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Intense Magnetic Fields Observed by Voyager 2 during 1998

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Abstract

A region of relatively intense magnetic fields with a radial extent of ≈ 13 AU was observed by Voyager 2 (V2) from approximately DOY 264 – 312, 1998. The heliocentric distance of V2 was R = 55.9 – 56.3 AU and its heliographic latitude was δ = -19.4° to -19.6°. The galactic cosmic ray intensity dropped following the passage of the MIR, so that the MIR acted as a barrier to these particles. A broad region of enhanced low energy protons (1.8 – 2.8 MeV) was observed ahead of the MIR, consistent with the idea that protons were swept up by the MIR but could not penetrate through it. No shock was observed in that region, suggesting that the particles were accelerated by shocks elsewhere and/or by non-linear waves related to jumps in the bulk speed.

1 Introduction:

Voyager 2 (V2) has been making observations of heliospheric particles and fields from 1 AU in 1977 to 56 AU in 1998. This paper will discuss data obtained from calendar day (DOY) 200 – 350, 1998, when Voyager 2 was at a radial distance of 56 AU and at a latitude δ = -19.6° south of the heliographic equator. The observations that we consider are the magnetic field strength B, the solar wind speed V, the intensity of cosmic rays with energies greater than 70 MeV/nucleon, and the flux of energetic protons with energies in the range 1.8 – 2.8 MeV.

Previous studies showed that extended regions of intense magnetic fields (Merged Interaction Regions, MIRs) form beyond several AU as a result of merging produced by stream interactions (Burlaga et al., 1985; Burlaga, 1995; Whang, 1991). In the region between ≈ 10 AU and ≈ 43 AU there was a close relation (the CR-B relation") between the change in the cosmic ray intensity and the magnetic field strength. When B is larger than average for a given year, the local cosmic ray intensity decreases at a rate proportional to B, and when B is less than average the cosmic ray intensity increases. MeV particles can be accelerated by shock waves in the heliosphere (Decker et al., 1991) and step-decreases in the cosmic ray intensity are associated with long-lasting enhancements in MeV particles (McDonald et al., 1994). From one to several AU there is generally a relation between B and the solar wind speed, but the nature of this relation evolves with increasing distance. At ≈ 43 AU there is little correlation between V and B profiles during the declining phase of the solar cycle (Burlaga et al., 1997). The purpose of this paper is to examine the relations among B, V, cosmic ray particles and 1 MeV particles at 56 AU during 1998 when solar activity was increasing.

2 Observations:

The observations made by Voyager 2 from day 200 to day 350, 1998 are shown in Figure 1. The top panel shows 24-hour averages of the PENH rate, which represents the galactic cosmic rays >70 MeV/n. The second panel shows 24-hour averages of the magnetic field strength for days 264 to 312.

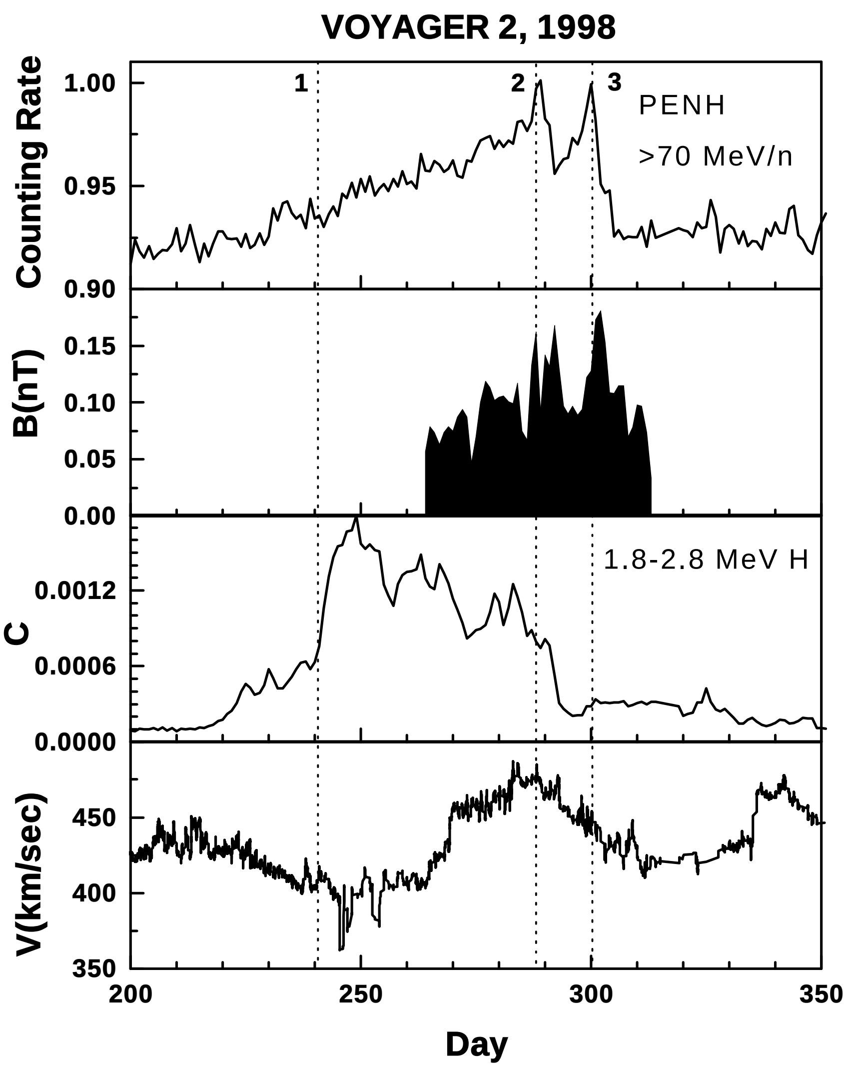

Figure 1: This figure shows Voyager 2 observations from DOY 200 to 350, 1998. From top to bottom the panels show measurements of the cosmic ray intensity, the magnetic field strength, the low energy protons, and the solar wind speed.

