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Solar Energetic Particle Events recorded aboard SOHO on December 24, 1996 and on May 6, 1998

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Abstract

The LION experiment on SOHO (which records protons from 44 keV-6 MeV and electrons from 44 keV-300 keV), and the energetically complementary EPHIN experiment (which measures protons + helium ions to >53 MeV/n and electrons to >5 MeV), each detected many energetic particle events (SEPs) in the early rising phase of Solar Cycle 23 (from ~ July 1996) – a period commonly associated with Coronal Mass Ejections (CMEs). The present paper contains an account of two representative rapid intensity increases recorded simultaneously by LION and EPHIN, each of which was accompanied by a CME and by impulsive type flaring. The SEPs have characteristics typical of both **Gradual** and I**mpulsive** events and may be described as '**Mixed'**.

1 Introduction:

During recent years our understanding of solar energetic particle events (SEPs) underwent a paradigm change (Reames, 1995). SEPs themselves are presently classified as ***Gradual*** (i.e. slowly rising) and ***Impulsive*** events. In the former case, energetic particles are accelerated at the point of intersection of the observer's magnetic field line with the distant shock surface associated with a Coronal Mass Ejection (CME). This point sweeps eastwards across the entire shock as a function of time as the observer progressively moves to new field lines because of solar rotation. Overall, ***Gradual Events*** are observed without latitude limitation. During impulsive flares**,** intense beams of electrons generate electromagnetic ion cyclotron (EMC) waves. These waves are resonantly absorbed by ^{3}He, as well as by heavy elements and, in these wave particle interactions, acceleration induced enhancements in the abundances of the elements concerned (e.g. Ne, Mg, Si and Fe). are produced In this case there is a direct magnetic connection between the source region and the observer and an ***Impulsive*** SEP is recorded. The two classes exhibit characteristic features in terms of time profiles, elemental composition and energy spectra.

Continuous observations made from aboard SOHO reveal that CMEs were quite frequent phenomena during the recent solar activity minimum and a rate of 0.8/day was found (Howard et al., 1997). The statistics of SEPs recorded during this period reveal the presence during practically all of these events, including those classified as ***Impulsive***, of CMEs (Bothmer et al., 1997). CME related events can be differentiated according to the speed and direction of propagation of the mass ejection. Further, while most SEPs are accompanied by west limb CMEs, 'fast halo' CMEs are usually associated with long ***Gradual*** energetic particle enhancements. Many SEPs are observed to occur near sector boundaries of the interplanetary magnetic field and are thus thought to be related to CMEs produced at the base of coronal streamers.

In the present paper two particle events are discussed, each of which was associated with a CME – as revealed by concomitant energetic particle and optical observations made aboard SOHO, complemented by

Solar Wind measurements made aboard WIND. Both were spatially and temporally associated with impulsive type flaring.

2 Instrumentation and data analysis:

The SOHO spacecraft was launched in December 1995 and, since March 1996, it has monitored the Sun continuously from its Halo Orbit around the L1 Lagrangian point (if we disregard the well known break in Summer 1998). The SOHO scientific payload includes 3 instruments designed to measure fluxes of energetic particles. Relevant here are LION and EPHIN, which form the COSTEP complex (Comprehensive Supra Thermal and Energetic Particle Analyser , Müller-Mellin et al., 1995).

The LION instrument consists of two, twin detector (D1/D2), solid state telescopes. Each pair of front detectors views an entrance aperture of 60 x 40 deg. T1 measures ions and electrons while T2 employs a deflection magnet to sweep away electrons up to about 300 keV. The measured energy spectra are in the range from 44 keV to 6 MeV for ions and from 44 keV to 300 keV for electrons. Detectors D1 and D2 in both telescopes have average look directions of 33^{c} and 57° respectively from the sunward direction in the ecliptic plane . The geometric factor is 0.35 cm^2 sr, (see McKenna-Lawlor et al., 1997). Count rates are recorded in 8 energy channels for both electrons and ions with a time resolution of 15 s.

