Investigate of 4 Strong Solar Eruptions in September 2017 and their Impacts on the Earth

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Abstract

We observed 4 Solar Energetic Particle SEP events by (Energetic and Relativistic Nuclei and Electron) ERNE onboard The (Solar and Heliospheric Observatory) SOHO spacecraft during September 2017. All the events have a similarity in the intensity time profile, they fit under the gradual type and associated with halo coronal mass ejections CMEs and three of them were associated with a solar flare. The acceleration of the impulsive phase should be a result of coronal shock due to investigations of the radio type II emission and the gradual part as a result of interplanetary shock, which caused a D-H radio emission. The record of the shock waves by (Charge, Element, and Isotope Analysis System) CELIAS onboard SOHO did not appear for two of those events although all the evidence suggested that there were strong shocks associated with those SEP events at the sun and interplanetary IP medium beside auroral observation at earth were seen in association of the arrival time. The observations suggested that the shocks that did not see on CELIAS were decelerating and gradually the mean free path of them reach the IP medium and the shocks dissolve in IP medium before passing SOHO but the characteristics of the intensity time were not online with this suggestion since acceleration were continued. We suggested that the magnetic field in the IP medium played a rule in changing the shock wave direction and hence it did not pass the spacecraft.

Key Words: Solar Flares, Coronal Mass Ejections, Shock Waves.

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Introduction

Solar monitoring has been and still important studies in space physics because the earth is closely related to the dramatic changes that occur on the sun. Eruptions that occur on the Sun affect the Earth with main two ways, solar flares accompanying hard and soft X-rays radiative, and /or by coronal mass ejections (CMEs) accompanying solar energetic particles (SEPs) (Howard, 2014). These Eruptions have been studied for two centuries and have been observed to be repeated periodically through a solar cycle almost every 11 years. Each solar cycle starts with a quiet sun and then becomes bound to reach the peak of activity and then retreats to inactivity, depending on sunspot numbers (SSN).

Solar flares give a large amount of energy essentially in form electromagnetic radiation and high-energy particles. Thus, glare sometimes causes rapid and significant differences in the near-earth space environment called space weather (Handzo *et al*., 2014; Hayes *et al*., 2017). Solar flares are classified based on their peak emission in the 0.1–0.8 nm spectral band (i.e., X-ray) and are mentioned as "A," "B," "C," "M," and "X," identifying X-class flares as the most intensive one with emission higher than 10^{-4} W m^{-2}.

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Coronal mass ejection (CME) is a marked as a change in coronal structure, occurring in a time range from a few minutes to several hours, and involves the outward appearance and movement of a new, discrete, bright white light property in the coronagraph field of vision (Hundhausen *et al*., 1984; Schwenn, 1996), CMEs consists mainly of hot (10^6 K) and ionized plasma.

In the solar corona, shock waves can occur as blast waves due to the flare process (Uchida *et al*., 1973; Vrsnak *et al*., 1995) or shocks driven by coronal mass ejections (CMEs) (Stewart *et al*., 1974b). Some of them might be traveling shocks in the interplanetary space.

Flares, Coronal mass ejections, and shock signatures, as well as solar energetic particles (SEPs), are usually closely temporally associated, and the association rate increases with the flare importance (Vrsnak and Cliver, 2008). SEPs are referred to as due to their high energy solar origin and behavior as single particles (Howard, 2014). The point of view presented in some studies that narrow fast CME is not associated with SEP events (Al-Sawad *et al*., 2012). The origin of the coronal shock waves is still not fully understood. A blast wave ignited by the pressure pulse of a flare, or/and a piston-driven shock due to a CME, both are two possible physical explanations. Most of the interplanetary shocks are CME-driven, while coronal shock waves can be attributed to solar flares, CME's, or some combination of these phenomena (Magdalenic *et al*., 2008; Al-Sawad *et al*., 2012).

(Reames, 1999) suggested that the impulsive events were associated with flares and the gradual SEP events were associated with coronal mass ejection (CME) driven coronal and interplanetary shocks.

There were a lot of controversial ideas about the role of flare and CME. CMEs have been shown to be escorted with gradual events of X-ray (Sheeley *et al*., 1983a) and with (IP) interplanetary shocks (Sheeley *et al*., 1983 b). Interplanetary proton events were shown to be escorted with gradual events (Nonnast *et al*., 1982) with CMEs (Kahler *et al*., 1984) and with interplanetary shocks (Cane and Stone, 1984).

