Determination of the MESEP Events of 2-9th April 2001 According to ERNE/SOHO Observation

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Abstract

On 2-9th April 2001 the Energetic and Relativistic Nuclei and Electron (ERNE) instrument on the Solar and Heliospheric Observatory (SOHO) observed three gradual solar energetic particle (SEP) events separated by 9 hour and 7days respectively, in association with three effective solar flares and coronal mass ejections (CMEs).

In this paper, a study of MESEP events was considered. As the definition of this phenomenon suggested there might be many sources for each MESEP event. This event has been examined in order to view the different sources that might relate to suspected accelerator of the SEPs. A careful analysis for the spectra and associated emission with such eruptions was made. Soft X-ray emission was observed by the Geostationary Operational Environment Satellite (GOES) was used to indicate the associated solar flares, earth radio stations were used to determine the associated radio emissions. While three instruments, beside (ERNE) were used from the SOHO satellite, the Large Angle Spectrometric Coronagraph (LASCO) to follow the CMEs, the Extreme-ultraviolet Imaging Telescope (EIT) for observing the Morton waves to indicate the CME location and the Charge, Element, and Isotope Analysis System CELIAS to indicate the shock waves caused by CMEs.

Keywords: acceleration particle-Sun, coronal mass ejections (CMEs), shock wave, Solar Energetic Particle SEP, Multi-Eruption Solar Energetic Particle (MESEP) events.

تحديد الاحداث الشمسية ذات الانفجارات المتعددة للحدث2-9.أبريل.2001 طبقا لرصد سوهو \ إيرنا

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الخلاصة :

في 2-9 أبريل 2001 لاحظ جهاز ERNE وهو احد الاجهزة المحمولة على المركبة الفضائية سوهو ثلاثة احداث نشطة لإنبعاث الجسيمات عالية الطاقة الشمسية (SEP) من النوع تدريجي ، مفصولة بمقدار 9 ساعات و7 ايام على التوالي، تكون مصاحبة الى 3 انفجارات فعالة (توهجات الشمسية ،ومقذوفات الكتل الاكليلية (CMEs)).

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في هذا البحث، تم التركيز على ظواهر الاحداث الشمسية متعددة الانفجارات. كما ان تعريف هذه الظاهرة اقترح بان قد تكون هناك مصادر عديدة لكل حدث شمسي متعدد الانفجارات، وقمنا بفحص كل حدث من أجل عرض المصادر المختلفة التي لها علاقة بكل تعجيل يشتبه في انتمائه الى احداث الشمسيه النشطه (SEPs). قمنا باجراء تحليلا دقيقا لاطياف والانبعاثات المرتبطه بهذه الانفجارات. انبعاث soft X-ray المرصود من قبل القمر الصناعي Geostationary Operational Environment Satellite (GOES)الذي يستخدم للدلاله على الانفجارات الشمسيه المرتبطه بها، واستخدمت المحطات الارضيه الراديويه لتحديد الانعاثات المرتبطه بها. بالاضافه الى استخدام جزء (ERNE) من القمر الصناعي سوهو تم استخدام ثلاث اجزاء اخرى منه،the Large Angle Spectrometric Coronagraph (LASCO) لتتبع مقذوفات الاكليليه الكتليه (CMEs)،(EIT) the Extreme-ultraviolet Imaging Telescope لرصد موجات مورتون للاشاره الى موقع CME واخيرا the Charge, Element, and Isotope Analysis System (CELIAS) للاشاره الى وجود موجات الصدمه الناتجه عن CME.

Introduction

A definition for the phenomenon of Multi-Eruption Solar Energetic Particle (MESEP) events has been introduced for the first time by Al Sawad et al.[1] as a combination of many SEP events each of which is associated with a single eruption can create one complex intensity-time profile that will result in masking the observation of the first injected particles detected near Earth for each participated eruption. The same study suggested that the investigations of the participation of each eruption (CME or flare) in injecting or accelerating particles are possibly accomplished if we use the Velocity Dispersion Analysis (VDA) and ^{4}He/P ratio.

