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Determining the Scale Size of the Heliosphere Using Global Cosmic Ray Transient Decreases

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Abstract

Large global transient cosmic ray decreases and their associated shocks are observed to move outward in the heliosphere past the IMP, Voyager and Pioneer spacecraft. At least two of these, the one observed at the Earth in July, 1982 and the other in May, 1991 apparently interacted with the Heliopause (HP) some 410 days later as evidenced by the low frequency radio emission detected on the Voyager spacecraft. These time delays were used to estimate a distance to the HP and thus the scale size of the heliosphere. On April 5, 1998, a large global cosmic ray transient decrease was observed at IMP. This transient was observed at Voyager 2 (56.5 AU) ~209 days later and Voyager 1 (72.4 AU) ~250 days later. We use the time delays and the relative amplitudes of these decreases to estimate the distance to the Heliospheric Termination Shock (HTS) and the HP.

1. Introduction

Two large low frequency radio events have been observed from the Voyager spacecraft since their launch in 1978, (Gurnett et al., 1993). The first radio event had its onset around day 215 in 1983, and the trigger for this event was probably the intense solar activity that produced disturbances that passed the Earth on DOY 195 in 1982, some 400 days earlier. The second radio event had it onset around DOY 200 in 1992 and the trigger for this event was probably the intense solar activity that produced disturbances that passed the Earth around DOY 150 in 1991, some 410 days earlier. The timing of the large cosmic ray transient decreases associated with these disturbances as they propagated outward past the V1, V2 and P10 spacecraft between 10 and 50 AU played an important role in understanding the origin of these radio events (Van Allen and Fillius, 1992, Webber and Lockwood, 1993). From these studies it was concluded that the largest radio events probably result when these disturbances reach the heliopause (HP), thus leading to a distance to the HP ~120-150 AU, an effective scale size of the heliosphere (Gurnett, et al., 1993).

On April 5, 1998, a very large cosmic ray transient decrease, the first of the new solar cycle, was observed at the Earth. The magnitude of this transient decrease was >20% in the >70 MeV rate used for these studies, comparable to the earlier transients that were later observed as radio events. This transient has now been observed (much weaker) at V2 at 56.6 AU, some 209 days later, and V1 at 72.5 AU, some 250 days later, (implying a propagation speed ~500 km/s). These locations are much further out in the heliosphere than for any of the earlier cosmic ray decreases, and the propagation times are ~0.5 of those associated with the earlier radio events. These events are thus important for our understanding of the scale size of the heliosphere. In what follows we will examine both the magnitudes of these decreases as they move outward in the heliosphere and their relative time delays to estimate the location of the HP and also the HTS.

2. Data Analysis and Results

We consider the time history of the April 5, 1998 event and how it fits into the time scales of the earlier cosmic ray and radio events. Figure 1 shows the 5 day running average of the >70 MeV rate at IMP and V2. The onset is clearly observed to occur on April 5, 1998 (DOY 92) at IMP and DOY 300 at V2. Figure 2 shows a possible sequence of times as the disturbance moves outward past the HTS and encounters the HP. The propagation speed is determined to be 0.29 AU/day or 500 km/sec, slower than the previous cosmic ray transients producing radio events. Note that, given the timing out to V1 at 72.5 AU, this disturbance should reach a distance ~90 AU on day 45 of 1999, and ~100 AU on day 80 of 1999. These are within the range of possible locations of the HTS and one should look carefully at the low frequency radio data and at the various cosmic ray energy channels including anomalous cosmic rays for possible signatures of this encounter. As the shock continues to move outward at a slower speed (assumed here to be 0.7 of the average speed inside the HTS) it would encounter the HP if it is located at ~130 AU, on day 230 of 1999. A schematic of the sequence of times Δt for the earlier two radio events and the recent event is shown in Figure 3 where these times are all referenced to the total time, T, from the trigger to the time the radio signal is observed. A radio signal near the expected time in 1999, implying a total transit time ~500 days for this latest event, will confirm the location of these points on the figure and lead to a more precise measure of the HP location.

Next we examine the amplitude of these transient cosmic ray decreases as they move outward in the heliosphere. Earlier it was observed that this amplitude appeared to decrease almost linearly with distance out to ~30 AU (Webber, Lockwood and Jokipii, 1986). Now we can extend this study to much greater radial distances using the April 1998 transient as well as the cosmic ray transient in 1991. The results on the radial dependence of the amplitude of the 3 largest transients are shown in Figure 4 referenced to the amplitude observed at Earth. There is considerable variability in this amplitude, but it is clear that this amplitude decreases in a roughly linear fashion with distance approaching zero at distances ranging from ~80-110 AU. It is as if these transients had a built-in knowledge of a scale size of this order.

