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Analysis of proton flux directionalities in four solar events detected by SOHO/ERNE

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Abstract. This work presents a study of the temporal development of directional proton intensities in four different solar events observed by SOHO/ERNE. ERNE/HED detects protons in energy range 12-100 MeV with 1 degree angular resolution. The studied events are divided into two types, depending on the rate of the initial intensity increase. In events that started on 16 June, 1998 and 3 May, 1999 the intensity rise was rather gradual, and in the ones on 24 April and 27 May, 1999, the flux enhancement took place in a relatively short time. We compare the time development of directionality in these different event types, especially in their rise phases.

1 Introduction

In this work we take a look at the directional structure of the flux of 16-20 MeV protons in four different solar events observed by ERNE (Energetic and Relativistic Nuclei and Electrons), one of the twelve scientific experiments on board SOHO (Solar and Heliospheric Observatory). Two of these events had a very rapid rise of intensity, and in the other two, the rise was more gradual. These four particular events were chosen for the analysis, because they were amongst the most intensive representatives of the two types. They also were temporally close to one another, three of them took place in a period of a bit more than one month. The objective of this work was to try to compare the characteristics of these two different event types, and see how the directional fluxes develop in these two types of events.

The High Energy Detector (HED) of ERNE consists of eight detector layers. The incident particle direction is determined by the four top-most ones, two pairs of $70mm \times 70mm$ silicon strip detectors. The strips are 1 mm wide, and in both pairs the detectors have their strips perpendicular to each other. With this configuration the particle trajectory can be determined with an accuracy of 1°. The geometric acceptance in the $120^\circ \times 120^\circ$ view cone is 25-36 cm^2sr depending on the particle energy, which ranges from 12-100 MeV/N. The detector axis is fixed to point towards the nominal direction of the interplanetary magnetic field, GSE polar latitude and longitude are 0° and 315°, respectively. A more complete description of the instrument is given by Torsti et al. (1995) .

The quantity named directionality (D) is a measure of anisotropy present in the flux. Under isotropic circumstances, D∼0. The higher the value, the more beamlike the detected flux is. Negative sign of directionality would mean particle streaming from the anti-solar direction.

2 Directionality analysis

Under assumption of isotropic scattering, the directional flux intensity can be written in as an exponential function of the pitch angle cosine

$$I(\theta) = a \times exp(b \times cos\theta). \qquad (1)$$

The parameter b describes the strength of particle flux anisotropy. This model is a simplification of model presented by Beeck and Wibberenz (1986). The simplification is justified by Monte-Carlo simulations by Vainio (1998).

Directionality is defined as

$$D = sgn(b)(exp|b| - 1), \qquad (2)$$

where the anisotropy parameter is obtained by fitting to the form of the detected directional distribution.

In our analysis the measurement of directional intensities in 240 directional elements within the HED view cone is used. Four minute data are integrated to ∼30 minutes to achieve sufficient statistics. In the analysis, we determined the value of D in 83 different directions in the hemisphere around the ERNE axis. The direction that gave the highest absolute value for directionality is assumed to be parallel to the magnetic field, and the D-value in question is called extreme directionality.

