Unusual Enhancements of MeV Ions and Electrons as Voyager 1 Approaches the Heliospheric Termination Shock

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Abstract

In mid-2002 as Voyager 1 moved beyond 85 AU there began an unusual increase of 2.5 MeV ions that remained at a level near 0.1 protons/cm^2-s-sr-MeV for some 6 months. Simultaneously there was an increase in the 2.5 - 70 MeV electrons and in the galactic and anomalous cosmic ray intensity. The electrons are most probably of galactic origin and like the cosmic ray ions are responding to the more favorable modulation levels in the distant heliosphere. It is proposed that the MeV ions are of solar/interplanetary (S/IP) origin with possibly a significant component of IP accelerated pickup ions that have been reaccelerated. Several possibilities for this reacceleration are discussed including the proximity of the termination shock (T.S.).

1. Introduction

The temporal and spatial variations of the different energetic particle populations probe heliospheric structures at distances that can extend far beyond the Voyager spacecraft. Galactic cosmic ray (GCR) ions and electrons traverse the heliosheath and cross the T.S. before interacting with the supersonic solar wind. The T.S. is also the most probable acceleration site for anomalous cosmic rays (ACR) [1] and the local reacceleration of GCRs [2] and may also play a role in further accelerating the S/IP ions associated with the GMIRs that sweep across it [3]. Increases in the intensity of these diverse energetic particle populations are one of the most probable harbingers of Voyager's approach to the T.S..

2. Observations

Starting near 2002.52, two of the cosmic ray telescopes on the Voyager 1 CRS experiment (Cosmic Ray Subsystem, E. C. Stone, P.I., [4]) observed an increase in the intensity of low-energy electrons (Fig. 1) that persisted for some

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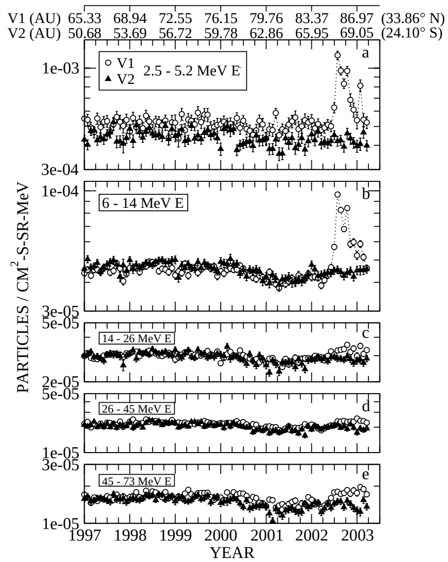
six months. The time history of 2.5 MeV H after 2002.5 is similar to that of the 10 MeV electrons both at the beginning of the event and for the shorter-term variations (Fig. 2). Over this period the ACR 48 MeV He intensity increases by a factor of 1.5 while the Pen L rate (70 - ∼300 MeV H, He > 70 MeV/n) increases by 15% (Fig. 2). The short term variations of these two components are similar and in a general way resemble those of the MeV ions and electrons. There is no evidence for the passage of even moderate interplanetary disturbances until 2003.09.



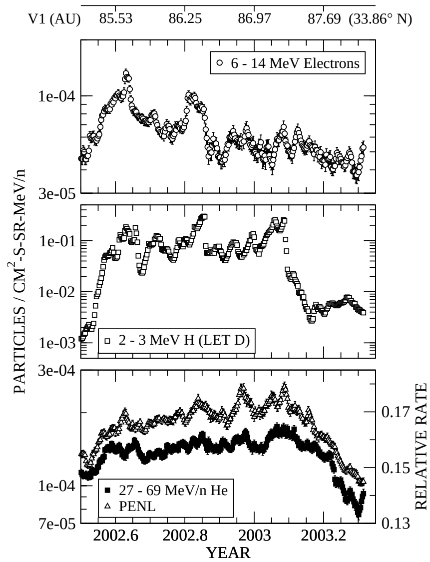


Fig. 1. (Left) Time histories (26 day averages) of the V1 and V2 electron intensities.

Fig. 2. (Right) V-1 time histories of the intensities (5 day mov avg) of 6 - 14 MeV electrons, 2.5 MeV H, and 48 MeV/n ACR He+ and the Pen L relative rate.

From 2000.8 - 2003.2 there is a series of six well-defined but modest enhancements of MeV protons at V-2 that occur at a quasi-periodic rate of ∼140 days and persist on the average for 0.3 years (∼4 solar rotations) (Fig. 3). Five of the events are closely associated with increases of 100 km/s in the solar wind speed which can be identified with specific periods of solar activity and which produce transient decreases in the GCR and ACR intensity levels. At V-1, events I - IV are observed after a delay on the order of 0.2 years corresponding to a solar wind speed of 420 km/s. For the first 3 events the V-1 peak intensity on the average is 40% of that at V-2 giving a mean radial intensity gradient of -5.5%/AU.

