Solar Energetic Particles Resulting from Weak Coronal Mass Ejections

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ABSTRACT
The Sun emits altitude -energy particles known as solar energetic particles (SEPs), commonly associated with solar flares and coronal mass ejections (CMEs). While strong, energetic particles usually connected to a robust coronal mass ejections, increasing evidence suggests that weak coronal mass ejections can also produce significant solar particle events. This research adds to our understanding of space weather phenomena. Recent results indicate that mild coronal mass ejections with Speeds below 500 km/s and magnetic force constraints can accelerate particles rapidly to high energy.Since these smaller coronal mass ejections occur more Common than the bigger ones, they clearly contribute significantly to the overall flux of solar particles.This study examined solar particle occurrences with mild coronal mass ejections using data from many satellites, including the Solar and Helio spheric Observatory (SOHO),Solar TerrestrialRelations Observatory[STEREO], andAdvanced Composition Explorer [ACE]Significant findings indicate that, albeit weaker than powerful coronal mass ejections, Weak coronal mass ejections use acceleration mechanisms including shock waves and magnetic reconnection events. Limiting the effects of solar particle outbursts on technology in space and on Earth.To enhance their forecasting models, it is essential to comprehend these components. The relevance of weak coronal mass ejections in relation to solar activity and space weather is highlighted by this study,As our reliance on technology grows, it highlights how important it is to continue monitoring and use state-of-the-art modeling approaches in order to better forecast and control the effects of solar energy particles.

Keywords: Solar energetic particles, Solar flare, Coronal mass Ejection

1. INTRODUCTION

The Sun is the primary source of energy and light for our solar system in addition to is also responsible for the construction of the space environment that encompass our planet . Acognition of the Sun-Earth interaction is crucial for robotic andhumanspace mission, in addition to comprehension solar activity,inclusivesolar energetic particles (SEPs) and coronal mass ejections (CMEs)[1]. hail from the solar corona,Massive plasma and magnetic field explosion called coronal mass ejections or CMEs[2].When pushed into space, these masses have the capacity to generate directional shocks and dead earnest disturb the solar wind. The connection between weak CMEs and SEPs Examining the relationship between energetic solar particles and weak coronal mass ejection is wonderful because it may provide new insights into the acceleration and space travel of Solar particles. Weak coronal mass ejections have the capacity to produce targeted shocks that accelerate particles to very high energies despite their precision [3].The role of shock waves in particle gathering speedWave shocks result from coronal mass ejections passing, through thesurrounding plasmafast-moving than the solar wind[4].Shocks are important in the acceleration of solar particles because they can increase particle energy through magnetic reconnection processes and other physical mechanisms. When a CME collides with the solar wind environment, it can accelerate energetic solar particles and cause powerful shocks. Even weak CMEs,which may not be as powerful as strong CMEs, can contribute to particle acceleration if conditions are fulfilled to generate an effective shock. Strong solar flare shocks produce impulsive SEPs, but shocks from coronal mass ejections produce Gradual SPEs.In exchange for that, shocks from CMEs cause slowSPEs[5].This kind of energy carrier is ability to execute traveling across many media[6].The relationship between coronal mass ejections (CMEs) and solar energetic particles (SEPs) is important because it aids in determining the frequency and intensity of geomagnetic disturbances on Earth.This is crucial foranticipate space weather and lowering the possibility that mishaps would interfere with satellite operations and power systems[7].whereby, these factors determine whether the shock generated by the CME will be powerful enough to do harm to SEP and if it will be able to accelerate solar particles to ruined speeds[8]. For example, while small coronal masses may not be as efficient as big ones in causing violent shocks, They could occasionally aid in the acceleration of particles.The impact that these mild CME shocks have on changing the spaceperimeter and increasing SEPs [9].Previous research has exemplifythat shock waves and magnetic reconnection are the two main methods that solar mass ejections accelerate solar particles, in addition to the complex interplay between SEPs and CMEs,As claimed by to a research by Reiter et al. (2015)[10].Coronal mass ejections, however, can produce energetic particles less successfully than strong particles, as shown by previous investigations, such as the one by Santana et al. (2019) [11].Nevertheless, these occurrences have a significant impact on the ecology around space radiation. Additionally, studies have shown that aequinoctial coronal mass ejection's capacity to expedite solar particles is determined by on a number of variables, such as the ejection's speed and the solar plasma's magnetic and temperature characteristics (Schrijver& Siscoe, 2010) [12].Tocomprehension the physical mechanisms behindthese Connections is one of the objectives of ourresearch. Through data analysis from space observatories and the presentation of an experimentallybased theoretical model that explains the connection between weak coronal ejections and active solar particles, the extent of the influence of weak coronal ejections on the acceleration and allocation of pulsed solar energy was estimated.

