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Solar Particle Eruptions Observed by SOHO/ERNE in November 1997

P. Mäkelä, M. Teittinen, and J. Torsti

Space Research Laboratory, Department of Physics, FIN-20014 Turku University, Finland

Abstract

In November 1997 a sequence of solar energetic particle eruptions occurred at the Sun. The Energetic and Relativistic Nuclei and Electron (ERNE) experiment onboard SOHO observed at least five separate flux enhancements of solar origin on 3, 4, 6, 13, and 17 November, 1997. In this paper we report a short overview of the measurements of solar energetic particles from these five solar events as observed by ERNE. Special attention is drawn to the onset times of flux enhancements of various types of nuclei. The analysis is based on calculation of path length particle has traveled from the first particle injection moment at the Sun to the moment of observation, instead of the usual arrival time which depends on energy.

1 Introduction:

In November 1997 a sequence of solar energetic particle eruptions occurred at the Sun. The observations of ERNE onboard SOHO indicate that at least five separate intensity enhancements of solar origin took place during the first half of November 1997. The enhancements above 2 MeV/nucleon were registered on 3, 4, 6, 13, and 17 November. The energy spectrum of both H and He nuclei extended to energies above 20 MeV/nucleon during the three middlemost events. The events on November 3 and 17 were minor events with low He intensities. In this paper we report an overview of the intensity measurements of solar energetic particles during 3–18 November, 1997, as observed by ERNE. Special attention is drawn to the onset time of flux enhancement of various types of nuclei, and association with the coronal mass ejection (CME) launch time observations by LASCO (Brueckner et al.,1995) on board SOHO and with the X-ray bursts observed by GOES.

2 Observations:

The ERNE instrument consists of two separate particle telescopes, Low Energy Detector (LED) and High Energy Detector (HED). Together the two telescopes cover an energy range from few MeV/nucleon up to few hundreds of MeV/nucleon. The measured energy range varies with an observed element, e.g. it is for proton 1.6–100 MeV and for oxygen 2.5–240 MeV/nucleon. Both telescopes can separate elements from hydrogen up to iron. The time resolution of measurements is one minute. All detected particles are identified and lighter elements (H and He) are also analyzed on-board by a scientific software. A more detailed description of ERNE is given in Torsti et al. (1995).

In Figure 1 we show the time development of proton and helium fluxes at 1 AU in the beginning of November 1997. Observations in the energy ranges of 3.3–6.4 MeV/nucleon and 25–51 MeV/nucleon extend from November 3 to November 18. Five particle events can be clearly separated even though events are overlapping. Particle intensities in the November 4 and 6 eruptions were about a factor of 100 and 1000 higher than in the November 3 event. The events on November 13 and 17 events were minor events, during the latter event only the proton channels were enhanced.

In what follows we present an analysis of the onset times of intensities of various nuclei during the November 1997 events. In the analysis we use, instead of the arrival time which depends on energy, the path length s particle has traveled from the first injection moment from the sun, t_i, to the moment of

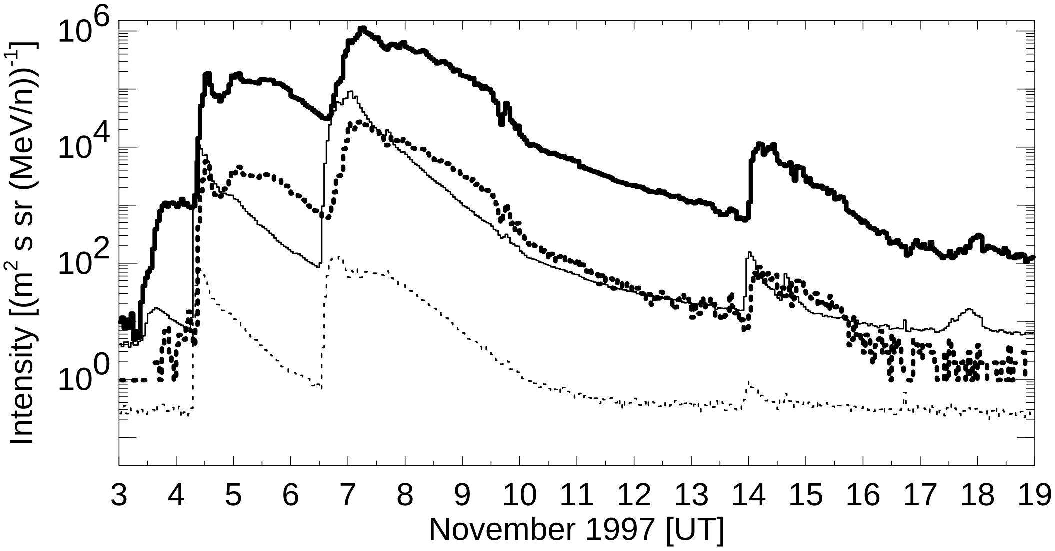

Figure 1: Hourly averaged time-intensity profiles of protons (continuous line) and He nuclei (dotted line) during November 3–18, 1997. The energy channels, 3.3–6.4 MeV/nucleon (thick line) and 25–51 MeV/nucleon (thin line), are from LED and HED sensors of SOHO/ERNE, respectively.

observation, t_o, as proposed by Ruffolo (1991). The distance is calculated as $s = v \cdot (t_o - t_i)$, where v is the velocity of particle.