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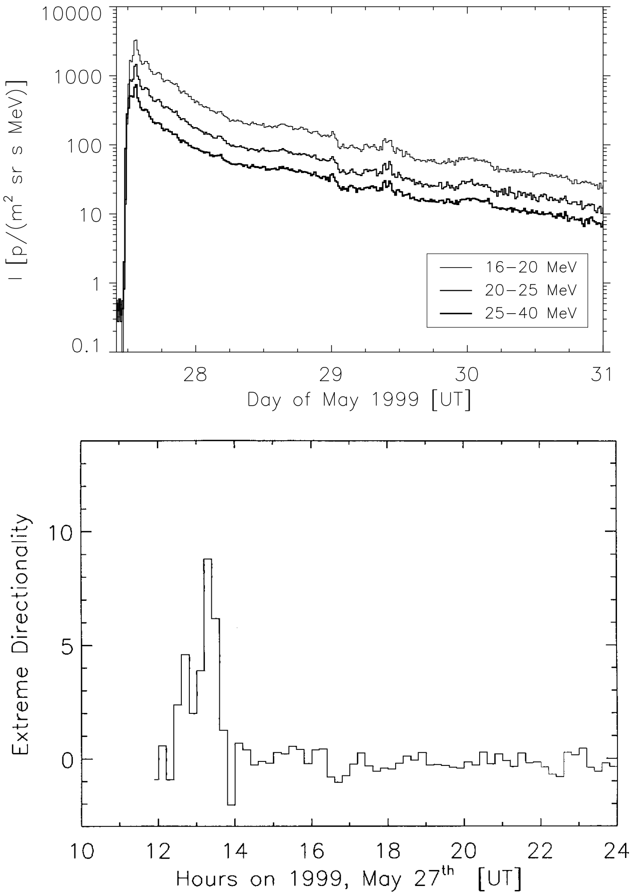

Fig. 1. The ERNE/HED intensity profile (*upper panel*) in three different energy channels and the development of flux directionality (*lower panel*) during 14 hours in the beginning of the May 27th, 1999 solar event.

3 Events with impulsive rise

3.1 Event of 1999 May 27

At 11:06 UT on May 27th, 1999, LASCO detected structured halo CME. It was brightest in the West, originating from the back side of the sun. [LASCO CME list on www]

In figure 1, ERNE/HED measurements from the period of event onset are presented. The upper panel displays the time development of intensity in three energy channels, 16-20 MeV, 20-25 MeV and 25-40 MeV. The lower panel shows extreme directionality during the same time interval.

The intensities started a rapid rise in all channels about half an hour after the LASCO CME observation. In about an hour the intensities had reached their maximum level. Very strong anisotropy was detected just before both of the two peaks in intensity (12:30 UT and 13:05 UT). In two hours the directionality had descended back to level of isotropy.

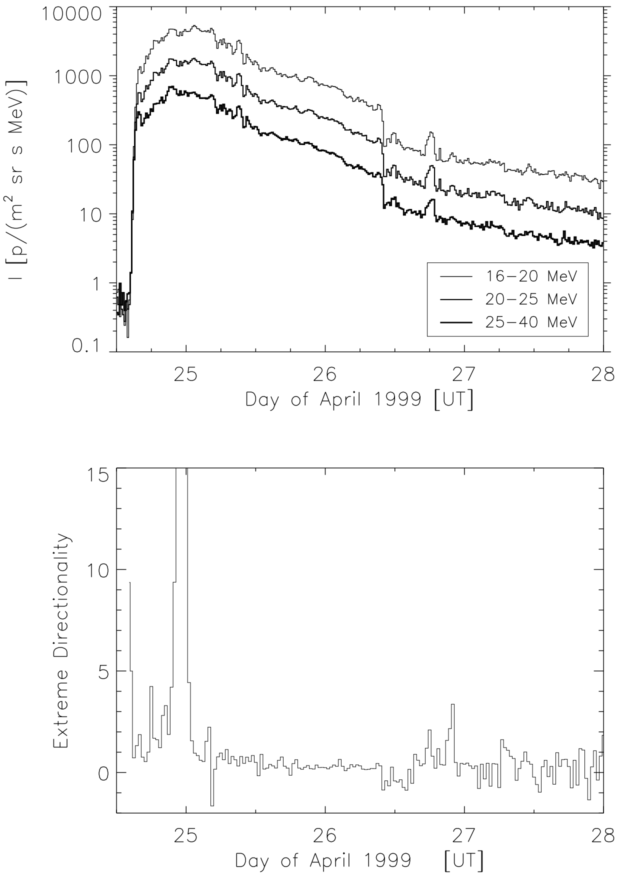

Fig. 2. The intensity profile (*upper panel*) in three energy channels and the development of flux directionality (*lower panel*) during the onset of April 24th, 1999 solar eruption.

