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Voyager Observations of Galactic and Anomalous Cosmic Rays in the Heliosheath and Over the Solar Maximum Period of Cycle 23

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The long term modulation in the distant heliosphere (> 80 AU) and the energetic particle populations observed by Voyager 1 at the termination shock were different from what was expected.

1. Introduction

At 1 AU the onset of modulation for GCR He began at ~1998.28 (Fig. 1), while in the distant heliosphere at V2 (61 AU) it started some two years later at 2000.25. At all three locations (IMP8, V1, V2), solar maximum intensities were reached following the passage of the large-scale interplanetary transient produced by the July 14, 2000 Bastille Day event. At 1 AU the intensity reduction of 265 MeV/n He from solar minimum to solar maximum is reduced by a factor of 4.36, very close to that of cycle 21. At V2 (64 AU) this reduction was 30% and 18% at V1 (81 AU). Following the reversal of the sun's magnetic field in 2000, the 1 AU GCR He intensity is relatively flat from 2001.5-2003.83 with a significant recovery immediately after the large solar events of late October to early November, 2003. Despite the factor of 16 difference in depth of modulation, the relative changes at V2 in the distant heliosphere over the plateau period and through the initial increase are similar in form to those observed at 1 AU.

At V1, some 17 AU beyond V2, the GCR and ACR intensity changes are significantly different. The differences are associated with the appearance of termination shock particle (TSP) events at V1 starting in 2002.54 [1, 2]. After this time, these large increases of low energy ions and electrons were a durable feature of the distant heliosphere. The first TSP increased persisted for some six months, followed in 2003.7 by a second year-long increase. These TSP events are highly variable, have relatively flat energy spectra, frequent periods of streaming along the expected direction of the interplanetary magnetic field and a charge composition at low energies resembling that of anomalous cosmic rays as defined by the high O/C ratio [2, 3, 4]. Two of the distinctive features of these events are the associated increases of relativistic 1-15 MeV electrons and the strong modulation of the ions and electrons at V1 by transient disturbances moving out in the IP medium. These TSPs are believed to have their origin at the Termination Shock (TS) and occur at times when there is a good magnetic connection between V1 and the TS shock. The V1 energetic particle observations represent a sample of the GCRs and ACRs at the TS.

The increases in 10 MeV electrons and 42-69 MeV H (TSP 1, Fig. 2) are clearly related to the TSP events. This, along with their impulsive nature and streaming (as discussed in Voyager related papers presented at this conference), clearly suggest that these particles have their origin (or reacceleration for electrons) at the TS. The increases in the intensity of 30-56 MeV/n He and 130-220 MeV H (Fig. 2, 3) at V1 and of the gradients are also consistent with acceleration or reacceleration at the TS.

On 2004.96, Voyager 1, at 94 AU and $\lambda = 34°$ N, crossed the heliospheric TS and entered the heliosheath where it has remained over the past 6 months. The Voyager 1 Galactic Cosmic Ray (GCR) and Anomalous Cosmic Ray (ACR) observations, at this particular location on the TS, have been quite different than expected, and from what was observed in the TSP events at energies above several MeV/n.