A CME is a large eruption of plasma and magnetic field from the Sun. It can contain a mass larger than 10^{13} kg and may achieve a speed of several thousand kilometers per second. A typical CME has a mass of around 10^{11}–10^{12} kg and has a speed between 400 and 1,000 km/s. It also typically spans several tens of degrees of heliographic latitude (and probably longitude) [2].

Fast CMEs with velocity >500 km s^{-1} are expected to form bow shocks at ~3−5 solar radii from the Sun and the CME driven shocks in interplanetary space are thought to be a source of accelerated particles in the gradual SEP events. In front of the CME bow shock, in its upstream region, the accelerated protons may excite MHD waves to form a turbulent sheath. Within the turbulent sheath, with its fluctuating magnetic field components, the energetic particle scattering mean free path is small and the diffusive shock acceleration of the particles is rapid. Behind the bow shock, the shock downstream region is also turbulent. There the upstream turbulence is compressed and enhanced by the shock. At small values of the mean free path the particle diffusion through the sheath is slow and the shock can accelerate particles to high energies. Such a regime is typically assumed for the SEP-productive shocks. At large values of free path the shock turbulent sheath is transparent for SEPs and the diffusive shock acceleration is not significant [3].

In this paper, one energetic proton event has been selected from 268 SEP events from Al-Sawad (2007) [1] with intensities larger than $10^{-3}cm^{-2}sr^{-1}s^{-1}MeV^{-1}$ for the energy range (1-116) MeV, detected by Energetic and Relativistic Nuclei and Electrons (ERNE) onboard Solar and Heliospheric Observatory (SOHO) from 2-9th April 2001.

The energetic proton data has been used from the SOHO /ERNE particle instrument, which consists of two particle detectors, Low Energy Detector (LED) and High Energy Detector (HED). The identification of protons is based on an on-board algorithm, which provides intensities in the energy ranges (1.3-14) MeV for LED and (13-140) MeV for HED, with one minute time resolution as a maximum. The particle data is accessible through the ERNE Datafinder application, which can be found at [4]. Analysis procedure followed in this paper is based on the following:-

Firstly: for the proton events, the onset time has been determined for the first peak in the MESEP events, and then the injection time has been calculated for the first non-scattered proton traveling on the nominal path length of 1.2 AU from eq. (1).

$t_{in} = (t_o - t_f) + 8_{min}$…………..……………………..(1)

where:

t_o = The onset time at different energies which can be determined by eye and observed by the detectors.
t_{in} =The injection time; the time when particles release from the source.
t_f = Flight time of particles during flight from source to the detectors.
8 *min*= represent the time for the light to pass the distance from the Sun to Earth.
Secondly: the associated eruption on the Sun have been investigated to determine the numbers of CMEs related to those events, and the injection time of the first protons have been compared to the liftoff time on the SOHO/LASCO catalog webpage at [5] to determine the closest CMEs to those events. Taking into consideration CMEs with a linear velocity greater than 500 km/s, and angular width greater than 60˚.
Thirdly: the solar geophysical data report NGDC can be used to find out the associated solar flare observed by GOES, for the SXR classes of M, X and long duration C class flares and excluded the B type since the majority of it cannot produce SEPs with MeV energy level.
Fourthly: the solar geophysical data report can also be used to determine the associated spectral radio emission (type II, and type IV). The metric radio emission of the types II&IV are used as an indicator of shock wave formation in the corona. Thereafter, the interplanetary shock passage time have been investigated which is registered near the earth orbit by SOHO/ CELIAS.

