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Voyagers 1 and 2 observe a GMIR and associated cosmic ray decreases at 61 and 82 AU

L. F. Burlaga[1], **N. F. Ness**[2], **and F. B. McDonald**[3]

[1]Laboratory for Extraterrestrial Physics, NASA/GSFC, Greenbelt, MD 20771, USA
[2]Bartol Research Institute, The University of Delaware, Newark, DE 19716
[3]Institute for Physical Science and Technology, University of Maryland, College Park, MD 20742, USA

Abstract. Voyager 2 (V2) observed a Global Merged Interaction Region (GMIR) during the year 2000, when V2 was located near 61 AU and 21.5° south heliographic latitude. This GMIR produced the first major step-like decrease in the cosmic ray intensity in the distant heliosphere during solar cycle 23. Voyager 1 (V1) observed a similar step-like decrease in the cosmic ray intensity near 82 AU and 33.7° north, approximately two months after the event seen at V2. The step decrease at V1 was produced by the same GMIR that was observed by V2. The maximum magnetic field strength in the GMIR was near 0.2 nT, but the field strength fluctuated, indicating that the GMIR was a cluster of strong fields. The magnetic field enhancement in this GMIR is smaller than in the GMIRs observed by V2 closer to the sun, possibly owing to the relatively high thermal pressure of pickup protons in the high-density regions. The radial extent of the GMIR was >15 AU at V2 and ≈30 AU at V1.

1 Introduction

Voyager 2 (V2) and Voyager 1 (V1) have been making observations of heliospheric particles and fields since 1977. This paper will discuss V2 and V1 data obtained during the year 2000, in solar cycle 23. We shall consider data from 1) V2 at a radial distance R = 59.8 to 62.2 AU and at a heliographic latitude δ = -21.0 to -21.9° south and from 2) V1 at R = 80.1 to 83.4 AU and at δ = 33.7 to 33.8° north. The observations that we consider are the magnetic field strength B and the intensity of cosmic rays with energies greater than 70 MeV/nucleon.

At large distances, where the heliospheric magnetic field is weak, the V2 magnetic field data are contaminated by magnetic fields produced by the spacecraft. After ≈1985, V2 magnetic field data are also contaminated by quasi-periodic oscillations observed in the magnetic field with periods of the order of ≈ 2 to 10 hours that are associated with the spacecraft telemetry system. There are two magnetometers mounted on a boom, the primary magnetometer at the end of the boom and the secondary magnetometer closer to the spacecraft. Typically, the heliospheric magnetic field strengths observed by the two magnetometers differed by less than 0.05 nT during the early years of the mission. Thus, we consider only data for which the difference σ in the 24-hour averages of magnetic field intensity measured by the primary and secondary magnetometers is $\sigma < 0.05$ nT.

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., 1984, 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 at a constant rate.

Step-like decreases in the cosmic ray intensity which propagate into the outer heliosphere at the solar wind speed were observed by McDonald et al. (1981). Earlier studies showed that the step-like decreases in the cosmic ray intensity are related to and presumably caused by Global Merged Interaction Regions (GMIRs), which are MIRs that extend over a wide range of longitudes around the Sun and extend to high latitudes (Burlaga et al., 1993). The purpose of this paper is to examine the relation between the first major step-like decrease observed during solar cycle 23 in the distant heliosphere and the magnetic field strength measured by V2 and V1.

Correspondence to:
L.F. Burlaga (u2leb@lepvax.gsfc.nasa.gov)

2 Observations

The cosmic ray observations made by V2 from year 2000.0 to 2000.8 are shown in the top panel of Fig. 1. The data are 24-hour observations of the counting rates of the galactic cosmic rays >70 MeV/n from the experiment of Stone et al. (1977). A step-like decrease in the cosmic ray intensity was observed by V2 beginning ≈2000.31 and ending 2000.53; the passage time is ≈3.1 solar rotations. On the scale shown in Fig. 1 the decrease in cosmic ray intensity appears rather broad, but on a scale of a solar cycle (11 years, ≈ 155 solar rotations) such a decrease does appear abrupt. Figure 1 shows the first step-like decrease observed by V2 in the distant heliosphere in solar cycle 23.

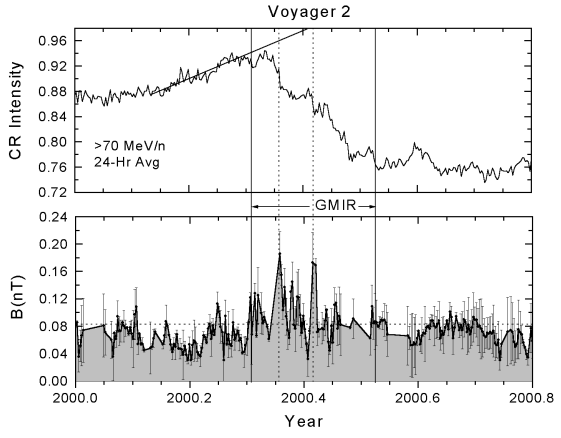

Fig.1. This figure shows 24-hr averages of Voyager 2 observations near 61 AU. The top panel shows the cosmic ray intensity > 70 MeV/nuc, and the bottom panel shows the magnetic field strength.