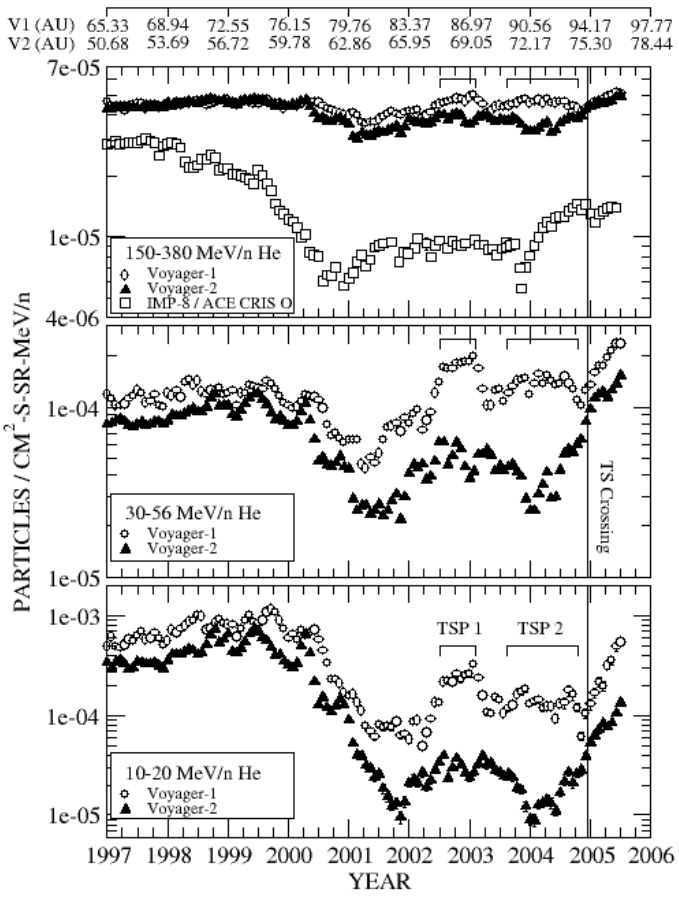

Figure 1. The GCR and ACR He intensities (26 day averages) for 1997.0 – 2005.5.

A more detailed look (5 day moving averages) of GCR and ACR H and He and 10 MeV electrons is shown in Fig. 2 for the 2001.0-2005.5 period.

At the termination shock crossing, the ACR H and He and 10 MeV electrons (Fig. 2) were well below both their expected intensity levels and what had been observed over TSP 1 and 2. However, there is a steady increase in all five V1 components (Fig. 2) that started in 2004.88, some 30 days before the TS crossing.

The radial intensity gradients (Fig. 3) for GCR He and H from 1997-2005.5 are well behaved and peak about the time the Bastille Day MIR reaches the TS. The V1/V2 265 MeV/n GCR He gradients are reasonably constant over the extended solar minimum period and decrease as the recovery from solar maximum conditions begin and with the approach and crossing of the TS.

The 130-220 MeV H and 30-56 MeV/n ACR He gradients are larger than expected and show significant structure. The increase in these gradients begins before the onset of TSP 1, due to intensity decreases seen at V2 but not at V1, and the decrease, around 2003.25, coincides with the interval between TSP 1 and 2. The 2nd peak in early 2004 is associated with TSP 2. The gradient data and the time histories shown in Figs. 1 and 2 suggest that 30-56 MeV/n He and the higher energy protons increase in TSP 1. Contrary to expectations, gradients decrease as the TS is approached.

