The Effects of the Intense Solar Activity of March/June 1991 Observed in the Outer Heliosphere

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ABSTRACT

The properties of the large scale Global Merged Interaction Region(GMIR) generated by the intense solar events of March and June 1991 with their marked south-north assymetry are studied using the available solar wind, interplanetary magnetic field and energetic particle data from the observing network of Pioneer 10 and Voyager 1 and 2 in the outer heliosphere.

1. INTRODUCTION

Following periods of enhanced solar activity, long-lived (> 0.5 years) increases in the flux of MeV ions are observed in the outer heliosphere, generally in conjunction with step decreases in the intensity of galactic and anomalous cosmic rays. These changes in the low and high energy particle populations are produced by the passage of large scale disturbances known as Global Merged Interaction Regions (GMIRs). Originally identified by Burlaga et al. (1984, 1985, 1993), GMIRs evolve with increasing heliocentric distance through the coalescence of interplanetary shocks associated with coronal mass ejections and high speed solar wind streams. They are a major element in producing the long-term 11 year cosmic ray modulation. (McDonald et al. 1993).

In December 1990, some 17 months after the period of maximum solar activity in cycle 22 there began a new increase in activity that culminated with 35 major flares (x-ray classification M-5 or higher) in March 1991, nearly all of which came from 3 active regions in the southern hemisphere of the sun. Over the next several months there was a dramatic decrease in this activity but in June, the premier active region of cycle 22 appeared in the northern hemisphere producing in a single passage 6 X-class flares, major solar energetic particle increases and one of the largest Forbush decreases ever recorded (Webber & Lockwood, 1993).

The isolated occurrence in time of these 2 major episodes of solar activity, their marked north-south asymmetry and the large increase of low energy ions and decreases in the galactic cosmic ray intensity in the outer heliosphere offer a unique opportunity to study the generation of GMIRs, their relation to cosmic-ray modulation and the acceleration and transport of low energy ions. These questions are explored in this paper using the solar wind, interplanetary magnetic field and energetic particle data available from the Pioneer and Voyager deep space missions.

2. OBSERVATIONS

The Pioneer 10 and Voyager 1/2 spacecraft constitute an excellent network for studying the spatial and temporal variations of these events in the outer heliosphere. In mid 1991 P-10 (52.4 AU) and Voyager 2 (35.3 AU) are near the plane of the ecliptic but separated by 153° in heliolongitude. Voyager 1 (45.8 AU) at a heliolatitude of 33°N extends a 3-dimensional perspective to these studies.

In the outer heliosphere the large number of SEP events observed at 1 AU in March and June 1991 merge into a single entity that for MeV ions extends over a six month period (Fig. 1). At P-10 and V-1 this is the largest low energy particle increase seen in cycle 22 while the Voyager 2 peak intensity is about the same as that produced by the late 1989 activity (McDonald & Selesnick 1991). The time histories of these 1991 events are remarkably similar at all three of the widely separated locations but there are also important differences. The overall structure of the low energy particle increase at all 3 spacecraft reflects the merging of the 2 different periods of activity. For the V-2 and P-10 data the 3 principal peaks in the solar wind velocity have been identified and labeled a, b and c. For V-1, the peaks in the MeV ion data were used to identify these features.

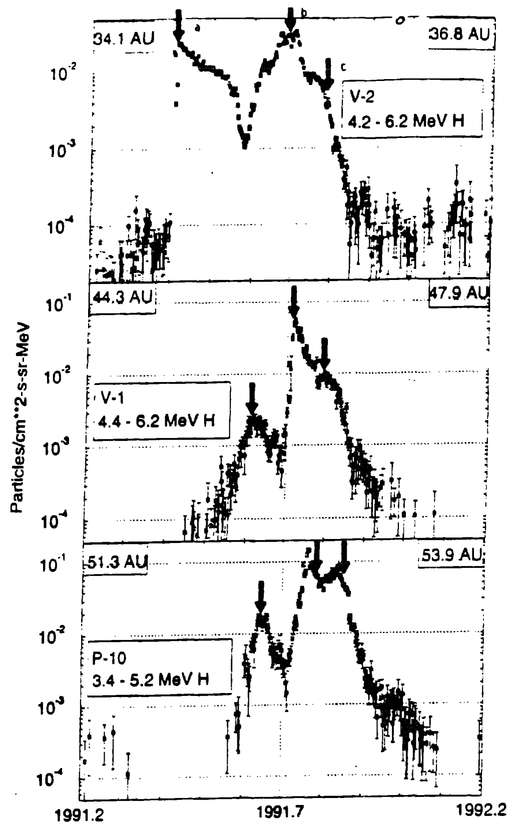

Fig. 1: The 3 arrows in each panel mark the location of the a,b and c peaks at the 3 spacecraft. These peaks were defined by the major increases in the plasma velocity at P-10 (Fig. 2) and V-2 (Fig. 3) and by the peaks in the MeV ion data at V-1 (Fig. 4)

At P-10 beyond 50 AU, there is a close correspondence between the profile of changes in the solar wind speed and the time history of 3.4-5.2 MeV H (Fig. 2). In particular, the coincidence between the 2 major peaks ("b" and "c") in the solar wind speed with maxima in the energetic particle intensity confirms the existence of an on going acceleration processes.

