Angular Distributions and Energy Spectra of Energetic Particles Observed by Voyager 1 at 85-88 AU

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Abstract

We describe energetic ion data obtained during 2002-03 by the Low Energy Charged Particle (LECP) instrument on Voyager 1 (V1). Our focus is the period ∼2002.5-2003.2, during which V1 moved from 85 to 88 AU, while at 34N° latitude. Starting in mid-2002, particle intensities at V1 showed a large rapid increase that remained at highly elevated levels until early 2003. The unique nature of the V1 data and absence of comparable structures in the Voyager 2 data [2,3] suggests that the V1 event is associated with the heliospheric termination shock (TS).

1. Introduction

Several independent techniques predict that V1 is close to the TS [1]. Voyager instrument teams continue to monitor their data closely for possible signatures of activity upstream of the TS or of a TS crossing into the subsonic heliosheath plasma. This report summarizes LECP angular distributions data and energy spectra of 40–4000 keV ions during the unusually high energetic particle intensity variations at V1 from mid-2002 to early 2003. Ion and electron intensity variations and ion composition data during this V1 "event" are summarized in companion papers [2,3].

2. Observations

Fig. 1 shows angular data for 0.57–1.78 protons measured at V1 during 2002.00–2003.23. The LECP instruments step through 8, 45° sectors, yielding particle angular information. The color diagram shows 3-day averaged data, with time along the abscissa axes, and sector number indicated along the left-hand ordinate axis. At each time, intensities in the seven (or, sometimes, six) active sectors (S1-S7) are normalized to the intensity in the peak sector. The color bar thus represents normalized intensity. Superposed on the color diagram is the scan-averaged intensity, with units along the right ordinate axis. The pie plots at the top show normalized intensities in the seven sectors at selected periods when the scan-averaged intensities were at local maxima. During the period of

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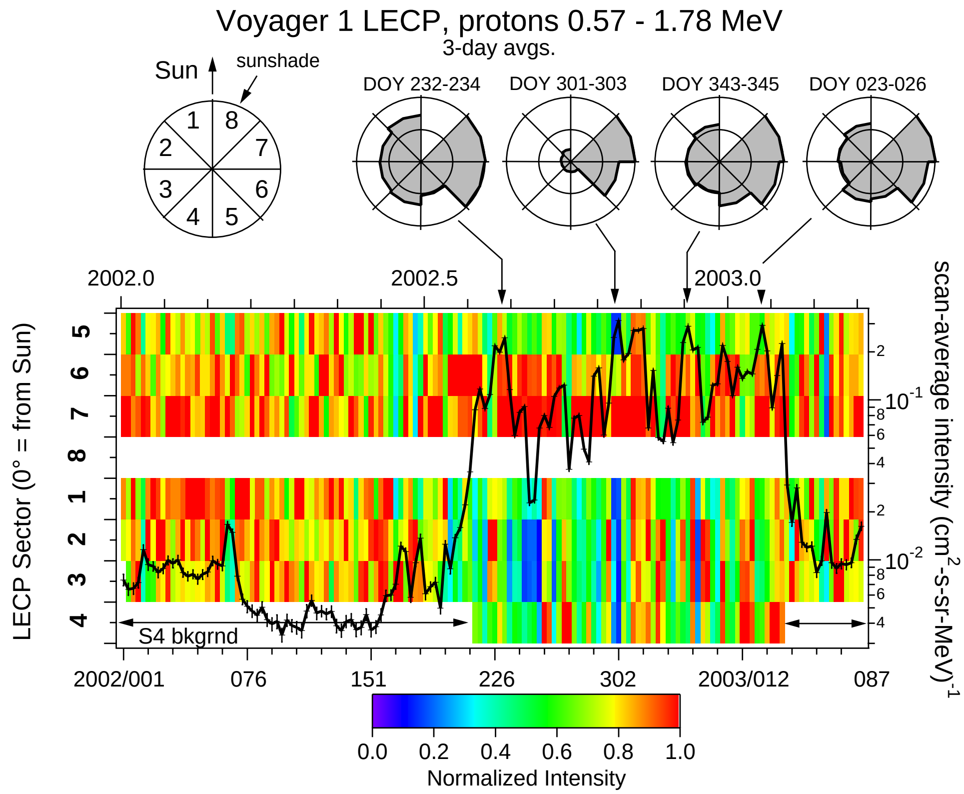

Fig. 1. Angular data for 0.57–1.78 protons measured by V1 during 2002/001 - 2003/085. The pie chart at the top left indicates the LECP scan plane orientation, and defines viewing directions of sector numbers indicated along the left-hand ordinate axis. Scan-average denotes an average over the 6 or 7 active sectors.

elevated and highly variable intensities starting in mid-2002, proton intensities peak predominantly in S7, with occasional peaks in S6. These data and those in other energy and ion species channels are consistent with one another, and with the presence of large, beam-like anisotropies of energetic ions headed outward from the Sun along the, presumed, nearly azimuthal heliospheric magnetic field.

Fig. 2 shows intensities in four of eight ion channels, covering 40–4000 keV, during 2002.4–2003.36. There are sustained intensity increases of ions from at least 40 keV to 4000 keV during the same period when the 0.57-1.78 MeV proton intensities (Fig. 1) were also greatly enhanced. In addition to the ∼0.6-year overall increase, these ion profiles display significant energy-dependent intensity variations, with time scales ranging from a few days to on the order of a solar rotation. Note, for example, the structure during period "D" is ∼10 days wide and dominant only at lower energies.