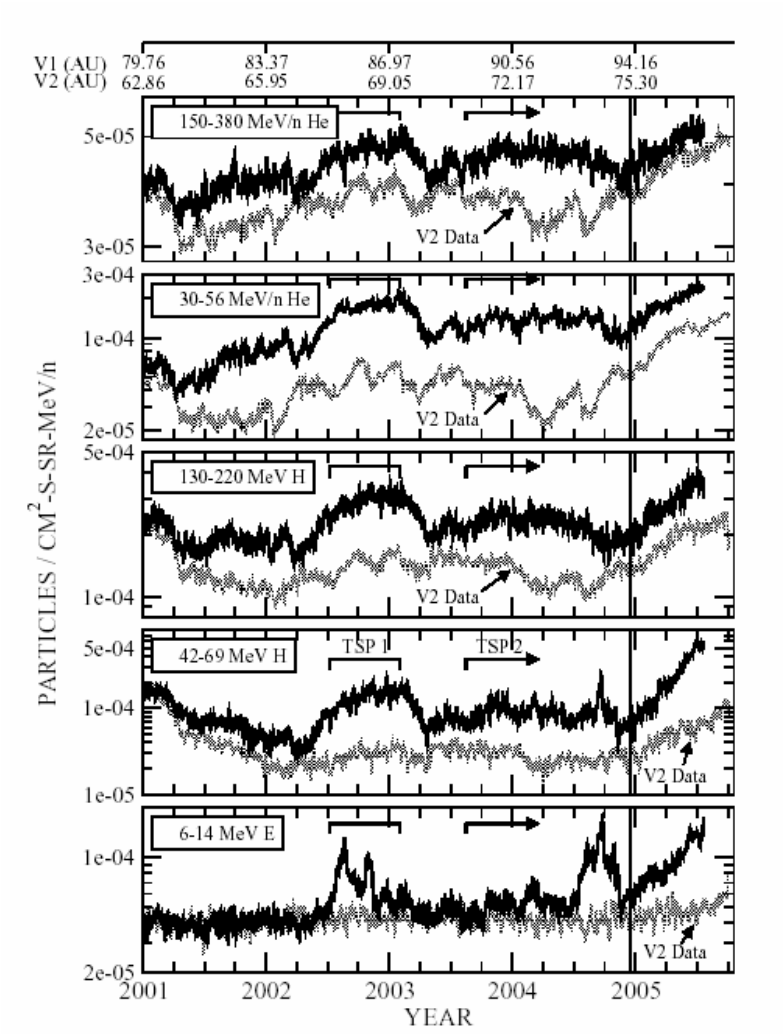

Figure 2. A detailed look at the temporal variations (5 day moving averages) of GCR and ACR H and He as well as Termination Shock Particle (TSP) events. In each panel the Voyager 1 data is the upper heavy line while the Voyager 2 data is the lower, lighter line. The vertical line at 2004.96 marks the Voyager 1 TS crossing time. A convection correction of 0.2 years has been applied to the Voyager 2 data. The GCR 130-220 MeV H may have some ACR H contamination.

2.Discussion

Where were these energetic particles when Voyager 1 crossed the TS?

Were they removed by the large MIR associated with the Halloween events and subsequent activity?

Are the particles being accelerated at a different location on the TS – the equator or the polar region?

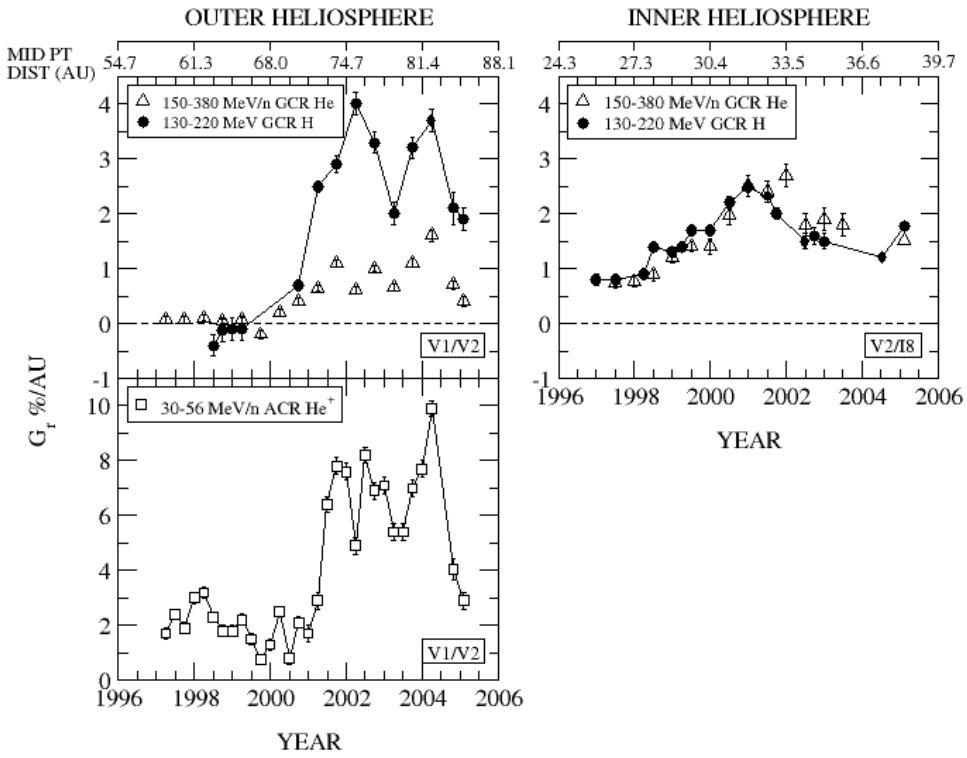

Figure 3. Radial intensity gradients from 1997.0 – 2005.0. A convection correction has been applied. The last 2 V1/V2 G_r values are at 2004.82 and 2005.32, just prior and some 4 months after Voyager 1 crossed the TS at 2004.96.

The smooth ACR and GCR recovery following 2004.88 establishes that modulation conditions play a dominant role.

The very small modulation observed at V1 from solar minimum to solar maximum suggests that the modulation in the heliosheath did not change significantly over that portion of cycle 23.

Future Expectations: The recovery process will go on toward solar minimum. Voyager 2 is still in the region of supersonic flow, and things should be much clearer by the next ICRC!

References

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