2. Theoretical

The process ofpinpoint and studying solar events and their properties comprises analyzing data the source space observatories,such as the Solar Dynamics Observatory (SDO) and others. In order to understand the complex physical processes involved in these events, computer simulation models will also bein employment.The solar flare, coronal mass ejection(CME), and spectroscopic thermal emission phenomena that cause photo emission and magnetic fields are monitored by instruments like the Large Angle Spectrometric Coronagraph (LASCO), Electron and Relativistic Nuclei Energetic (ERNE),plus Geostationary Operational Environmental Satellite (GOES).Since 1996, CMEs have been manually identified using the (LASCO) on the (SOHO) project. LASCO is composed of three telescopes: C1, C2, and C3. A year-month framework with a monthly list of CMEs, each of which represents one CME, is the top level of the catalog. Halo CMEs are those that appear to be 360 degrees wide. There are three speeds in every CME: speed squared, speed derived from, and speed measured at a level of 20 solar panel radii when the CME is present. CMEs can travel inside the LASCO FOV by accelerating, decelerating, or approaching zero. The position angle used to assess height over time is displayed in the next column; the results produced are frequently ambiguous.[13]ERNE is used as adetector to calculate the intensity, energy, and directionality of solar particles.[14](GOES)It is a series of satellites to detect X-rays emanating from Flare.[15]

3.RESULTS AND DISCUSSIONS

In solar cycle 24, we observed 4,566 events by using LASCO; 1106 eventswere selected with criteria as follows: angular width less than 60 degrees and linear velocity less than 500 km/s.Two events were found.that had particles. Recent research suggests that weak coronal mass ejections can propel high-energy particles at speeds of less than 500 km/s.The angular width is less than 60. These weak coronal mass ejections are likely responsible for a significant portion since they occur more frequently than the most potent particles of the total flux of solar energetic particles. This work studies solar particle events associated with weak coronal mass ejections using data from multiple spacecraft, including ACE, STEREO, and SOHO. Significant results indicate that acceleration mechanisms for weak coronal mass ejections are less
dependent on shock waves and magnetic reconnection processes than for massive coronal mass ejections. Although more and more data suggest that moderate coronal mass ejections can lead to sizeable solar particle events, strong coronal mass ejections are usually associated with massive solar particle events. By examining the properties and processes of solar particle
production by light coronal mass ejections, this work contributes to our growing understanding of space weather phenomena. Among these events studied during solar cycle 24 are shown inTable (1.1):

Table 1. Properties of weak coronal mass ejections with solar energy particles.

	CME				Flare		SEP			
No.	Data	Lift off time	Angular Width	Speed Lenier	Max Time	*class*	Particle Flux Density ((particles m^{-2} s^{-1} sr^{-1})	Energy (MeV)	Energy Flux Density(W/m^2)	Source
1	2011/9/23	[00:12:05]	40˚	327	[00:33:06]	$M_{1.38}$	10 1 0.1	10 < 50 < 100 <	1.6×10^{-11} 0.8×10^{-11} 1.6×10^{-12}	NO9E89
2	2012/3/6	[20:57:26]	43˚	176	[21:06:26]	$M_{1.2}$	8 4.5 1.5	10< 50 < 100 <	1.6×10^{-10} 8×10^{-11} 1.6×10^{-11}	N19E32