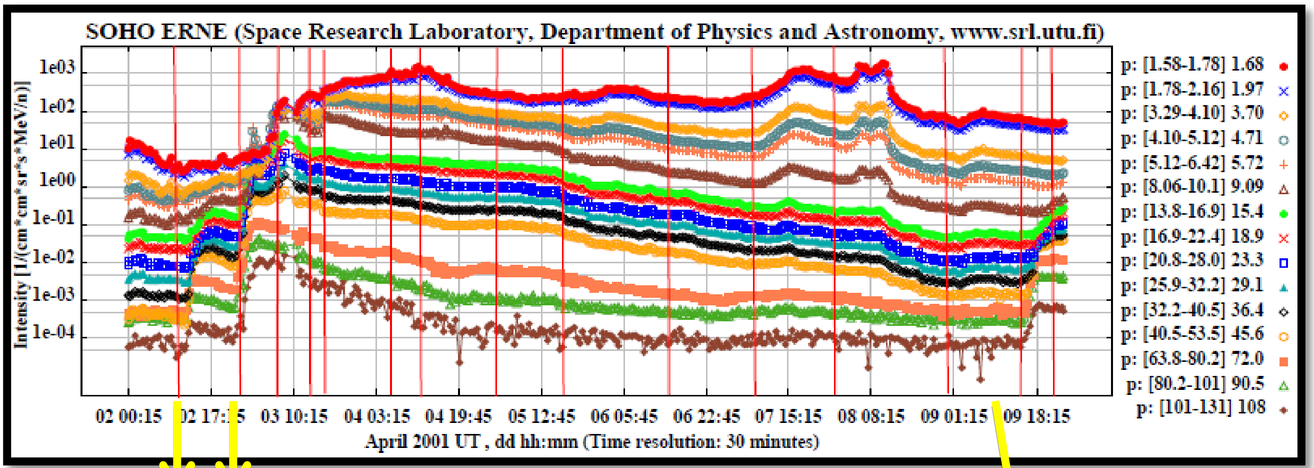
Data analysis

On 2–9th April 2001 the proton intensity onboard SOHO/ERNE rose on up to tens of MeV energy over the cosmic ray background in each event, indicating a clear SEP event that was related to eruptions at the Sun. The intensity– onset time of the channel 36.4 MeV was at 13:05 UT, and the injection time calculated was at 12:37 UT for the first non-scattered proton traveling on the nominal path length of 1.2 AU. The intensity time profile of this event has multi– eruption (means15 CMEs associated with 6 solar flares) peaks and by using ^{4}He/P ratio and VD measurement can be computed the number of effective eruptions. The effective eruptions for this event are computed 3CME and 3 flare and are shown in figure-1. The event could be explained as follows:

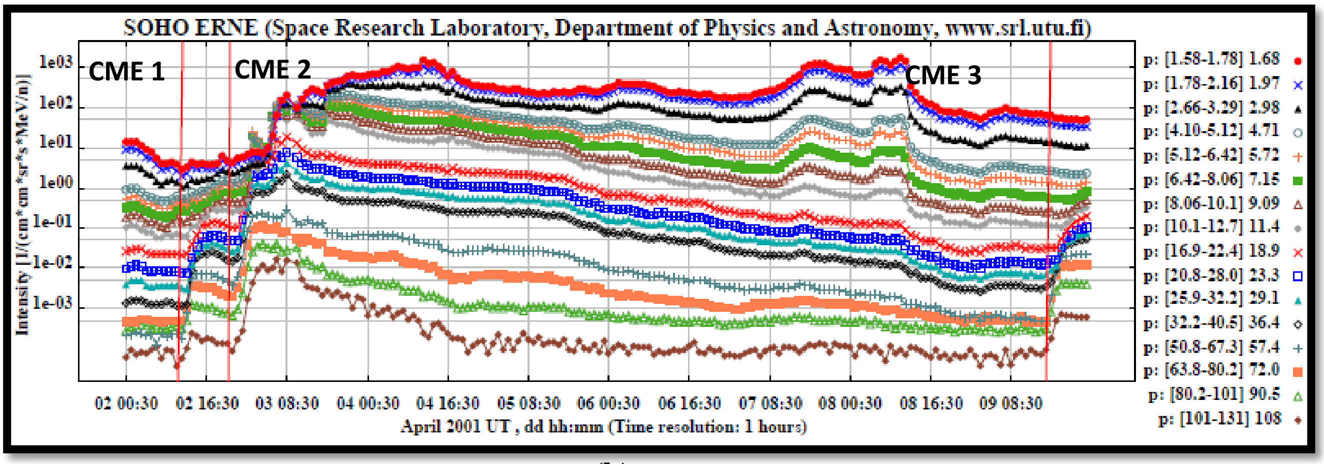
On April 2, GOES detected a solar flare1 of class X1.1with the SXR emission started at 10:58 UT, peaked at 11:36 UT and ended at 12:05UT lasting till 1:07 UT (considered as a gradual flare) with Hα location at N16W62 in NOAA active region 9393. Later, SOHO/LASCO observed a CME1 FC2AT at 12:50 UT at a heliocentric location 5.14$R_\odot$, calculation of the CME location at injection time was at 09:28$R_\odot$ with different position of solar flare1 NW from western hemisphere at 257˚ CPA, AW 155˚with linear velocity 731 km/s, and acceleration of 14.4 m/s^2. Then, spectral radio emission registered Type II burst started on 2nd April at 11:10-11:13 UT in association with solar flare1 and CME1 indicated a formation of shock wave. Type IV started at 11:05-11:19UT.

