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Coronal Mass Ejections: Their Propagation and Associated Storms in the First Phase of Solar Cycle 25

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Abstract

We have investigated of about 50 coronal mass ejections from 2022 to 2024 in first phase of solar cycle 25. We have investigated about the velocities, angular widths and central width of those coronal mass ejections. The interplanetary consequences of those ejections particularly to a height of 30 $R_{\odot}$ in the range of sun-earth distance. The ejections mostly investigated have DST above -70nT, the ejections have affected the geomagnetics and have auroral onset in the lower latitudes. For each of the ejections these properties like the speed and kp were observed from the onboard SOHO SPACE mission by the LASCO coronagraphs. The ranges of velocities of the coronal mass ejections were from, about 400Km/sec to 900Km/sec. although some of the ejections have caused the high intense geomagnetic storms like in May 2024 but most of them have moderate storms in the magnetosphere. It has been found that as the solar cycle 24 saw less coronal mass ejections the ejections have shown some sharp rise as in the beginning of solar cycle 25.. We have also presented some consequences of interplanetary coronal mass ejections (ICMEs). Some of the halo CMEs with angular width (>180) .were also observed and investigated in this study.

Key Words: Coronal Mass Ejection, Solar Cycle , Geomagnetic storm

1. Introduction

Coronal Mass Ejections are powerful events originating from the Sun's corona, and they have a significant impact on space weather and our technological infrastructure. We present a report of the most recent progress on the topic of understanding solar coronal mass ejection (CME) onset. The impact of Coronal Mass Ejections (CMEs) on geomagnetism is typically monitored and assessed. Keeping an eye on geomagnetic indices, such as the Kp index, Dst index, and the AE index. These indices provide quantitative measures of geomagnetic activity. A coronal mass ejection is a significant release of plasma and magnetic fields from the Sun's corona into space. These ejections can travel at speeds ranging from 20 to over 2,000 kilometers per second. also coronal mass ejections that are directed from the front twords the earth are halo coronal mass ejections. Ejection is highly dependent on the solar activity. Solar activities have been distributed on the basis of solar cycles. Currently we are in the solar cycle 25 which started in 2019. The peak of this cycle is expected to be in the mid july of 2024. A large number of ejections have already been observed in the rising phase of this cycle. The geomagnetic storms and the auroral activity have been seen in this phase due to onset of coronal mass ejections.

Causes: CMEs is basically the releases of magnetics energy stored in the sun which formed near the highly sensitive regions known sunspots. Generally those sunspot regions are cool with respect to their surroundings of the sun's atmosphere which may generally be around 2000K less as compared to the surrounding temperature. This is because of the convection in the region which is due to high concentration of magnetic field in the sunspot region. The strongest part in the sunspot region with a huge magnetic field concentration is known as umbra and the part with lighter magnetic field in the sunspot region is known as penumbra. Sunspots could have a life span of around a few days which may go upto several months. By the national oceanic and atmospheric administration these highly concentrated magnetic field regions of sunspots are assigned the names which are recognized by active regions. The most

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active sunspot region in 2024 was AR-3697 which is responsible for the most number of solar flares and the coronal mass ejections. Infact magnetic of the two oppositely directed magnetic field releases a huge amount of energy which is responsible for the acceleration and heating of plasma which breaks out in the form of ejection of coronal mass ejection. CMEs are often associated with solar flares, but they can also occur independently. They typically happen due to the sudden release of magnetic energy stored in the Sun's atmosphere.