In Event 1 on 23 September 2011 ,the lift-off time of the CME wasrecorded at 00:12:05, its linear speed was 327km/s, its acceleration was -42.4*1 m/S2, and its angular width was 40˚ degrees. The maximum time of SXR that emissionfrom location NO9E89 was 00:32:06 with class $M_{1.38}$. The results showed significant increases in charged particle activity, coronal mass ejection height, and X-ray intensity. These events suggest a major solar outburst that might increase radiation and affect satellites and communication networks. The figure displays the coronal mass ejections' height, andEven though it moves slowly if it accelerates faster than the sound speed in the solar plasma, it can cause a frontal shock. Through a process known as spike acceleration, the charged particles are accelerated by this shock even at low speeds as a result of their interaction with the solar wind. The interaction between the CME and the magnetic field of the solar wind can lead to magnetic reconnection, and this releases additional energy to accelerate the particles, as the CME carries a strong magnetic field that can trap the particles through a mechanism known as the magnetic explosion[16].This magnetic field helps accelerate the particles to higher energies, even if The original CME velocities were low .These particles reach the Earth and are observed with a noticeable increase in the SEP flux, as the rise in the upper panel coincides with the increase in the X-ray flux in the lower panel, which indicates that solar flares are the main driver of the increase in SEP, in addition to the presence of CME in the same period. We infer that the reason for the increase in SEP is an impulse resulting from a series of solar flares and CME simultaneously or successively [17]in the period from 22 to 23, as solar flares release significant quantities of particles. While the CME contributes to the acceleration of these particles at high levels, causing a noticeable increase in the SEP flow, this leads to an increase in the observed flow [18].As shown in the Figure(1) and Figure (2):-

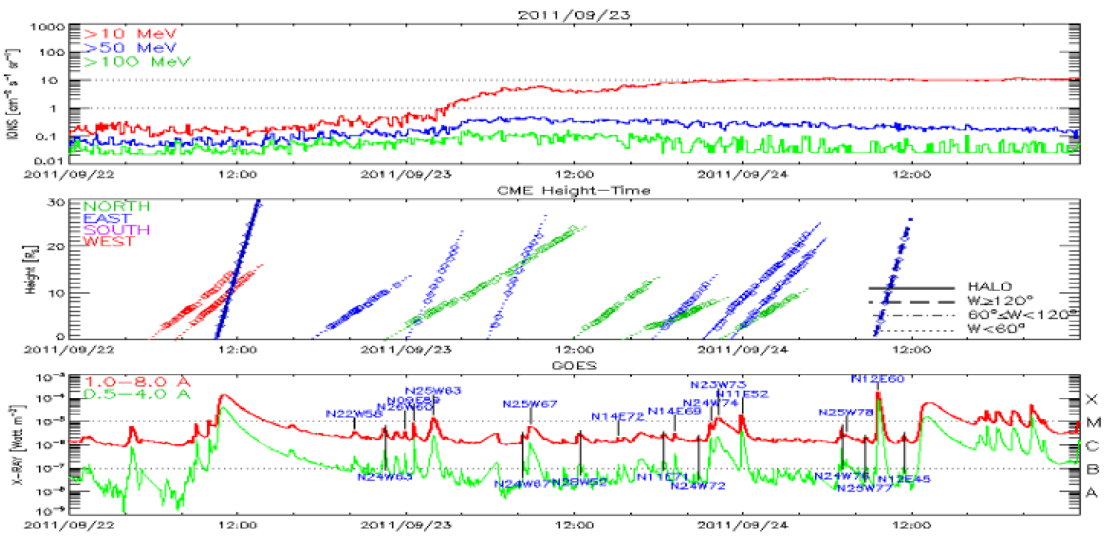

Figure 1. Exhibiting the relation between the location of solar eruptions with the intensity ofSEPs and solar flare as a function of time for event 1

