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Voyager 2 Observations of MeV Ions in the Outer Heliosphere Over the Solar Maximum Period of Cycle 23

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Over the period 2001.0 - 2005.4, (63 - 74 AU) Voyager 2 observed a series of 9 energetic particle increases that persist over some 3 - 4 solar rotations, occur with a quasi-periodicity of some 145 days and are generally associated with the passage of a merged interaction region. With the onset of GCR recovery from solar maximum levels in 2004.6 there is a marked change in the nature of the V2 energetic particle increases that suggest these new events originated at the termination shock.

1. Introduction

One of the significant, dynamic features of the outer heliosphere are long-lasting increases of MeV ions which are generally associated with the passage of large-scale interplanetary disturbances know as Merged Interaction Regions (MIRs) formed through the coalescence of multiple interplanetary coronal mass ejections and high speed solar wind streams (ICMEs) [1]. Periods of stronger activity can produce larger systems, known as Global Merged Interaction Regions (GMIRs) that span 360° in helio longitude and extend to high latitudes. The MeV ions associated with the MIRs and GMIRs may have been accelerated at the Sun and/or by ICMEs and the energetic particles increases are referred to as S/IP events.

The study of these events and their solar associations are important for identifying the conditions that led to the formation of these large structures, to understand their long-term effect in the heliosphere, their role in the modulation process and changes in the character of the events with increasing heliocentric distance and with changes in the level of solar activity. It is also important to identify the changes these S/IP particle increases and their associated interplanetary disturbances produce in the Termination Shock Particle (TSP) events observed at Voyager 1, at a heliocentric distance some 19 AU greater that that of Voyager 2.

Over the past 33 years the Pioneer 10 and 11 (through 1996) and Voyagers 1 and 2 mission have provided an opportunity to observe these events over 3 solar cycles out to heliocentric distances that now extend beyond 95 AU [5]. In this paper we focus on the properties of S/IP events as observed at V2 from the maximum of cycle 23 in mid-2000 through 2005.5. The S/IP effect on the V1 TSP increases is discussed in a companion paper.

2. Observations

This study makes use of the data from the Voyager 2 Cosmic Ray Subsystem (CRS) Experiment (E.C. Stone, PI), the Magnetic Field (MAG) Experiment (N. Ness, P.I) and the Plasma Subsystem (PLS) Experiment (J.R. Richardson, P.I.).

The data set for a typical event is shown in Figure 1. For this event there is a close correlation between the S/IP event, the increases in the magnetic field, B, the solar wind velocity, V and the GRC decrease. [7] observed the shock passage time of 2002.033 which essentially coincides with the onset of the GCR decrease.

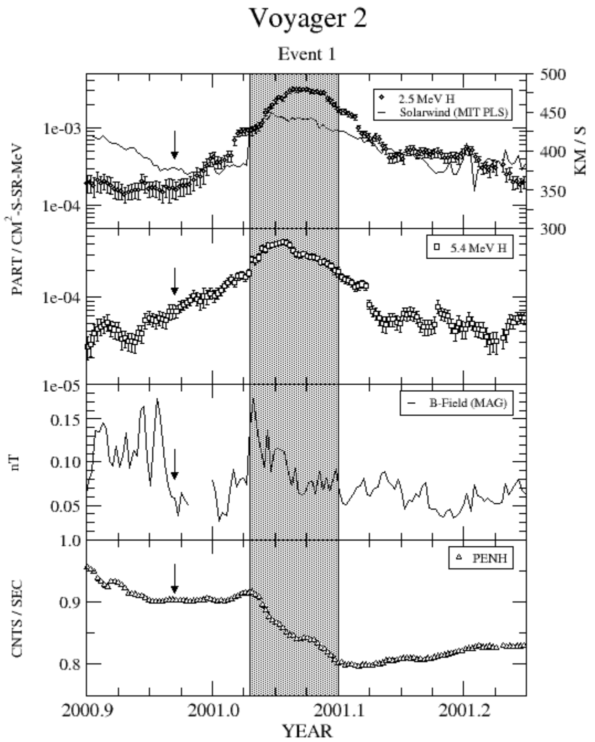

Figure 1. CRS, PLS and MAG data for Event 1 at Voyager 2. The arrow marks the time of onset for the 2.5 MeV H while the shaded region is defined by the onset time and minimum time of the penH rate (energies > 70 MeV/n). The CRS data are 5 day moving averages while the PLS and MAG data are daily averages.