The magnetic field strength observations from the experiment of Ness et al. (Behannon et al., 1977) made by V2 from year 2000.0 to 2000.8 are shown in the bottom panel of Fig. 1. These observations are plotted as solid circles in Fig. 1 and Fig. 2, and straight lines connect the points. The data selection criterion produces data gaps that are evident by the absence of dots and by relatively long lies connecting some successive dots. Estimates of the uncertainties in the measurements are indicated by the bars through the data points with lengths equal to $\pm\sigma$.

A region of enhanced magnetic field (a MIR) was observed in association with the step-like decrease in the cosmic ray intensity beginning ≈2000.308 (doy 113) and extending to at least 2000.46 (doy 168) and possibly to 2000.525 (doy 192). Thus, the MIR acts as a barrier to the cosmic rays. The passage time of the MIR corresponds to a radial extent of ≈15 to 20 AU. The width of the MIR might extend throughout the 56-day duration of the step-decrease, but we do not have reliable magnetic field data for the latter part of the step-decrease. We shall show below that V1 also observed a MIR and a step-like decrease in cosmic ray intensity after an appropriate delay, so that V1 and V2 were probably observing a single GMIR.

The cosmic ray observations made by Voyager 1 from year 2000.08 to 2001.0 are shown in the top panel of Fig. 2.

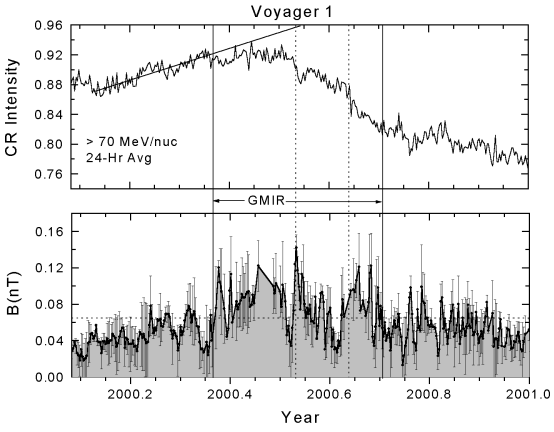

Fig.2. This figure shows 24-hr averages of Voyager 1 observations near 82 AU. The top panel shows the cosmic ray intensity > 70 MeV/nuc, and the bottom panel shows the magnetic field strength.

The data are 24-hour observations of the counting rates of the galactic cosmic rays >70 MeV/n from the experiment of Stone et al. (1977). A step-like decrease in the cosmic ray intensity was observed by V1 beginning ≈ 2000.37 and ending ≈ 2000.71, which is ≈4.8 solar rotations. Figure 2 shows the first step-decrease observed by V1 at ≈ 82 AU in the distant heliosphere in solar cycle 23, and it corresponds to the step-like decrease observed by V2 at ≈ 61 AU discussed above.

The magnetic field strength observations made by Voyager 1 from year 2000.08 to 2001.0 are shown in the bottom panel of Fig. 2 in the same format as in Fig. 1. A GMIR was observed in association with the step-like decrease in the cosmic ray intensity beginning ≈ 2000.37 (doy 134) and extending to at least 2000.71 (doy 259). The passage time of the GMIR is ≈4.8 solar rotations, corresponding to a radial extent of ≈30 AU.

Given an estimate of the uncertainties in B, we can draw several additional conclusions about the relation between B and the cosmic ray intensity from Fig. 1 and Fig. 2. First, the GMIR consists of clusters of strong fields, rather than a single broad region of strong fields. Second, the step-like decreases in the cosmic ray intensity are not smooth decreases, but they contain some relatively large and abrupt decreases, each of which is related to a localized peak in B. Third, prior to the step-decreases, B was relatively low and the cosmic ray intensity was increasing. Fourth, following the step-decreases the cosmic ray intensity was relatively constant and the magnetic field strength was near average. This type of behavior (decreasing cosmic ray intensity when B is relatively strong, increasing cosmic ray intensity when B is relatively weak, and constant cosmic ray

intensity when B is near average) has been observed by V2 and V1 for many years, beginning at approximately 11 AU in 1981 (Burlaga et al., 1985).

3 Summary

1. A Global Merged Interaction Region was observed by Voyagers 2 and 1 at ≈61 AU and ≈82 AU, respectively, during 2000. This GMIR produced the first step-like decrease in the cosmic ray intensity observed in the distant heliosphere during solar cycle 23.

2. The GMIR and step-like decrease in cosmic ray intensity occurred later at V1 than at V2, the time delay being approximately the propagation time of the GMIR from V2 to V1 at the solar wind speed.

3. There is a correlation between the strongest fields in the GMIR and the changes in the cosmic ray intensity which is qualitatively the same as that described by the CR-B relation (decreasing cosmic ray intensity when B is relatively strong, increasing cosmic ray intensity when the magnetic field strength is relatively weak, and constant cosmic ray intensity when B is near average).

4. The radial extent of the GMIR was ≈15 - 20 AU at V2 and ≈30 AU at V1.

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