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Identifying the most notable events at the first stage of the solar cycle 25

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Abstract: This study documented 359 occurrences during the initial phase of solar cycle 25, spanning from December 2019 to April 2023. These events were the most powerful coronal mass ejections (CMEs). Out of the total of 359 events, four of them did not have any solar flares, whereas the remaining 355 events were linked to solar flares. This study involved the observation and analysis of solar events, which led to the identification of two significant coronal mass ejections that displayed robust shock waves. Both of these events displayed rapid linear velocities and significant angular widths. The coronal mass ejections were accompanied by solar flares that displayed exceptional intensity in the form of X-rays. The shock waves generated during these events provided valuable insights into the dynamics and transmission of coronal mass ejections. These findings enhance our comprehension of the impact of powerful events on the space environment by analyzing the attributes of shock waves.

Keywords: *Coronal mass ejections, Geomagnetic disturbances, Solar cycle 25, Solar flares, Space weather forecasting, Space weather.*

1. Introduction

Coronal mass ejections (CMEs) are large quantities of magnetized plasma that are expelled from the Sun's corona and travel through space. These phenomena have substantial ramifications for space weather and have the potential to impact various technological systems on Earth, including satellites, power grids, and communications networks [1]. An in-depth comprehension of the characteristics and behaviors of CMEs is essential for enhancing space weather prediction and mitigating their potential consequences. Coronal mass ejections (CMEs) and the shock waves they produce are a primary source of solar energetic particles. Moreover, Coronal Mass Ejections (CMEs) are widely acknowledged as the primary factor accountable for severe space weather incidents on Earth. Moreover, Coronal Mass Ejections (CMEs) are widely acknowledged as the primary factor accountable for severe space weather incidents on Earth. These clouds have the ability to burst in any direction and continue moving in that path, crossing through the solar wind. The likelihood of impacts caused by a coronal mass ejection (CME) depends on the alignment of the cloud with Earth. Solar wind streams moving very quickly come from places on the sun called coronal holes. There are many places on the sun where holes can appear, but the winds from them usually only affect Earth when they are close to the solar equator. A group of charged particles called solar energetic particles (SEPs) have a lot of energy. Most scientists think they come from shocks at the front edge of solar flares and coronal mass ejections (CMEs). When a coronal mass ejection (CME) cloud moves through the solar wind, it can send out solar energy particles moving at very high speeds. Because these particles are charged, they must follow the lines of the magnetic field that goes through the space between the Sun and Earth. So, the only charged particles that will collide are those that stick to the lines of the Earth's magnetic field [2]. Previous studies have shown that there is a strong correlation between the sunspot numbers (SSN) and solar activities, as it was observed that the correlation coefficient between the number of sunspot numbers (SSNs) and the occurrence of coronal mass ejections is 0.975 [3]. In the same context, previous studies have confirmed that solar eruptions begin with the increase in sunspots and then solar flares, which are characterized by a sudden release of electromagnetic radiation followed by the emission of coronal mass

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ejections that quickly launch, forming what is called a shock wave, which in turn helps accelerate the activated solar particles. Solar flares are often followed by coronal mass ejections, and the intensity of the X-rays emitted from these flares is a measure of the strength of the coronal mass ejections. Conversely, shock waves spread through interplanetary space due to coronal mass ejections [4, 5]. The analysis indicates that X-class solar flares often occupy a central location within the corresponding CME. In contrast, C-class flares tend to extend more toward the outer edges of the CME region [6, 7]. Understanding the mechanisms behind these disturbances helps to avoid their potential impacts on the space environment [8, 9].

2. Data and Methodology

We gathered information for this study from a variety of sources, including the Large Angle Spectrometric Coronagraph (LASCO) [10] which is comprised of three coronagraphs: C1, C2, and C3. Coronagraphs measure the corona from 1.1 to 30 RΘ and record data about CME events, such as their width, speed, duration, and angle of occurrence. While this study does include some C3-extended perspective observations, the primary focus is on data collected with the C2 instrument. Also, using the Geostationary Operational Environmental Satellite (GOES), we need to gather data on the corresponding solar flares' intensities, which need to be categorized according to their size and class. Space weather is monitored by the GOES satellites, which are operated by NOAA. They continuously measure solar X-rays and other parameters related to solar flares. It is plasma in the corona, the sun's upper atmosphere, heated to more than a few million Kelvin and causes flare emission at this wavelength. This standard way of measuring flare output is used to figure out how big a flare is. Following this rule, a flare is in the A, B, C, M, or X class if its highest soft X-ray energy is less than 10^{-7}, 10^{-7}-10^{-6}, 10^{-6}-10^{-5}, or 10^{-5}-10^{-4} > 10^{-4} Watts per meter square. X-class flares have a lot more energy than C-class flares because they use a logarithmic scale. A full statistical analysis of a set of events was done. Each event was carefully studied, and its traits were carefully analysed. Two important events were found to have happened during this time of study. For each ejected solar mass, the take-off time and landing time were found. After that, the times that were calculated were compared to the first eruption of the matching solar flares to see if they were linked to the same event. Also, the shock waves' following travel was tracked, and the time at which they reached the Earth's magnetic field was studied. Information on shock wave events is obtained from different observational characteristics, such as radio emissions or variations in plasma density. assume that this point is the closest one to Earth and track their related IP shock wave till it passes the SOHO spacecraft.

