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Development of directional flux anisotropy during the solar event on June 16, 1998

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Abstract
In the analysis of the proton event observed by energetic particle telescope ERNE onboard the SOHO spacecraft during 16-21 June, 1998, we found two phases of strong anisotropy in the directional intensities of protons in energy range 16-40 MeV. The first one was during the beginning of the event, and the other about 39 hours from the event onset. The anisotropy at the latter time was stronger than anytime during the major 10-hour plateau type intensity phase. The ratio of intensities in two pitch angle ranges I(0-25º)/ I(60-90º) was ≈1.4, during 10-15 UT. The anisotropy was followed by average intensity enhancement which was roughly about 100 % higher than the intensity decay level of the major peak.

1 Introduction:

The solar particle event on June 16, 1998, was one of the largest ever since the launch of the Solar and Heliospheric Observatory SOHO, an international co-operation project between ESA and NASA. The event was associated with coronal mass ejection on the west limb. The major characteristics of the ejection were registered by the Large Angle Spectroscopic Coronagraph (LASCO) on board SOHO as follows: The first appearance in the C2 camera was at 18:27 UT. The central position angle (PA), angular width, and primary speed were respectively 3260, 2520, and 1650 km/s. Associated with the coronal mass ejection was a M1.0 class X-ray flare, with maximum at 18:42 UT, and of long duration, 85 minutes from start to the end. The first enhancement of the proton flux at SOHO [(252,-74,-16) R_e in GSE], was measured by the telescope HED of ERNE in energy range 25-40 MeV at 19:30 UT. The respective travel time from Sun is about 35 minutes. Therefore it is quite possible that the CME shock might have injected the observed particles right from the beginning. Kahler (1994) analyzed SEP injection profiles and found that the peak in the injection profile of protons at high energies occurs when the CME height reaches 5-15 R_{sun}.

The energetic particle telescope ERNE, one of the twelve scientific instruments on board SOHO, registered an intensity profile of typical shape: 10-hour rise phase, broad 20-hour maximum phase, and a smooth, 3-4 day decay phase measured by the High Energy Detector HED of ERNE. The size of HED view cone is 120° x 120°. This wide view cone enables the analysis of the variation of directional intensity with accuracy of a few degrees. In this work we give results on proton directional intensity analysis. This analysis became feasible after installation of new analysis software in the ERNE on-board computer in December 1997.

2 Intensity time profiles of protons:

The intensity profiles of protons are shown in three energy channels in Figure 1. The maximum intensity in energy channel 16-25 MeV is ≈400 p/m^2 s sr MeV. The intensity increase towards the maximum is slow. In energy channel 16-25 MeV it takes 10 hours to reach 70 % from the maximum, which occurs at 7 UT on June 17. The profile of the maximum is quite broad. The intensity stays above the 70 % level for about 20 hours, until 3 UT on June 18. The decay phase is long, lasting at least 4 days, and is cut by a new event rise on June 22. Thus the duration of the event in channel 16-25 MeV is six days. The maximum energy channel, 40-80 MeV, shows enhancement for about two days, from late hours on June 16 until the end of June 18.

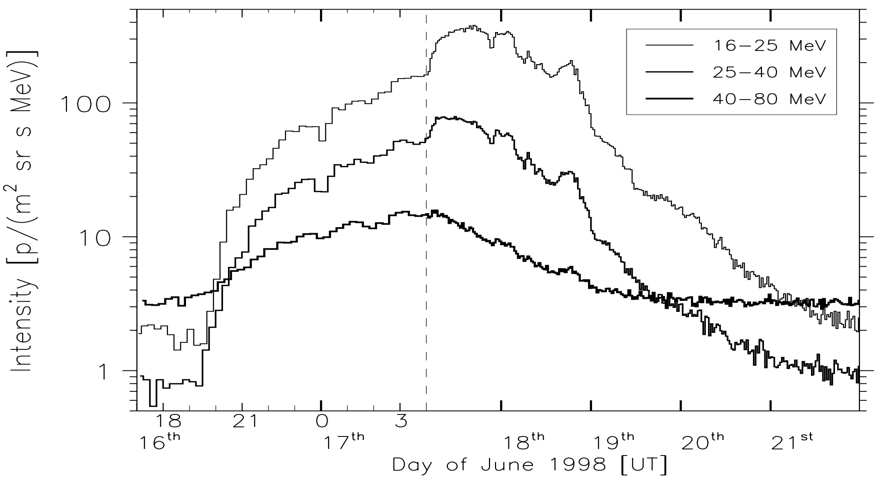

Figure 1. Proton intensity profile measurements by ERNE/HED in three energy channels of the energetic particle event in June, 1997. The vertical line separates the rise phase from the whole event period. The rise phase is shown in more accurate time scale.