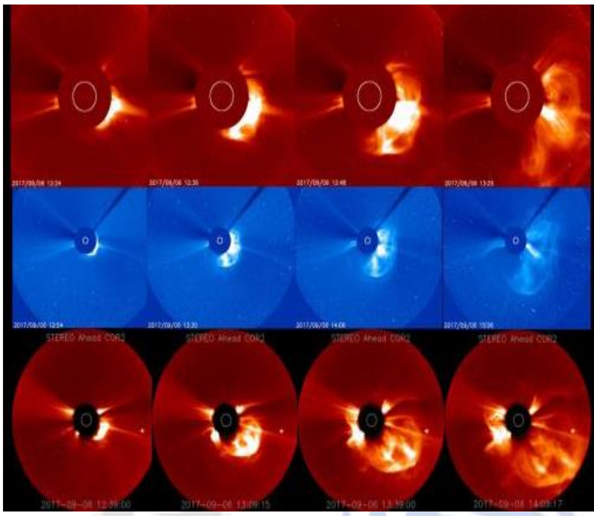

Fig 1

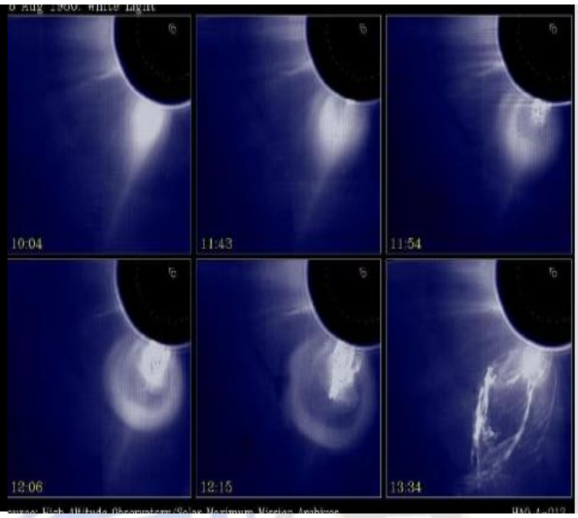

fig 2

Effects on Earth: When a CME is directed toward Earth and interacts with our magnetosphere, it can cause geomagnetic storms. These storms can disrupt satellite operations, power grids, and radio communications. They may also lead to stunning auroras in regions close to the poles.

Observation and Forecasting Space agencies like NASA and NOAA continuously monitor the Sun's activity using various instruments, including space-based observatories like the Solar Dynamics Observatory (SDO) and the Solar and Heliospheric Observatory (SOHO). NASA's parker solar probe which is closest to has provided some key data in this study of of coronal mass ejections. Also it provided the present measure of estimates of the magnetic field.

These observations help in predicting the occurrence and potential impacts of CMEs on Earth. A glancing coronal mass ejection (CME) occurs when a CME is not directly Earth-directed but instead travels in a trajectory that only partially interacts with Earth's magnetosphere.

When a CME is glancing, it may still cause some geomagnetic activity, though typically to a lesser extent compared to a direct hit. The effects of a glancing CME depend on factors such as the speed, density, and magnetic orientation of the ejected material, as well as the orientation of Earth's magnetic field at the time of impact.

Glancing CMEs can still pose risks to satellite operations, power grids, and communication systems, especially if they coincide with other solar activity or if Earth's magnetosphere is already disturbed. However, their impacts are generally milder than those of direct-hit CMEs.

Space weather forecasters monitor glancing CMEs along with other solar phenomena to assess potential impacts and issue warnings to operators of critical infrastructure and satellite systems.

As we are in the solar cycle 25 which is an eleven year cycle of solar activities. This cycle started in 2019 marked to end of solar cycle 24 which had shown tremendous fluctuations in the solar activities solar flares and most importantly coronal mass ejections. Even in the phase of solar minimum a remarkable number of coronal mass ejections were observed in this cycle. In this cycle the number of coronal mass ejections, the frequency and intensity is expected to be higher.

DATA AND METHODS

Keep an eye on geomagnetic indices, such as the Kp index, Dst index, and the AE index. These indices provide quantitative measures of geomagnetic activity. An increase in these indices indicates the onset of

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geomagnetic storms caused by CMEs. We used LASCO CME catelogs . The data from different passbands of AIA on board SDO (Lemen et al. 2011) and EIT (Delaboudinière et al. 1995) on board SOHO were used to identify the source regions of CMEs that were coming from the front side of the Sun. the table 1 gives the real time data of k indices of one month from 22-03-20-2024 at different locations taken from the national oceanic and atmospheric administration (NOAA) – space weather prediction centre. This dataset is provided by GFZ and derived from indices or near real-time geomagnetic observatory data provided by 13 contributing observatories. The Kp index and the derived products are distributed by GFZ and they are redistributed by various data centers and databases. When using the Kp index or any of the derived products of this dataset, more data from the instruments like COR1 and COR2 coronagraphs shows the geoefectiveness of the coronal mass ejections like whether they are earth directive or not. That tracking of CMEs interaction with the solar wind was determined by the SoloHI the heliospheric imager.