Fig. 3 shows energy spectra (open symbols) during the five specific time intervals indicated in Fig. 2 as periods A-E. These periods were chosen because

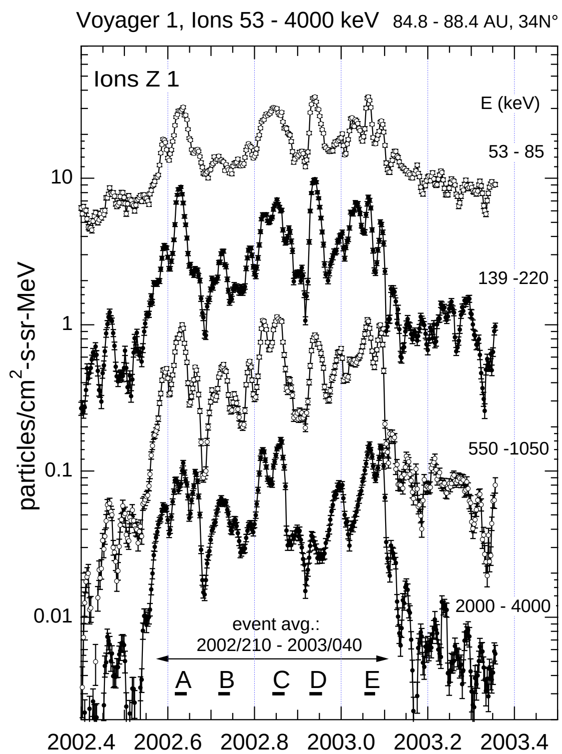

Fig. 2. Intensities of Z≥1 ions at four selected energies from 53-4000 keV during 2002.40–2003.36. Data are 5-point running averages of daily means, and intensities were calculated using energy passbands for protons.

they include peak intensities. The spectrum shown by solid circles is the event average covering the period 2002.57 (2002/210) to 2003.11 (2003/040). These are remarkably flat and intense energy spectra, considering that they are observed at radial distances $\geq$ 85 AU. Spectra for periods A, B, C, E, and for the event-average are well-fit by power law laws, $j(E) \propto E^{-\gamma}$, with $\gamma = 1.46\pm0.05$, 1.36 ± 0.06, 1.34 ± 0.05, 1.46 ± 0.05, and 1.41 ± 0.06, respectively. Spectrum D is not of power-law form, but rather has a local slope $\sim3/2$ at low energy and steepens with increasing energy to a local slope ~2 at the high energy. (For reference, if the power-law spectra were produced by shock acceleration, then steady-state diffusive shock acceleration theory would imply a shock compression ratio $r = 2(\gamma+1)/(2\gamma-1) = 2.5$ for $\gamma = 3/2$). We note that ACE/EPAM and Ulysses/HI-SCALE ion intensities measured during the first half of 2002 (not shown here) are also power-laws with $\gamma\sim1.5$. These data also show that $\sim$50-5000 keV ion intensities decrease from 1 to 85 AU inversely as radial distance, strong evidence that the ions observed at V1 have undergone additional acceleration, probably by shocks and turbulence in the solar wind and also quite possibly at the TS.

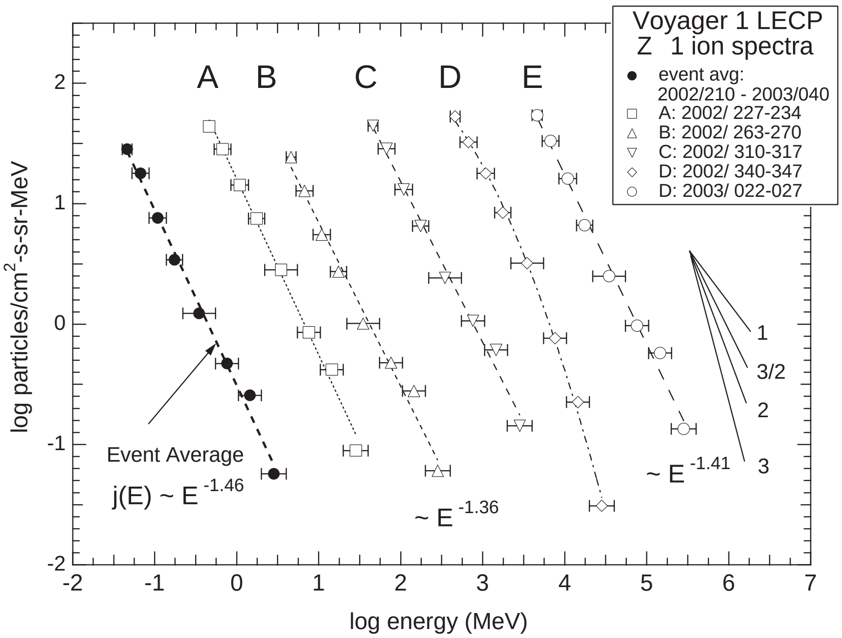

Fig. 3. Energy spectra of Z≥1 ions with energies 40-4000 keV, during the five periods A-E indicated in Fig. 2 (open symbols), and during the entire event (solid circles). Spectra A-E are shifted rightward in energy by log10 factors 1-5, respectively.

3. Summary

We have shown 0.6–1.8 MeV proton angular data and 40–4000 keV ion energy spectra during the remarkably intense, long-lived (∼0.6-year) event at V1 during ∼2002.5–2003.2. The protons showed beam-like anti-sunward streaming along the, presumably, nearly azimuthal magnetic field at ∼85 AU, and the ion intensities were high and relatively hard, with a power-law spectral slope ∼1.5. The origin of these unique data remains unclear, but at least two scenarios are being investigated. In one, V1 is in the near upstream region of the TS, and the observed event results from connection to the TS. In the other scenario, V1 is beyond the TS in mid-2002, and the particle intensity [2], anisotropy, and composition[3] variations are indicative of conditions in the heliosheath [4]. This work was supported by the Voyager Interstellar Mission under NASA Grant NAG5-4365.

4. References

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