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Anisotropy Observations by ERNE/LED

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Abstract.

The Low Energy Detector (LED) of Energetic and Relativistic Nuclei and Electrons (ERNE) experiment onboard Solar and Heliospheric Observatory (SOHO) spacecraft consists of two detector layers. The upper detector layer consists of seven different windows, D11-D17 with a common lower layer D2. The middle window D17 is parallel with D2 and the other six windows are tilted by 16º from it into directions separated by 60º from the adjacent. In conditions, when the interplanetary magnetic field (IMF) direction is close to the nominal direction of ERNE, and not fluctuating strongly, LED is able to make rough anisotropy measurements. In this paper, the proton anisotropy measurements by LED during the early phases of July 9, 1996 solar energetic particle (SEP) event in the energy range 3-6 MeV are presented. The results show that the proton flux is becoming isotropic slower in these energies than in the energy range 14-35 MeV, where more accurate anisotropy measurements are made by High Energy Detector (HED) of ERNE.

1 Introduction:

The directional anisotropy measurements of energetic particles have traditionally been done by instruments onboard rotating spacecraft. By dividing the rotation period into subperiods, it has been possible to reach information of particle intensities in directional sectors typically 45°-60° wide. In the case of a three-axis stabilized spacecraft, such as SOHO, the instrument itself must be able to detect the direction, from which a particle penetrates into the detector. Instruments like ERNE/HED, which are based on strip detector technology, had improved the accuracy of anisotropy measurements, reaching ~1° accuracy of directional information of a particle. ERNE/LED is a much more simple detector, but as it consists of seven detector windows tilted into different directions, the structure of it makes it possible to make rough anisotropy measurements. The purpose of this paper is to study the ability and limitations of LED anisotropy measurements. The data from the early phases of SEP event on July 9, 1996 is used to demonstrate these properties of LED.

2 The Instrument:

The ERNE/LED instrument consists of seven front detectors D11-17 with a common lower detector D2. The middle window D17 is parallel with D2 and the other six windows are tilted by 16º from it into directions separated by 60º from the adjacent. While the half angle of each window is 16º, together they provide a view cone with a half angle of ~32º. When the anisotropy distribution is assumed to be symmetrical with the maximum at the direction of IMF, and the parameters for this distribution (see below and Sahla and Torsti, 1999) are measured by ERNE/HED, this provides us possibility to make rough estimations of development of anisotropy in low vs. high energies, despite of the small separation between the pitch angles of different windows of LED. The complete description of both detectors of ERNE is given by Torsti, et al. (1995).

3 The Method:

In order to measure anisotropy by ERNE/HED, an analysis method to compensate the dependence of the geometric factor of HED on three dimensional direction in the view cone, have been developed. The view cone is divided into 240 small solid angle elements in such a manner that in isotropic conditions the number of particles detected in each element is roughly equal. The element separation is made for ten different penetration angle rings, each of which is divided into 24 sections, each of 15° wide. The intensity is measured in each of them in 40 logarithmically divided energy ranges between 14 and 35 MeV as a compromise between reasonable statistics and an energy range, which is narrow enough to avoid too strong fluctuations in anisotropy parameters due to the fact that development of anisotropy is velocity dependent. The observed pitch angle distributions are fitted with using an assumption of symmetric anisotropy distribution:

$$I(\mu) = b_0 \exp(b_1 \mu), \qquad (1)$$

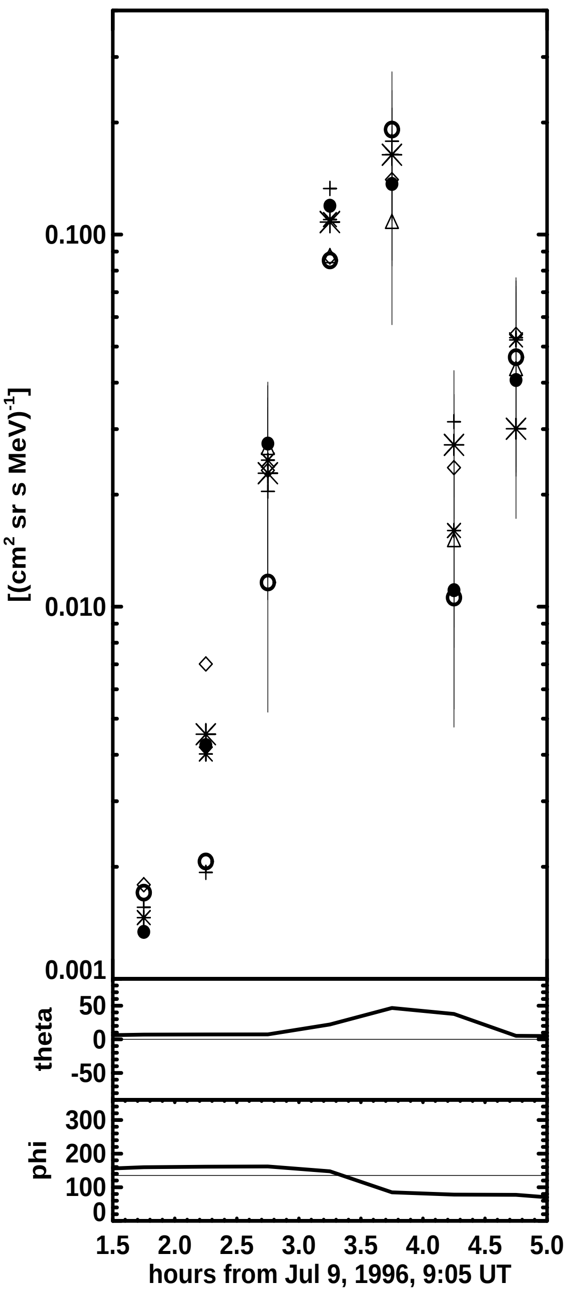
where $I(\mu)$ is the intensity in protons/(cm^2 sr s MeV), μ is the particle pitch angle (i. e. angle between the particle velocity vector and the IMF) cosine, b_0 and b_1 are fitting parameters. For a complete description of anisotropy measurements by HED see Sahla and Torsti (1999). The interplanetary magnetic field (IMF) direction is obtained from the measurements of Magnetic Field Investigation (MFI) instrument onboard WIND spacecraft. The spatial distance between SOHO and WIND spacecraft is taken into account as a temporal difference. The achieved anisotropy distribution as a function of pitch angle is then compared with the intensities measured by the seven detectors of LED.

4 Results:

The anisotropy studies by ERNE/LED were started during the studies on Earth-directed coronal mass ejections (CMEs) on April 7 and May 12, 1997 (Torsti, et al., 1998; Anttila et al., 1998). During the CME of April 7, 1997, the IMF direction was far away from the nominal direction of ERNE and fluctuating strongly, therefore the error limits of anisotropy measurements of HED were large, and observations by LED laid within them. During the early phases of the CME on May 12, 1997 the IMF direction laid stably within the ERNE view cone, and observations showed some evidence of different anisotropy development in low vs. high energies, but in order to find more satisfactory results, the SEP event on July 9, 1996, during which the directional SEP distributions showed strongest anisotropy during the SOHO flight (Torsti, et al., 1997), was studied.

During the early phases of the July 9, 1996 event, the IMF was directed well within the view cone of ERNE, but the particle fluxes were rather low, and therefore the statistical errors of the fitting method of Sahla and Torsti (1999) were for the most of the time very high. This can be seen from Fig. 1, where the 30-minute averaged proton intensities in seven detectors of LED, corrected by anisotropy distribution acquired from the Eq. 1, in the energy range 3-6 MeV are shown during the period 10:35-14:05 UT. The intensities are calculated as averaged intensities over the whole sphere by assuming that the distribution of the HED anisotropy measurements is also valid in LED energies. The error bars represent the error as a sum of the error of anisotropy fitting method and statistical error of LED count rates. In order to keep the figure more comfortable to watch, the error bars have been left off, when the error is greater than the intensity itself, as is the case during three of the seven 30-min periods.

The July 9 event was characterized with fast intensity increase (with onset at the Sun at ~9:05 UT) due to extremely long mean free path (MFP) of protons (more than 1 AU, Torsti, et al., 1997). At ~12:50 UT the SOHO spacecraft entered into an IMF flux tube, where the MFP was much shorter (and simultaneously particle intensities decreased strongly as seen in Fig. 1). Therefore only the periods before 12:50 UT are of interest for this study, because it is clear that during the periods of weak anisotropy, the LED instrument cannot detect directional distributions because of its limited view cone. The most interesting period was 11:35-12:05 UT (i. e. the third data point in Fig. 1). Fig. 2 shows the intensities measured by LED detectors



