THE STATISTICAL ANALYSIS OF CORONAL MASS EJECTION DURING THE ASCENDING PHASE OF SOLAR CYCLE 24 AND 25.

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Abstract
We analysed the angular width and linear speed of all kinds of CMEs, including intermediate (20°<W<200°), wide (W≥ 200°), and linear speed 500 km/s, during the ascending phase of solar cycles 24 and 25. Solar cycle 24 has intermediate CME 434 which is 4.5 times more than solar cycle 25. On the other hand, there was no noticeable difference in the number of large CMEs during solar cycles 24 and 25 (405 and 406, respectively). The striking finding is that the angular distributions for the ascending phase of solar cycles are quite similar. The maximum speed observed during ascending phase of solar cycle 24 is 2658 km/s (wide) and the maximum speed in ascending phase of solar cycle 25 is 2669 km/s (wide). The maximum number of wide Coronal Mass Ejections are occurred in the year of 2022.It was noticed that the maximum speed of solar cycle 24 is higher than the solar cycle 25.

Keyword: Coronal mass ejection, Angular width, linear speed, Narrow, Intermediate, Wide.

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DOI: 10.53555/ecb/2022.11.12.289

INTRODUCTION

The most energetic occurrences in the solar environment are called coronal mass ejections (CMEs). The Seventh Orbiting Solar Observatory (OSO-7) was used to detect CMEs for the first time in coronagraph photos in 1971 (Tousey 1973). To examine the faint corona structures outside the occulting disc's periphery in the photospheric light dispersed by these structures, most coronagraphs use an occulting disc to intentionally eclipse the bright photosphere. Today's astrophysics is studying the Sun's huge and perpetually active environment, which is a result of the Sun's magnetic field's ongoing alterations. The Sun undergoes surface changes over the course of its 11-year cycle, and its magnetic flux has a significant impact on the entire environment. The 11-year term was originally used to define the sunspot number change (Schwabe *et al.*, 1844). Solar cycle 25, which started in December 2019 and is the one we are presently in, is more potent than solar cycle 24. When coronal mass ejections (CMEs) leave the solar atmosphere and enter the heliosphere, they do so at speeds that can range from 100 to 3,000 km/s Yashiro et al. (2004). In the coronagraph field of view (FOV), they appear as white-light features that are brilliant and move outward (Hundhausen *et al.*, 1984). Tousey *et al.*, (1973) was the first to notice CMEs in coronagraph images, despite the fact that the earliest observations of CMEs were made in the 1970s (Hansen *et al.*, 1971) (see a recent study of the history of CMEs by Gopalswamy *et al.*, (2016)).CMEs are regularly tracked by the Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) on the Solar Terrestrial Relation Observatory(STEREO) (Howard *et al.*, 2008).

The sun's closed magnetic areas, active regions, filament regions, active region complexes, and Tran's equatorial linking regions are the sources of CMEs, which are large-scale magnetized plasma structures. CMEs have posed a serious threat to the upper atmosphere's dynamic and unpredictable circumstances. According to studies conducted over the past fifty years, CMEs constitute the heliosphere's most energetic event (Gopalswamy *et al.*, 2006; Richardson *et al.*, 2000).Although the resolution of the SECCHI sensor prevents us from seeing it, it's likely that certain narrow CMEs do have observable structure. The narrow CMEs appear to be mass flows in vertical flux tubes, according to another observation. They looked into the narrow CME's characteristics and discovered that they occur more frequently as the sun approaches its maximum (Yashiro *et al.*, 2003). They demonstrated that the average speed of intermediate CMEs increases from 146 km/s during the solar ascending phase (2009–2010) to 2268 km/s at the solar maximum phase (2012– 2013). They also considered the angular width (20° $<W<200^\circ$) for intermediate CMEs (Mittal *et al.*, 2009). (Yashiro *et al.*, 2008) analysed the statistical characteristics of 24th cycle CMEs by automatic and manual approach, in which they omitted the CMEs with angular width 30^o since such CMEs are very subjective. They discovered certain differences between intermediate and normal CMEs. Our main goal in this work is to evaluate how the features of these three groups vary from one solar cycle to the next while examining the speed, angular width, and linear speed of intermediate and wide CMEs throughout solar cycles 24 (2008-2012) and 25 (2019-2022).