In this study, we observe 4 strong Halo CMEs, two of them were associated with interplanetary shock waves were hit the earth. We focus on those events because, despite the low solar activity period in September 2017, a series of powerful SFs occurred. As well as quite period of Sun gives us a clear view to avoid masking between the origin of multi eruptions events.

Data and Methods

The data used in this study obtained from different sources. (Solar and Heliospheric Observatory) SOHO satellite devices have been used for collecting the information. Solar flare data obtained from (Geostationary Operational Environmental Satellite) GOES. Were the speed and acceleration of the CMEs and the time of sequence are taken from the (Large Angle and Spectrometric Coronagraph) LASCO. The SEPs intensity-time profile was obtained from ERNE (energetic and relativistic nuclei and electron) detector on board of SOHO. [https://srl.utu.fi/erne_data/datafinder/df.shtml].

The 10 min time resolution were used for energy channels 1-72 MeV, chosen according to the first rise of the intensity over the cosmic-ray background.

When the shock wave hits SOHO the CELIAS instrument will record the changes in the solar wind parameters, such as the speed, thermal variation, density, and magnetic field alteration.

The method used in this study depends on the empirical approach in order to estimate the travel time of the shock wave that hit the earth when CELIAS did not record it.

First: LASCO will give the extrapolation of the fitting for the CME after taking many shots by the camera on it and use two kinds of the fitting, linear and quadratic. The mean value for them will be to obtain the calculated liftoff time for the CME and will be considered as a starting time for the travel of the shock until the shock passage on earth.

Second: When CELIAS record a shock passage within 1-3 days after the liftoff, the time will be recorded as a time arrival to earth since we can ignore the 150,000 km for the location of SOHO from Earth toward Sun, compared with about 150 million km, the distance between earth and sun.

Third: There are two cases that relate to the calculation of CELIAS for the travel time of the shock and thus the determination of the source of it at the sun.

In some cases, CELIAS will give the travel time and determine the source accordingly and in this case, their results will be considered and compared to the source we found on LASCO. In another case, there is no monitoring for the travel time neither the source, in those cases it will be estimated and

then used to obtain the calculation for the travel time and source.

Fourth: The aurora events will be monitored on earth, after which the recorded shock wave passage, the correlation will be found in the two methods above.

Finally: Calibrating the results calculated by our composition and CELIAS through comparative statistics in order to determine the associated aurora certainty and sun eruptions.

We have calculated the liftoff time for the CME and the starting of the soft X-ray emission for the solar flare. The effect of the parameters of those CMEs and flare were studied during the time of the bulk of the acceleration for the protons.

Results and Discussions

It is still unaccomplished and hard task of tracking the CME propagation in the interplanetary medium and its driven shock wave because of the lack of the tracking space instruments along this propagating path which is about 1AU.

In this study, four of the CMEs were selected for September 2017. Those events a discrete as a Halo type, which usually has a high speed and accompanied by strong solar flares, we could see for all of those eruptions as shown in Table 1. All those CMEs have DH type II radio emissions and geomagnetic storm effects the earth. In the days following the CME eruptions from the sun, there were two shock waves were observed by CELIAS onboard SOHO as shown in Table 2. The record of the shock waves by CELIAS onboard SOHO did not appear for two of those events although all the evidence suggested that there were strong shocks associated with those SEP events at the sun and IP medium beside auroral observation at earth were seen in association of the arrival time.

Table 1. Properties of coronal mass ejections and solar flares with geomagnetic storms

Events	Data Time dd.mm.yyyy	Start eruption	Linear speed (Km/s)	Lift Of Time	Class of X-ray flare	Peak Flare	DH type II (kHz)	Geomagnetic Storm
1	04.09.2017	20:36	1418	20:18±4	M5.5	20:33	14000-210	Kp3+
2	06.09.2017	12:24	1571	12:01±00	X9.3	12:02	16000-70	G4
3	10.09.2017	16:00	3163	15:52±2	X8.2	16:06	16000-150	Kp3
4	17.09.2017	12:00	1385	11:40±3	NO	N0	16000-900	Kp4

Table 2. Shock waves properties and Geomagnetic storms events.