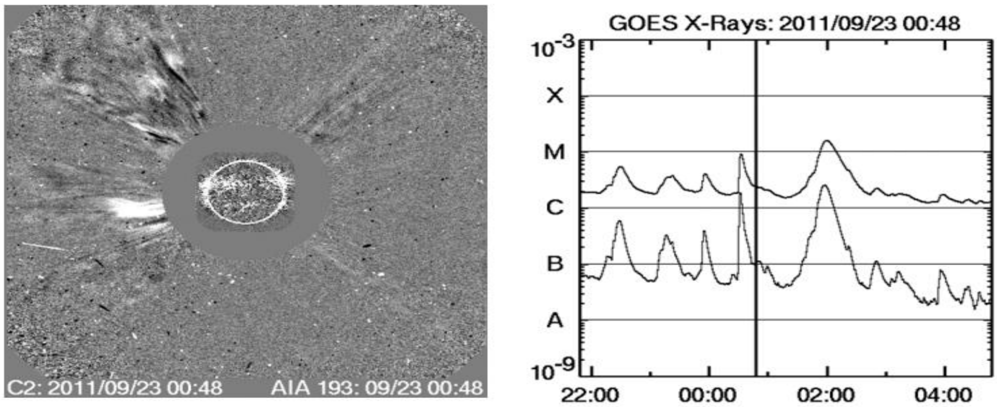

Figure 2. Shows LASCO/C2 movies and different EIT images [https://cdaw.gsfc.nasa.gov/movie/make_javamovi].

In Event 2 on 6th March 2012, the lift-off time of the CME was recorded in [20:57:26], its linear speed was 176 km/s, its acceleration was 24.4*1 m/S2, and its angular width was 43° degrees. The maximum time of SXR that emission from location N19E32 was 21:06:26 with class $M_{1.2}$. We also observe an important event where a significant increase in SEP flux coincides with large CME activities and X-ray bursts. It can be inferred that solar flares (as seen from the increase in X-rays) were accompanied by fast, high-intensity coronal mass ejections (CME). The primary cause of the SEP rise was the strong CME activity and solar flares, which accelerated particles and caused them to disperse throughout space.There was a little drop in flux levels on March 5, 2012. It can be attributed to the very calm solar activity era that preceded this decline in SEP flux. The equipment detects less SEP flow during this time because the Sun produces less energetic particles.[19] Following this decrease, there is a notable increase in SEP flux that starts on March 6, 2012, peaks later in the day and stabilizes on March 7, 2012, which is when the notable height increase was seen on March 6-7. The SEP flow is closely linked to solar events such as solar flares and coronal mass ejections (CMEs).The central figure, which plots the CME growth data across time, suggests that March 6, 2012, was a significant CME event. Big plasma and magnetic field explosions, or CMEs, occur when particles from the Sun's corona are propelled to extremely high energies. When these energetic particles arrive on Earth, they are subsequently seen as a high SEP flux. The steep increase indicates the arrival of these accelerated particles. A large CME seen on March 6 it shows how CMEs are growing over time. This is consistent with the increase in SEP flux seen in the first picture. Solar flares are represented as peaks on the X-ray flux levels displayed at the bottom. Solar flares and CMEs that are thought to be causing the rise in SEP are corroborated by increased X-ray activity around the same time.[17] Together with solar flares, a CME event that occurred on March 6, 2012, enhanced particle activity, and these data, coordinated across many visualizations, support the conclusion that this was the cause of the rise in SEP flux. According to Figure(3) and Figure(4):-