DATA and METHODOLOGY

The data used in present study was obtained from the Solar terrestrial Relations Observatory (STEREO) mission's SECCHI coronagraph as compiled in the CME catalogue. https://secchi.nri.navy.mil/cactus/. The catalogue provides the CME data from 2006 to present day. The SECCHI instrument consist of two coronagraph cor1 and cor2. Cor1 is the inner coronagraph and Cor2 is the outer coronagraph. All events in our study were divided into three categories: (I) narrow CMEs, with the angular width $\leq 20^\circ$ (Yashiro *et al.*, 2004); (ii) intermediate CMEs, with the angular width in the range 20° < width < 200° and (iii) Wide CMEs, with the angular width $\geq 200^\circ$ (Gopalswamy *et al.*, 2001). In our present study, we observed total 1670 CMEs events out of which 1060 events found from December 2008 to December 2012 and 428 event from January 2020 to September 2022 during ascending phase of the solar cycle 24 and 25 respectively. The sunspot data used in present study obtained from SILSO and the link is https://www.sidc.be/SILSO/datafiles.

RESULT and DISCUSSION

For all categories of CMEs, including narrow, intermediate and wide ones, the primary properties of CMEs that we have researched are angular width and linear speed. In the subsections that follow, each property is covered individually.

Angular width:

The position of the angular event in the sky plane in degrees is commonly referred to as the angular width of CMEs. The measured width is likely to be an overestimate for CMEs that originate from the limb, but it will be accurate for those that do. CMEs that originate from close to the limb have angular widths that resemble real width when measured, ranging from 2º to 360º (Gopalswamy *et al*., 2001). We looked at the angular width distribution forthe years 2008 to 2012 and 2019 to 2022. Figure 1 and Table 1 exhibit the observed numbers of CMEs for each year. The distribution of angular width for the years 2009–2012 and 2019–2022 was different according to these figures, although the narrow CMEs for solar cycles 24 and 25 exhibited the same behaviour.

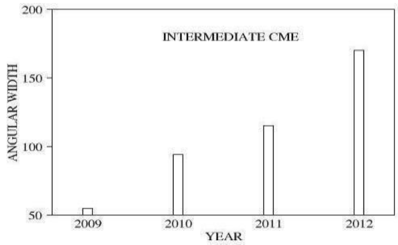

Figure 1: Angular width of Intermediate CMEs in ascending phase of solar cycle 24.

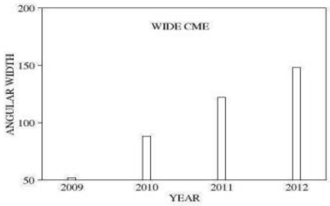

Figure 2: Angular width of Wide CMEs in ascending solar cycle 24.

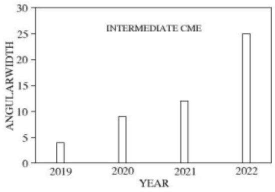

Figure 3: Angular width of intermediate CMEs ascending solarin solar cycle 25.

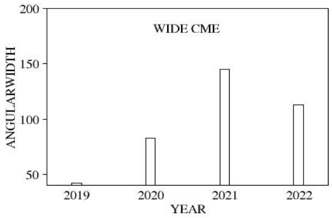

Figure 4: Angular width of Wide CMEs in Cycle 25.