The increase in 2.5 MeV ions begins some 5 AU in front of the shock, suggesting there could still be some on-going particle acceleration. Both [8] and [7] have modeled the multiple interplanetary disturbances observed at 1 AU that were associated with the solar events near the time of the 14 July 2000 event and accurately predicted the evolution and time of arrival of the resulting MIR some 6 months later at V2.

The V2 2.5 MeV H, V, B and penH data from the period 2000.8 - 2004.7 are shown in Figure 2. Of the 9 V2 S/IP increases over this period, 7 are associated with increase in V of 50 km/s or higher. They are no interplanetary disturbances associated with event 2 while event 6 is contained between 2 large MIRs as defined by the increase in V and B [2]. However, the GCR decrease is dominated by the lead MIR. Events 5 and 7 are of shorter direction but are associated with well defined increases in V and B and decreases in the GCR > 70 MeV rate.

The 2.5 MeV/n H/He ratio and spectral index (3.3 - 7.8 MeV) (Figure 3) show large dispersion. But the V1 data H/He for the events 1 - 4 (prior to the TSP increases) indicates this ratio is decreasing with increasing heliocentric distance. For these same events the spectral index (Figure 3b) does not appear to evolve significantly with heliocentric distance although the dispersion is large at both spacecraft.

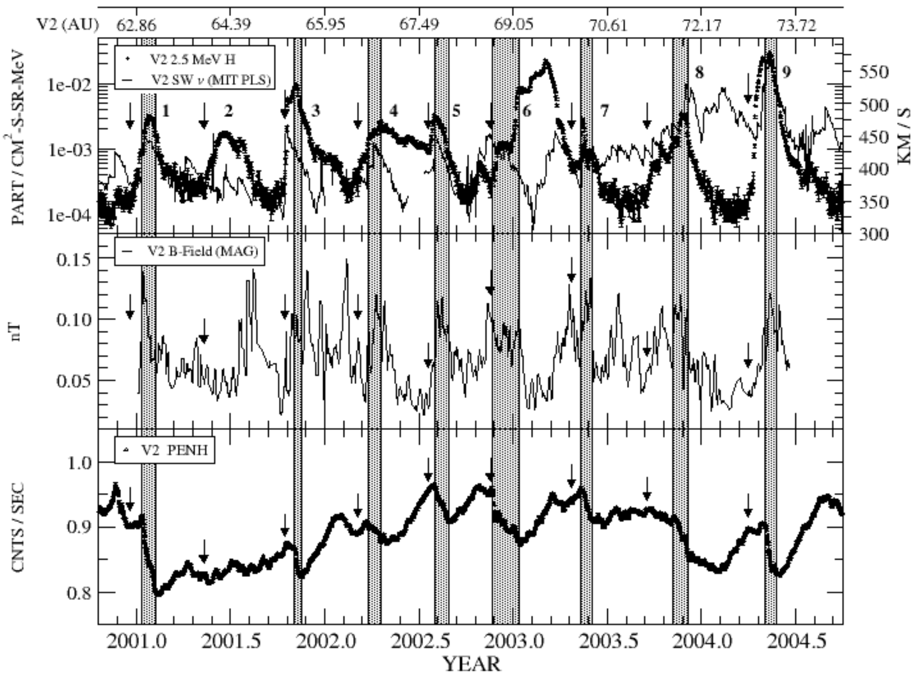

Figure 2. Voyager 2 time-history showing events 1-9. The arrow marks the time of onset for the 2.5 MeV H while the shaded region is defined by the onset time and minimum time of the penH rate (GCR integral rate, energies > 70 MeV/n). The CRS and MAG data are 5 day moving averages while the PLS data are daily averages.

For most of these events including events 1, 2, 3, 4, 6 and 9 there is a clear association with specific periods of solar activity. [3] has shown that event 8 is related to the appearance of high speed solar wind steam typical of the period of declining solar activity. Further study is necessary, to identify the solar activity that produce the other S/IP increases.

