during 2007– 2014

Table 2:: Twin-CME (L1-point) large SEP events in solar cycle 24

ОБ ИЗМЕНЕНИИ ХАРАКТЕРА СВЯЗИ КОРОНАЛЬНЫХ ВЫБРОСОВ МАССЫ С СООТВЕТСТВУЮЩИМИ РЕНТГЕНОВСКИМИ ВСПЫШКАМИ В ТЕЧЕНИЕ 11-ЛЕТНЕГО СОЛНЕЧНОГО ЦИКЛА

Е.В.**Иванов**

ИКИ-**2014**, Сессия: Солнце
http://plasma2014.cosmos.ru/presentations