3. Results and Analysis

The events were selected from December 2019 to April 2023 as they represent the upward phase of the solar cycle 25. Growth in solar activity is usually inferred by monitoring the increasing number of sunspots [11]. In this study, the number of sunspots was compared with each year, and an escalation was observed in the graph, as shown in Figure 1. According to the criteria for strong events, which are that the speed of each event is equal to or higher than 500 km/s and its angular width is equal to or larger than 50°, 359 events were chosen for the Coronal Mass Ejection. These events were chosen because they met the criteria for strong events. Gopalswamy et al., found that in the rising phase of Solar Cycle 24, statistical analyses suggest that the average width of a CME is approximately 55° (obtained from non-halo CMEs exclusively), and the median speed of a CME is approximately 650 km/s [12]. Before that, Gonzalez et al. said that the global Dst and Kp values are found by measuring the horizontal part of the magnetic field on the ground. This is used to figure out how active the geomagnetic field [13]. Many researchers have used these markers to measure changes in the magnetosphere and atmosphere. Many studies focused on the effects of solar events on the Earth's ionosphere and troposphere layers [14, 15]. For measuring how strong the equatorial ring current is, the DST index is used. It is also used to group geomagnetic storms into different categories. Kp. On the other hand, is a measure that works in mid-latitude areas and is affected by both auroral and equatorial currents working together. It is used to set different levels of alert for geomagnetic storms on the NOAA Space Weather scale.

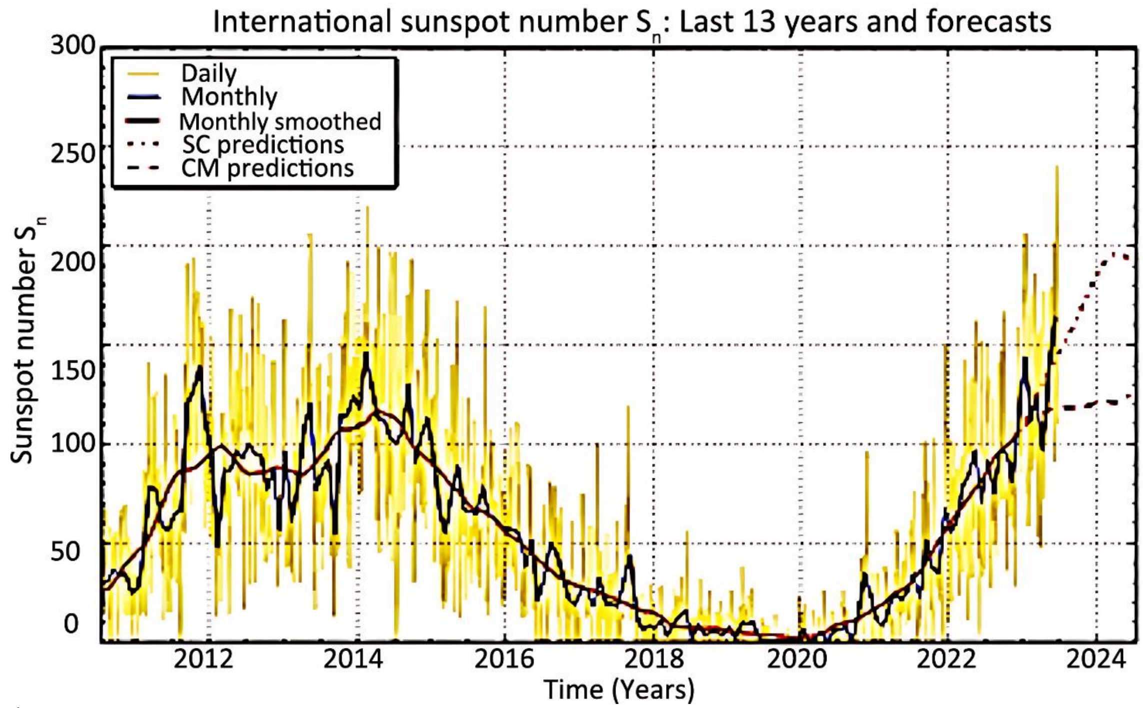

Figure 1.
Sunspot numbers with time at solar cyle 24 and beginning of solar cycle 25 (http://sidc.be/silso) Royal Observatory of Belgium 2023 July.

In the current study, we found 359 events have a specific linear speed and angular width, which were classified according to Table 1.

Table 1.
Description of CMEs events numbers with associated solar flares.

Events with speed ≥500 Km/S and Angular width ≥ 60 ⁰	**359 events**
Normal CMEs	287
Halo CMEs	72
B class of solar flares	31
C class of solar flares	186
M class of solar flares	123
X class of solar flares	15
No flares	4
Events with magnetic storm	2
Number of events 2020	9
Number of events 2021	53
Number of events 2022	202
Number of events 2023	95