As an example we give in Figure 2 scatter diagrams of CNO nuclei path lengths based on two assumptions of the onset time of the interplanetary (IP) injection on November 4, 1997. The first moment of time, 05:50 UT, represents the maximum of the X-ray burst at the Sun. The latter moment, 06:08 UT, represents our best fit for the start of the injection to match the requirement that the rise of flux enhancements at all energy channels starts after particles have traveled an equal distance.

Based on the similar scatter diagrams we show in Figure 3 the energy dependence of the path length for He nuclei injected on November 4, 1997. As an injection time we use the time of the maximum of X-ray flare, 05:50 UT, which gives the best fit for the criterion that the front of particle flux in all energy channels reaches the spacecraft after passage an equal distance of 1.2–2.5 AU in interplanetary space. The vertical axis in the Figure 3 represents the deviation of the frequency from the average background frequency just before the flux enhancement. The unit of the distribution is the standard deviation of the background distribution. It is calculated either from normal distribution or Poisson distribution. The Poisson distribution is used for frequency channels of low average background.

The estimated solar injection times for proton, helium and CNO nuclei with available CME and X-ray burst parameters are given in Table 1.

3 Discussion and Conclusions:

Figures 2 and 3 indicate that the adopted analysis method gives useful information on the start of the energetic particle injection associated with dynamic solar processes. Inspection of Table 1 reveals that there existed a 60-minute delay between the maximum of the X-ray burst at the Sun on November 6, and first interplanetary injection of the CNO nuclei. If particles were injected much earlier, the first CNO nuclei would have been traveled well more than 3 AU in interplanetary space before getting to SOHO. In addition, the high energy nuclei around 80–100 MeV/nucleon would have been traveled a longer distance,

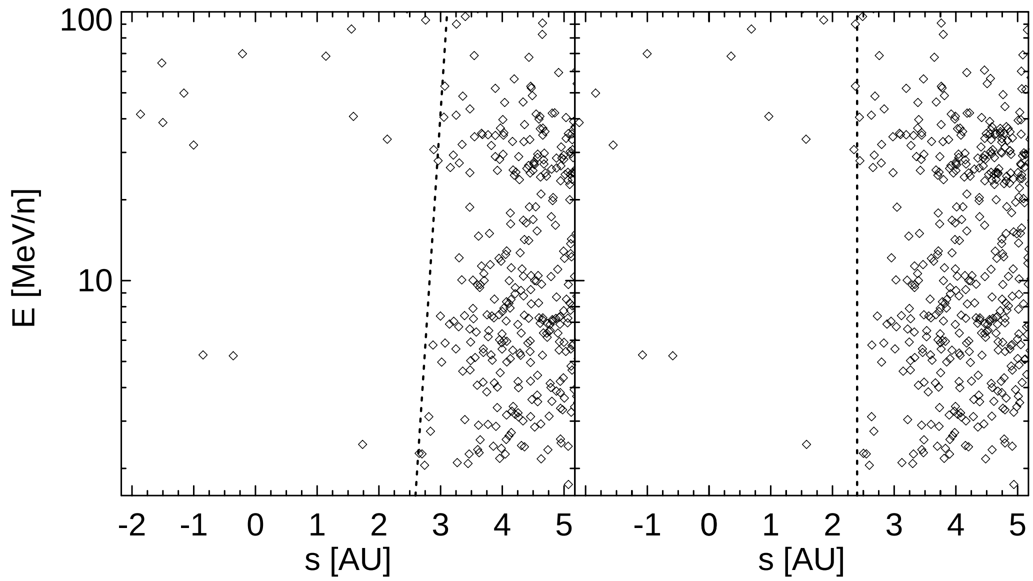

Figure 2: Scatter diagram of particle energy versus path length of the CNO nuclei in energy range 2.5–30, and 23–100 MeV/nucleon respectively in LED and HED based on the start of solar injection at 05:50 UT (left) and 06:08 UT (right) on November 4, 1997.