3.2 Event of 1999 April 24

Another impulsive event was that of April 24th, 1999. At 13:31, LASCO registered the onset of a halo CME. The event, which was first visible in the West, and later extended all around the occulter, was determined to be a backside event [LASCO]. This assumption is supported by the fact, that no optical or x-ray flares were detected on the disk at that time [Solar-Geophysical Data (SGD)].

As can be seen in figure 2, the ERNE/HED count rates started to rise very rapidly after 14 UT on that day. Again, maximum intensity was reached in less than two hours. Strong anisotropy is detected for one hour associated with the initial rise. Strongest anisotropy is detected between 22-24 UT, associated with rise to event maximum intensity. The flux fades back to state of isotropy within an hour after the peak.

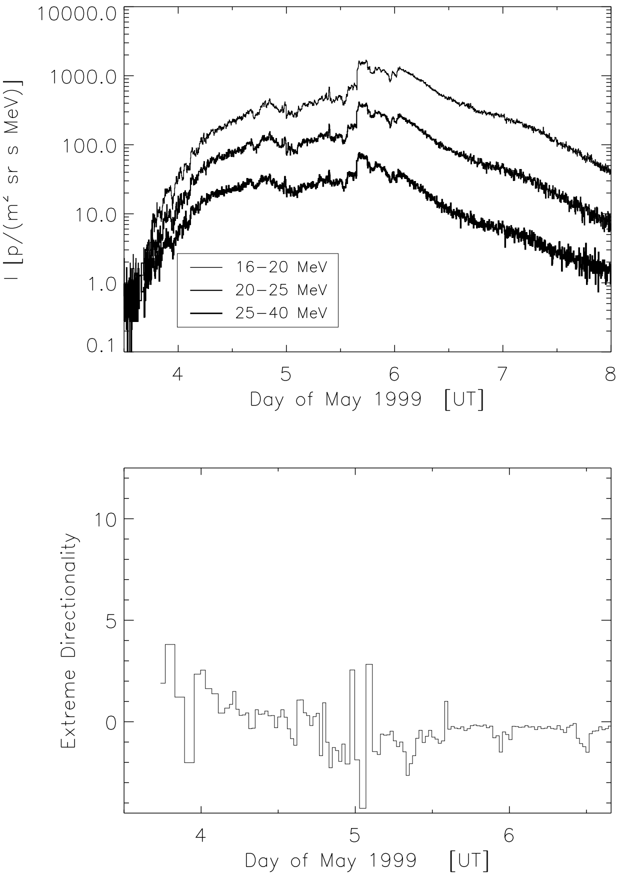

Fig. 3. The intensity profile (*upper panel*) in three energy channels and the development of flux directionality (*lower panel*) during the 1999 May 3^{rd} solar eruption.