While the CME1was propagated in the interplanetary medium toward the Earth, at 22:06 UT After few hours on April 2, SOHO/LASCO observed another CME appeared on the southwest of the solar disc (CME 2), first seen at 5.92$R_\odot$ .a liftoff time for CME2 at 21:41 UT±2 min from western hemisphere at 261˚ CPA, AW 244˚ with linear velocity 2505km/s, and acceleration 108.5 m/s^2.
Also, GOES detected another gradual solar flare2 with different position of CME 2of class X20 with a SXR emission started at 21:32 UT, peaked at 21:51 UT and ended at 22:03 UT lasting 31 min with Hα location at N19W75 from NOAA AR 9393. Spectral radio emission registered Type II burst started at 21:49-21:52 UT in association with solar flare2 and CME2 indicated a formation of shock wave. Two days later, on April 4, SOHO /CELIAS/MTOF registered the interplanetary shock passage near the Earth orbit at 14:21UT. This shock was considered the origin of April 2 of CME2 and solar flare2 at 21:51UT with X20 SXR in AR 9393; travel time 40.5 hours.

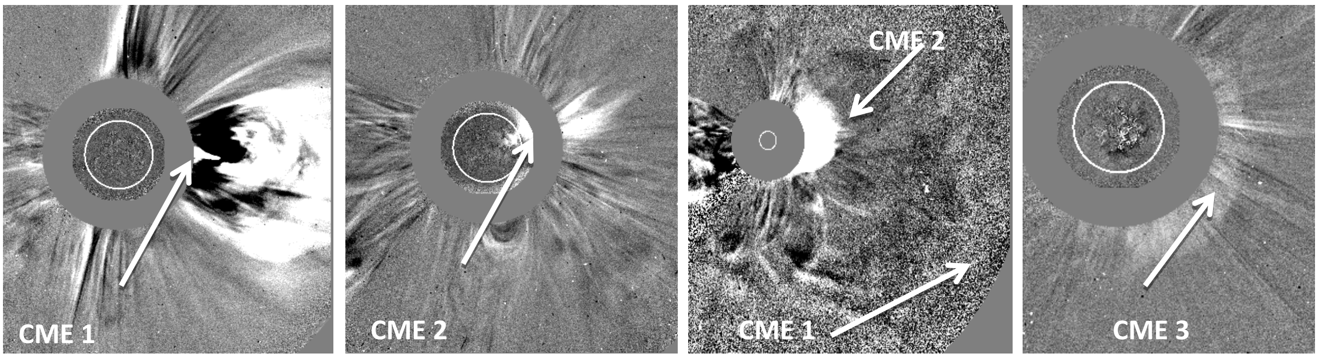
On April 9, GOES detected a gradual solar flare3 of class M7.9 with a SX R emission started at 15:20 UT, peaked at 15:34 UT and ended at 16:00 UT lasting 40 min with Hα location at S21W04 from NOAA AR 9415. After that, SOHO/LASCO observed a halo CME3 with symmetry (S) at 15:31 UT±1 min liftoff time from the same active region of the solar flare3 from western hemisphere with linear velocity 1192 km/s, and acceleration 1.3 m/s^2. Spectral radio emission registered Type II burst started at 15:25-15:28 UT in association with solar flare3 and CME3 indicated a formation of shock wave. To continue for a few minutes, type II accompanied by a more prolonged type IV burst started at 15:23-15:58UT.