Figure 1 shows the Angular width of Intermediate CMEs during the ascending phase of solar cycle 24 (2009-2012). A total of 434 coronal mass ejections were observed and In 2009, 55 (56%) intermediate coronal mass ejections were observed and in 2010, there are 94 (52%) intermediate CMEs are occurred and then in the year of 2011, there are 115 (49%) intermediate CMEs are observed and also in the year of 2012, there are 170 (53%) Intermediate CMEs are observed. The total number of CME observed in ascending phase of solar cycle 24 is 839 at that time the Intermediate CMEs are 434. The large number of Intermediate CMEs are occurred in the year of 2012.The Angular width of Wide CMEs during Solar Cycle 24's ascending phase (2009–2012) is depicted in Figure 2. A total of 148 (47%) Wide CMEs were seen in 2012, which is higher than the 122 (51%) Wide CMEs that were received in 2011 and the 122 (48%) Wide CMEs that were noticed in 2009. In 2009, there were 52 (54%) Wide CMEs recorded, followed by 88 (48%) Wide CMEs in 2010 and 122 (51%) Wide CMEs in 2011. There were 839 CMEs observed in total during the ascending phase of solar cycle 24, of which 405 were Wide CMEs. The year 2012 saw a significant increase in the number of wide CMEs because the Sun activity is much higher than the other events in solar cycle 24. Regarding its central angular width, the majority of solar minimum CMEs are restricted to areas ≈30° about the solar equator. From 2010 to 2012, the distribution of central CME angular width expands over the whole spectrum of angular width that are available to COR-2 as solar activity rises and approaches the solar maximum period. The equivalent central angular width distribution for heliospheric CMEs broadens, but not as much as it does for coronal CMEs; instead, it seems to stay more concentrated around the equator R.A.

Harrison *et al*., 2018. In Figure 3 shows the Intermediate CME Angular width during the 2020–2023 climbing phase of Solar Cycle 25. There were 25 (18%) intermediate CMEs in the years 2021 and 2022, compared to no intermediate CMEs in the years 2019 and 2020. There were no intermediate CMEs noted in 2019. Since 2009 Sun activity was relatively low, there were very few intermediate CMEs observed; hence, in 2020 there were none. There were 433 CMEs detected during solar cycle 24's ascending phase, 25 of which were Intermediate CMEs. The number of Intermediate CMEs increased significantly in 2023 because in this year the Sun activity trend was increase. Figure 4 shows the Wide CME Angular width during the 2020–2023 ascending phase of Solar Cycle 25 In 2019, 46 (100%) wide CMEs were recorded. In 2020, 92 (100%) wide CMEs were detected. In 2021, 157 (100%) wide CMEs were observed. Last but not least, 113 (88%) wide CMEs were observed in 2022.

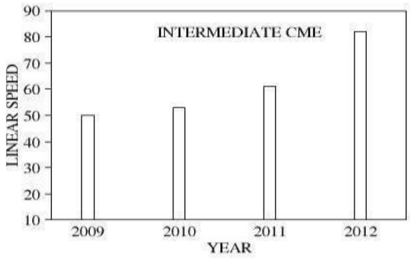

Figure 5: Linear speed of intermediate CME in in ascending phase ofascending phaseof solarcycle 24.

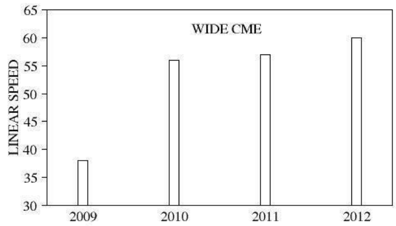

Figure 6: Linear speed of Wide CME solar cycle 24.

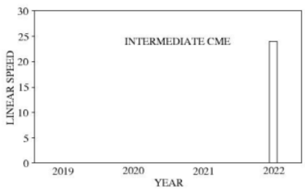

Figure 7: Linear speed of intermediate CME in phase ofascending phaseof solarcycle 25

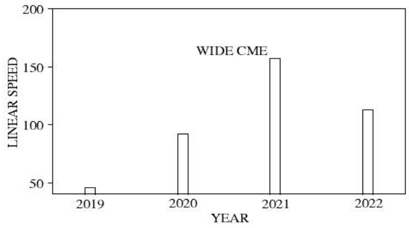

Figure 8: Linear speed of Wide CME in ascending solar cycle 25.