The major source of our data were obtained from the from the ui.adsabs.hatvard.edu which is the database provided by the astrophysics data system (ADS) by NASA. The ESU European space agency also provided the useful data about the geomagnetic storms the impact of coronal mass ejections on the space weather and earths magnetic field and hence on the geomagnetic effects. A major chunk of data was obtained the NOAA using http://www.swpc.noaa.gov and https://soho.nascom.nasa.gov/. they have also provided the extensive images and the data related to those images .

The different methods and models used in the prediction of coronal mass ejections are effective acceleration model (EAM) which is based on the observation in the solar cycle 24 purely an empirical model basically an improvement of shock time of arrival model with high consideration of change in speed due to the interaction of solar wind. Some analytical models like solar wind drag model has also provided the estimates of coronal mass ejection speeds with some reasonable amount of accuracy. Some stimulation techniques like WSA-ENLIL and cone model has provided in advance the impact of incoming coronal mass ejection.

The updates about the solar cycle and solar activity were continuously monitored by using the NASA's solar cycle and progression and forecast which provides the information about the sunspot numbers and the measurement of solar flux. The forecast provided by the helio forecast the solar wind data from the STEREO, ACE, DESCOVR has provided some useful solar images which are most recent.

We had shown some drivers based on the NOAA scale of storm and classification with respect to their Kp index the geomagnetic storm by using the figure in the 24 solar cycle and using some earlier solar cycles. Note that this analysis assigns the drivers to three categories of slow and fast solar wind, and "CME-associated" structures which include the sheath and ICME/magnetic cloud.

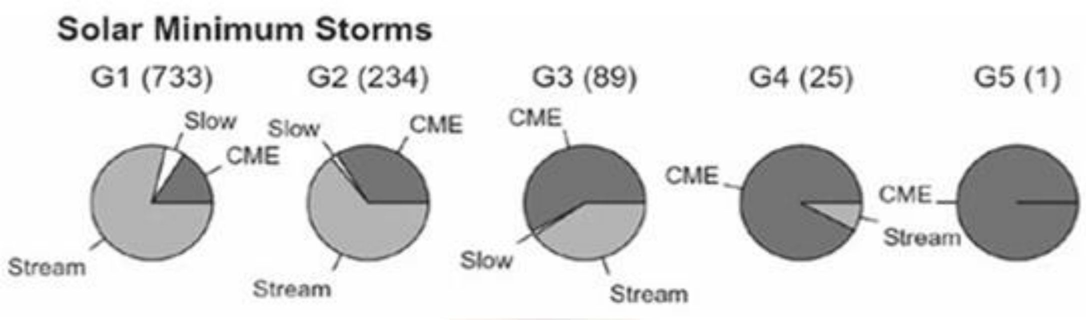

Figure 3 . categories of solar storms in the minimum of solar cycle

For the classification of these storms disturbance storm time index (DST) and new auroral electrojet (AE) offered a better tracking methods and techniques. These indices have helped in the improvement of the accuracy to ensamble real time solar wing and coronal mass ejections to adjust their predictions dynamically.

Analysis and results

The statistical measure of various various factors like angular width, solar wind speed, magnetic flux and the major events of coronal mass ejections in the begning of solar cycle 25 had shown different results as predicted by Dipali S. Burud et al (2007). The major events of coronal mass ejections for the year 2022 have shown a rise in the frequency of coronal mass ejections in the begning of solar cycle 25. Which is likely due increase in the number of