SOHO ERNE (Space Research Laboratory, Department of Physics and Astronomy, www.srl.utu.fi)
Intensity [1/(cm*cm*sr*s*MeV/n)]
1e03
1e02
1e01
1e00
1e-01
1e-02
1e-03
1e-04
02 00:15
03 10:15
04 03:15
04 19:45
05 12:45
06 05:45
06 22:45
07 15:15
08 08:15
09 01:15
09 18:15
April 2001 UT , dd hh:mm (Time resolution: 30 minutes)
p: [1.58-1.78] 1.68
p: [1.78-2.16] 1.97
p: [3.29-4.10] 3.70
p: [4.10-5.12] 4.71
p: [5.12-6.42] 5.72
p: [8.06-10.1] 9.09
p: [13.8-16.9] 15.4
p: [16.9-22.4] 18.9
p: [20.8-28.0] 23.3
p: [25.9-32.2] 29.1
p: [32.2-40.5] 36.4
p: [40.5-53.5] 45.6
p: [63.8-80.2] 72.0
p: [80.2-101] 90.5
p: [101-131] 108

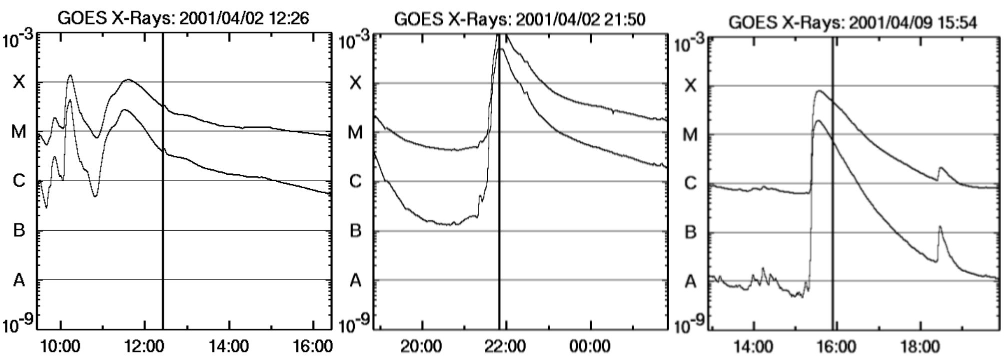
(a)


SOHO ERNE (Space Research Laboratory, Department of Physics and Astronomy, www.srl.utu.fi)
CME 1
CME 2
CME 3
Intensity [1/(cm*cm*sr*s*MeV/n)]
1e03
1e02
1e01
1e00
1e-01
1e-02
1e-03
02 00:30
02 16:30
03 08:30
04 00:30
04 16:30
05 08:30
06 00:30
06 16:30
07 08:30
08 00:30
08 16:30
09 08:30
April 2001 UT , dd hh:mm (Time resolution: 1 hours)
p: [1.58-1.78] 1.68
p: [1.78-2.16] 1.97
p: [2.66-3.29] 2.98
p: [4.10-5.12] 4.71
p: [5.12-6.42] 5.72
p: [6.42-8.06] 7.15
p: [8.06-10.1] 9.09
p: [10.1-12.7] 11.4
p: [16.9-22.4] 18.9
p: [20.8-28.0] 23.3
p: [25.9-32.2] 29.1
p: [32.2-40.5] 36.4
p: [50.8-67.3] 57.4
p: [63.8-80.2] 72.0
p: [80.2-101] 90.5
p: [101-131] 108

