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SOHO/ERNE measurement of directional proton intensities during the coronal mass ejections in April and May 1997

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Abstract

On April 7 and May 12, Earth directed coronal mass ejections were observed by the Large Angle Spectroscopic Coronagraph (LASCO) on board SOHO. Both CME's were associated with a long lasting flux of protons above 10 MeV detected by the Energetic and Relativistic Nuclei and Electron experiment (ERNE). In this work we give an analysis on how the flux anisotropy of protons ejected from the interplanetary CME develops during its journey from Sun to 0.99 AU distance. After the passage of the shock the low statistics of the proton flux allows us only give a tentative estimation on the flux directionality.

1 Introduction:

In this work we present the analysis of the ERNE/HED (High Energy Detector) observations on the development of proton intensities in energy range 16-40 MeV during the April and May events in 1997. The HED view cone with axis fixed along the direction of the nominal Archimedean magnetic field line (GSE polar latitude and longitude are 0^0 and 315^0, respectively) limits the total spread of the detected pitch angle range typically from 0^0 to about 90^0. We show that during the May event protons arrive as a narrow beam, indicating that they had been transported coherently during the first 60-120 minutes. Instead no coherent transport can be distinguished during the April event, where the particles arrive as a quite wide beam from the very beginning.

2 Observations:

The large and wide HED view cone facilitates measurements on the development of intensities of particles injected from the Sun. The geometric factor of HED varies from 25 to 46 cm^2 sr depending on the particle energy. The width of the square-shaped view cone is 120º×120º. The geometric acceptance has its maximum in the direction of the view cone axis, and decreases with the increase of the incident angle. This variation in the geometric acceptance has been taken into account in the analysis. The three-axis stabilized SOHO spacecraft presents a new way to measure 3-dimensional intensities of energetic particles compared to the previous measurements, which, as far as we know, have been based on observations with detectors on spinning platforms. The threshold energy of anisotropy measurements in HED is 14 MeV/nucleon for protons and helium, somewhat higher than the energy of lowest detectable energy for particles arriving vertically e.g. 12 MeV/nucleon.

Figure 1 shows 15-minute intensity profiles of protons during the CME events in April and May 1997. The passage of the shock as observed by the CELIAS/Proton Monitor is shown in figures as dotted vertical lines. In both cases the maximum proton intensities in the lowest energy channel, 16-25 MeV, are about the same, 200-300 p/(m^2 s sr MeV). The profiles are broad around the maximum, and decay slowly. According to Reames (1994) the flat profile of the low energy particles is a typical signature of large gradual events, produced by CMEs near the central meridian.