~4 AU, whereas the low-energy CNO particles at energies 20–30 MeV/nucleon and 3–5 MeV/nucleon were capable to reach the ERNE instrument respectively after interplanetary path of 3–4 AU and 2–3 AU.

Another way to present the front of arriving particles is a 3-dimensional frequency histogram (Figure 3) which is probably better justified than a scatter diagram. The advantage is that the frequencies in adjacent narrow energy channels as normalized so that the background counting rate is zero. In addition we give the frequencies in units of standard deviation of counting rate during the background period. This way we can emphasize the statistical significance of the flux enhancement and make comparison between different channels easier. The error of the injection time depends on the statistics in a whole energy range. In the examples we dealt in this work the error in the injection time varies between 5–20 minutes.

As seen in Table 1, the first injection moment of energetic light nuclei precedes the first appearance of CME as observed by LASCO during the November 4 and 6 events except for He nuclei on November 6. During the November 3 and 13 events the closest CME launch occurred 2 and 1 hours later, and cannot play a role as a first injector of H and He nuclei into interplanetary space. Also on November 17 there is no association with the first injection moment and observed interplanetary CME event.

The particle events on November 4 and 6 were also connected to the X-ray flares. The estimated injection moment of heavy nuclei show a delay of about 60 minutes on November 6. The estimated delay on November 4 is shorter, about 20 minutes. The analysis of the November 6 event is complicated by the close proximity of the two intense particle events and also by the fact that the shock front from the November 4 event arrived at 1 AU at the end of November 6.

The estimated path lengths are in all cases between 1.2 and 2.5 AU and a significant flux enhancement becomes detectable in all energy channels in almost all cases in that distance range. Despite that we are not willing to claim that particles would have traveled in interplanetary space that nominal distance. However, we conclude that this method is useful in the analysis of the onset of the energetic particle injection at the Sun.

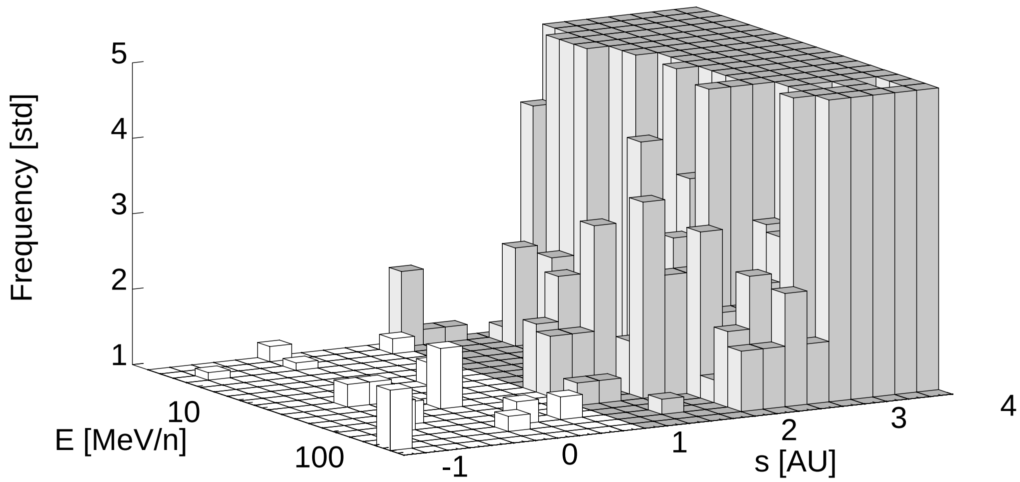

Figure 3: Frequency distribution of the path length of helium nuclei during the time of the onset of the November 4 event. The injection moment at the Sun is 5:50 UT. The gray-colored columns represent path lengths ≥ 1.2 AU.

Table 1: Characteristics of the flare and CME during or close to the time of first injection of energetic particles in November 1997. The injection times of different nuclei species represent the estimated start of the particle injection at the Sun.

	X-ray maximum (Solar Geophysical Data, 1998)			CME (LASCO)		Energetic particles solar injection time (UT)		
Day of 1997	Time (UT)	Type	Location	Start* (UT)	Speed (km/s)	p	He	CNO
Nov.3	0910	M1.1/1B	S20W15	1111	369	0902±10		
Nov.4	0558	X2.1/2B	S14W33	0610	830	0550±5	0550±10	0608±5
Nov.6	1155	X9.4/2B	S18W63	1210	1560	1147±5	1220±10	1245±15
Nov.13	2018	C1.7		2225	449	2135 ±5	2135±5	
Nov.17	1510	C8.6/SF	N21E30	1930	387	1505±20		

* first appearance in C2 at 1.5 R_{sun}, (ftp://lasco6.nascom.nasa.gov/pub/lasco/status/Version2_CME_Lists/)

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