The V-1 event beginning in 2002.5 (Fig. 2, 3) persisted for more than 6 months at an intensity level that is at least 20 times, and sometimes 500 times greater than that at V-2. Such a feature has not been previously observed.

At V-1 the cosmic ray decreases associated with events I and III (Fig.

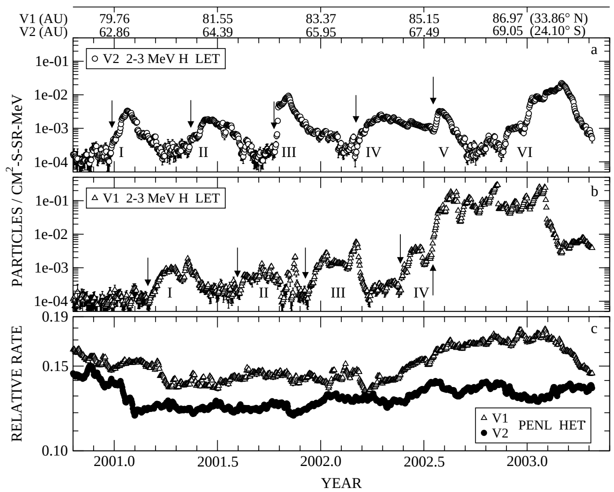


Fig. 3. V-1, V-2 time histories (5 day mov avg) of 2.5 MeV H, and the Pen L rate.

3) are comparable to those at V-2. It is not possible to identify any significant interplanetary disturbance in the V-1 cosmic ray data in the 9-month period from 2002.3 to 2003.09. However, beginning in 2003.09, the 2.5 MeV H intensity decreased by a factor of ∼50 in two steps in coincidence with similar but smaller decrease in the Pen L rate (Fig. 2, 3) -indicating the passage of an interplanetary disturbance which was probably produced by the increased solar activity in July, 2002. For 2.5 MeV H this reduced level is still larger than the V-1 plateau intensities of events I-III.

3. Discussion

Over the past 17 years the largest increase in 2.5 MeV ions (Sept. 1991, 46AU) was some 3x larger than that observed in 2002. If this latter increase was treated as being of solar origin then applying the radial gradient correction (-5.5% AU) between 86 and 46 AU would make the 2002 V-1 increase 3x larger than that of 1991. The 1991 event produced the largest neutron monitor Forbush decrease ever observed at 1 AU, a large transient decrease at V-1 and long-lasting radio emission from the region beyond the T.S. [5,6,7]. There have been similar MeV electron events of S/IP origin observed at V-2 (30 AU) over the 1989 - 1991 period but they had large negative radial gradients and were barely detectable at V-1, then only some 10 AU further out [8].

We suggest two possible interpretations of the V-1 ion and electron enhancements.

(1) There is a reduction in the modulaton level in the distant heliosphere in mid-2002 as shown by the simultaneous increase of GCRs, ACRs and MeV ions and electrons. The 2.5 - 70 MeV electrons most probably are of galactic

origin and establishes that very low rigidity particles can travel from the termination shock to V-1. At this time the 2.5 MeV ions observed after 2002.54 are the S/IP ions from events IV and V (as identified at V-2) that have been reaccelerated at the termination shock. The 2003.09 decrease in GCRs, ACRs and MeV ions and electrons is exactly what would be expected from the passage of a small to moderate interplanetary disturbance through a pre-existing population of these components. The earlier commonality of short term changes would be their response to much smaller transients.

There are two major difficulties with this interpretation:

(i) The peak of the ACR He intensity at this time is near 25 MeV/n compared to the value of 6.5 MeV over the 1998 solar minimum-suggesting there is still significant modulation between V-1 and the T.S. *(ii)* There are periods of very large anisotropies in the MeV H ion data, which is predominantly field aligned, that flow in the direction away from the Sun.

(2) *A second possible interpretation* of these observations is that the MeV-proton increase is associated with the heliospheric current sheet and the stream interaction region at the edge of a coronal hole. The tilted current sheet is carried outward by the solar wind, arriving at Voyager 1 about one year after leaving the Sun. Using an average speed of 400 to 450 km/s, it is projected that the current sheet tilt and the edge of a polar coronal hole were in the vicinity of Voyager 1 at 34° N during the last half of 2002. This suggests the possibility of acceleration or flux compression associated with the velocity shear at the interaction of the fast wind in the coronal hole with the slow solar wind near the current sheet. A correlation between shorter duration MeV-proton enhancements and extensions of a polar coronal hole has been reported from earlier observations at radial distances of 11 to 20 AU [9].

The origin of these unusual enhancements of ions and electrons beyond 85 AU should become clearer as Voyager 1 continues to approach the termination shock and as the tilt of the current sheet continues to evolve with declining solar activity over the next several years.

4. References

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