(b)


CME 1
CME 2
CME 2
CME 1
CME 3

(c)


GOES X-Rays: 2001/04/02 12:26
GOES X-Rays: 2001/04/02 21:50
GOES X-Rays: 2001/04/09 15:54
10^{-3}
X
M
C
B
A
10^{-9}
10:00
12:00
14:00
16:00
20:00
22:00
00:00
14:00
16:00
18:00

(d)

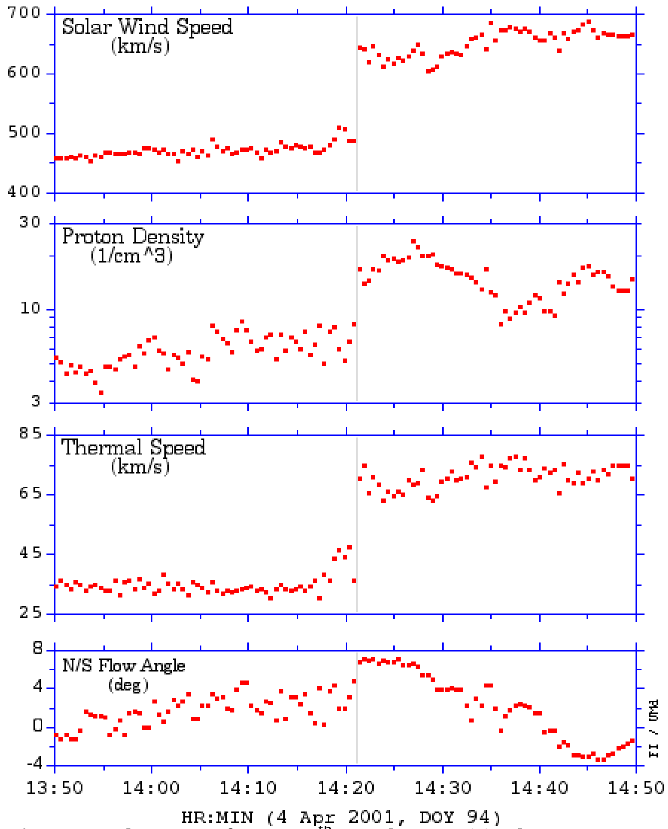


Figure 1-The event from 2-9th April 2001 (a) The intensity- time profile with 30 minute time resolution with 15 associated CME drawn in red line. (b) The intensity- time profile with one hour time resolution shows the 3 effective CME drawn in red line. (c) SOHO/LASCO difference images showing CME1 FC2AT at 12:50UT, primary CME2 FC2AT at 22:06 UT, The 22:18 UT image LASCO/C3 shows both the CMEs (CME1 & CME2) in a single frame and CME 3 FC2AT at 15:54UT. (d)From left to right indicate its soft X-ray detected by GOES, in respectively. (e) the shock wave registered by SOHO/CEILAS/MTOF at 14:21 UT.

Conclusion

The recent paradigm of the shock wave acceleration for the SEPs in the impulsive phase and continuing in the interplanetary medium especially in the gradual events has been challenged by many empirical approaches through many studies using careful analysis in the observation of the MESEP events. The SEP observed from behind previous CMEs (SEP from CME2 penetrating shock wave of CME1) is likely happened because the shock wave of the CME1 is decelerating. Our observation showed that the shock waves associated with the CMEs in the event of, were not able to accelerate protons over 20 MeV in the interplanetary medium and most probably that such protons penetrate the IP shock wave from behind which it strengthen the results suggested by previous studies. The VD analysis showed that both peaks associated with the multi-eruption were coming from a source on the Sun and not in the IP medium. Different ratios of ^{4}He/p in different peaks can be indicated different components; these ratios associated with clear VD can be indicated a new acceleration from a source of a different seed population which has fuller different tubes of the SEP accelerated by different eruptions.

References

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