3. Summary and Conclusions

The large transient cosmic ray decrease observed at the Earth on April 5, 1998, and some 210-250 days later in the outer heliosphere between 56 and 72 AU, provides valuable information on the scale size of the heliosphere. Using the relative amplitudes of this transient and two earlier transients at various heliocentric distances one can determine that this amplitude decreases in a linear fashion with distance. The distance at which this amplitude becomes zero, 80-110 AU, serves as a reference for the scale size of the cosmic ray modulation region around the sun. The time sequence of events associated with this transient as it propagates into the outer heliosphere beyond 72 AU, in conjunction with the known time delays associated with the two earlier low frequency radio events, is important for refining estimates of the distance to the heliopause. If radio emission is observed in conjunction with this latest event near the predicted time in August, 1999, the distance to the HP should be determined to within ±10 AU.

References

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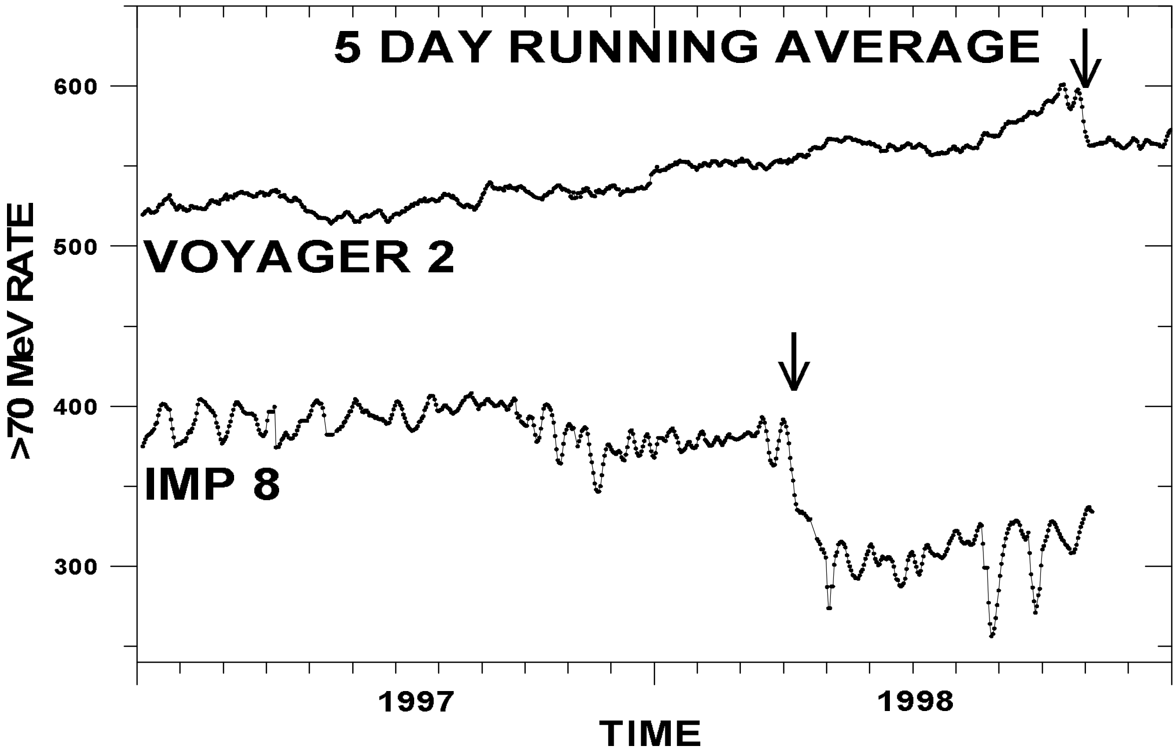

Figure 1. Five day running average counting rates of >70 MeV particles at IMP and V2 in 1997 and 1998 showing the onset of the large transient decrease at 1 and 56.5 AU.