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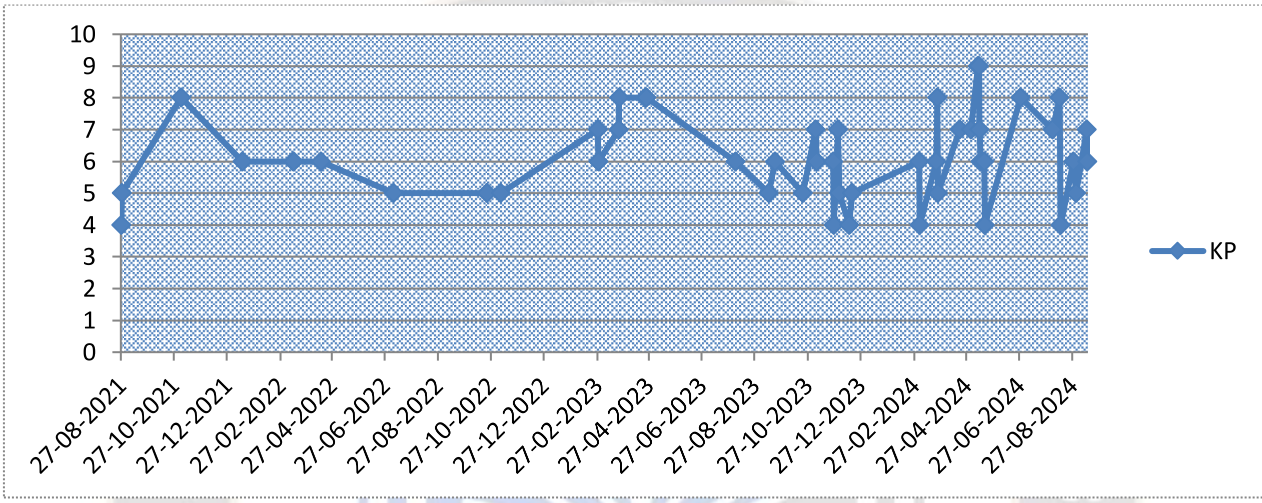
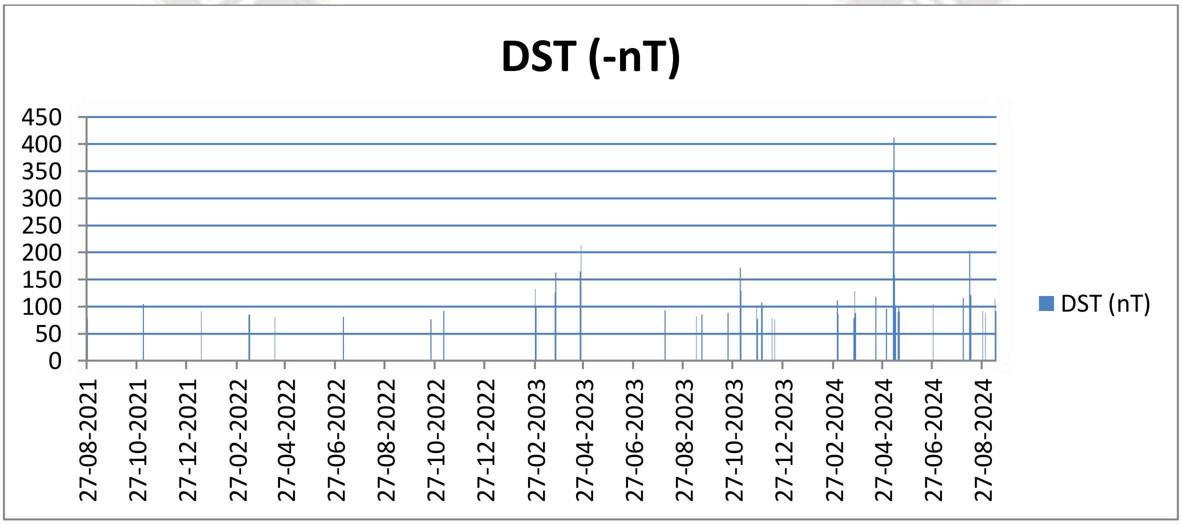
active sunspots. The intensity of the coronal mass ejections also had shown a sudden rise with Kp index greater than 6 for most of the eruptions. Which lead to major geomagnetic storms at times. The table 1 shows that the angular width ranges mostly above 100 in 2022 which has been also supported by the rise of coronal mass ejections with greater Kp index greater than 5 and high DST corresponding to a to same dates. There has been a steep rise in the linear seed also as was seen by SDO on board coronagraphs. The linear speed of the coronal mass ejections for the same dates have also shown the same results as expected which the another evidence of rise in the frequency of coronal mass ejections. The CMEs of moderate intensity were also observed in the same time in large numbers. The beginning of solar cycle has shown a remarkable number of coronal mass ejections which were not expectable in this period of time. The disturbance time index (DST) were also having a high negative value in this period of time which has strongly affected the geomagnetism.