Events	Arrival Time CELIAS (hh:mm) dd.mm.yyyy	Travel Time CELIAS (hours)	Active Region	Estimated travel Time (hours)	Error Rate	Active Region	Acceleration [m/s^2]
1	23:13 06.09.2017	51	12673	52.5	0.8597	S10W12	47.5
2	22:38 07.09.2017	35	12673	39.6	0.9755	S08W33	-0.3
3	No	No		29.09	2.875	S09W92	-232
4	No	No		42.06	1.074	S08E170	-32.8

On the event 1, 4th of September, GOES detected X-ray solar flare with class M5.5 and accompanied by halo CME, this was followed by the start of gradual SEPs, which continued two days, 5th and 6th of September, as shown in Figure 1, the injection time of SEPs was calculated for two energies. From

Table 2 we could see this event has acceleration 47.5 m/s^2. From the gradual curve of solar energetic particle intensity, we could conclude that interplanetary shock, which caused a D-H radio emission starts with 14000 kHz and end in 210 kHz.

A shock wave arrival was observed on the 6th of September 2017 at 23:13 UT as shows in (Figure 3a) and caused by the above-mentioned CME with 51 hours traveling time and calculated estimated traveling time with 52.5 hours.

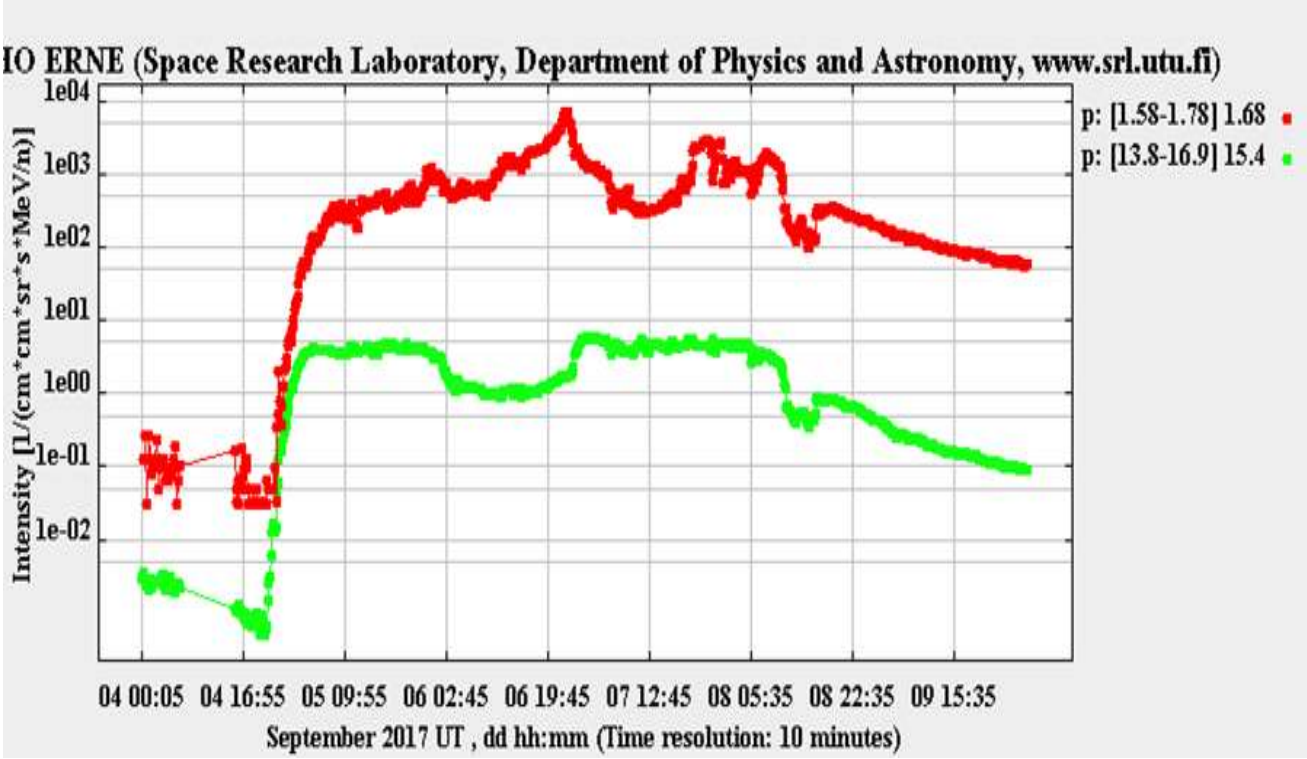

Fig. 1. Intensity time profile of SEPs on 4th September 2017 with two energy channels. (ERNE)