Several events, 355 were observed associated with X-rays of the solar flare. In brief, the solar activity linked to the two frontside halo coronal mass ejections (CMEs) on the 28th of October 2021 and the 21st of April 2023 commonly exhibited the following characteristics: There are three main phenomena observed in relation to solar activity: (1) the occurrence of large-arc coronal mass ejections (CMEs) originating from surface activity near the centre of the Sun, indicating eruptive events directed towards Earth; (2) the presence of surface events characterized by flares of varying energy levels, which are associated with long-lasting coronal arcades within small emerging or rapidly changing active regions; and (3) the identification of coronal dimming regions, which are likely caused by localized reductions in the preexisting density of the solar corona. The CMEs analyzed, 287 were categorized as "normal CMEs," while 72 were identified as "halo CMEs." Halo CMEs are noteworthy because they have the potential to have a more direct impact on Earth. The study recorded different solar flare intensities linked to the examined CME events: 31 B-class solar flare occurrences were linked to them. Class C solar flares were linked to 186 incidents. M-class solar flares have been linked to 123 occurrences. The X-class solar flares were linked to 15 incidents. Four events, as Fig. (2) illustrates, showed no solar flare activity. Only two CME events were linked to magnetic storms, indicating that not all CMEs cause geomagnetic disturbances.

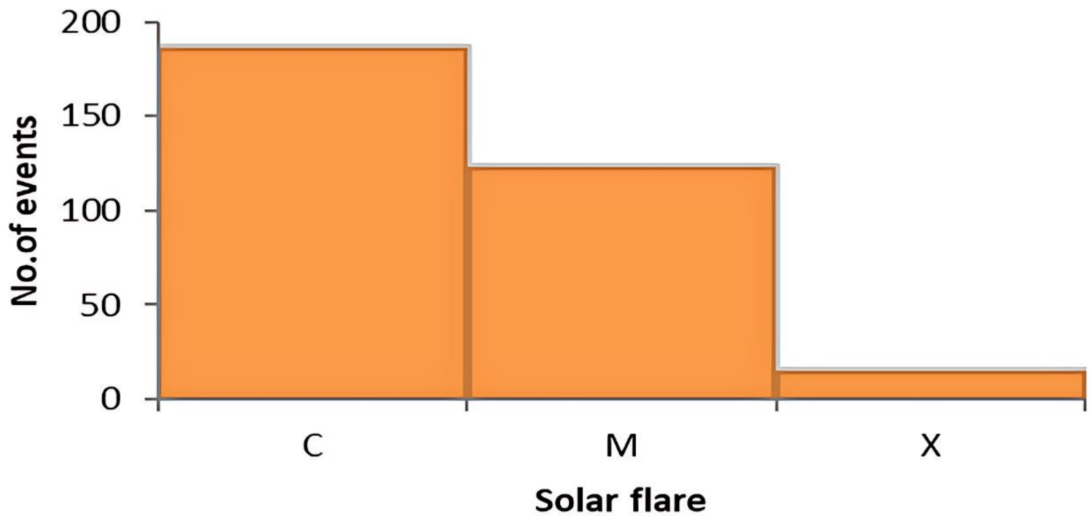

Figure 2.
Represent the number of Solar flares with magnitude amount of its during present study time.

The analysis revealed a fluctuating number of CME occurrences throughout the years, as shown in Fig. 3. There were 9 CME events in 2020, 53 CME events in 2021, 202 CME events in 2022, and 95 CME events in 2023. This analysis reveals that during the initial phase of the present solar cycle, there were notable occurrences of powerful events. However, it is worth noting that only two significant events were identified, both of which involved the generation of a powerful shock wave leading to the formation of a magnetic storm. We will thoroughly examine these two incidents.

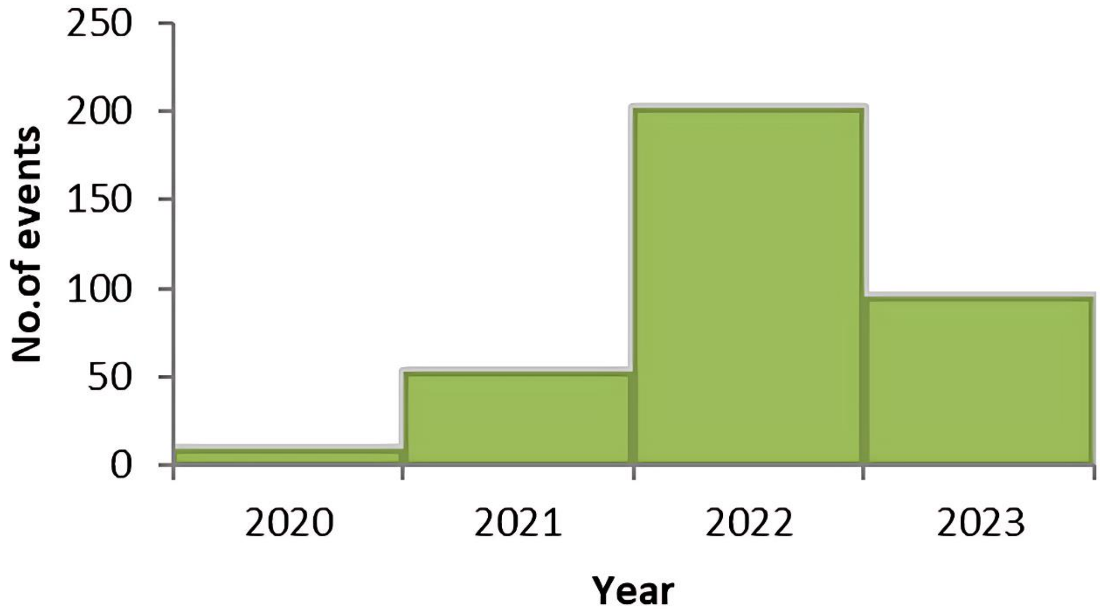

Figure 3.
Represent number of strong normal CMEs with years at CS25.