The EPHIN sensor constitutes a multi-element stack of 6 silicon detectors, surrounded by a plastic scintillator, which provides an anti-coincidence shield. With a geometric factor of 5.0 cm^{2}sr , EPHIN can detect protons and helium nuclei in the energy range 4.3-53 MeV/n, as well as electrons between 0.25 and 10 MeV. The particles are identified using the dE/dx vs. E method.

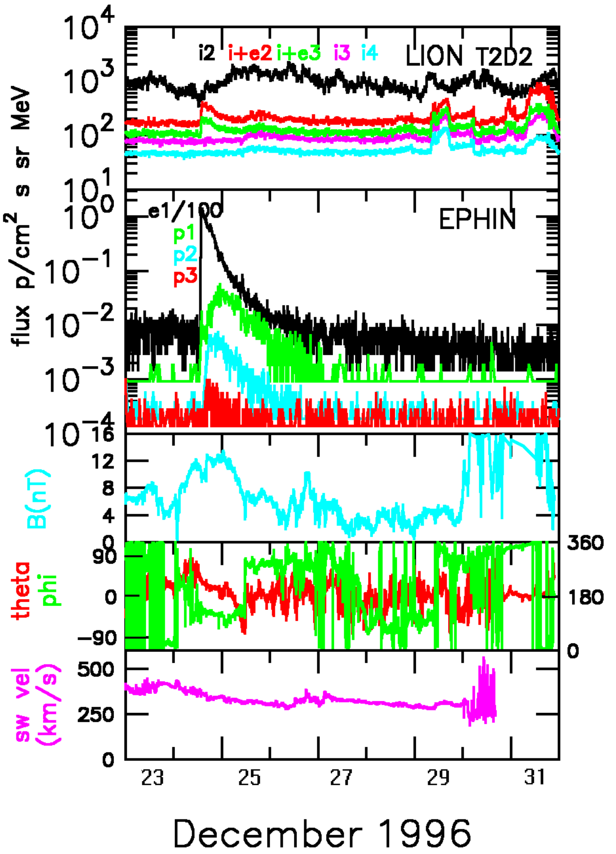

Figure 1: Time profiles of LION ions (82-120-180-310 keV), ions+electrons (82-120-180 keV), EPHIN electrons 0.25-0.7 MeV and protons (4-8-25-41 MeV); B, ϵ, ς, and solar wind velocity from WIND for the period of December 23-31, 1996.

3 The 24 December 1996 event:

After a quiet period in December 1996, a relatively large solar particle event occurred on December 24, 1996 (designated Event I). Preceded by a small particle increase about 15 hours earlier, Event 1 started as 300 keV electrons arrived at 1326 UT at SOHO (see Fig. 1) in association with a class C2.1 X-ray flare which took place between 1303-1323 UT with maximum intensity at 1311 UT - according to the observations of the GOES-7 spacecraft (see Bothmer et al., 1997). A Type II radio burst was recorded at 1309 UT.

Fig. 1 presents the time profiles of LION low-energy particle fluxes in 5 energy channels and of EPHIN high energy electrons and protons, together with Solar Wind and magnetic field measurements from the SWE and MFI instruments aboard WIND. The average positions of SOHO and WIND were, in GSE coordinates (1.59,-0.37,-0.05)$\times 10^6$ km and (0.4,0.2,-0.05) $\times 10^6$ km, respectively i.e. WIND was outside the terrestrial Bow Shock.

The electron fluxes reached peak values at around 1420 UT, and attained a factor of 300 above the background. This event was recorded in all the proton channels of EPHIN, in the LION electron data, as well as at >300 keV in the LION ion channels. Practically no increase was found in the helium data.