The linear speed of Intermediate CMEs during Solar Cycle 24's rising phase (2009–2012) is depicted in Figure 5. In 2009, there were 50 (45%) intermediate CMEs, with the maximum speed that year being 579 km/s. In 2010, there were 53 (58%) intermediate CMEs, with the maximum speed that year being 1965 km/s. In 2012, there were 82 (54%) intermediate CMEs, with the maximum speed that year being 2763 km/s. The large number of Intermediate CMEs are occured in the year of 2012. speed that year being 1965 km/s. In 2011, there were 61 (73%) intermediate CMEs, with the maximum speed that year being 2370 km/s. The average linear speed of intermediate CME in solar cycle 255 km/s (Hemlata *et al*., 2021). Figure 6 shows the Linear speed of Wide CMEs during the ascending phase of solar cycle 24 (2009-2012). In the year of 2009, there are 38 (43%) Wide CMEs and the maximum speed in this year is 550 Km/s are observed and in 2010, there are 56 (51%) Wide CMEs and maximum speed of this year is 1248 Km/s are occurred and then in the year of 2011, there are 57 (48%) Wide CMEs and the maximum speed of this year is 1943 Km/s are recorded and also in the year of 2012, there are 67 (45%) Wide CMEs and the maximum speed of this year is 2658 Km/s are observed. The large number of Wide CMEs are occurred in the year of 2012.The solar wind appears to have a more distinct structure during solar minimum; it is typically varied from the Sun's equator but quicker (between 750 and 800 km/s) above this band and towards the Sun's poles Shannon Jones *et al*.,(2022). Figure 7 depicts the linear speed of intermediate CMEs during solar cycle 25's ascending phase (2019–2022). There were no intermediate CMEs observed in 2019, 2020, 2021, or 2022. Themaximum speed recorded during this year was 1490 km/s. There have been 523 CMEs observed in total during the climbing phase of solar cycle 25, of which 24 are Intermediate CMEs. The large number of Intermediate CMEs are occurred in the year of 2023. Figure 8 depicts the linear speed of wide CMEs during solar cycle 25's ascending phase (2020– 2023). In the year 2020, 45 (100%) Wide CMEs with a maximum speed of 1081 km/s are recorded. In the following years, 99 (100%) Wide CMEs with a maximum speed of 1456 km/s are recorded, 154 (100%) Wide CMEs with a maximum speed of 2624 km/s are received, and 110 (82%) Wide CMEs with a maximum speed of 2669 km/s are recorded in 2021 and 2022, respectively. The total number of CME observed in ascending phase of solar cycle 25 is 523 at that time the Wide CMEs are 498. The large number of Wide CMEs are occured in the year of 2022. Solar cycle 24's maximum speed for intermediate CMEs (2763 km/s) is higher than solar cycle 25's (1460 km/s). The maximum speed of wide CMEs for solar cycle 24 (2658 km/s) and solar cycle 25 (2669 km/s) do not differ significantly from one another. Wide CMEs with velocities greater than 500 km/s had a speed distribution of 48.5% during Solar Cycle 24 (Gopalswamy *et al.*, 2009) and 93.5% during Solar Cycle 25. In comparison to solar cycle 25, when the average speed of Intermediate CMEs was 1490 Km/s, solar cycle 24 has an average speed of 1919 Km/s. According to (Gopalswamy *et al.*,2022) the average speed of wide CMEs during solar cycle 24 is lower than that of solar cycle 25 (1957.5 Km/s). When comparing the speeds of the two phases, the CME speed of the 25th solar cycle is higher than that of the 24th solar cycle.

Sunspot number:

Several characteristics of sunspot cycles 24 and 25 ascending phases presented in Table 1. We find that the length of solar cycle, position of ascending phases of sunspot cycle from years of 2009-2012 and 2019-2020 and the maximum sunspot number differ from cycle to cycle (Pandey *et al.*,2010). The variations in length of sunspot cycles 24 and 25 (ascending phase) is shown in Figure 9 and 10.

YEAR	NO/OF. SSN
2008	480
2009	6465
2010	6328
2011	6077

Table 1: No of Sunspot number in solar cycle 24.

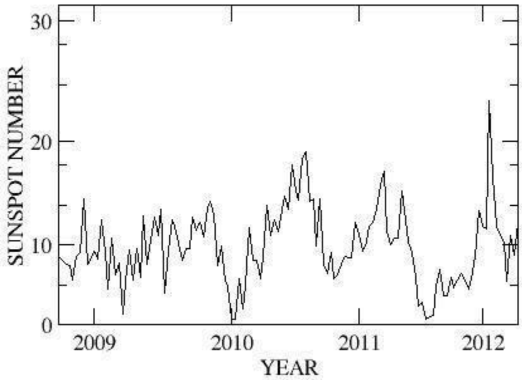

Figure 9: Sunspot number for rising phase of solar cycle 24.