Following MIR 9 (produced by the large Oct., Nov. 2003 Halloween events) [4] there is a marked change in the V2 ion increases (Figure 4). The sharp increase in V at 2004.65 produces a small; short-lived increase in 3.5 - 7.4 MeV H which is not seen above the background level of 1.9 - 2.6 MeV H. Beginning in 2004.88 there are a series of small, impulsive ion events; superimposed on a steadily increasing intensity of both the low energy ions and the GCR integral rate, along with a corresponding decrease in V from ~ 500 km/s to 355 km/s. The energy spectra of the ion increases, is very flat at low energies (Figure 3). It is most probable that V2 at 75 AU is seeing energetic ions from the termination shock.

3. Discussion

The 9 S/IP events observed at V2 from 2001.0 - 2005.4 reflect a period of significant but sporadic solar activity that produces MIRs in the distant heliosphere with a quasi-periodicity of some 145 days. Despite a spacecraft separation of some 90 AU and 60° in heliolatitude, there is a close correspondence between the time histories of the first 4 S/IP events at V2 and V1 indicating the large scale coherence of their associated MIRs. However the temporal extent of each episode of solar activity is limited so these are probable not GMIRs. Event 1 produces a longer term depression of the GCR intensity (Figure 2), but, there is a more rapid recovery after the passage of the other MIRs. A striking feature is the large scale recovery following event 9 (produced by the October/November 2003 period of relatively intense solar activity) (Figure 4).

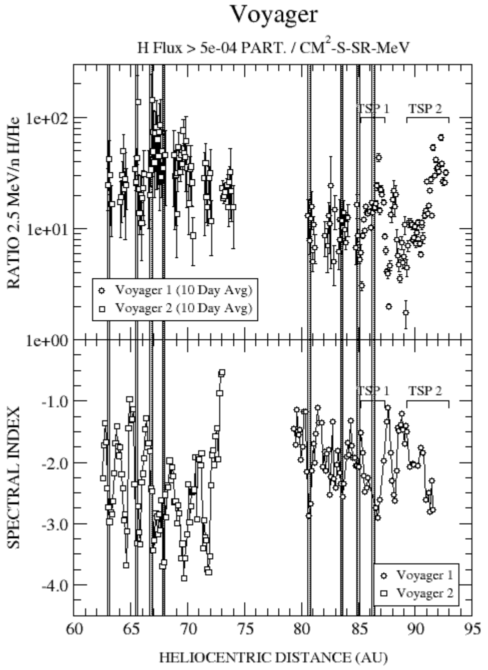

Figure 3. The top panel shows the 2.5 MeV/n H/He ratio. Ratios whose H intensity < 5e-04 Particles/cm^2-s-sr-MeV were excluded. The bottom panel shows the spectral index, γ, (3.3 - 7.8 MeV) over the same time period. The four bands indicate events 1-4 at V2 and events 1-4 time-shifted to V1.

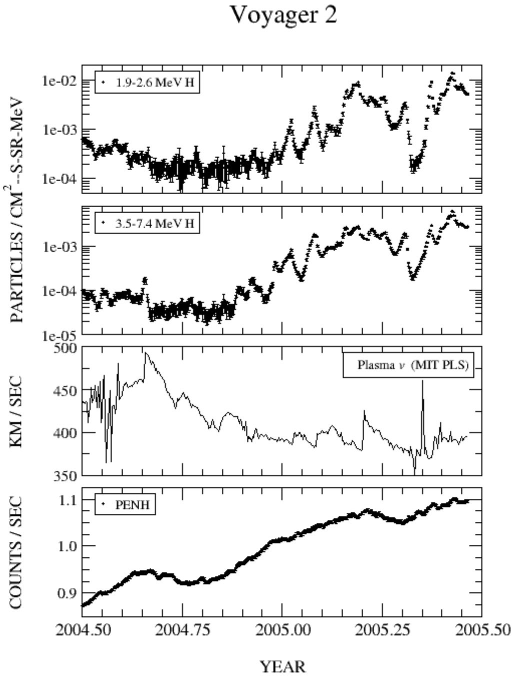

Figure 4. Time-history of Voyager 2 low energy ions and GCR integral rate (CRS) and plasma velocity (PLS) for 2004.5-2005.5 indicating a significant change in the ion increases.

[6] observed that beyond 65 AU, the MIRs discussed here (Figure 2) display large, in-phase fluctuations or speed, density, and magnetic field magnitude that constitute large pressure pulses. This represents a change from the inverse correlation between density and B seen at smaller heliocentric distances. This change should not effect energetic particle acceleration and transport but as [6] note, it should lead to a stronger interaction with the T.S.

References

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