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Voyager 1 Observations of Termination Shock Particle Events – The Effect of Interplanetary Transients

F.B. McDonald[a], Edward C. Stone[b], Alan C. Cummings[b], Bryant C. Heikkila[c], Nand Lal[c] and William R. Webber[d]
(a) Institute for Physical Science and Technology, University of Maryland, College Park, MD
(b) California Institute of Technology, Pasadena, California
(c) NASA/Goddard Space Flight Center, Greenbelt, Maryland
(d) Department of Physics and Astronomy, New Mexico State University, Las Cruces, New Mexico
Presenter: F.B. McDonald (fm27@umail.umd.edu), usa-mcdonald-FB-abs2-sh31-oral

The increases in MeV ions and electrons, observed by the Voyager 1 CRS experiment as it moved beyond 85 AU, have persisted over most of the ensuing 3 year period and represents a new particle population in the distant heliosphere - Termination Shock Particle (TSP) events. The properties of these TSP events are strongly influenced by the passage of interplanetary transients.

1. Introduction

The temporal and spatial variations of the diverse energetic particle populations in the distant heliosphere probe the structure of the heliospheric Termination Shock (TS) and the hot turbulent region of the heliosheath that lies beyond it at distances that can extend far beyond the Voyager space craft.

In mid 2002, some two years after the cycle 23 solar maximum, there began an unusual increase of MeV ions and electrons at Voyager 1 (85 AU) [1,2] that persisted for some 6 months at intensity levels at least 20 times and sometimes 500 times greater than that at Voyager 2 (68 AU). In 2003.7 there was a second year-long increase that reached even higher intensity levels. Over this period these unusual enhancements are a durable feature of the distant heliosphere and must be related to the close proximity of Voyager 1 to the TS.

These two increases (termed *Termination Shock Particle* – TSP – increases) are characterized by temporal variations on a variety of time scales, frequent periods of streaming along the expected direction of the interplanetary magnetic field, relatively flat energy spectra and a charge composition at low energies resembling that of anomalous cosmic rays as defined by the high O/C ratio [2,3,4].

Large scale interplanetary disturbances modulate the TSP intensity and appear to play a role in the follow-on increases of 2-15 MeV electrons and higher energy protons extending up to > 50 MeV. There is a close correspondence between the intensity changes of the electrons and the higher energy protons. The latter component often exhibits significant beaming along the nominal interplanetary magnetic field suggesting a direct connection to the source regions. The electrons are assumed to be interstellar in origin that have experienced local re-acceleration at the TS.

In this paper we use the V2 data to identify the passage of interplanetary disturbances and then study their effects on the Voyager TSP events.

2. Observations

The V1 time histories of 2.3 MeV H, 10 MeV electrons, 48 MeV/n ACR He and the GCR PenL rate are shown in Fig. 1 for 2002.2–2005.5 along with the identification of TSP 1, 2 and 3. The simultaneous increase of all 4 components in 2002.54 following the passage of an IP transient and the close correspondence between the time history of the 2.3 MeV H and the GCR PenL rate for this TSP indicates a decrease in the modulation level at this time. The arrow at TSP 3 marks the crossing of the TS and the passage of V1 into the region of the heliosheath as defined by the magnetic field data [5], confirming that TSP 1 and 2 did indeed originate at the TS.

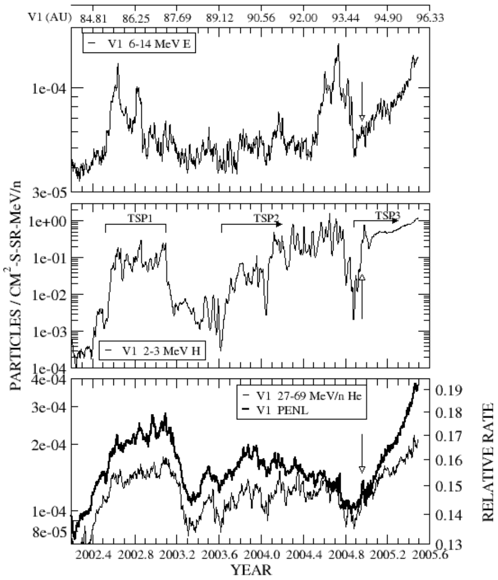

Figure 1. V1 time-history of CRS data 2002.2-2005.5. The 48 MeV/n ACR He in the bottom panel is shown by a light line and the GCR penL rate (70-300 MeV H, > 70 MeV/n He) is a dark line. All data are 5 day moving averages.