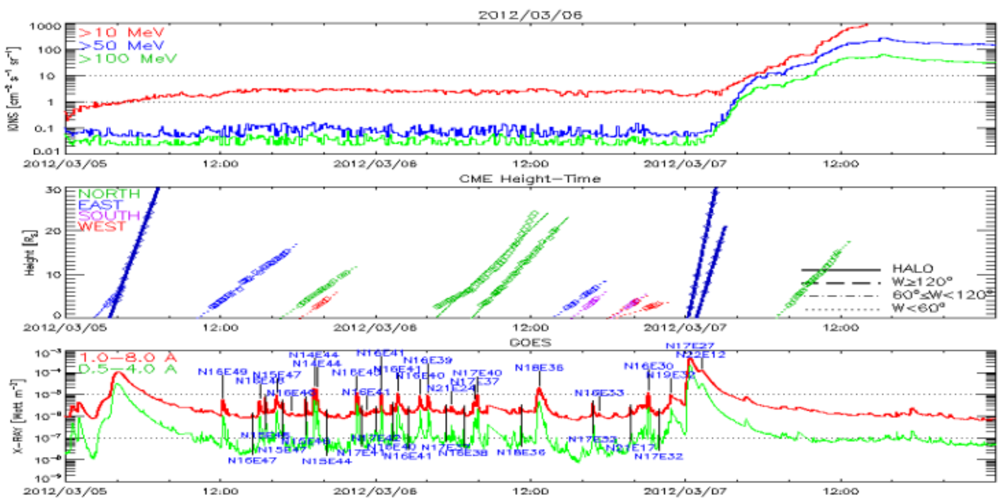

Figure 3. Exhibiting the relation between the location of solar eruptions with the intensity of SEPs and solar flare as a function of time for event 2

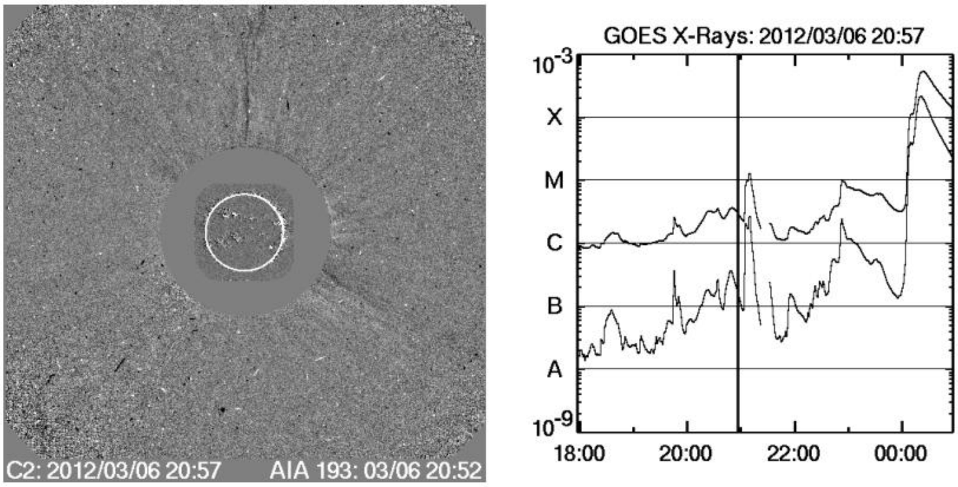

Figure 4. Shows LASCO/C2 movies and different EIT images [https://cdaw.gsfc.nasa.gov/movie/make_javamovi].

CONCLUSION

The impact of solar energetic particles (SEPs) on weak coronal mass ejections (CMEs)

1. Particle acceleration is less effective when weak masses accelerate at speeds lower than 500 km/s because they produce smaller shock waves.
2. Weak coronal mass ejections with a narrow angular width affect a small portion of space, which reduces the chance of their interaction with solar particles.
3. Weak coronal masses have less impact on solar energetic particle density (SEP) than strong coronal masses.
4. The influence of weak coronal mass masses may be amplified by interaction with terrestrial and solar magnetic fieldsbut it will always be weaker than that of large coronal masses.
5. Low-intensity SEP episodes are frequently linked to weak coronal mass ejections and less intense solar flares.
6. Weak coronal mass masses combined with solar flares, like the M1.2 flare, accelerate particles more quickly, raising the SEP flux
7. In 2012 March 6 data demonstrate the consequences of the M1.2 flare, notwithstanding their weakness, with an intense SEP flux and weak coronal masses.
8. Strong magnetic fields and weak masses can interact throughelectromagnetic radiation to boost the efficiency of particle acceleration.
9. The Earthly Southern Pole is less affected by weak coronal mass ejections that are not aimed straight at the planet.
10. Weak coronal mass ejections can cause a significant rise despite their small linear speed.

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