3.1. Event 1

A halo was seen with FC2AT on October 28, 2021, at 15:48 UT, at a heliocentric height of 3.45 R. It came from the western hemisphere. Based on Fig. 4, it is moving at a straight line speed of 1519 km/s and an acceleration of -61.1 m/s2. A long-lasting X1.0 solar flare was seen by SXT starting at 15:17 UT and ending at 15:48 UT in the H position (S26W09), which was part of NOAA Active Region 2887. The EIT detector confirmed that the CME was connected to this flare. At 9:34 UT on October 31, 2021, a shock wave was seen to arrive.

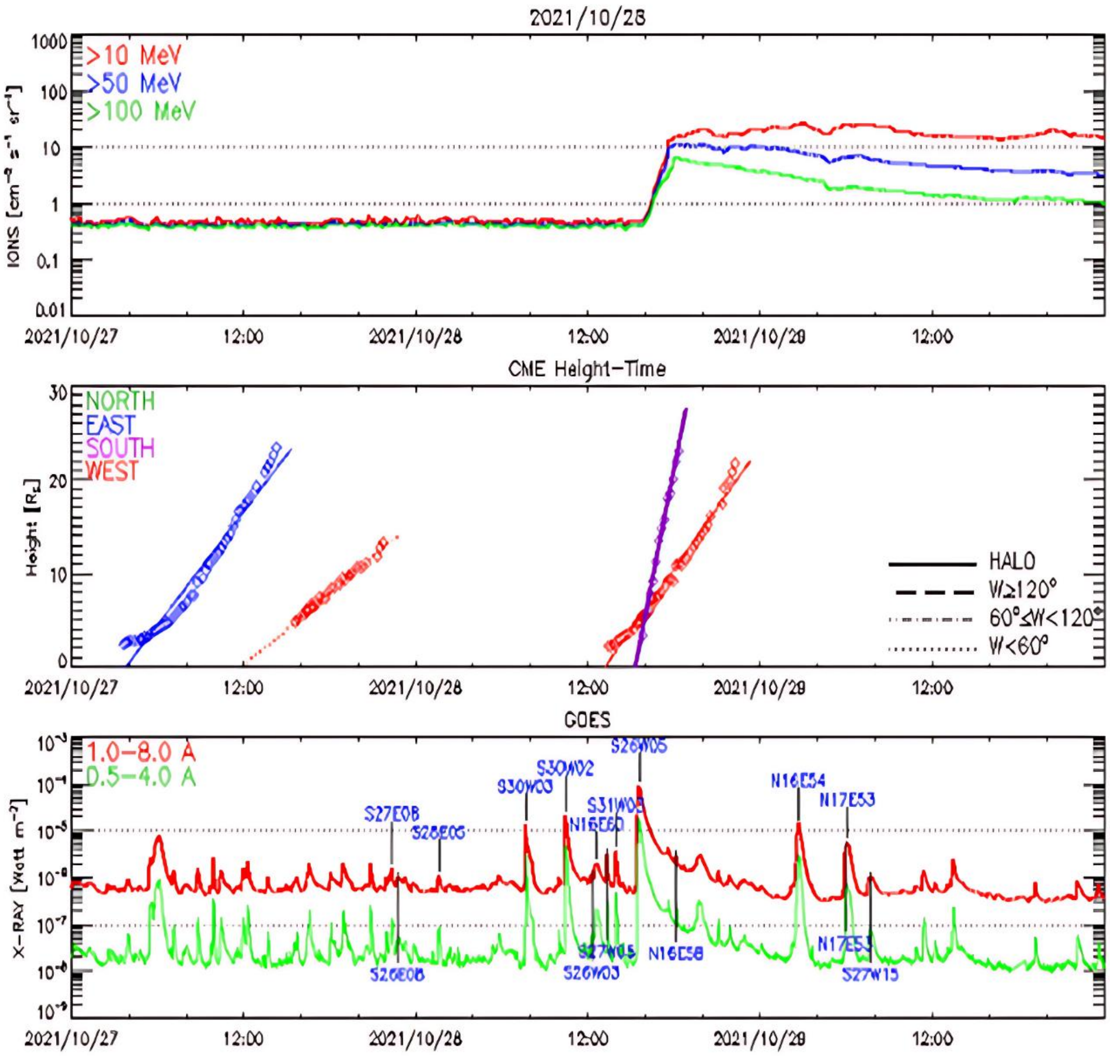

Figure 4.
Represents three cases describing On 28th of October 2021 event, the upper panel represents the intensity and energy of SEP, the middle panel represents the direction and type of CME, the lower panel represents the X-ray intensity of the solar flare and the location of the active region.

Based on Figure. 5, this was caused by the CME we already talked about, which travelled for 66 hours. On October 31, two coronal mass ejections hit Earth's magnetic field. It started around 10:00 UT. The impact was not at all what we thought it would be a "big hit", and it caused a G1-class geomagnetic storm that was also not very strong.