In our analysis we separate three phases according to the general behavior of the intensity profile of the 16-40 MeV proton channel,

- rise phase A; phase, which extends from the observation of first intensity enhancement of protons until the intensity has risen about to 70 % level from the maximum, 19 UT June 16 - 7 UT June 17;
- maximum phase B; when the intensity is at least 70 % from the maximum, 7 UT June 17 - 3 UT June 18, and
- decay phase C; until the intensity has dropped to level of about 2 % from the event maximum, 22 UT June 18 - 12 UT June 20. At the end of the period the intensity is still above the background by a factor of 3.

In addition we pay attention to whether a few major fluctuations in the intensity are associated with changes in anisotropy.

3 Analysis of particle flux directionality:

We updated the ERNE On-Board scientific software in December, 1997, with an analysis program which counts the number of protons in 240 small solid angles in the HED view cone. The integration time is constant, 4 minutes, and does not depend on the magnitude of the intensity. The directional intensities are registered in three energy ranges for protons, i.e. 15.9-20, 20-25.2, and 25.2-40 MeV. The HED view cone is divided in 10 rings in the θ-direction from the sensor axis, and in 24 sectors in φ-direction. The objective in the selection of small solid angle bins was to find such division that the counting rates would be roughly equal in all bins under isotropic flux conditions. Because the proton intensity is measured in each of these 240 bins, the deviations counting rates from equality thus reveals a situation where the directional proton intensities are anisotropic.

In the present analysis we combine all three energy channels of the OB proton directionality measurements to one combined channel from 15.9 to 40 MeV. In addition, to increase the statistics further we combine four successive time spans, for a 16-minute counting rate. During the maximum intensity phase B the total HED counting rate of the 15.9-40 MeV protons in a 16-minute bin is about 12 000. Thus the average counting rate per one solid angle bin was thus about 50, reasonably high for a tentative directional analysis.

In the analysis we define the maximum intensity direction from the flux directionality:

$$\max_{\hat{s}} d(\hat{s}) = \frac{\sum_i \operatorname{sgn}\theta_i \left(f_i^{obs} - f_i^{iso} \right) \left|\cos\theta_i\right| \Delta\Omega_i}{\sum_i f_i^{iso} \Delta\Omega_i}$$

where f_i^{obs} and f_i^{iso} are the observed and theoretical counting rates, respectively. Theoretical counting rate is calculated from the total observed counting rate, assuming strict isotropy. The optimum direction is the one that gives maximum directional intensity. $\Delta\Omega_i$ is a solid angle element in the sensor view cone and θ_i represents the angle between the flux directionality and direction of the solid angle. Factor sgn shows the point where the directional profiles of f_i^{obs} and f_i^{iso} intersect, = 1 (-1) respectively for $\theta_i < \theta_c$ showing that $f_i^{obs} > f_i^{iso}$ (for $\theta_i > \theta_c$ when $f_i^{obs} < f_i^{iso}$).

Figure 2 shows the average 1-hour directionality during 16-19 June, 1998. The directionality is largest, about 4-6 %, in the beginning of the event. From 22 UT on June 16 onwards the directionality is low, of the order of 2 %. It becomes stronger during the second half of June 17, and reaches the maximum value, 8 %, at noon of June 18. This anisotropy maximum is connected to the maximum intensity prevailing in the intensity profiles in Figure 1.