On the event 2, 6th of September, the halo coronal mass ejection was observed accompanied by a very strong solar flare soft X-ray class X9.3. This eruption was accompanied by the generation of solar energetic particles observed through the ERNE, where we also observe a large propellant that shows that these particles continue to be accelerated for a long time due to their continuous power supply.

A shock wave arrival was observed on the 6th of September 2017 at 22:38UT as shows in (Figure 3b) and caused by the above-mentioned CME with 31 hours traveling time and calculated estimated traveling time with 39.6 hours.

On the event 3, 10thof September, the coronal mass ejection was the fastest in this month at a speed of 3163 km/s, but with very great deceleration - 232 m/s^2 accompanied by a strong solar flare X8.2 with the same active region 2673 of the event on 6th of September. Figure 2 shows there was a gradual intensity time profile of solar energetic particles with injection time matching lift of time of CME and peak of the soft x-ray. In this event, CELIAS did not register any shock wave signal.

Event 4, there was no any solar flare on the 17th of September, while we observed halo coronal mass ejection at 12:00 with high linear speed 1385Km/s. Also not any solar energetic particles had observed at this time.

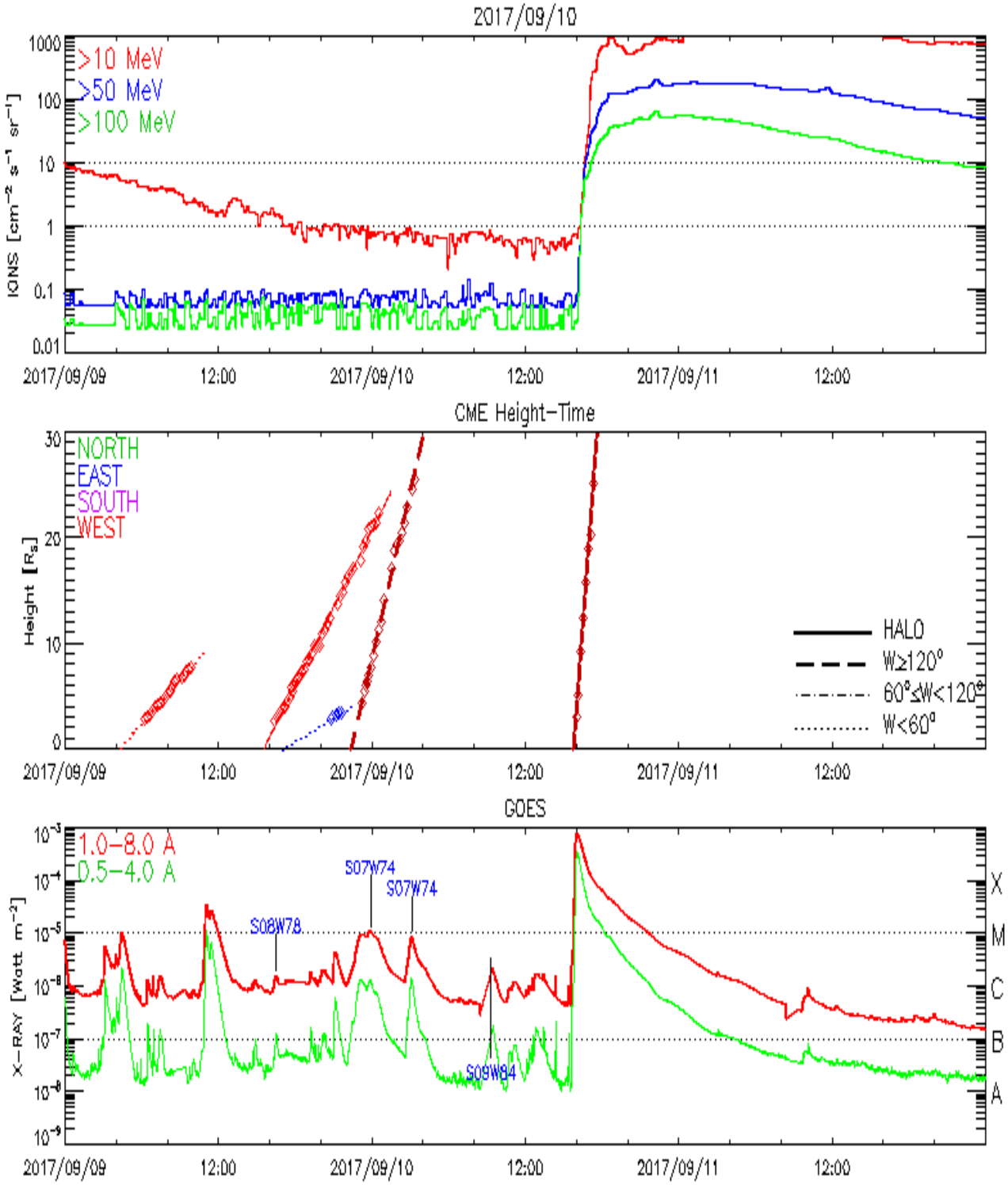

Fig. 2. An event on the 10th of September 2017 at 12:00 UT.(top panel) Intensity time of particle profile, (middle panel) shows the coronal mass ejections, (bottom panel) solar flares profile. (LASCO CATALOG)

We monitoring with those events there were two shock waves starts at 4th and 6th (Table 2), those shock waves arrived at the earth at 23:13 at 6th and 22:38 7th of September causing geomagnetic Storms Kp3+, G4 respectively as shown in Figure 3a,b