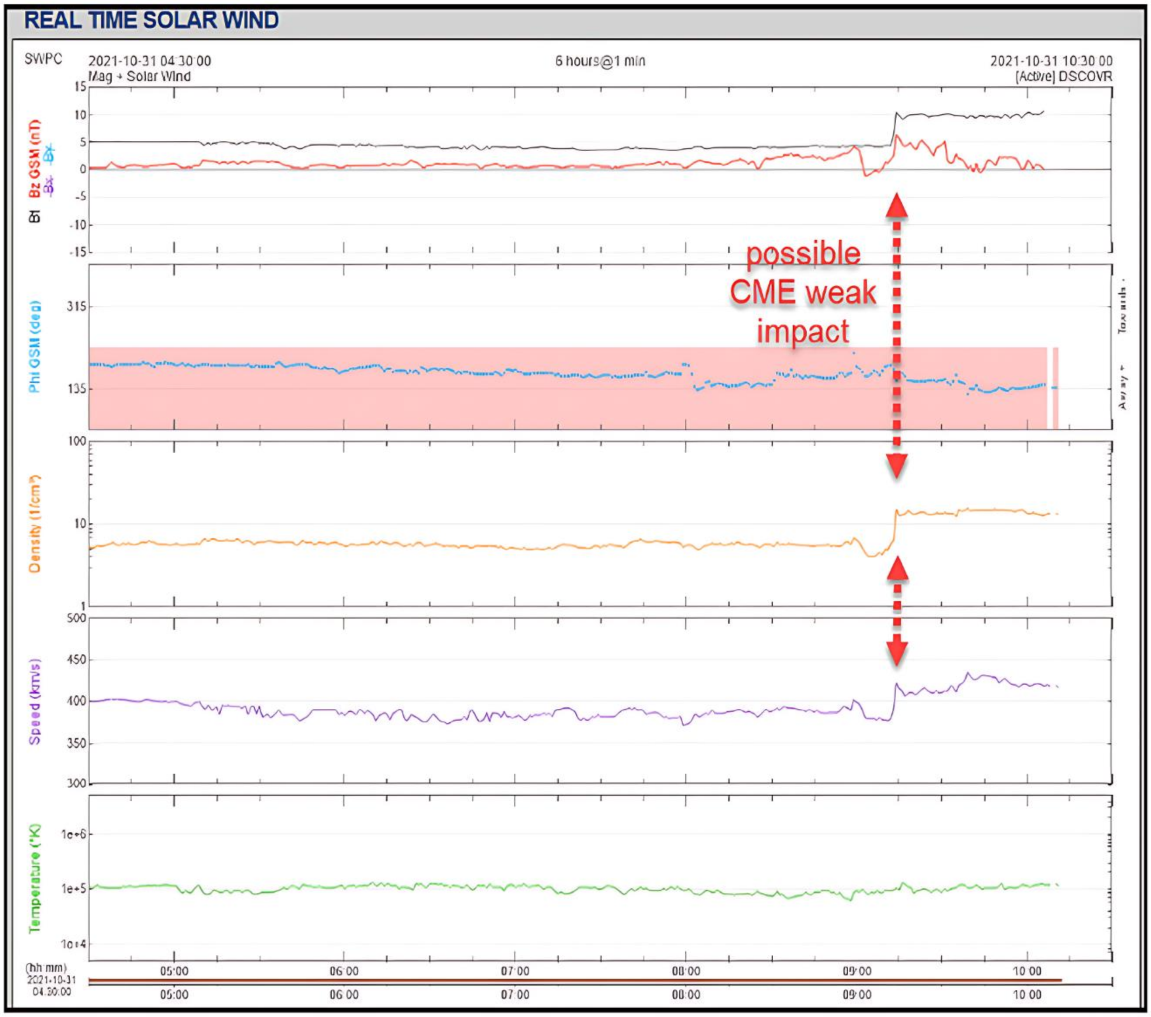

Figure 5.
Represent coronal mass ejections proprieties when it hit Earth's magnetic field on Oct. 31st.

3.2. Event 2

FC2AT saw a halo on October 28, 2021, at 15:48 UT, at a height of 3.45 R from the sun. It was from the western part of the world. Based on Fig. 4, it's going at 1519 km/s in a straight line and -61.1 m/s2 per second. For a long time, SXT saw an X1.0 solar flare in the H position (S26W09), which was part of NOAA Active Region 2887, from 15:17 UT to 15:48 UT. The CME was linked to this flare, as shown by the EIT monitor. A shock wave was seen coming in at 9:34 UT on October 31, 2021. Figure 5 shows that this was caused by the CME we talked about earlier. It went around for 66 hours. Ions from the sun hit Earth's magnetic field twice on October 31. Around 10 UT, it began. It wasn't at all a "big hit" like we thought it would be, and it only caused a G1-class geomagnetic storm that wasn't very strong either. A shock wave was seen coming in at 9:34 UT on October 31, 2021, as shown in Figure 6.