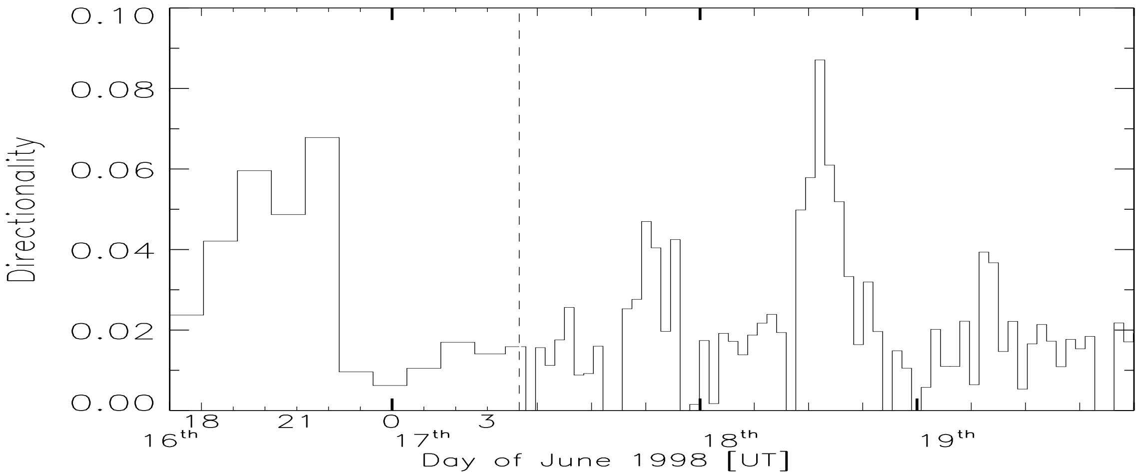

Figure 2: Average 1-hour directionality of energetic protons in energy range 16-40 MeV during the 1998 June 19 event.

In figure 3 we show the directional distribution during the period of maximum directionality. The anisotropy is strong. The angular width of the maximum intensity is about 20-30^0. The maximum intensity is about 40 % higher than the intensity in the angular range 60-100^0 from the maximum direction.

4 Discussion and conclusions:

The anisotropy is significant but not large during the broad intensity maximum phase B. The obvious reason for this is that the direction of maximum intensity is at the edge or outside the ERNE view cone. This observational result indicates that the flux directionality calculated in the sensor view cone far from the

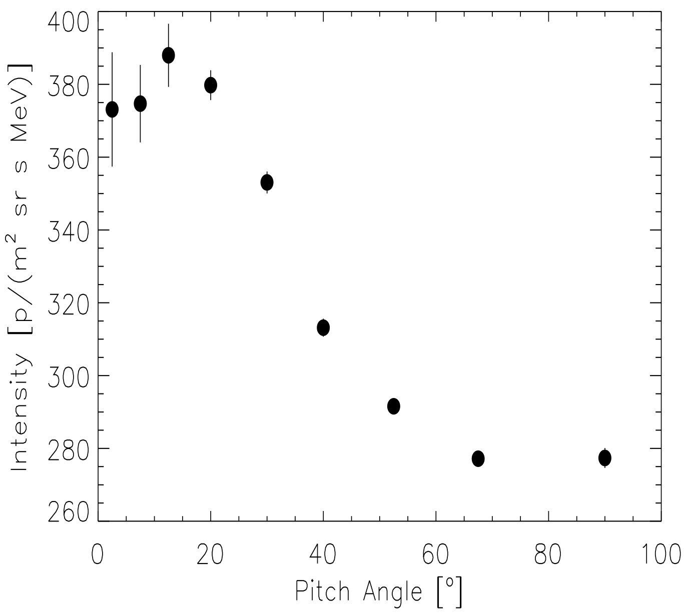

Figure 3. Pitch angle distribution during 10-15 UT on June 18th, 1997

maximum intensity direction is not as large as it might be in a cone with the maximum intensity direction well inside. This presumption is partly supported by the secondary maximum of the intensity during 14-24 UT, June 18. The deviation of the secondary intensity peak from the exponential intensity decay of the major peak, just before and after the secondary peak, at 18-19 UT, is about 100 %. The directionality is highest before the rise of the peak. During the presence of the secondary peak the maximum intensity is close to the center of the ERNE view cone. Thus we cannot exclude the possibility that there might also exist higher directional intensities outside the ERNE view cone during the plateau phase B.

Most interesting result of this work concerning the analysis of the June 1998 event might be the clear anisotropy slightly preceding the start of the secondary peak during the decay phase C of the particle event. The anisotropy starts about 39 hours after the event onset. This leads to the start of proton intensity enhancement, which is distinguishable at 14 UT, June 18. The anisotropy is strong, stronger than anywhere during the major peak. The ratio of intensities in two pitch angle ranges, $I(0\text{-}25^0)/ I(60\text{-}90^0)$ was ≈1.4, during 10-15 UT on June 18. The anisotropy disappears rapidly, and is minor at the maximum of the secondary peak at about 20 UT (Figure 1).

The origin of the secondary peak needs further analysis. At the moment we might speculate that the elapsed time from the onset of CME to the maximum of the peak, ≈48 hours, indicates, that the interplanetary CME shock was propagating close to 1 AU. Then an obvious reason for the anisotropy and average intensity peak would be the injection of particles from the nearby shock front. Similar intensity enhancements are well known in low energies around 1 MeV and less. The fast decay of intensity and disappearance of the directional anisotropy might then indicate the passage of the front. As far as we know no detection of the shock passage has, however, been reported.

Acknowledgements

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References

Kahler, S., ApJ, 428, 837, 1994.