plot 1 Kp vs date

From the plot of Kp of fifty CME events in the rising of solar cycle 25 from it has been observed the index for most of the CMEs were above 4 and has taken the value of about 9. The major peaks were seen in 2024 which was actually the May 2024 where a significant geomagnetic storm occurred which had a high potential impact on earth. The high Kp indices of the coronal mass ejections were mostly evident by the auroras that were seen at the lower latitudes than usual which lead to a significant disturbances in the geomagnetics.



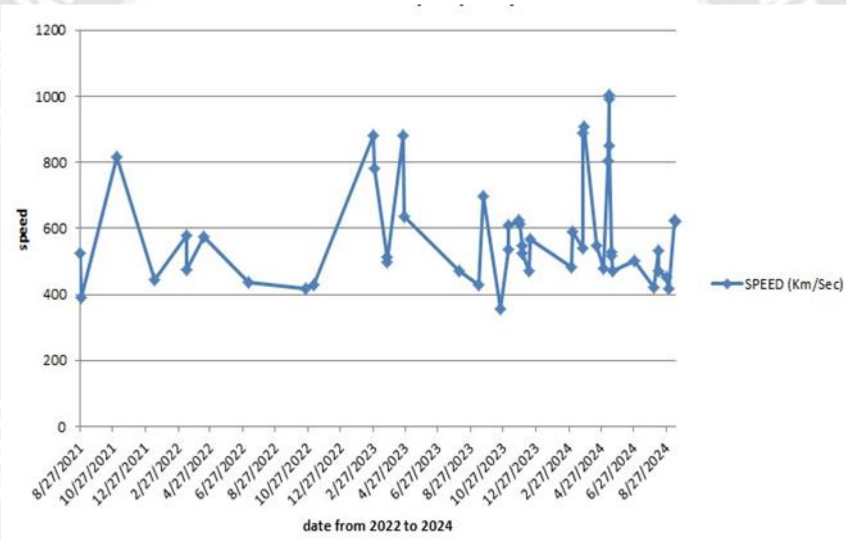
Plot 2 (DST In negative values vs date)

The results are well supported by big lines on DST corresponding the dates particularly in 2024. A DST value of -400nT was attained in May 2024 during which a huge burst of strong magnetic field effected the earth's magnetosphere which was due the onset of coronal mass ejection. The geoeffectiveness of the CMEs in the rising phase of solar cycle 25 was much severe as was predicted by SDO on board coronagraphs.

The details from a distance of about ~30$R_\odot$ have been obtained from the LASCO coronagraph onboard the SOHO spacecraft from where the details of the propagation of the coronal mass ejections were fully analyzed. It was assumed that the propagation of the coronal mass ejections are at constant acceleration so that we can use the classical kinematical equations get the velocity and fit the velocity with that of the data obtained from the data sources. Using for R(t) less or equal to R_m it was assumed that the dynamic is purely governed by the aerodynamic drag in the presence of solar wind. The speeds obtained for various CMES using these methods are summed in the given table 2.

the extrapolations suggest the speed of coronal mass ejections at the peak of solar cycle 25 may be extreme and may range from 2500 to 3000 km/sec even though they may be rare. The DST may also be around -200nT.

In the beginning of solar cycle 25 from 2022 t shown the monotonic rise but have some oscillatory behavior as analyzed from the data. There are o 2024 it kinematics particularly the speed of the of the coronal mass ejections have not some peaks in the plot of speed of coronal mass ejections to some particular coronal mass ejections which are mostly in 2024. These oscillations suggest the highly complex behavior of dynamics of coronal mass ejections.