Abrupt changes in the azimuthal angle of the interplanetary magnetic field on 22-23 December from inward to outward polarity and back at around 1100 UT on December 25th, indicates that WIND was close to a sector boundary. Moreover, the crossing of two magnetic field tubes can be identified. The SEP event can be inferred to have occurred inside a magnetic cloud. A CME which was associated with the particle event was observed on the west limb of the Sun at around 1358 UT. It had a speed of about 290 km/s and its position angle was 264 deg. During the evolution of this event, only a slight acceleration was observed. At the speed measured, the CME was expected to hit the Earth (or SOHO and WIND) on December 30. Indeed, the arrival of a large magnetic structure can be recognized in WIND/MFI magnetograms from 23 UT on December 29 (corresponding to a speed of about 320 km/s). A large increase in Solar Wind speed was recorded some 3 hours later and also a slow variation in the azimuthal angle of B. Minor increases in low energy proton counts are visible in LION profiles recorded on December 30th and these are interpreted to reflect the occurrence of a small energetic storm particle event.

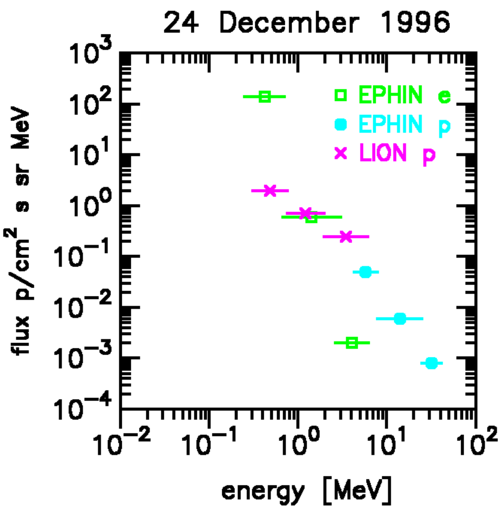

Figure 2: Proton and electron energy spectra of the December 24, 1996 SEP.

Fig. 2 provides a composite energy spectrum of EPHIN protons and electrons and of LION T2D1 ions, based on the maxima of the time profiles associated with this SEP. The two proton spectra match relatively well. However, the low energy slope is less steep. Low energy protons can be seen above the background at >300 keV. The spectral index deduced for protons above 2 MeV is -2.55. The energy spectrum of EPHIN electrons is much softer, the best approximating power function providing a slope of -4.8.

4 The 6 May 1998 event:

This particle event designated Event II was associated with X-ray activity between 0606 and 0745 UT on May 6, 1998, culminating in an X2.7 flare between 0758 and 0820 UT, main phase: 0809 UT (according to GOES-7 observations). The flare which was of importance 1N at S11, W65, was well connected magnetically to the Earth (the footpoint of IMF lines is extrapolated to about W43 based on the solar wind speed of ~530 km/s). Detector C2 of the LASCO experiment recorded a CME at 0804 UT at position angle 311 ^{c} i.e. at the northern part of the west limb. The calculated velocity was very high (1053 km/s). The CCDs of

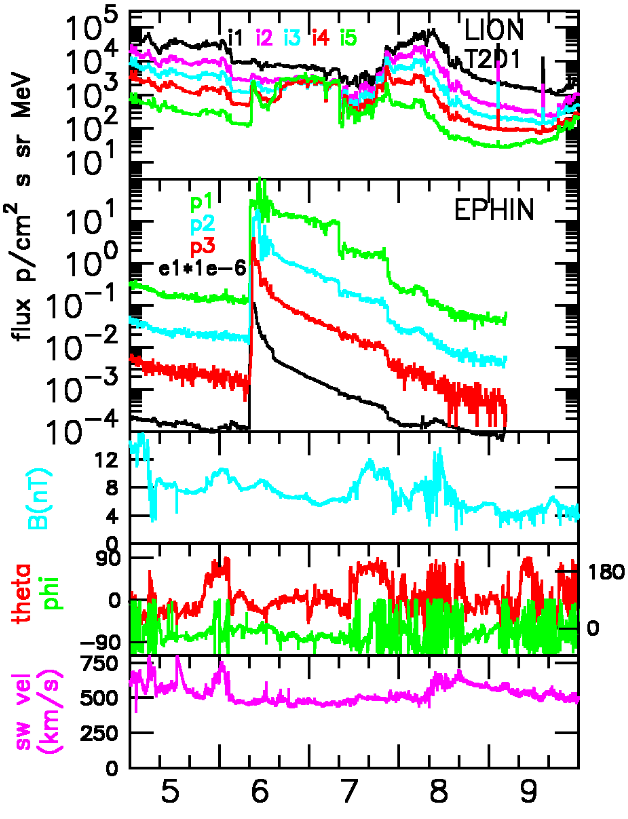

Figure 3: Variation of energetic particle (LION ions: 44-750 keV in 5 intervals) and solar wind parameters during the May 6, 1998 event