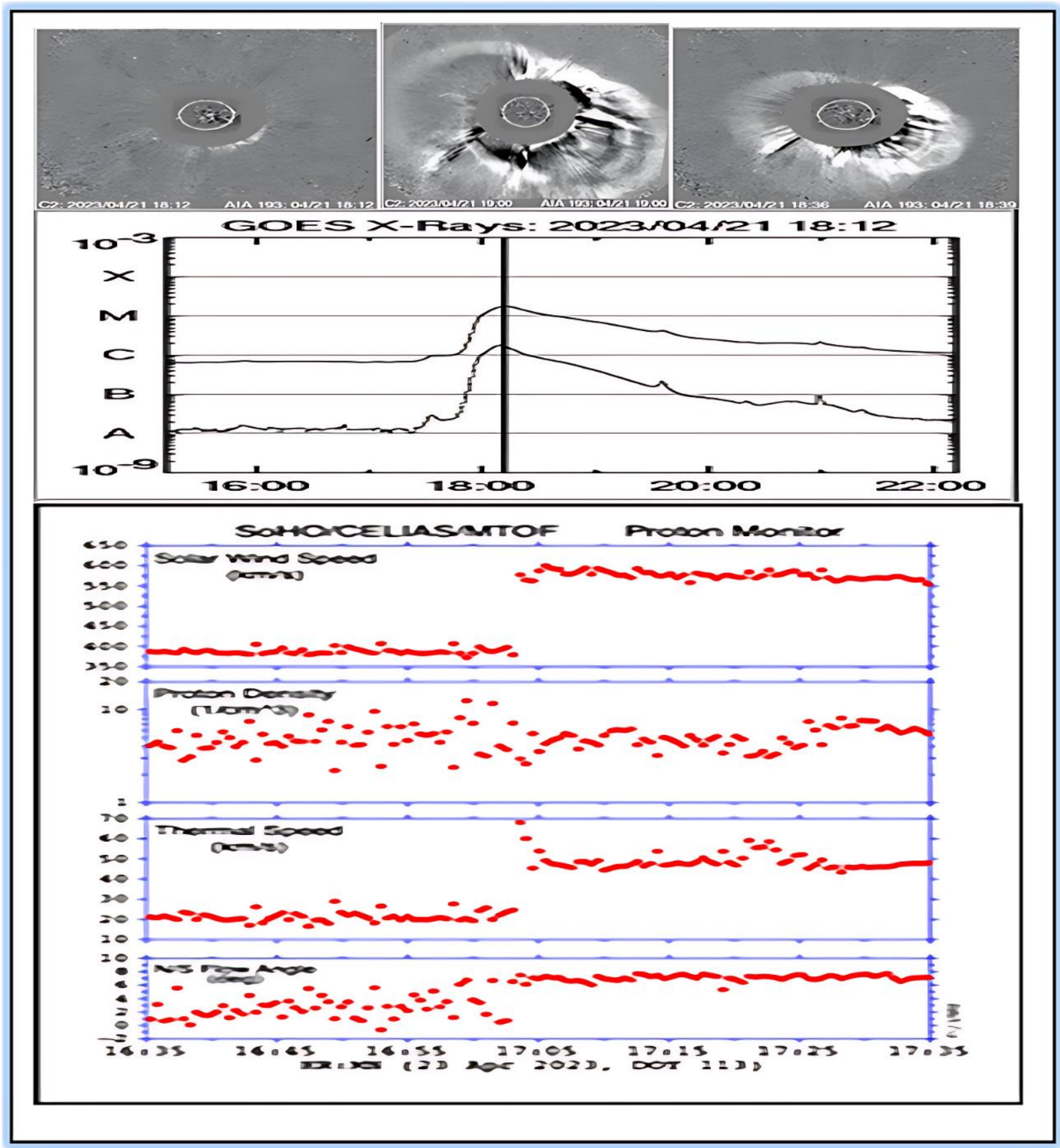

Figure 6.
The analysis of the 21^{th} of April 2023 event upper panel CME position, mid panel solar flares and down panel shock wave.

4. Discussions

The present section will engage in a discussion of the findings and subsequently draw conclusions based on the obtained results. Principal findings concerning CME characteristics, solar flare intensities, and the occurrence of shock waves of the 359 CME events that were analysed had a velocity ≥500 km/s and an angular width ≥ 60 degrees. This indicates that many CMEs rapidly expanded during the study period. These results emphasize the prevalence of fast and broad CMEs during the study period and the various solar flare intensities associated with these events. Constellations of massive Earth quakes raise concerns that space weather and the planet's magnetic field could be impacted. Additionally, the temporal distribution implies that CME activity varies with time. However, the fact that only a handful of CMEs were associated with magnetic storms suggests that not all CMEs cause such major disturbances to space weather. Research on space weather and solar energetic particle (SEP) production has been conducted in relation to CME characteristics. Lario, et al. [16] looked into the relationship between CME characteristics and the strongest solar energetic particle events. Particle acceleration and its underlying processes were clarified by this investigation. Throughout Solar Cycle 24, our results are consistent with those of other researchers who have found similar patterns in CME characteristics. For instance, Gopalswamy [17] investigated CME events during the same solar cycle. They found that fast and large-scale CMEs were more likely to produce high-energy solar particle events. This aligns with our observations, where we noted higher solar flare intensities and SEP production associated with fast and wide CMEs. Also, this study compares the occurrence rate and properties of Halo CMEs during the beginning stage of solar cycles 23, 24, and 25. In SCs 23, 24, and 25, the number of Halo CMEs normalized to the number of sunspots is 1.20, 1.57, and 1.56, respectively. The rates are comparable in cycles 24 and 25 but approximately 30% greater than in solar cycle 23. Two times as many halos originate from CME ≥ 60° in Solar Cycle 24 as in Cycle 23, one of the early discoveries on the locations of halo CME sources. In the comparison of source locations during the rising phase of the three cycles, the larger average CME for Solar Cycle 24 Halo CMEs and the higher abundance of Halo CMEs [18, 19] highlight that Halo CMEs from CME ≥ 60° in Solar Cycle 25 are similar to those in SC 24 but higher than those in Solar Cycle 23 by a factor of 2. Zhao, et al. [19] Eighteen studied the relationship between angular width and CME intensity, which showed the significance of wide CMEs in the generation of SEP. In 2020, Allawi, et al. [20] discovered four progressive SEP events. The shock waves that accompanied those events demonstrated that their radio emission association eliminated all of the shock acceleration properties in those events, and the shocks should continue to accelerate for the SEPs to Earth. Although our analysis yielded valuable insights, it is important to recognize that there are some limitations and challenges:

There may be gaps or limitations in coverage in the available observational data that the analysis relies on, which could impact the completeness of our results.

The goal of multi-instrument analysis is to improve our understanding of CME properties and their effects on space weather by combining data from different instruments and observational platforms. Modelling and Simulations: To help interpret observational data, use sophisticated numerical simulations and modelling techniques to mimic the dynamics of CMEs, solar flares, and shock waves. Investigate potential changes in CME characteristics over longer time periods by expanding the analysis to encompass numerous solar cycles. By tackling these limitations and delving into new research areas, we can enhance our comprehension of CME events and how they impact weather forecasting and the space environment. Following the propagation of a coronal mass ejection (CME) and the shock wave it generates through the interplanetary (IP) medium is an unfinished business.

The absence of tracking space sensors along the propagation path, which spans approximately 1 astronomical unit (AU), accounts for this phenomenon. The current satellite coverage of the heliosphere and geosphere is insufficient to encompass the entirety of these distances. It is currently not feasible to track objects within a range of around 70 solar radii from the Sun up to the outer boundaries of the magnetosphere, spanning a distance of approximately 1.5 million kilometers. This limitation particularly applies to tracking in white light. Therefore, certain research has used radio emission monitoring to compare it with electron density models for the sun, as referenced [21]. The tracking process relies on estimating velocity changes, which depends on estimating acceleration. Further investigation is required to compare the plane sky survey with existing research to assess the disparity in acceleration (whether decelerated or accelerated) [22]. The challenges, among others, can only be accurately assessed with a minimal margin of error if we discover an improved methodology for characterizing the transmission process of coronal mass ejections (CMEs) from the Sun's corona to the interplanetary (IP) medium and subsequently to Earth.

5. Conclusions

The following conclusions can be derived from the provided data on CME characteristics, solar flare intensities, and shock wave occurrences:

1. Characteristics of CME: 359 events have a speed of less than 500 km/s and an angular width of less than 60 degrees. 72 of the total events are halo CMEs (CMEs that appear to surround the solar disk), while 287 are conventional CMEs (not halo).
2. Solar Flare Strengths: The study considered different classes of solar flares associated with the CME events. There were 31 events with B-class solar flares, 186 with C-class solar flares, 123 with M-class solar flares, and 15 with X-class solar flares. Additionally, four events were found to have no associated flares.
3. Shock Wave Happenings: Two of the analyzed CME events were associated with magnetic storms, indicating a potential impact on Earth's magnetic environment.
4. Temporal Dispersion: In 2020, nine events were recorded. In 2021, 53 occurrences occurred. The greatest number of events, 202, were recorded in 2022. In 2023, 95 occurrences were recorded.

Based on the provided data, the conclusions of the findings related to CME characteristics, solar flare intensities, and shock wave occurrences are as follows:

This study comprehensively analyses 359 coronal mass ejection events, focusing on their speed and angular width. The research also considered the associated solar flare intensities and the occurrence of magnetic storms. By isolating the two most powerful events accompanied by shock waves, the study enhances our understanding of the dynamics and characteristics of CMEs during the early stages of solar cycle 25. The findings on the distribution of CME events across the years suggest variations in solar activity during the analysed period. Such insights are valuable for space weather forecasting and understanding solar behaviour. These conclusions are based on the presented data and specific analysis criteria (velocity, angular width, solar flare classes, etc.). These findings can contribute to the understanding of solar-terrestrial interactions by shedding light on the behaviour of CMEs, solar flares, and shock waves during the specified period. To further interpret the implications of these findings, it would be advantageous to analyze the effects of these CME events and solar outbursts on space weather, geomagnetic storms, and the potential effects on Earth's technological infrastructure. In addition, examining these CME events' spatial distribution and magnetic properties could provide a deeper comprehension of their effects on the space environment. As with any scientific analysis, it is essential to consider the limitations of the data and methods employed, and future research can concentrate on refining the analysis techniques and incorporating data from multiple observational sources for a more thorough investigation of solar phenomena.