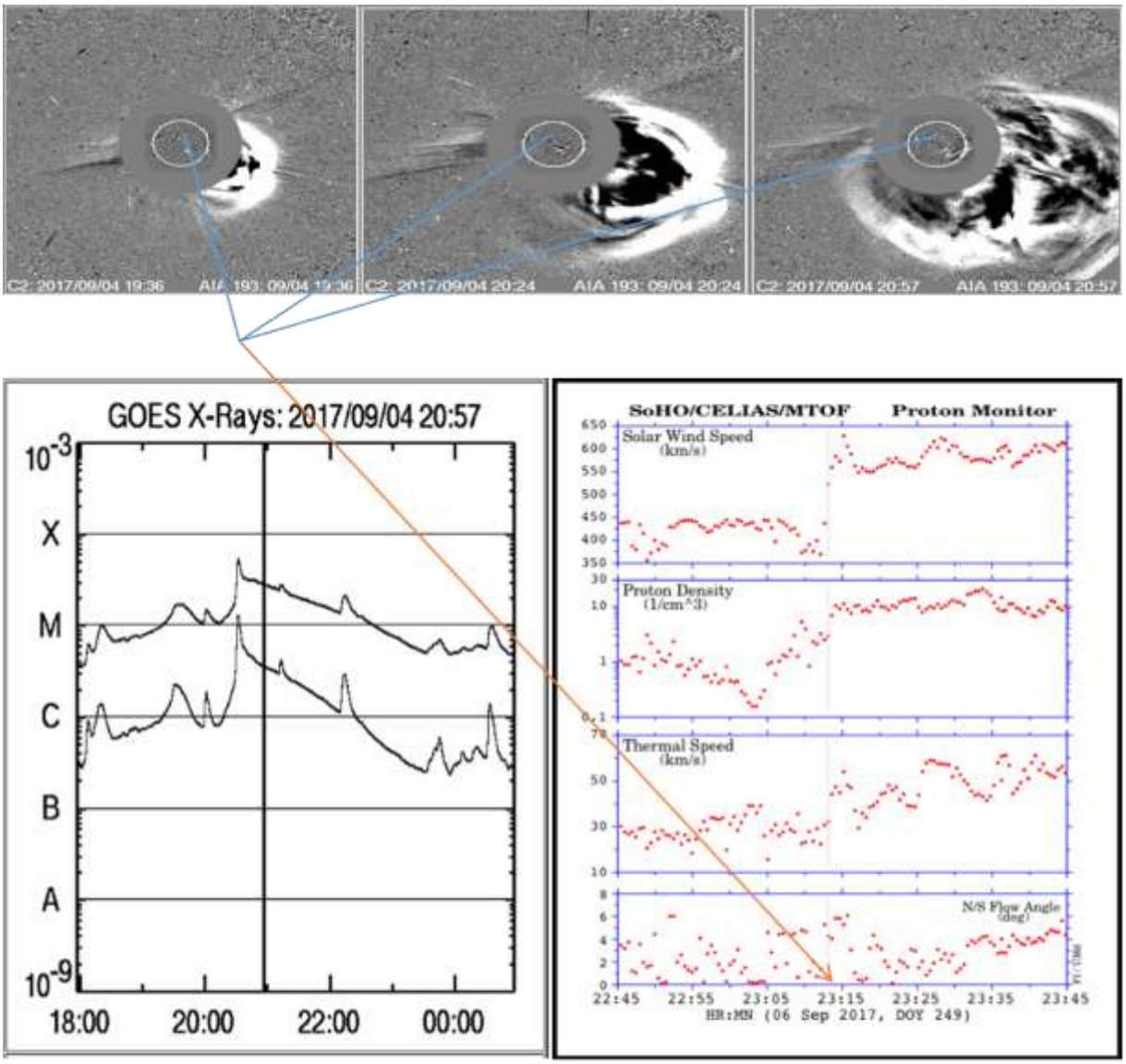

Fig. 3a. Shock waves caused by CME 4th of September 2017 as detected from SOHO/CELIAS at arrival time 6th and 7th September. (upper panel) indicates the FC2AT of the CME detected by SOHO/LASCO. (middle left panel) The soft X-ray detected by GOES satellite for the associated flare. (middle right panel) CELIAS/MTOF registered shockwave arrival time and the end of injection. (bottom panel) aurora phenomena from space weather.