In the V-2 data at 35 AU the GMIR as defined by the MeV ions and the integral cosmic ray intensity changes is contained between the "a" and "c" peaks in the solar wind velocity (Fig. 3). The onset is characterized by a very rapid rise in the intensity of low energy particles in association with an increase in the solar wind velocity from 365 to 590 km/s and a factor of 3 increase in the interplanetary magnetic field — almost certainly signifying the passage of a strong interplanetary shock. However most of the higher energy activity is associated with the "b" peak where a X4 increase in the interplanetary magnetic field produces the maximum intensity in the 30-56 MeV protons, a small increase above background of 2-8 MeV electrons and a large decrease in the galactaic cosmic ray intensity. The subsequent decrease in the MeV ion intensity and the recovery of the cosmic-ray intensity tracks the decrease in the solar wind speed in the "c" peak.

At λ = 32°N, the V-1 MeV ion intensity for the "a" peak is an order of magnitude smaller and the rise-time is longer than at V-2 while the V-1 "b" MeV ion peak is comparable to that of V-2 and with a much faster rise time (Fig. 4). The time history of the 30-56 MeV ions at V-1 resembles a 1 AU energetic storm particle event except on a time scale of days instead of hours. This relatively sharp feature suggests that these higher energy particles result from the interaction of the ambient low energy ions with the a strong shock associated with the "b" peak as Lopate(1989) has suggested previously for these more energetic ions.

