Voyager 1 Observations of the Anisotropies of Enhanced MeV Ion Fluxes at 85 AU

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Abstract

We report on the diffusive flow anisotropies observed in low-energy protons during intensity increases at Voyager 1 in 2001 and 2002. We propose that the unusual increased intensities after mid-2002 are due to particles accelerated by the solar wind termination shock or by the turbulent interface between the high-speed and low-speed solar wind flows.

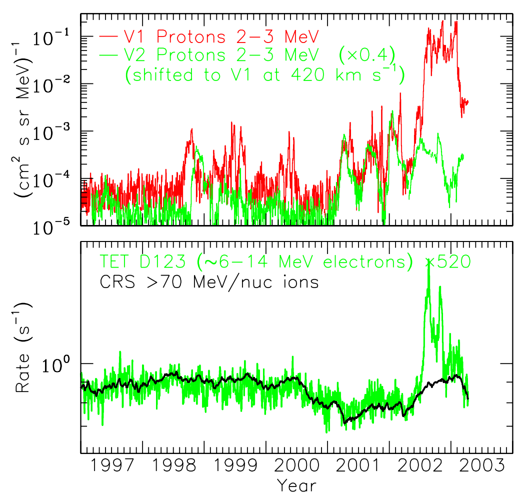

Fig. 1. (top) Three-day moving average intensity of 2-3 MeV protons at V1 and V2 vs. time. (bottom) Five-day moving average intensity of electrons and >70 MeV/nuc galactic cosmic rays at V1.

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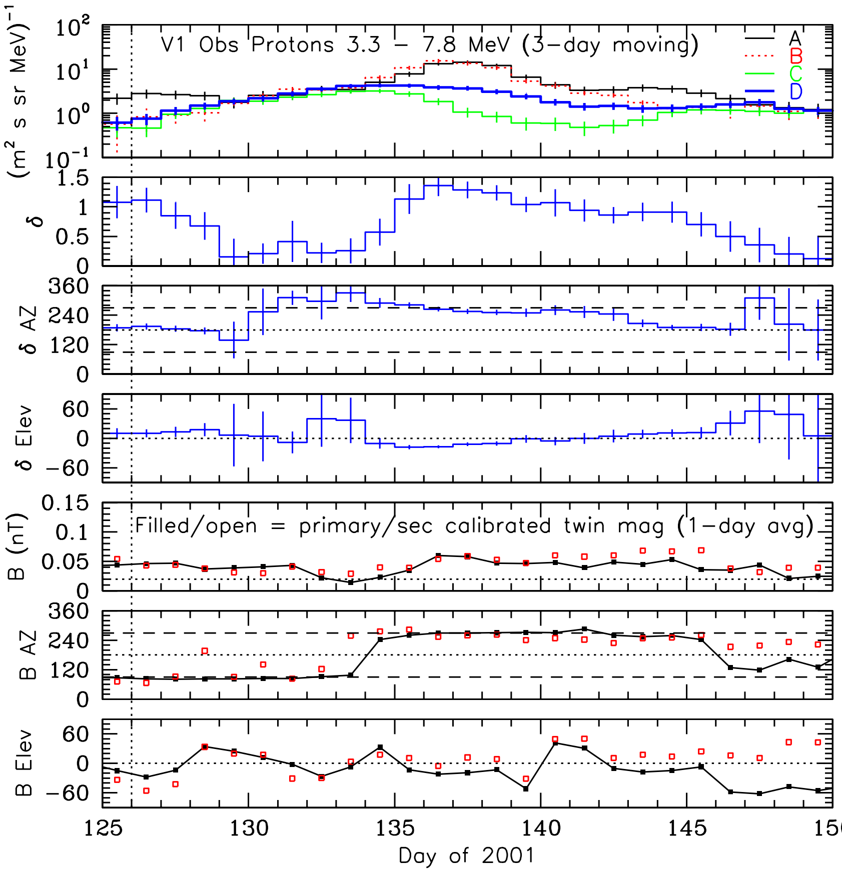

Fig. 2. Intensity of 3.3-7.8 MeV protons at V1 in the 4 LET telescopes (labeled A, B, C, and D), diffusive anisotropy of the flow (magnitude "δ", azimuth "δ AZ", and elevation "δ Elev"), and similar quantities for the magnetic field for 2001/125-150 as described in the text. The RTN coordinate system is used, with 270° in δ AZ representing flow outwards from the Sun along the nominal magnetic field line. The vertical dotted line marks a spacecraft maneuver for which the anisotropy determination is uncertain.

1. Introduction

In mid-2002 the cosmic ray (CRS) instrument [4] on the Voyager 1 (V1) spacecraft began to observe an unprecedented simultaneous increase in the intensity of electrons, galactic cosmic rays, and low-energy ions as shown in Figure 1 (also see [3]). The increased 2-3 MeV proton intensity is >100 times that at Voyager 2 (V2) and lasts for ~6 months. There are also smaller intensity "spikes" (by factors of ~10) at V1 over that at V2 during 1999 through 2001.