LASCO and EIT registered a proton snowstorm at that time. A part of this CME may have hit the Earth late on May 8 as can be inferred from an increase in B. (An earlier increase on May 7th was probably caused by an earlier CME). The average positions of SOHO and WIND were (1.62, 0.40, 0.06) 10^6 km and (1.35, 0.6, 0.18) 10^6 km respectively (in GSE coordinates).

The particle event started at around 0811 UT when the intensity of electrons recorded by EPHIN started to increase, attaining a peak at around 0835 UT (Fig. 3). Sudden large increases were present in all the proton channels of EPHIN, as well as in the electron and high energy proton records (above ~ 100 keV) of LION. The CME that hit SOHO seems to have been associated with an interplanetary shock which caused the increase recorded by LION in ambient particle intensities at ~1600 UT on May 7th. On the other hand, the magnetic field profiles clearly exhibit two distinct increases, one before and one after this time, suggesting that this was not a single *in situ* event as probably two different magnetic clouds passed the Earth, giving rise to two distinct shock related events as seen in the LION profiles.

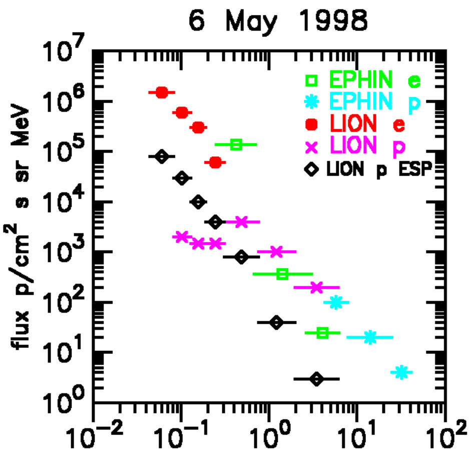

Figure 4: Energy spectra of protons and electrons (SEP), and of protons for the energetic storm particle event.

The differential energy spectra of protons and electrons based on the peak fluxes are shown in Fig. 4. The proton spectra of LION and EPHIN match even better than was the case during Event I. The slopes are coincident with γ = -1.7 (taking only points above 300 keV into account). The electron spectra are much harder than during the December 1996 event, with an index of -2.8. The spectrum of energetic storm particles also closely fit a power-law, with slope -2.6.

5 Discussion:

The two solar energetic particle events presented are seemingly not clearly classified as ***Impulsive*** or ***Gradual,*** but rather constitute 'Mixed' events, although Event I is closer to a Gradual type, while Event II has more Impulsive features. The impulsive characteristics include, in each case, proton increases of duration about two days and impulsive X-ray enhancements. Gradual features include a He/H ratio of 40 to 50 for Event II measured by EPHIN (no He increase accompanied Event I) and a Type II radio burst during Event I. The e/p ratio was near 1 for Event I and between 10 and 20 for Event II. The differential energy spectra of protons are relatively hard in both cases with spectral indices of –2.55 and -1.7. Both events were accompanied by west-limb CMEs, however, seemingly due to a different direction of propagation, the energetic storm particles events at their passage were quite different: Event I was accompanied by little shock acceleration, while Event II was associated with a large ESP increase.

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References

Bothmer, V. et al. 1997, Proc. 31st ESLAB Symposium, ESA SP-415, 207
Howard, R.A. et al. 1997, in: "Coronal Mass Ejections", Geophys. Mon. 99, 17
McKenna-Lawlor, S. et al. 1997, Ann. Geophys. 15, 1
Müller-Mellin, R. et al. 1995, Solar Physics 162, 483
Reames, 1995, Revs. Geophys. Suppl. 33, 585.