The passage of event "a" interrupts the recovery of galactic cosmic rays at P-10

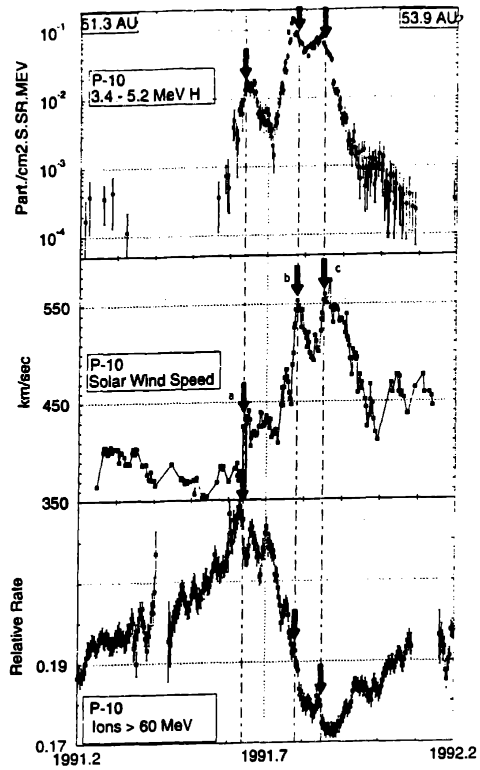

Fig. 2

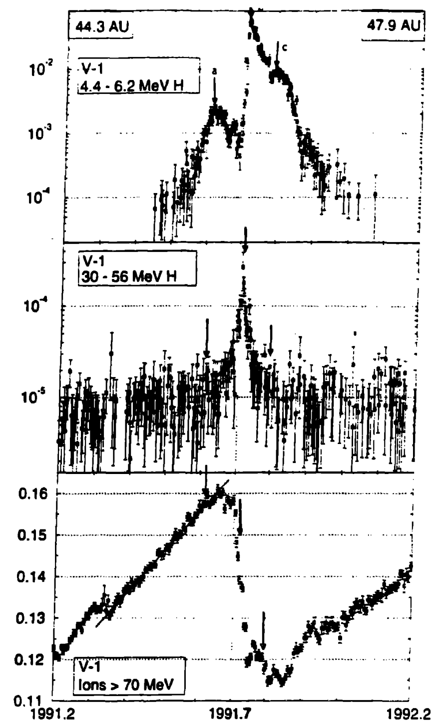

Fig. 4

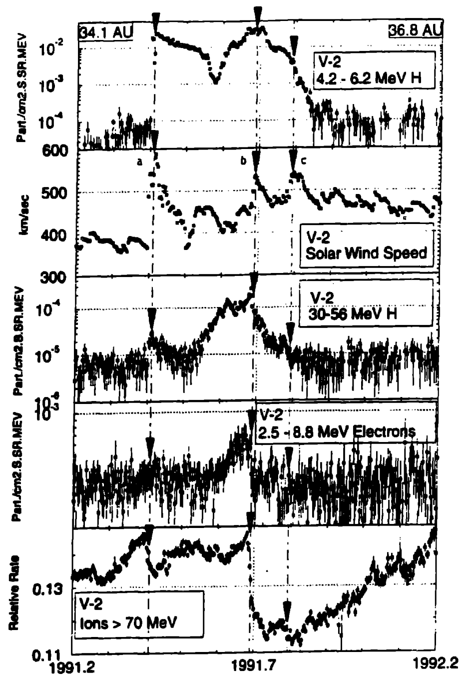

Fig. 3

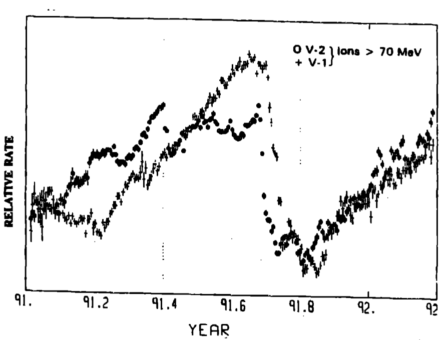

Fig. 5

and V-2 (Fig. 2,3) but it arrives later and has a much smaller effect at V-1. Events "b" and "c" produce a 23% decrease at P-10 and V-2 and a 28% deacrease at V-1. However, the net effect of the GMIR on the galactic cosmic ray intensity was the same at all 3 spacecraft. The integral rate at the 2 Voyager spacecraft (Fig. 5) were comparable at the beginning of 1991 and after the passage of the "b" and "c" disturbances as well as during the ensuing recovery period. The relatiave changes reported here are in accord with the previous reports on P-10/11 by Van Allen and Fillius (1993) and Webber and Lockwood (1993) on P-10 and V1/2.

The H rigidity spectra at the "a" peak confirms the lower intensity and softer spectrum at V-1. For the "b" period the intensity at all 3 spacecraft is essentially the same from 2-60 MeV with a spectral form that is consistent with an exponential in rigidity. The almost identical fluxes seen at all 3 spacecraft solar events is regarded as fortuitous and probably reflects the relative location on the Sun of the coronal mass ejections. These rigidity spectra are in accord with the model for shock acceleration by corotating interaction regions combined with the effects of adiabatic deceleration proposed by Fisk and Lee (1980).

3. CONCLUSIONS

The combination of solar wind, magnetic field and energetic particle data confirm the concept of the formation of large scale disturbances, a GMIR, moving out in the solar wind. The inferred structure of this disturbance reflects the asymmetry in solar activity with the March events in the southern hemisphere having a very limited effect at V-1 at $\lambda = 32°$N but the cumulative effect on the integral cosmic ray intensity is the same at all 3 spacecraft. At both V-2 and P-10 the GMIR coincides with the prolonged period of enhanced plasma velocity and the MeV ions having a profile similar to that of the solar wind speed. The galactic cosmic rays respond in a more global fashion. As observed in the outer heliosphere the combination of these disturbances does not represent a closed shell but should evolve into one at larger distances.

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5. REFERENCES

Burlaga, L.F., F. McDonald, N.F. Ness, R. Schwenn, A.J. Lazarus, and F. Mariana, *J. Geophys. Res.*, **89**, 6579, 1984

Burlaga, L.F., F.B. McDonald, M.L. Goldstein, and A.J. Lazarus, *J. Geophys. Res.*, **90**, 12,027, 1985

Burlaga, L.F., F.B. McDonald, N.F. Ness, *J. Geophys. Res.*, **93**, 1, 1993

Fisk, L.A., and M.A. Lee, *Astrophys. Jour.*, **237**, 620, 1980

Lopate, C., *J. Geophys. Res.*, **94**, 9995, 1989

McDonald, F.B., and R.S. Selesnick, *Proc. 22nd ICRC*, **3**, 189, 1991

McDonald, F.B., N. Lal, and R.E. McGuire, *J. Geophys. Res.*, **98**, 1243, 1993

Van Allen, J.A., and R. Walker Fillius, *Geophys. Res. Lett.*, **19**, 1423, 1992

Webber, W.R. and J.A. Lockwood, to be published *J. Geophys. Res.*, 1993