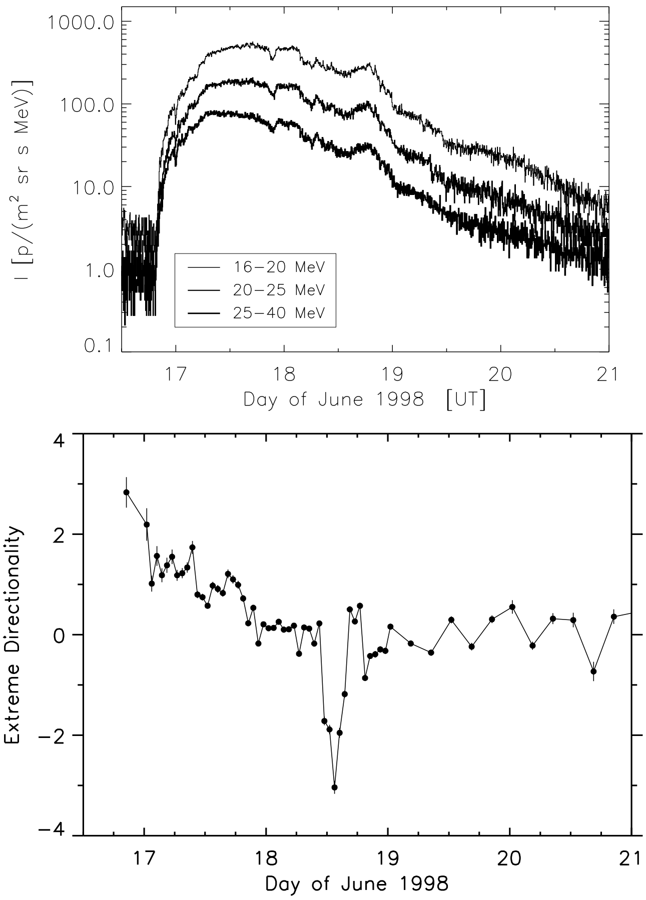

Fig. 4. The ERNE/HED intensity profile (*upper panel*) in three energy channels and the directionality (*lower panel*) during the June 16^{th}, 1998 solar event.

4 Events with gradual rise phase

4.1 Event of 1999 May 3

On May 2^{nd}, 1999, two CMEs were detected by LASCO in the NE region. The first one started at 15:50, and at 19:26 another CME followed a similar trajectory [LASCO]. These eruptions are the most likely source of the particle event that ERNE detected the following day.

ERNE intensities shown in figure 3 started to rise very slowly around 16 UT on May 3. The increase was extremely gradual: maximum intensity in the 16-20 MeV proton channel was reached in about 48 hours after the onset. The statistics during the first eight hours or so are below the level of reliability for purposes of our analysis, and thus the degree of anisotropy associated with the event onset can not be quantitatively determined. After sufficient count rate has been achieved around the beginning of May 4^{th}, the directionality can be seen to decrease steadily from 2.7 to 0 in nine hours. But based on that steady descend, and the first few points in the directionality graph, one can only state that probably some directionality was present also during the first eight hours. Thus declining anisotropy would have been present in the event particle flux for the first 17 hours.

4.2 Event of 1998 June 16

On June 16^{th}, 1998, LASCO detected a fast (1650 km/s) CME at PA=326° at 18:27 UT. It was $252°$ wide, strongest in the West, faint in the North East. [LASCO] Associated with the CME, GOES observed a long duration (85 min) M1.0 class X-ray flare with maximum at 18:42 UT [SGD]. The first enhancement in the proton flux at ERNE was detected $\sim$ 19:30 UT. The rise to 70% of maximum intensity lasted for about 12 hours.

Some weak anisotropy is detected associated with the onset of the event as expected. The directionality decays to isotropy rather slowly, in about 20 hours. As seen in figure 4, about 39 hours after the onset, another period of anisotropy is detected. This time the directionality is negative, meaning that the particle beam is directed towards the sun. The anisotropy is followed by a 100% increase in intensity a few hours later.

This second anisotropic period is most probably caused by an interplanetary effect, not a second injection, as there is no change in the proton spectrum. The timing of the effect, anisotropization and intensity increase all point towards the possibility of a shock passing the spacecraft at that time, although no shock associated with this event has been reported by other instruments.

5 Summary

Four solar energetic particle events were studied. Two of these had a rapid intensity rise, and in the other two, the flux enhancement was more gradual. In all the events, periods of high directionality were usually followed by a corresponding increase in the intensity.

Stronger directionality was associated with the impulsive type events. The two impulsive events were recorded by LASCO as backside events. Thus in these events, where intensity increase is more rapid, the active areas on the sun have a direct magnetic connection to the spacecraft, and the initial beam-like structure is more pronounced than in events with gradual intensity rise. In case the gradual rise is a result of the origin being on the East limb, the weaker anisotropy associated with these events may be caused by that magnetic connection between the spacecraft and the injection site on the takes place some time after the onset of the event, during which the flux usually is most anisotropic.

The duration of anisotropic periods was clearly longer in the gradual rise -type of events. The times for the initial directionality to fade out in the two cases of that kind were 17 and 20 hours. In events with rapid intensity rise, the anisotropic periods were less than five hours in duration.

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