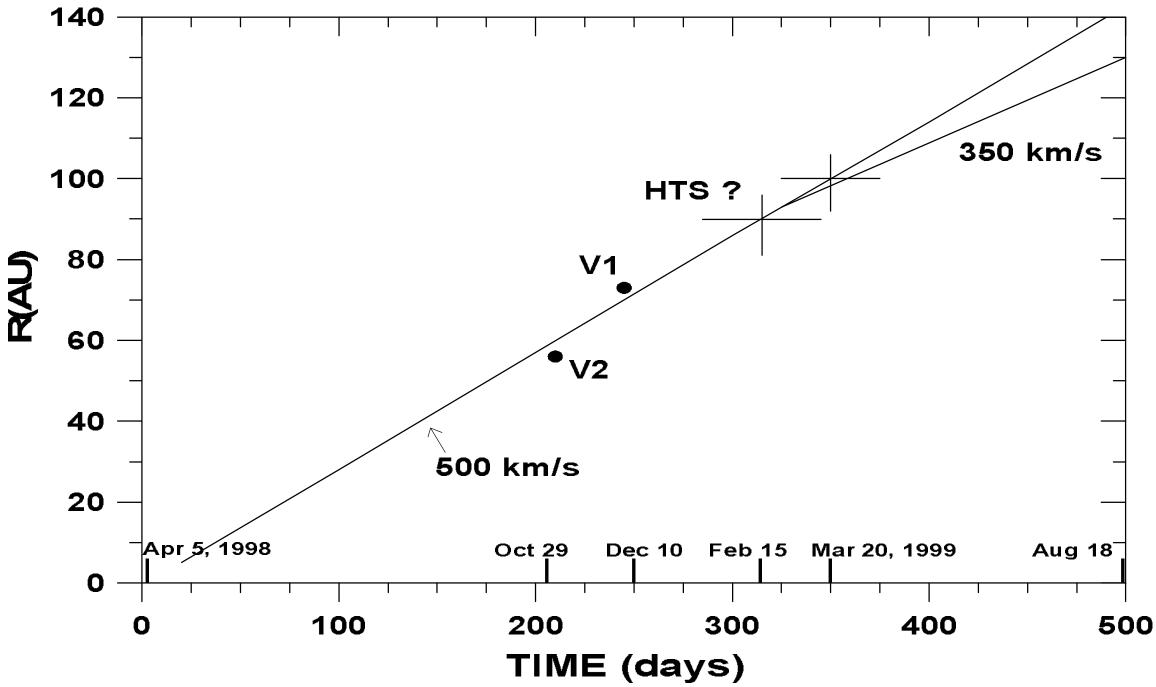

Figure 2. Possible sequence of events following the large transient decrease observed at the Earth on April 5, 1998. Propagation speed of 500 km/s is measured between IMP and V1 and V2. HTS location assumed to be between 90-100 AU, and the propagation speed beyond the HTS assumed to be 350 km/s.