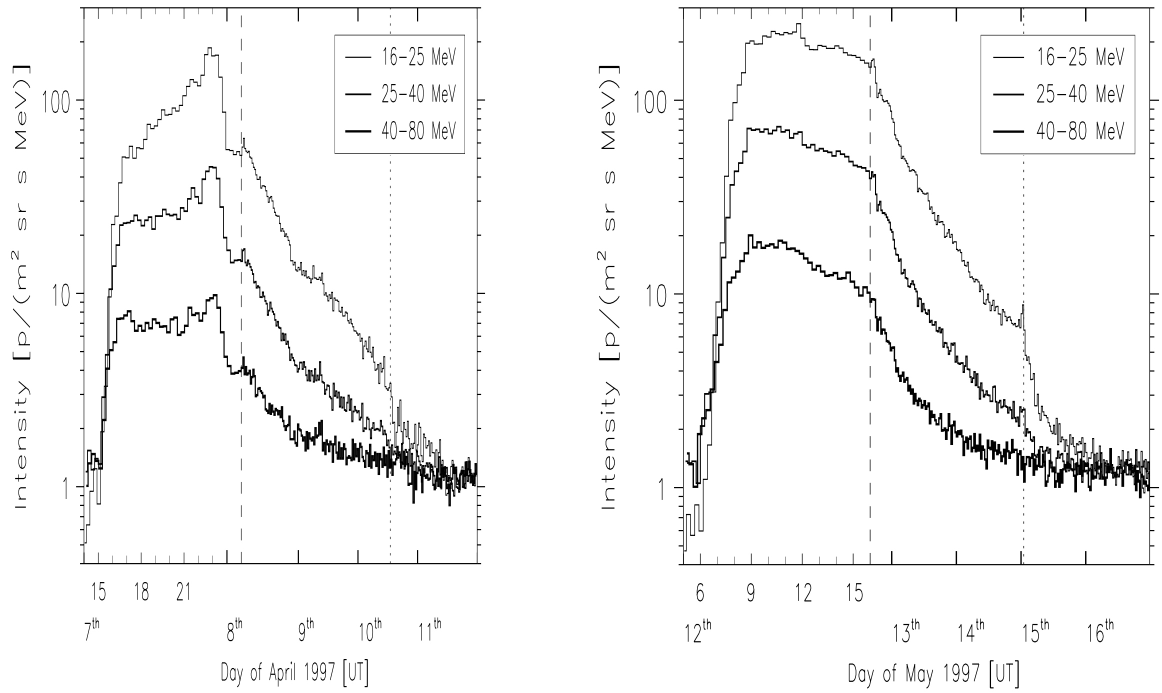

Figure 1: Proton intensity profile measurements by ERNE/HED of the energetic particle events in April and May, 1997, in three energy channels. The dashed vertical lines separate the rise phases from the whole event periods. The rise phases are shown in more accurate time scale.

The first 10 hours, our periods of the study of the directional proton intensities, are shown in Figure 1 in a broadened time scale for both events. The energy range of the directional intensity analysis extends from 14 to 35 MeV. 15-minute observations were used to get the directional intensity profiles with respect to the average of the magnetic field of the MFI instrument on board WIND. The magnetic field measurements were shifted in time to match the separation of the SOHO and WIND spacecraft. The typical number of protons during this analysis per 15 minutes was about 500-1000, which allows fitting of the directional intensity distribution with reasonable accuracy, especially during the presence of strong flux anisotropy. Because it is expected that during the initial rise phase of the proton event the flux anisotropy is high, we used tight pitch angle division close to the maximum intensity direction.

Figure 2 shows the development of anisotropy. Each anisotropy distribution represents an 1-hour average of four 15-minute subdistributions. These subdistributions consist of ±0.5 hour gliding averages. Thus some correlation between neighboring time spans exists, but the adopted presentation makes it easier to see the structures. The reference direction is the WIND/MFI magnetic field measurement shifted by -37 min for April and by -45 min for May event, to account for the spatial separation of the SOHO and WIND spacecraft.

We determined the best fits of the observed directional intensities to the theoretical distribution of the form

$$\mathbf{I(\cos\alpha) = a\cdot\exp(b\cdot\cos\alpha).}$$

We found that mediocre anisotropy existed for quite a long time after the onset, i.e. from 10 UT until 16 UT. There were, however, large fluctuations in certain short time intervals, with b close to 0 (distribution almost isotropic). The reason for the fluctuation is not clear to us and needs further study. Possible sources of the fluctuation might be the statistics, rapid fluctuation of the local magnetic field, or change in transport interplanetary transport conditions.