The third panel in Figure 1 shows 24-hour averages of the flux of protons with energies in the range 1.8 – 2.8 MeV, the units of C being particles/cm^2-s-sr-MeV/n. The bottom panel of Figure 1 shows the bulk speed measured by the MIT instrument on Voyager 2.

The magnetic field intensity tends to decrease with increasing distance roughly as 1/R, although the solar cycle variations of the solar magnetic field strength and the latitude/solar cycle variations in V produce significant deviations from this simple law in accordance with Parker's model (Burlaga et al., 1998; Parker, 1963). Thus, at 56 AU one expects the magnetic field strength to be of the order of 6/56 ≈ 0.1 nT. The field strength is smaller than the simple law predicts near solar minimum and at higher latitudes where the speed is higher than average. Based on two decades of experience with the Voyager magnetic field data, we estimate that one cannot obtain accurate measurements of the magnetic field when $B < 0.05$ nT. The field was weak at Voyager 2 during most of 1998, so that the only meaningful measurements available at present are those from DOY 264 – 312, 1998, when the magnetic field was relatively strong. This paper focuses on the relation between these intense magnetic fields (which for the most part form a MIR) and the other observations listed above. The V2 magnetic field observations are at times influenced strongly by a noise signal generated in the spacecraft telemetry system, so that the preliminary observations discussed below may contain an additional uncertainty of the order of 25 – 50%. This noise is not present in Voyager 1 data.

The relatively strong magnetic fields from DOY 264 – 312 demonstrate the presence of a MIR. From the average speed of the material in this region, 448 km/s, we estimate that its radial extent was ≈ 13 AU. These intense fields are possibly related to an increase in solar activity and a step-like decrease in cosmic ray intensity at 1 AU in early April, 1998 (McDonald et al., these ICRC Proceedings). Previous studies showed that from ≈ 10 AU to ≈ 45 AU a MIR is associated with a decrease in the rate at which the cosmic ray intensity is changing. Thus an increasing cosmic ray flux is expected to increase less rapidly when a MIR moves past the spacecraft, and a constant cosmic ray flux is expected to decrease when a MIR moves past the spacecraft. The relation between B and the cosmic ray intensity in Figure 1 is more complicated than expected. The cosmic ray intensity continues to increase rapidly with time as the front of the MIR passes. This increase is unusual, and it might represent a new effect, distinct from the usual recovery (McDonald et al., these ICRC Proceedings). The intensity begins to decrease only when the B exceeds 0.15 nT, as shown by the vertical dashed line marked “2”. When the magnetic field intensity drops below 0.1 nT, the cosmic ray intensity increases for several days. Finally, when B exceeds 0.15 on day 300 (marked by the vertical dashed line marked “3”) the cosmic ray intensity drops appreciably to a plateau. Thus, the MIR does appear to act as a barrier to the cosmic rays, and there is the expected qualitative relationship between the cosmic ray intensity when the magnetic field is higher than average in the MIR. However, the profile relation is quantitatively different from that which one would compute from the CR-B relation. This departure from the CR-B relation could be the result of several factors, including the limited interval of magnetic field observations, increased uncertainties in the magnetic field measurements, and new dynamical phenomena at distances as large as 55 AU.

A broad increase in the intensity of low energy (1.8 – 2.8 MeV) protons was observed between DOY 240 and 292, in front of the MIR. In the region between a few AU and ≈ 30 – 40 AU, increases in particles of this energy are associated with shock waves, as discussed by Decker et al. (1991) and McDonald et al. (1994). Preliminary results indicate that there was no shock at V2 during the interval of enhanced low energy protons in Figure 1. The hypothesis that particles might be accelerated by a nonlinear wave associated with the jump in V in Figure 1 should be examined. However, the results in Figure 1 are consistent with the more conventional idea that the low energy particles were swept up by the MIR and could not effectively penetrate through the strongest fields of the MIR.

The relation between B and V in Figure 1 is not that which one observes at 1 AU. Close to the sun B is highest in the region of increasing V and is relatively low in the region of decreasing V. At this large distance, the magnetic field is most intense in the trailing part of the stream and weaker (but still stronger than average in the region of increasing speed.). It has been noted previously that the relation between B and V at large distances can be very different from that at smaller distances (Burlaga et al., 1997; Whang, 1991). Theoretical models show how the interaction of streams can greatly modify the relation between B and V at increasing distances from the sun.

3 Summary:

A Merged Interaction Region with a radial extent of ≈ 13 AU was observed by Voyager 2 at 56 AU during 1998. This MIR was followed by a drop in the cosmic ray intensity. There is some correlation between the strongest fields in the MIR and the changes in the cosmic ray intensity, but the CR-B relation does not describe the relation between B and the cosmic rays as well as it did in earlier years and at smaller distances. This limitation in the CR-B relation might reflect new properties of the magnetic fields and cosmic rays at 56 AU, uncertainties in the magnetic field measurements or both. The MIR was preceded by a broad (≈ 50 day) period in which the 1.8 – 2.8 MeV proton intensity was enhanced. It is possible that the MIR swept up particles accelerated by shocks closer to the sun. The enhancement of low energy particles was also associated with a jump in the speed, suggesting that one should consider the possibility that pickup protons can be accelerated by nonlinear waves that have a jump in B but are not necessarily shocks.

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4 References

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