Plot 3. The speed of major CMEs in first phase

S No.	Date	SPEED Km/sec	S No.	Date	SPEED Km/sec	S No.	Date	SPEED Km/sec
1	8/27/2021	525.4	18	9/12/2023	428.6	35	5/2/2024	477.2
2	8/28/2021	389.3	19	9/19/2023	698.1	36	5/10/2024	804.7
3	11/4/2021	817.3	20	10/21/2023	356.6	37	5/11/2024	993.2
4	1/14/2022	443	21	11/5/2023	534.6	38	5/12/2024	1005
5	3/13/2022	580.1	22	11/6/2023	610.5	39	5/13/2024	850.5
6	3/14/2022	475.5	23	11/25/2023	626	40	5/16/2024	528.9
7	4/14/2022	574.8	24	11/26/2023	613.8	41	5/17/2024	517.2
8	7/7/2022	437.9	25	12/1/2023	546.6	42	5/18/2024	473
9	10/22/2022	417.6	26	12/2/2023	525.8	43	6/28/2024	500.2
10	11/7/2022	429.2	27	12/14/2023	469.7	44	8/4/2024	422.6
11	2/27/2023	882.5	28	12/17/2023	565.3	45	8/12/2024	533.6
12	2/28/2023	781.4	29	3/3/2024	481.2	46	8/13/2024	470
13	3/23/2023	513.3	30	3/4/2024	590.8	47	8/28/2024	452.3
14	3/24/2023	499.4	31	3/23/2024	540.5	48	8/31/2024	415.9

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15	4/23/2023	880.8	32	3/24/2024	887.2	49	9/12/2024	622.6
16	4/24/2023	635.7	33	3/25/2024	909.4	50	9/13/2024	618.6
sss17	8/5/2023	470.3	34	4/19/2024	548.9			

Table 2. the speed of coronal of major events of coronal ejections in the rising phase of solar cycle 25 from the year 2022 to 2024.

Summary and Conclusion

From the velocities and various other factors like Kp index , Ap index , DST and other factors like angular width of the coronal mass ejections in the first phase which is mostly expected to less ejection had shown some reversal and increased number of ejections. That could be the reason for the enhanced auroral activities in the rising phase of the solar cycle 25. The extrapolation of the plots suggest the increase of CMEs in the number and intensity as the solar cycle 25 progress.

For the future, the data can be acceded from future coronagraphs from the on board spacecraft of LOSCO and Venkata et.al (2017) could help and will be more useful in the estimation of more accurate results for the onset of coronal mass ejections. This may also include the CMEs having wider range of velocities and angular widths. In order to generalize the results in more precise these coronagraphs can be more helpful.

Below table 3 shows the central width and angular width of the major coronal mass ejections in the rising phase of solar cycle 25 from the year 2022 to 2024 . the angular width shows a sharp rise in in 2024

First C2 Appearance Date Time [UT]	Central PA [deg]	Angular Width [deg]	Linear Speed [km/s]	2nd-order Speed at final height [km/s]	2nd-order Speed at 20 Rs [km/s]	Accel [m/s^2]	Kinetic Energy [erg]
1/14/2022	122	32	233	335	853	29.2*1	2.60E+28
3/13/2022	99	71	140	204	524	11.5*1	2.40E+28
3/14/2022	242	38	243	350	814	26.6*1	2.40E+28
4/14/2022	229	42	205	254	601	13.9*1	3.40E+28
7/7/2022	207	225	740	526	451	-27	1.6e+31*2
10/22/2022	242	38	243	350	814	26.6*1	2.40E+28
2/27/2023	317	92	273	326	328	2.5*1	8.20E+29
2/28/2023	243	103	452	452	452	0	1.70E+30
3/23/2023	211	81	520	623	700	13.2	2.00E+30
3/24/2023	266	62	311	180	0	-17.3	2.50E+29
4/23/2023	67	91	714	559	605	-15.3	3.70E+30
4/24/2023	257	159	292	514	509	10.4	1.2e+30*2
8/5/2023	208	129	665	687	686	2.3	1.3e+31*2
9/12/2023	276	65	566	473	214	-15.9	5.70E+29
9/19/2023	114	152	490	556	595	7.3	2.2e+30*2
10/21/2023	193	120	421	606	713	18.5*1	1.30E+30
4/19/2024	264	97	476	325	0	-32.2	6.20E+30
5/2/2024	80	102	265	531	587	14.2*1	1.20E+30
5/10/2024	254	125	532	569	553	2.5	6.1e+30*2
5/11/2024	282	77	490	441	321	-7.9	8.20E+29
5/12/2024	160	107	253	140	0	-13.2	3.90E+29
5/13/2024	41	106	341	548	521	10.5	1.90E+30
5/16/2024	114	143	228	261	454	7.0*1	5.0e+29*2
5/17/2024	169	117	248	249	252	0.1*1	2.70E+29
5/18/2024	357	115	813	910	950	16.3	2.40E+30

