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LONGITUDINAL DISTRIBUTION OF COSMIC RAYS IN THE HELIOSPHERE

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ABSTRACT

The longitudinal distribution of cosmic ray intensity has been examined during the years 1974-1976 when the persistent high speed solar wind stream structures produced a well-ordered inner heliosphere. Solar wind velocity is mapped back to the sun and compared with cosmic ray intensity which is represented relative to the solar rotation average. Low solar wind velocity is observed to be a necessary, but not sufficient, condition for the occurrence of higher cosmic ray intensities at 1 AU. These relative enhancements cover a restricted range of heliographic longitudes and persist for several solar rotations. The observed solar wind and cosmic ray intensity relationships are consistent with a simple model suggested here in which cosmic ray modulation is very weak in the inner heliosphere, sunward of the first shock crossing on each field line and more intense in the outer heliosphere.

1. Introduction. The extremely well-ordered and persistent high speed solar wind stream structure during the years 1974 through 1976 provide us with a unique opportunity to compare cosmic ray intensity with solar wind velocity. Earlier studies [1, 2, 3, 4] have shown that no simple relationship exists at 1 AU; but, direct correlations between velocity and intensity may hold only over restricted time periods. The very persistent streams in the ecliptic plane that resulted from extensions of the solar polar coronal holes in the years 1974-76 provide us with a new perspective in which the relative cosmic ray intensity changes over restricted longitude ranges may be compared because the average cosmic ray intensity was only changing slowly over the time scale of many solar rotations. This quasi-equilibrium in the cosmic ray intensity is disturbed during the rest of the solar cycle by transient phenomena related to solar activity; hence the choice of this period for study.

2. Observations. The solar wind data used in this study were from the near-earth observations in the Omni Tape of J. King (NSSDC) supplemented with the isolated data points available from Pioneers 6 through 9. The solar wind observations were mapped back to the sun using the approximation of radial propagation at constant velocity as described in [5, 6]. Each solar wind observation is assumed to have originated at the subsolar point and propagated to the spacecraft with the observed speed. The emission longitude from the sun is therefore $\phi_E = \phi_o - \Omega_\odot R/V$

where ϕ_o is the subsolar longitude at the time of observation, $\Omega_\odot$ is the solar sidereal rotation rate, R is the heliocentric radial distance of the observing spacecraft and V is the solar wind velocity. Each of the observed velocities was assigned to the mapped longitude, which is also the foot point of its field line, and plotted in Figure 1 at the emission time (t_E) resulting from the constant velocity approximation $t_E = t_{OBS} - R/V$, where t_{OBS} is the observation time. The near-earth cosmic ray intensity was determined from the CPME experiment on IMP-8. The M scintillator channel responds to all ions $\gtrsim$ 35 MeV/nuc. Details of the CPME experiment are contained in [7]. Each M scintillator observation was associated with the mapped heliographic longitude of the solar wind observed at the same time. These cosmic ray intensities were then plotted in Figure 2 as a function of ϕ_E and t_E. The intensities are represented as the ratio to the average intensity at all longitudes with the same emission day (i.e., each vertical cut through Figure 2 averages to a value of 1.0).

3. Discussion and Conclusions. The cosmic ray intensity in Figure 2 shows relative enhancements over restricted ranges of heliographic longitude that extend over several months in 1975. The largest increases are seen between 150-240° in April through June and 270-330° in September through December. These correspond to the regions between the high speed streams seen in Figure 1. Similar periods are found in the 1974 and 1976 data as well. The 1975 data are shown here because they are free of large solar flare effects and Forbush decreases which disturb some of the solar rotation averages during high activity periods in 1974 and 1976. However, there are well defined cosmic ray enhancement periods during each of the years in the study period. During each of the cosmic ray enhancements, the observed solar wind velocity is low. These enhancements tend to fall in the gaps between the high speed streams and near the edges of the stream seen at 1 AU. However, low solar wind velocity is not always associated with enhanced cosmic ray intensity on the corresponding field lines within the study period. Thus, low solar wind velocity appears to be a necessary, but not sufficient, condition for relative cosmic ray enhancements of restricted azimuthal size that persist for several solar rotations.

The relationship between solar wind velocity and cosmic ray intensity during the interval 1974-76 can be clarified by referring to the solar wind mapping in Figure 3. This is an R-ϕ plot with radial distance increasing downward and heliographic longitude increasing to the right, modulo 360°. The line at the top shows the approximate solar wind velocity profile at the high corona that would produce a stream configuration like that observed between April and July 1974. The mapping was constructed using the observed velocities in May 1974. The CIR boundaries in the figure were determined by connecting the appropriate points in the mapped solar wind data from near-earth and Pioneer 11. The field lines were drawn by extrapolating the near-earth velocity outward until it encountered a CIR boundary. The CIR's are shaded and note that beyond ~ 10 AU all field lines from the inner heliosphere have intersected at least one shock. The region of enhanced cosmic ray intensity in May 1974 is shown as the heavy bar at 1 AU centered near 180°. The enhanced cosmic rays are seen on field lines that extend to large radial distances before they intersect a shock. This suggests a very simple model for relative variation of cosmic ray intensities in the inner heliosphere.