The changes in the Sunspot number between 2009 and 2012 are shown in Fig. 9, which demonstrates that the Sun is quiet at the beginning of Solar Cycle 24 with a low sunspot number and solar activity Abha Singh *et al.*, (2021). Figure 9 shows the Sunspot number of ascending phase of soar cycle 24 and 25. In the year of 2009, there are 6465 sunspots are observed, It was only in December that the highest sunspot number was recorded ad 12.7. The mean value of the solar indices is modest for 2009, with the respective values of 0.02, according to the annual solar indices and sunspot number Abha Singh *et al.*, (2021). In the year of 2010, there are 6328 sunspots are occurred and the highest sunspot number in this year is recorded as 42.5 (December) and also in the year of 2011, 6077 sunspots are observed and the the highest sunspot number is noted as 92.5 and in the year of 2012, there are 5753 sunspots are observed and the highest sunspot number of this year is recorded as 98.3 (March).The lowest Frequency has been 46 in August 2009. The frequency increases in the year 2010 to a maximum of in the month of November. In 2011 CME frequency increases further, reaching a maximum of 227 in the month of October (Aradhna Sharma *et al.*, 2013). Solar Activity during the Rising Phase of solar cycle 24. So the Sunspot number is lower than the previous solar cycle. Kane *et al.*, 2008, has mentioned that sunspot areas and sunspot numbers are very highly correlated. Therefore, sunspot number, sunspot group number and sunspot area could be used as good proxies for each other.

YEAR	NO.OF SSN
2019	14440
2020	15233
2021	15258
2022	8459

Table 2: No of Sunspot number in solar cycle 25.

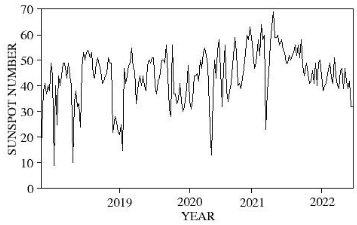

Figure 10: Sunspot number for rising phase of solar cycle 25.

It has been three years and 11 months since the start of solar cycle 25. The last accessible reading, from May 2022, has a value of 96.5, which is the highest monthly sunspot number so far for this cycle. In 2022 May (84.1), the second-highest value, and in 2021 March (78.5), the third-highest value. In November of 2021, the last one available, the highest smoothed monthly sunspot number was 50.6.The first month for each cycle in figure 10 represents the minimum of each solar cycle. At this stage of the cycle, only five cycles had lower readings than solar cycle 25. Solar Cycle 1 at the middle of the 18th century, Solar Cycles 5 and 6 during the Dalton Minimum, and Solar Cycle 24 are these cycles. The average monthly sunspot number for solar cycle 25 in the month of solar cycle 24 (50.6) was approximately 63% smaller than this figure.

CORONAL MASS EJECTION:

Here, the characteristics of the entire CME sample are our main concern instead than the development of a specific event. In order to handle every event as a separate data point, we must extract a representative set of parameters for each occurrence at a particular time point (Vourlidas *et al*., 2010). Between 2009 to 2012 and 2019 to 2022, we have a total of 3294 CMEs in ascending phase of solar cycle 24 and the total number of 3986 CMEs in ascending phase of solar cycle 25 from STEREO Observation. These events cover a range of different signatures, including standard Full halo CMEs and Partial halo CMEs. More CMEs are occurring in 2012 and most of the events occurring 2010 to 2012 (Phillip Hess *et al*., 2017) in ascending phase of solar cycle 24 and more CMEs are occurring in 2022 and most of the events occurring 2021 to till now.

YEAR	TYPES OF CME	NO OF EVENTS
2009	HALO CME	1
	PARTIAL HALO CME	2
2010	HALO CME	11
	PARTIAL HALO CME	41
2011	HALO CME	41
	PARTIAL HALO CME	143
2012	HALO CME	54
	PARTIAL HALO CME	189

Table 3: Shows the Types of CMEs and its No of events in solar cycle 25.