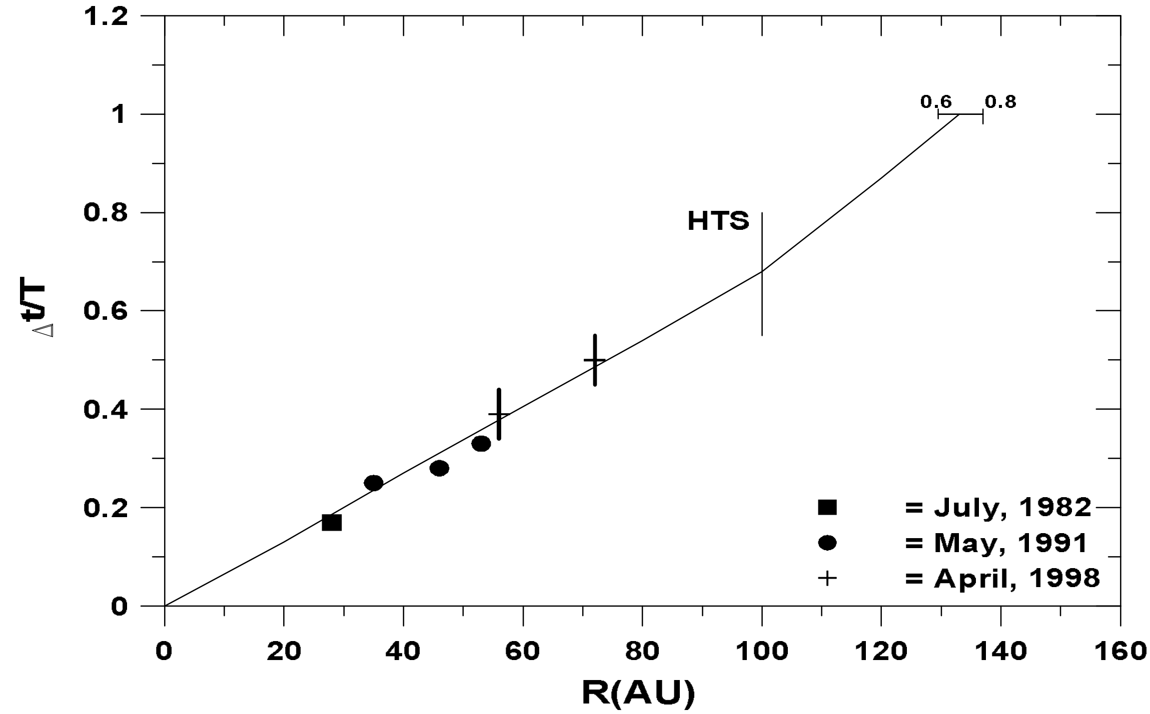

Figure 3. Fraction of time from trigger to time for radio emission to begin, Δt/T≡1.0, and for the transient disturbance to reach the location of Voyager and Pioneer spacecraft as determined by the cosmic ray decrease, for the three events indicated. A projection is made of the April, 1998 event to first arrive at the HP in 500 ± 50 days and produce radio emission. The solid line is a best fit for all three events out to the HTS. A decrease in speed of 0.3 is assumed to occur at the HTS which is taken to be at 100 AU.

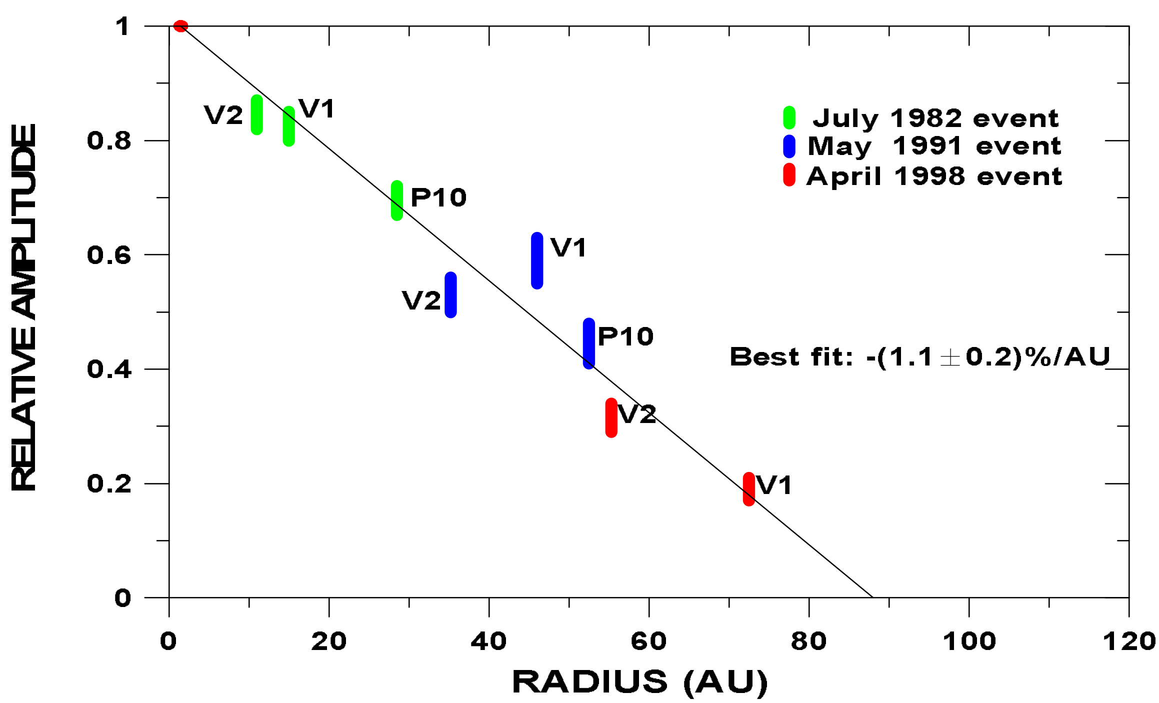

Figure 4. Relative amplitude of 3 large transient decreases at IMP, V1, V2 and P10.