In the outer heliosphere, from the heliopause all the way inward to the innermost shock boundary, all of the plasma has been through a shock. Now imagine that this "shocked" plasma defines a uniformly modulating region for cosmic rays. This is the shaded region in Figure 3 and it determines the long term intensity variations throughout the heliosphere. Let the inner heliosphere (where the field lines are visible in Figure 3) modulate the cosmic rays only very weakly. Then we would expect a general pattern in which the relative intensity within a solar rotation at 1 AU would be enhanced on field lines that extend far out into the heliosphere before they encounter a CIR shock boundary. This condition is generally found in the trailing edge of large solar wind streams where the velocity is relatively low. The theoretical implications of this model are discussed by Roelof [8] in this conference.

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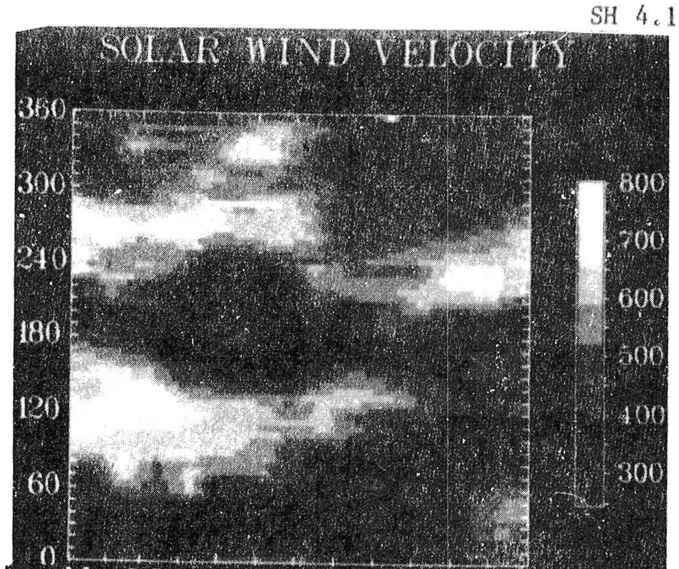

Fig. 1. Solar wind velocity during 1975 expressed as a grey shade from 250-800 km/sec. The data are plotted at the heliographic longitude of the foot point of the field line on which they were observed and at their emission time from the sun.

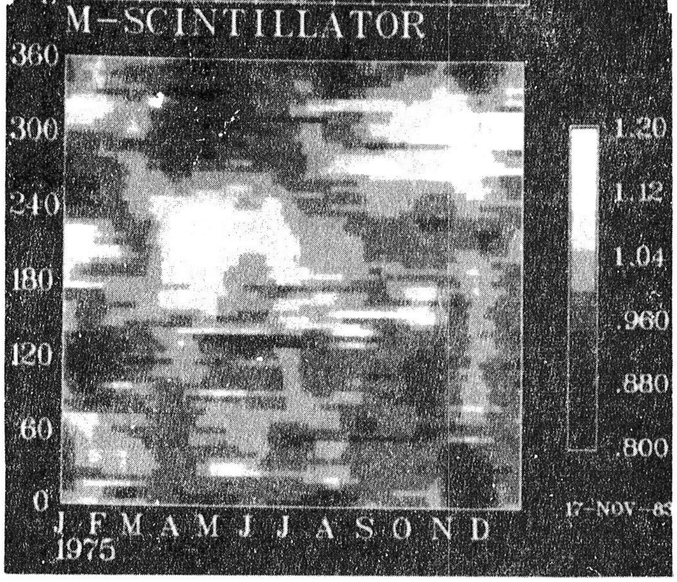

Fig. 2. Cosmic ray intensity ($\gtrsim$ 35 MeV) from the M scintillator channel of the CPME experiment on IMP-8. The data are plotted at the same coordinates as the solar wind velocity observed at the same time. Intensity is expressed as a ratio to the average over all longitudes for the corresponding emission time. Thus any vertical stripe in the figure will average to unity.

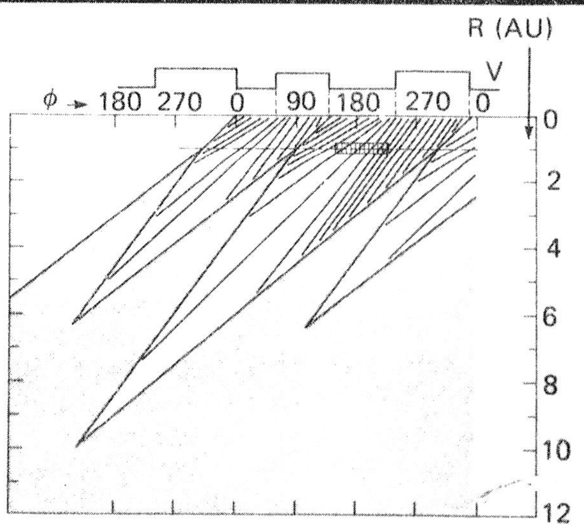

Fig. 3. A radius-longitude plot of the solar wind streams during May 1974. The line at the top is the approximate velocity profile at the sun that would produce the observed speeds at 1 AU. The field lines are extrapolated from the observed solar wind speeds at 1 AU. The shaded area is CIR. The CIR boundaries are reconstructed from Pioneer 11 and near-earth data. The cross-hatched area at 1 AU near 180° shows the region of enhanced cosmic ray intensity.