From 2001.0–2004.5, V2, which is some 19 AU closer to the sun than V1, observed a series of 9 increases of 2.3 MeV ions that persist over some 3–4 solar rotations (Fig 2a). Seven of these events are associated with the passage of a merged interaction region (MIR) as indicated by the accompanying increase in solar wind velocity, V, and the interplanetary magnetic field, B, and a decrease in the GCR integral rate, penH (Fig 2 b-d). An 8^{th} increase (event 6) is contained between 2 MIRs. The vertical shaded areas in Fig. 2 mark the onset at V2 of the GCR decrease and the time of minimum intensity and is regarded as a measure of the radial extent of the MIR. There is a close correspondence between the V1 and V2 time histories (the V2 data has been corrected for the V2 to V1 convection time) for events 1–4 except the V1 peak intensity is smaller. This similarity establishes the global extent of the events. At V1, TSP 1, 2, and 3 start immediately after the passage of MIRs associated with events 4, 7 and 9. TSP 1 is terminated by the passage of event 6 [6]. The MIR of event 8 produces a sharp decrease in the V1 TSP 2 intensity.

The look direction of the bi-directional V1 HET telescope is approximately aligned along the nominal B direction providing a means of detecting the streaming of 16–56 MeV ions. The HET J_A and J_B intensities (Fig. 3a) show strong episodic increases in 35 MeV H with the largest increases following the predicted time of passage of MIRs 8 and 9. Smaller increases were noted for events 5 and 6. The streaming of these 35 MeV H ions is generally along the magnetic field ($J_A > J_B$) (Fig. 3b) in the direction away from the Sun, consistent with that reported for lower energy ions. [2,3,4]. The net streaming is reduced after V1 passes into the region of the heliosheath.

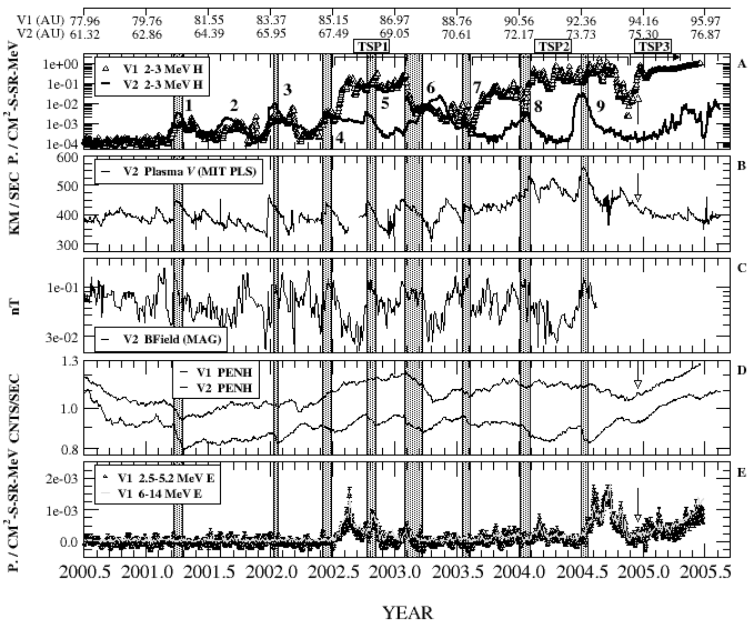

Figure 2. Voyager time-history of CRS, PLS and MAG data 2000.5 - 2005.5. All of the V2 data has been time shifted to correct for the convection time between V2 and V1 (0.19 years in 2002). The electron data (e) has been background corrected. The CRS and MAG data are 5 day moving averages while the PLS data are daily averages.

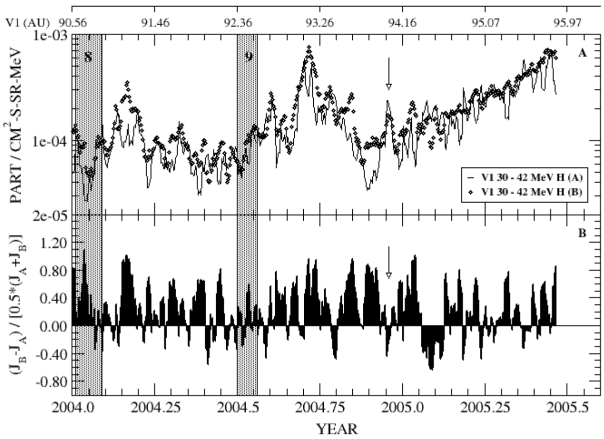

Figure 3. V1 35 MeV H for the A and B direction of the HET (a) and 35 MeV H streaming along the magnetic field (b).