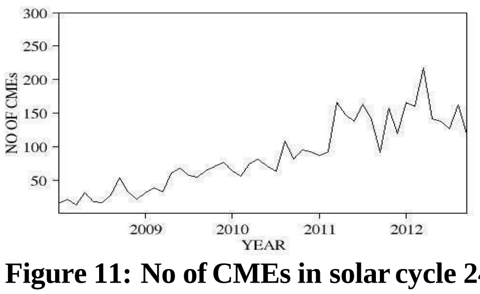

Figure 11: No of CMEs in solar cycle 24.

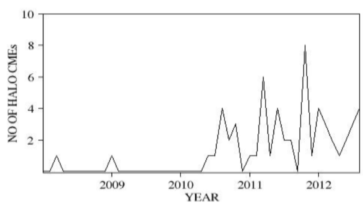

Figure 12: No of Halo CMEs in solar cycle 24.

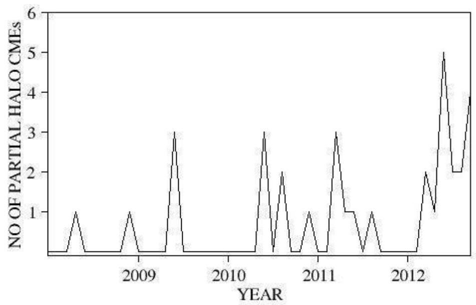

Figure 13: No of Partial Halo CMEs in solar cycle 24.

The Coronal Mass Ejection from (2009-2012) is shown in Figure 11. During the ascending phases of solar cycles 24, we excreted 107 Halo CMEs occurrences and 375 Partial Halo CMEs, respectively. 27.43% of Halo CMEs and 93.57% of partial Halo CMEs were occurred during solar cycle 24. Figure 11 shows the No of CMEs in ascending phase of solar cycle 24. In the year of 2009, there are one CME that is 0.94% CME is occurred and in 2010, there are 11 CMEs that is 10.28% CMEs are occurred and in 2011, there are 41 CMEs that is 38.32% CMEs are occurred and also in 2012, there are 54 CMEs that is 50.47% CMEs are occurred. The halo heights in cycle-24 are much less (Gopalswamy *et al.*,2020). Figure 12 shows the No of halo CMEs in ascending phase of solar cycle 24. Halo CME is the term for CME that seems to encircle the occulting disc and has an angular width of 360º (Devendra *et al.*, 2022).In the year of 2009, there are one halo CME that is 0.94% halo CME is occurred and in 2010, there are 11 halo CMEs that is 10.28% halo CMEs are occurred and in 2011, there are 41 halo CMEs that is 38.32% halo CMEs are occurred and also in 2012, there are 54 halo CMEs that is 50.47% halo CMEs are occurred. Figure 13 shows the No of Partial halo CMEs in ascending phase of solar cycle 24. In the year of 2009, there are two Partial halo CME that is 0.53% Partial halo CME is occurred and in 2010, there are 41 Partial halo CMEs that is 10.93% Partial halo CMEs are occurred and in 2011, there are 143 Partial halo CMEs that is 38.13% Partial halo CMEs are occurred and also in 2012, there are 189 Partial halo CMEs that is 50.40% Partial halo CMEs are occurred.

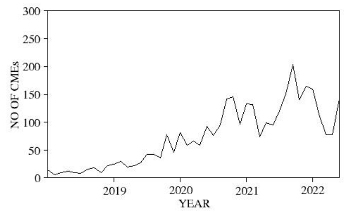

Figure 14: No of CMEs in solar cycle 25.

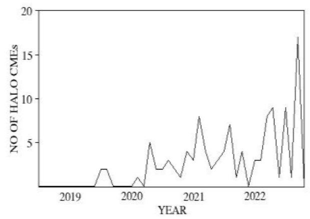

Figure 15: No of Halo CMEs in solar cycle 25.

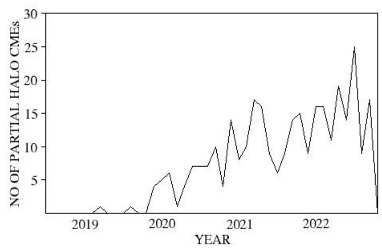

Figure 16: No of Partial CMEs in solar cycle 25.