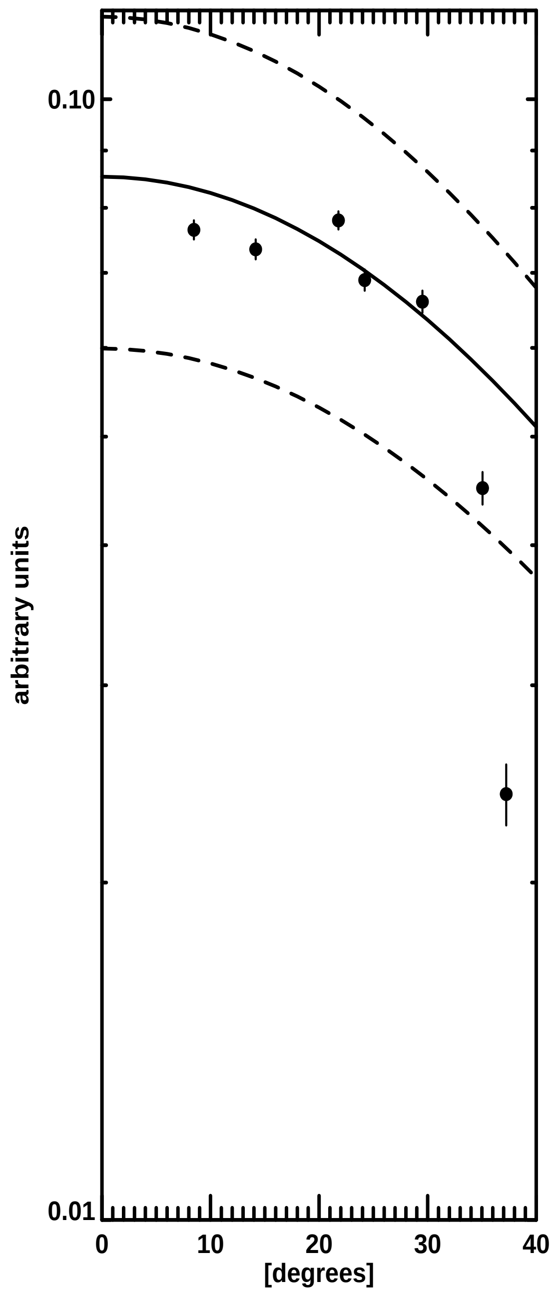


Figure 1 (left)**:** 3-6 MeV Proton intensities measured by seven LED detectors (uppermost panel); D11 (cross), D12 (small asterisk), D13 (large asterisk), D14 (diamond), D15 (triangle), D16 (open circle) and D17 (filled circle). IMF θ in GSE coordinates (middle panel, thick line) shown with ERNE nominal direction (thin line). IMF φ in GSE coordinates (lowest panel, thick line) shown with ERNE nominal direction (thin line). For more detailed explanations, see text.

Figure 2 (right)**:** 3-6 MeV Proton intensities (filled circles) measured by seven LED detectors as a function of angular distance between a detector and the IMF direction. The error bars correspond the statistical 1 σ limits. Also shown are proton anisotropy distribution fit (solid line) in 14-35 MeV channel and its 1 σ error limits (dashed lines). For more detailed explanations, see text.

during that period as a function of angular distance from the IMF direction. The solid line shows the fit from the HED anisotropy observations for Eq. 1 normalized to LED intensities, and the dashed lines are the 1 σ error limits for that fit. For angles <30° HED and LED observations seem to fit with each other, but the two detectors with angles >30° lay below the intensities assumed in the case that anisotropy distribution is similar in 3-6 as in 14-35 MeV energies. This is a sign that anisotropy is stronger in low energies, which is expectant, if the anisotropy depends on particle velocity. When compared to Monte Carlo simulated anisotropy distributions (Torsti, et al., 1996), it is clear that the proton MFP is more than 0.5 AU. As a scientific result this is not very valuable, but purpose of this paper was to show that, at least in ideal conditions (i. e. strong anisotropy and IMF direction close to the nominal direction of ERNE), the LED detector is capable of detecting anisotropy. In the future, it is possible to study anisotropy distributions as a function of energy by ERNE also in low energies, which is more than was expected before the launch, and is a certificate of high quality of the instrument.

5. Conclusions:

The proton anisotropy distributions during the early phases of the July 9, 1996 SEP event have been studied by ERNE/LED. The observations show that anisotropy is stronger in 3-6 than in 14-35 MeV energies, as was expected. The main result of this paper is that also ERNE/LED is capable to measure anisotropy, at least in ideal conditions. This is more than was expected for the detector before the flight, and gives in the future an opportunity to study the energy dependence of anisotropy distributions.

Acknowledgments

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