An enhancement of MeV electrons and higher energy ions associated with the passage of MIRs 5 and 6 and following events 8 and 9 is shown in Fig 4 along with the 2.5 MeV H and > 70 penH rate. Short-term fluctuations are assumed to be associated with the presence of local transients in the interplanetary medium. The sharp decrease in 2.5 MeV H produced by the passage of MIR 8 is followed by an increase in all 4 components (2004.9–2004.23) with the temporal structure of the TSPs being similar to that of the GCR. After the predicted time of passage of MIR 9 there are especially strong increases and fluctuations in the intensity of MeV electrons and the higher energy ions.

3. Discussion

The passage of an MIR can produce intensity decreases that are often followed by enhancements of H ions (extending up to 60 MeV) and 2.5–14 MeV electrons. These H enhancements can show significant streaming along the expected direction of the IPB field and there is frequently a correspondence between the temporal variations of 43 MeV H and 2.5–14 MeV "ultra-relativistic" electrons. The electrons are assumed to be galactic in origin and have experienced some re-acceleration at the termination shock [7]. If valid, this assumption would rule out the S/IP ions as the source of the H and electron enhancements. The MIR could also change the location of the field line connecting V1 to the TS. Most probable it reflects the dynamic interaction between the MIR and the TS. The entry of V1 into the heliosheath occurred some 0.3 years after the passage of the MIR produced by the intense solar activity of Oct/Nov 2003 which resulted in the largest increase in high energy H and electrons observed to date for TSP events (Fig. 1,3,4). The continuing increase of 30-56 MeV H and 2.5–14 MeV electrons after V1 crossed the termination shock may reflect the recovery from the interaction of the TS. with the MIR, along with the continuing recovery toward solar minimum.

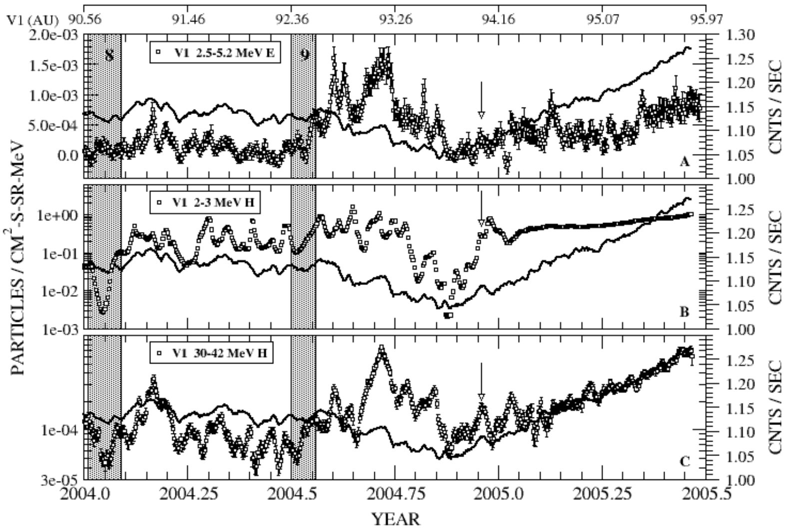

Figure 4. Correspondence between the intensity changes of the MeV electrons (a) and the 45 MeV H (c) for the period 2004.0–2005.0. The 2.3 MeV ions are shown in panel c and the GCR integral rate, penH, is shown in each panel. All data are 5 day moving averages.

References

[1] McDonald, F.B., Cummings, A.C., Stone, E.C., Heikkila, B.C., Lal, N and Webber W.R., Nature 426, 48, 2003
[2] Krimigis, S.M., Decker, R.B., Hill, M.E., Armstrong, T.P., Gloeckler, G., Hamilton, D.C., Lanzerotti, L.J. and Roelof, E.C., Nature, 426, 45, 2003
[3] Cummings, A.C. *et al.,* Proc. 28th, Int'l Cosmic Ray Conf. (Tsukuba) 7, 3777, 2003
[4] Decker, R.B., Krimigis, S.M., Roelof, E.C. and Hill, M.E., Proc. 28th Int'l Cosmic Ray Conf. (Tsukuba) 7, 3773, 2003
[5] Burlaga, L.F. *et al*., To Be Published, Science, 2005
[6] Burlaga, L.F. *et al*. 2003
[7] Potgieter, M.S. and Ferreina, S.E., Journal Geophys Res 107, A7, 10.1029/2001, JA009040, 2002