YEAR	TYPES OF CMEs	NO OF EVENTS
2019	HALO CME	4
	PARTIAL HALO CME	2
2020	HALO CME	16
	PARTIAL HALO CME	55
2021	HALO CME	40
	PARTIAL HALO CME	143
2022	HALO CME	48
	PARTIAL HALO CME	111

Table 3: Shows the Types of CMEs and its No of events in solar cycle 25.

Figure 14 shows the No of CMEs in ascending phase of solar cycle 25. In the year of 2019, there are 178 CME that is 4.45% CME is occurred and in 2020, there are 577 CMEs that is 14.43% CMEs are occurred and in 2021, there are 1300 CMEs that is 32.5% CMEs are occurred and also in 2022, there are 1230 CMEs that is 30.75% CMEs are occurred. In the projection of the plane, the observation coronagraph's occulting disc is surrounded by a halo CME. Howard *et al*., (1982) were the first to register halo CMEs. Figure 15 shows the No of halo CMEs in ascending phase of solar cycle 25. In the year of 2019, thereare 4 halo CME that is 3.60% halo CME is occurred and in 2020, there are 16 halo CMEs that is 14.41% halo CMEs are occurred and in 2021, there are 43 halo CMEs that is 38.74% halo CMEs are occurred and also in 2022, there are 48 halo CMEs that is 43.24% halo CMEs are occurred. The quickest CMEs are often those with entire halos and partial halos (R. A. Howard *et al*., 2010). Figure 16 shows the No of Partial halo CMEs in ascending phase of solar cycle 25. A CME is referred to as partial halo CME if its angular width is greater than 120^0 around the disc (Devendra *et al.,* 2022). In the year of 2019, there are two Partial halo CME that is 0.63% Partial halo CME is occurred and in 2020, there are 55 Partial halo CMEs that is 17.30% Partial halo CMEs are occurred and in 2021, there are 143 Partial halo CMEs that is 38.13% Partial halo CMEs are occurred and also in 2022, there are 111 Partial halo CMEs that is 34.91% Partial halo CMEs are occurred. In this study we compare the statistical analyse of Angular width, Linear speed,CME, Halo CME and Partial Halo CME in solar cycle 24 and 25. For full halo CMEs, the angular width was 360º, while for partial halo CMEs, it was 121-359º Zeinab *et al*., 2019. Additional angular width sizes include spikes (less than ~ 5º) and narrows (~ 5º to 120º).CMEs in solar cycle 25 is 1.21 times greater than solar cycle 24, the Halo CMEs in solar cycle 25 is 0.96 times higher than solar cycle 24. The partial Halo CMEs in solar cycle 24 is 1.18 times higher than solar cycle 25.

Conclusion:

The following findings are based on analyses of 839 and 433 CMEs with widths ≤20˚ (narrow), 20º < Width < 200˚ (intermediate), and ≥ 200º (Wide), respectively, that were recorded between 2009 to 2012 and 2019 to 2022 during the ascending phases of solar cycles 24 and 25.

1. In our research, we discovered that solar cycle 24 had 434 intermediate CMEs, which is 17.36 times more than solar cycle 25 (25). When comparing the number of wide CMEs from solar cycles 24 and 25 (405) and 406, we found no discernible variation. CME angular widths during the ascending phases of solar cycles 24 and 25 were primarily between 30 and 90 degrees.
2. Solar cycle 24th ascending phase had intermediate CME average speeds of 1919 km/s, which is higher than solar cycle 25th (1490 km/s) readings. The average speed of wide CMEs in the ascending phase of solar cycle 24 is therefore lower than in the declination phase (1958 Km/s) of solar cycle 25.
3. The maximum speed of CMEs during solar cycle 24 (2658 Km/s) is lower than during solar cycle25(2669 Km/s).
4. No of CMEs in solar cycle 25 is higher than the solar cycle 24 that is 0.96 times higher than 24thsolar cycle.
5. No of Halo CMEs in solar cycle 25 is higher than solar cycle 24 that is 0.96 times higher than 24th solar cycle.
6. No of Partial Halo CMEs in solar cycle 25 is lower than solar cycle 24 that is 1.18 times lowerthan solar cycle 25.

We conclude from the study mentioned above that there are some discrepancies between theout comes of Intermediate and Wide CMEs and earlier results.

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