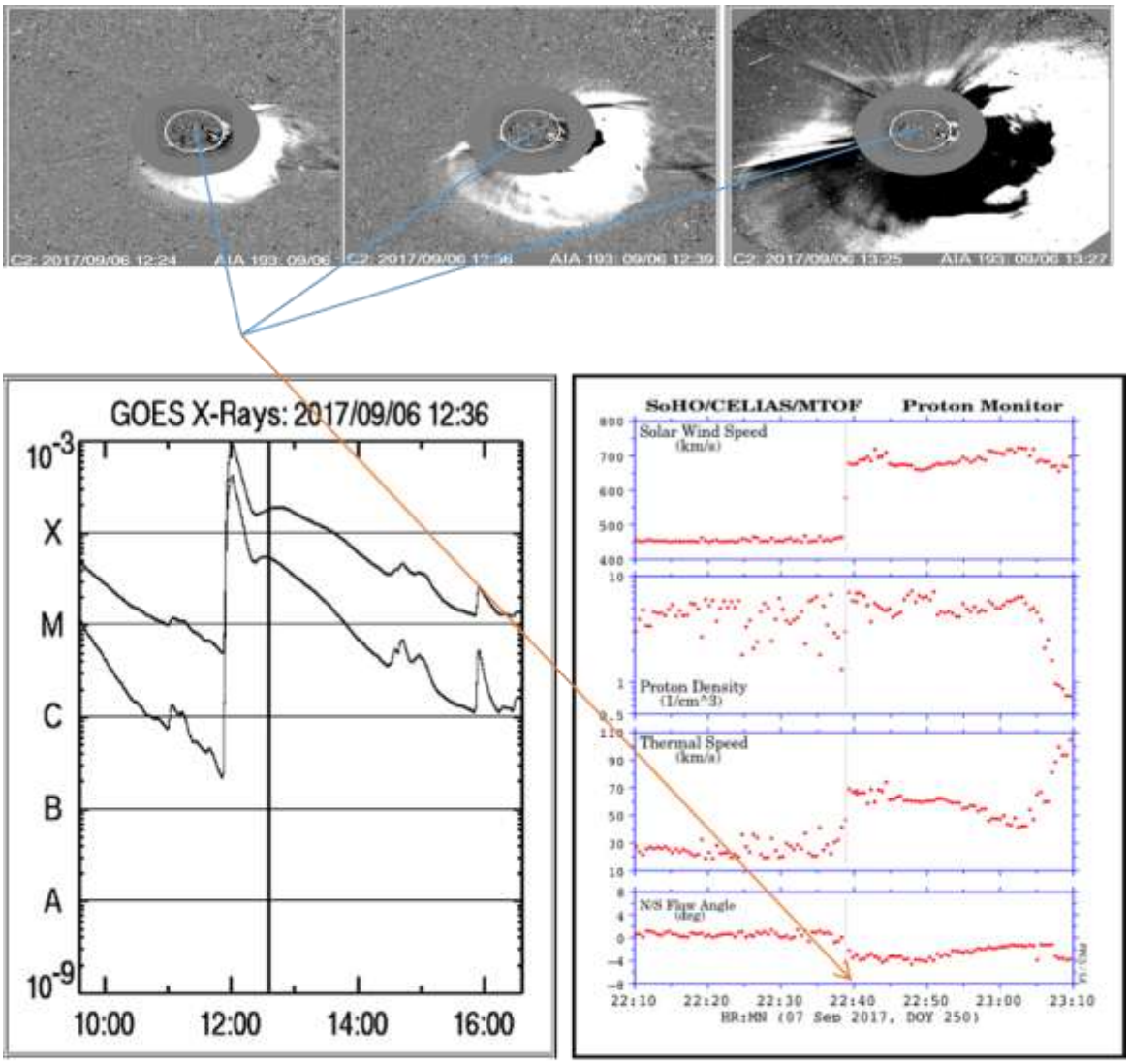

Fig. 3b: Shock waves caused by CME at 6th of September 2017 as detected from SOHO/CELIAS at arrival time 6th and 7th September. (upper panel) indicates the FC2AT of the CME detected by SOHO/LASCO. (middle left panel) The soft X-ray detected by GOES satellite for the associated flare. (middle right panel) CELIAS/MTOF registered shockwave arrival time and the end of injection. (bottom panel) aurora phenomena from space weather.