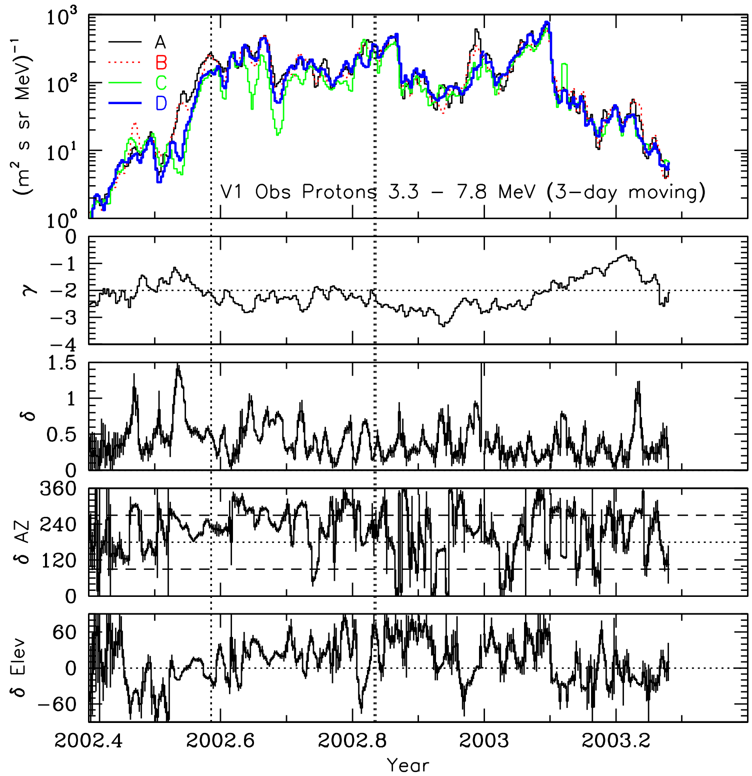

Fig. 3. Similar to Figure 2 except magnetic field data is not plotted, the power-law spectral index is added, and the time period is 2002.4 to 2003.0. The spectral index is estimated by the ratio of intensities in two intervals, 3.3-5 MeV and 5-7.8 MeV.

2. Observations

At slightly higher proton energies on V1, the three-dimensional components of the particle flow can be measured by comparing the rates from the four Low Energy Telescopes (LETs) on CRS. The four identical telescopes are pointed in different directions in space. In Figure 2 we show an example of the diffusive particle anisotropy (anisotropy corrected for Compton-Getting effect) and magnetic field data during one of the V1 intensity spikes in 2001. Note that the magnitude of the anisotropy increases significantly on day 135, shortly after a sector crossing. The anisotropy remains large during the positive sector. The particle flow is generally in the R-T plane, outwards from the Sun along the magnetic field direction.

V1 anisotropy data is shown in Figure 3 for a time period covering the large intensity increase in mid-2002. The anisotropy magnitude appears to be quasi-periodic reaching very large values ($\geq$1), the flow appears to be mostly outwards from the Sun along the nominal magnetic field line, and the flow appears to be predominantly upwards with respect to the R-T plane.

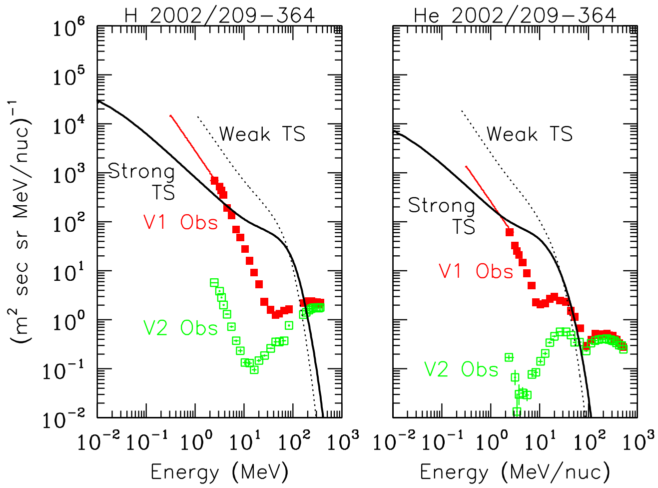

Fig. 4. (left) Energy spectrum of protons at V1 and V2 during the intensity increase from 2002/209-364. Spectra expected for strong and weak termination shocks are also shown [2]. (right) Same except for He. Note that the ACR He appears to be heavily modulated from the energy spectrum expected at the termination shock.

3. Discussion

To maintain such large anisotropies as shown in Figures 2 and 3 implies that the spacecraft is within a few mean free paths of where the particles were accelerated or reaccelerated. For these low-rigidity particles, the mean free path is expected to be fractions of an AU. If the particles are coming from the termination shock, then the higher rigidity anomalous cosmic rays (ACRs) ought to also be present. However, as shown in Figure 4, the mid-energy ACR He ions appear to be heavily modulated. It may be that the low-energy component is accelerated in a localized region of the termination shock that is nearby, while the higher energy ACRs are accelerated in a much larger-scale region that is much further away.

Another possibility is that the low-energy particles are accelerated at the turbulent interface between the low and high speed solar wind flows. Voyager 1 is at $\sim 34°$ N heliographic latitude, near the expected location of the maximum northward extent of the current sheet in 2002 [1], which marks the boundary between the high-speed and low-speed solar wind flow.

4. References

1. Burlaga, L. F., Ness, N. F., Richardson, J. D. 2003, submitted
2. Cummings, A. C., Stone, E. C., Steenberg, C. D. 2002, Astrophys. J, 578, 194
3. McDonald F. B., Cummings, A. C., Stone, E. C., et al. 2003, this conference
4. Stone, E. C., Vogt, R. E., et al. 1977, Space Sci. Rev. 21, 355