Table 3 of the coronal mass ejections showing their angular width and central width along with speed and calculated kinetic energy at the height up to 30 $R_\odot$

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REFERENCES

1. Antiochos SK, DeVore CR, Klimchuk JA. A model for solar coronal mass ejections. The Astrophysical Journal. 1999;510(1):485.
2. Forbes TG. A review on the genesis of coronal mass ejections. Journal of Geophysical Research: Space Physics. 2000 Oct 1;105(A10):23153-65.
3. Zhang J, Richardson IG, Webb DF, Gopalswamy N, Huttunen E, Kasper JC, Nitta NV, Poomvises W, Thompson BJ, Wu CC, Yashiro S. Solar and interplanetary sources of major geomagnetic storms (Dst≤− 100 nT) during 1996–2005. Journal of Geophysical Research: Space Physics. 2007 Oct;112(A10).
4. Webb DF, Howard TA. Coronal mass ejections: Observations. Living Reviews in Solar Physics. 2012 Dec;9(1):1-83.
5. Mishra W, Srivastava N. Estimating the arrival time of Earth-directed coronal mass ejections at in situ spacecraft using COR and HI observations from STEREO. The Astrophysical Journal. 2013 Jul 8;772(1):70.
6. Mishra W, Srivastava N, Chakrabarty D. Evolution and consequences of interacting CMEs of 9–10 November 2012 using STEREO/SECCHI and in situ observations. Solar Physics. 2015 Feb;290:527-52.
7. Murray SA, Guerra JA, Zucca P, Park SH, Carley EP, Gallagher PT, Vilmer N, Bothmer V. Connecting coronal mass ejections to their solar active region sources: Combining results from the HELCATS and FLARECAST projects. Solar Physics. 2018 Apr;293:1-27.
8. Raghav AN, Kule A, Bhaskar A, Mishra W, Vichare G, Surve S. Torsional alfvén wave embedded icme magnetic cloud and corresponding geomagnetic storm. The Astrophysical Journal. 2018 Jun 7;860(1):26.
9. Mishra W, Srivastava N, Wang Y, Mirtoshev Z, Zhang J, Liu R. Mass loss via solar wind and coronal mass ejections during solar cycles 23 and 24. Monthly Notices of the Royal Astronomical Society. 2019 Jul;486(4):4671-85.
10. Shaikh ZI, Raghav A, Vichare G, Bhaskar A, Mishra W, Choraghe K. Concurrent effect of Alfvén waves and planar magnetic structure on geomagnetic storms. Monthly Notices of the Royal Astronomical Society. 2019 Dec;490(3):3440-7.
11. Maunder ML, Foullon C, Forsyth R, Barnes D, Davies J. Multi-Spacecraft Observations of an Interplanetary Coronal Mass Ejection Interacting with Two Solar-Wind Regimes Observed by the Ulysses and Twin-STEREO Spacecraft. Solar Physics. 2022 Nov;297(11):148.
12. Mishra W, Teriaca L. Propagation of coronal mass ejections from the Sun to the Earth. Journal of Astrophysics and Astronomy. 2023 Mar 24;44(1):20.