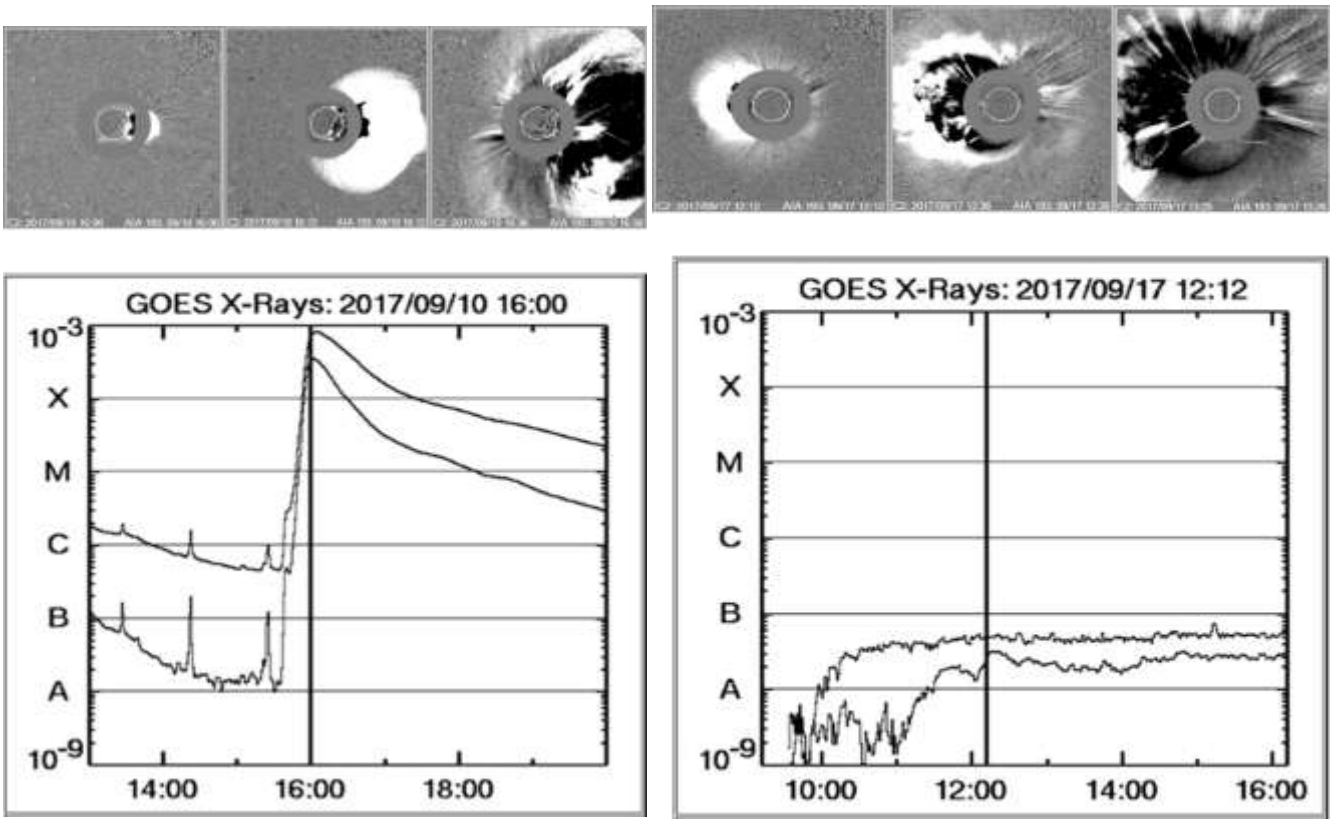

Fig. 4. Events without shock waves. Left side event 3, right side event 4. For both upper panel three shots of coronagraph from LASCO, bottom panel GOES x-ray density time profile.

The question now why there were just two shock waves on the 4th and 6th of September but not for the events 10th and 17th of September? even they have the same strength properties as halo class and fast linear speeds? We studied positions and sunspots regions, we found that three of these eruptions have west side during these eruptions, two of them have a shock wave. also, we pay intentions for acceleration we find that both of CMEs with shock waves they have 47.9 and -0.3 m/s^2 respectively, and CMEs without shock waves have deceleration -232 and-32.8 m/s^2. One can see for event 3 there has a strong CME with the western side toward the earth but it had very high deceleration that may be affected to not reach the earth. But in event 4 had eastern side of eruptions with deceleration.

While we can accumulate detailed information on the ICME, we cannot obtain a huge amount of accurate information about its origins (Howard 2011). Since we do not have certain information on the development from CME to ICME, one can only make general associations between them. For example, an ICME monitored near the earth with an insitu spacecraft can be matched with an earth-directed CME from a reasonable extrapolation based on the speeds of each, and ICME images can be matched for location and timing with their CME counterparts (Howard 2005&Cane 2003).

A tracking in distance from the sun till near the border of the magnetosphere of earth about 150 million Km is not possible yet, especially in white light. Thus, some studies took the advantage of radio emission tracking, then compare it to some models of electron density for Sun (Reiner 2007). The estimating between velocity and therefor acceleration was depending on this tracking, this comparison still needs for plane sky survey with such studies to estimate the difference in the (decelerated or accelerated). Still, the comparison needed for plane sky surveys with such studies in order to estimate the difference in the acceleration (Kocharov 2009).

The travel time determination depends on the clear association between Coronal mass ejection erupted at Sun and the arrival time of the shock passage at earth. During the solar minimum, CMEs erupt very rear, so one might find few CMEs eruptions simultaneously. On the other hand, uncertainty can be achieved for the association of interplanetary shock to coronal shock with multi solar eruptions unless very intensive analysis takes place with multi-monitoring points. Moreover, sometimes in one AR can occur two eruptions in the association,

such solar flare followed by a CME. In this case, it is very hard to know to which one eruption the shock wave belongs. If two AR at the sun in the same half of solar disc then it is also the same as the previous case. These difficulties and many more can only be determined with a low error limit, if we find a better way for fitting for the propagation proses for the CME from corona to IP and then earth.

Conclusion

We investigated 4 gradual SEP events and their associated shock waves and we found that:
All the characteristics of the shock acceleration (coronal and IP) in those 4 events were cleared with their radio emission association and the shocks should continue their acceleration for the SEPs all the way to Earth. The observation of two of those shocks was not found on the available installments. The suggestion that the mean free path of those shocks was getting larger until the shocks dissolved in the IP medium do not fit with the continual acceleration. We suggested that the IP magnetic has changed the direction of those shocks so they could not be detected by CELIAS/SOHO.

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