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References
[1] D. F. Webb and T. A. Howard, "Coronal mass ejections: Observations," *Living Reviews in Solar Physics*, vol. 9, no. 1, pp. 1-83, 2012.
[2] N. Gopalswamy, "Coronal mass ejections: An introduction," in coronal mass ejection." Cham: Springer, 2016, pp. 1-25.
[3] Z. F. Hussein, "Relation between coronal mass ejections and sunspot number during solar cycle 24," *Iraqi Journal of Science*, vol. 60, no. 8, pp. 1860-1867, 2019. https://doi.org/10.24996/ijs.2019.60.8.23
[4] K. Shibata and T. Magara, "Solar flares: Magnetohydrodynamic processes," *Living Reviews in Solar Physics*, vol. 8, no. 1, pp. 1-99, 2011. https://doi.org/10.12942/lrsp-2011-6
[5] B. Vršnak *et al.*, "Coronal shocks: Unresolved issues and prospects for their observation with forthcoming missions," *Solar Physics*, vol. 285, no. 1-2, pp. 295-315, 2013.

[6] S. Yashiro, G. Michalek, S. Akiyama, N. Gopalswamy, and R. Howard, "Spatial relationship between solar flares and coronal mass ejections," *The Astrophysical Journal*, vol. 673, no. 2, p. 1174, 2008. https://doi.org/10.1086/524927

[7] M. A. Johnson, "Solar flare and coronal mass ejection observations in the 21st century," *Space Science Reviews*, vol. 216, no. 3, p. 60, 2020.

[8] B. Vršnak *et al.*, "Propagation of interplanetary coronal mass ejections: The drag-based model," *Solar Physics*, vol. 285, pp. 295-315, 2013. https://doi.org/10.1007/s11207-012-0035-4

[9] H. Xie, P. Mäkelä, O. St. Cyr, and N. Gopalswamy, "Comparison of the coronal mass ejection shock acceleration of three widespread SEP events during solar cycle 24," *Journal of Geophysical Research: Space Physics*, vol. 122, no. 7, pp. 7021-7041, 2017. https://doi.org/10.1002/2017ja024218

[10] G. E. Brueckner, R. A. Howard, and M. J. Koomen, "SoPh," vol. 162, pp. 357-402, 1995.

[11] F. K. Dagnew, N. Gopalswamy, S. B. Tessema, S. Akiyama, and S. Yashiro, "Effect of the heliospheric state on CME evolution," *The Astrophysical Journal*, vol. 936, no. 2, p. 122, 2022.

[12] N. Gopalswamy, "Anomalous expansion of coronal mass ejections during solar cycle 24 and its space weather implications," *Geophysical Research Letters*, vol. 41, pp. 2673-2680, 2014. https://doi.org/10.1002/2014gl059858

[13] W. D. Gonzalez, "What is a geomagnetic storm?," *Journal of Geophysical Research*, vol. 99, pp. 5771-5792, 1994.

[14] H. S. Garee and K. A. Hadi, "Evaluation of the annual correlations between different solar-ionospheric indices during solar cycles 23 and 24," *Iraqi Journal of Science*, vol. 63, no. 10, pp. 4587-4600, 2022. https://doi.org/10.24996/ijs.2022.63.10.40

[15] R. S. Al-Awadi, O. T. Al-Taai, and S. A. Abdullah, "Assessment of outer space events on troposphere and climate change over Iraq," *Iraqi Journal of Science*, vol. 64, pp. 4278-4289, 2023. https://doi.org/10.24996/ijs.2023.64.8.44.

[16] D. Lario *et al.*, "Longitudinal properties of a widespread solar energetic particle event on 2014 February 25: Evolution of the associated CME shock," *The Astrophysical Journal*, vol. 819, no. 1, p. 72, 2016. https://doi.org/10.3847/0004-637X/819/1/72

[17] N. Gopalswamy, "Extreme solar energetic particle event of 2022 May 23," *The Astrophysical Journal Letters*, vol. 952, p. L1, 2023. https://doi.org/10.3847/2041-8213/acdde2

[18] F. K. Dagnew, N. Gopalswamy, S. B. Tessema, S. Akiyama, S. Yashiro, and T. Y. Tesfu, "Intercycle and intracycle variation of halo CME rate obtained from SOHO/LASCO observations," *The Astrophysical Journal*, vol. 903, no. 2, p. 118, 2020. https://doi.org/10.3847/1538-4357/abb887

[19] X. H. Zhao, X. S. Feng, H. Q. Feng, and Z. Li, "Correlation between angular widths of CMEs and characteristics of their source regions," *The Astrophysical Journal*, vol. 849, no. 2, pp. 1-7, 2017. https://doi.org/10.3847/1538-4357/aa8e49

[20] H. Allawi, A. Al-Sawad, and R. Mazher, "Investigate of 4 strong solar eruptions in september 2017 and their impacts on the earth," *NeuroQuantology*, vol. 18, pp. 25-34, 2020. https://doi.org/10.14704/nq.2020.18.9.NQ20212

[21] M. Reiner, M. L. Kaiser, and J.-L. Bougeret, "Coronal and interplanetary propagation of CME/shocks from radio, in situ and white-light observations," *The Astrophysical Journal*, vol. 663, no. 2, p. 1369, 2007. https://doi.org/10.1086/518683

[22] T. Kocharov, A. Laitinen, A. Al-Sawad, O. Saloniemi, E. Valtonen, and M. J. Reiner, "Gradual solar energetic particle event associated with a decelerating shock wave," *The Astrophysical Journal*, vol. 700, pp. L51-155, 2009. https://doi.org/10.1088/0004-637x/700/1/l51