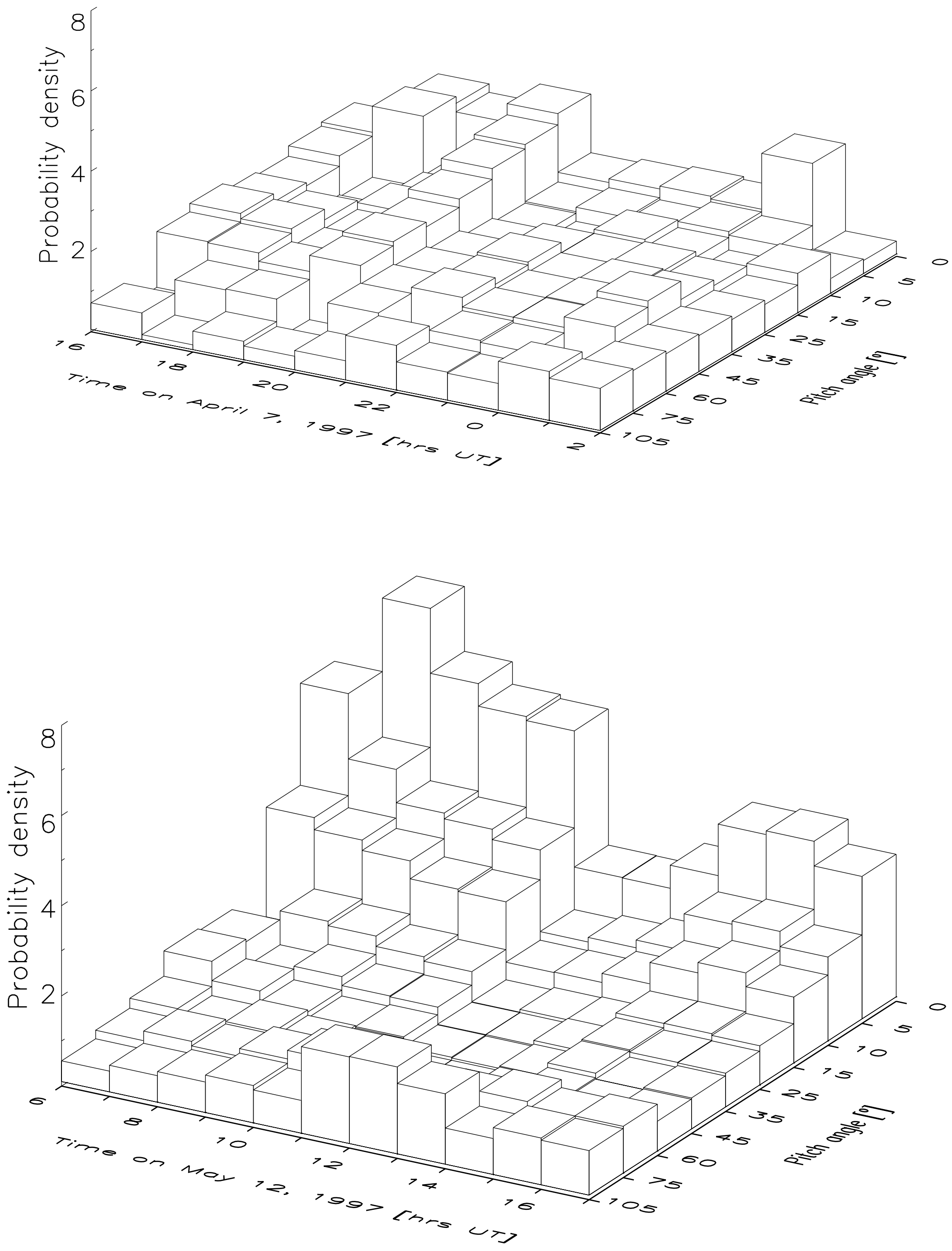

Figure 2: Development of time profiles of proton directional intensities with respect to the magnetic field direction measured by WIND/MFI. The energy range of protons is from 14 to 35 MeV.

3 Discussion:

The most obvious feature in anisotropy profiles in fig. 2 is the strong anisotropy in the beginning of the May 12 event. Detected proton flux is dominated by a narrow beam of particles for about 4 hours. The half width of the beam is 15-25^0. At 11-12 UT, the narrow peak disappears. The flow is still dominated by particles traveling along the field line to anti-solar direction. During the following 6 hours the intensity stays clearly anisotropic. The passing particle beam is, however, broad, but not yet isotropic. After about 12 hours the angular distribution becomes almost isotropic. The statistics does not allow to dismiss the assumption of the isotropization e.g. constancy in the figure presentation (=1).

The first enhancement of protons took place during 0600-0615 UT. These particles might belong to a precursor population dominating the particle flux enhancement until about 0700 UT, before the main rise of the intensity profile (Torsti et al 1998). Recently Van Allen (1998) reported on a detailed analysis of eight impulsive solar electron events, based on observations of Mariner V and II. In these events the electron signatures exhibit a two-phase structure: an early scatter-free peak of duration of < 20 min and a subsequent main phase. Van Allen mentions that the guiding centers of such electrons are scattered in random directions by kinks of radii less or of the order of 150 km. In the case of 20 MeV protons, the size of scattering kinks would be 1000 times larger, i.e. ≈0.001 AU.

Evenson and Meyer found large anisotropies in the flux of protons in the 1978 September 23 solar event (N35,W50). The proton energies were between 32 and 150 MeV. Several hours after the onset, the anisotropy nearly disappeared in a timescale of minutes. The distribution was distantly bimodal. The initial pulse resembled a gaussian with a σ 1 h, the latter flat-topped region had a timescale of ≈10 hours. These characteristcs apply quite well to the 1997 May 12 event.

4 Conclusions:

During the May event the first protons in energy range 16-40 MeV arrived as a narrow beam. The half-width of the beam was of the order of 15º-25º. Their transport from Sun to Earth distance was almost scatter-free, and thus they were first messengers of the solar injection process. The anisotropy development as shown in figure 2 indicates that the directional distribution from 7 UT onward still contains a narrow forward peak, though the arrival of the angular spread of the major phase is much wider. Our analysis of the April event did not reveal the presence of a coherent particle propagation. We are not able to claim that a coherent particle transport during the beginning of event did not exist because the narrow beam of the coherent peak might have located outside the ERNE view cone.

Acknowledgements

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References

Evenson, P., Meyer, P., 1979, 16th ICRC 5, vol 5, 211.

Reames, D.V., 1994, Third SOHO Workshop: Solar Dynamic Phenomena and Solar Wind Consequences, Estes Park, CO, September 16-30.

Torsti, J., Anttila, A., Kocharov, L., et al., 1998, Geophys. Res. Lett. 25, 2525.

Van Allen, J.A., 1998, J. Geophys. Res. 103, 29,665.