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The Onset of Solar Cycle 23 at 1 AU and at 70 AU

F. B. McDonald[1], N. Lal[2]. and R. E. McGuire[2]
[1] *I.P.S.T., University of Maryland, College Park, MD 20742, USA*
[2]*NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA*

Abstract

The onset of solar activity at 1 AU began in November 1997 with several modest events and was followed by an enhanced period of solar activity in April and May 1998. This latter series of events produced a well-defined step decrease in the cosmic ray intensity at 1 AU as observed by the Goddard MED experiment on IMP 8. At V-1 (72 AU, 34^{o}N) and V-2 (56 AU, 24^{o}S) there are transient increases in the intensity of 1.8-3 MeV H that mark the passage of a large interplanetary disturbance around 1998.75 that appears to be produced by the April-May activity. However through 1999.36, there is no significant decrease observed in the galactic or anomalous cosmic rays. What is unique about this event in the outer heliosphere is the large precursor increase in the anomalous cosmic ray intensity that appears to be associated with this interplanetary disturbance.

1 Introduction:

Over solar minimum, the effects of solar activity are at their lowest level, the cosmic ray intensity attains its highest level and the influence of gradient and curvature drifts in the large-scale heliospheric interplanetary magnetic field should be most prominent. The onset of a new cycle is marked by increasing solar activity and enhanced modulation of galactic and anomalous cosmic rays. For the solar minimum to solar maximum period of 1977-1980 when the drift-imposed flow of positive ions is inward over the solar poles, the long-term intensity decreases of cosmic ray ions, electrons and the anomalous component occurred through a series of well-defined step decreases that propagated radially outward with a velocity of ~450 km/s (McDonald et al., 1981; McKibben et al., 1982; Lockwood and Webber, 1984). These step decreases in the cosmic ray intensity are produced by large-scale, long-lived interplanetary disturbances known as Global Merged Interaction Regions (GMIRs) [Burlaga, et al., 1984, McDonald and Burlaga, 1997]which are created during solar active times by the coalescence of CME-generated interplanetary shocks and high speed solar windstreams. For the 1977-80 period, drift effects did not appear to be important in the long term modulation of cosmic ray ions (McDonald et al. 1993). However drifts were an important factor in cosmic-ray modulation over the 1987-88 period at the onset of cycle 22 with GMIRs becoming dominant for the 1989-91 period (McDonald et al., 1993; Popielawski, 1995). Such variations of drift effects over successive cycles had been predicted by the detailed simulations of Le Roux and Potgieter (1990).

The onset of significant solar activity in cycle 23 began in April and early May 1998 producing a significant step-like decrease at 1 AU. At this time V-1 is at 70 AU (34.3^{o}N) and V-2 is at 57 AU (22.5^{o}S), making it possible to observe this onset of solar activity at 1 AU and in the distant heliosphere during a qA>0 epoch.

2 Observations:

It is of interest to compare the solar minimum periods and onset of modulation at 1 AU over the last 3 cycles using GCR 180-450 MeV/n He intensities from identical detectors flown on IMPS 6, 7 and 8 (Fig. 1). For all 3 solar minimum periods the intensity levels are remarkably similar despite the completely different nature of the recovery periods. Drifts appear to play a

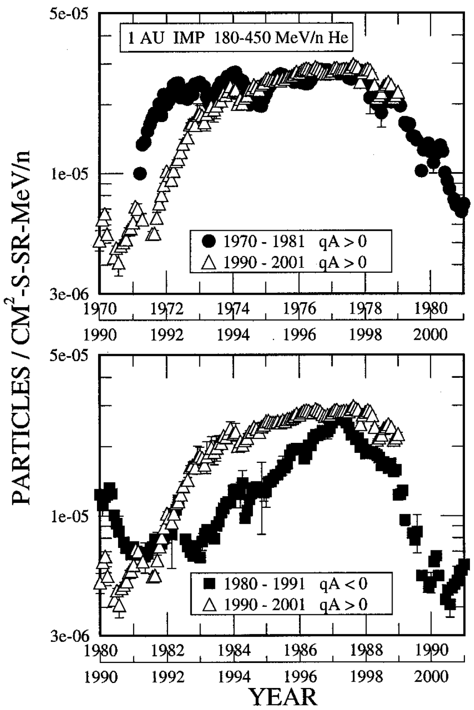

Figure 1: Comparison of time histories (1972-1999.0) (26 Day AVG) for different qA epochs. The intensities are the absolute values as measured with no normalization between data sets.

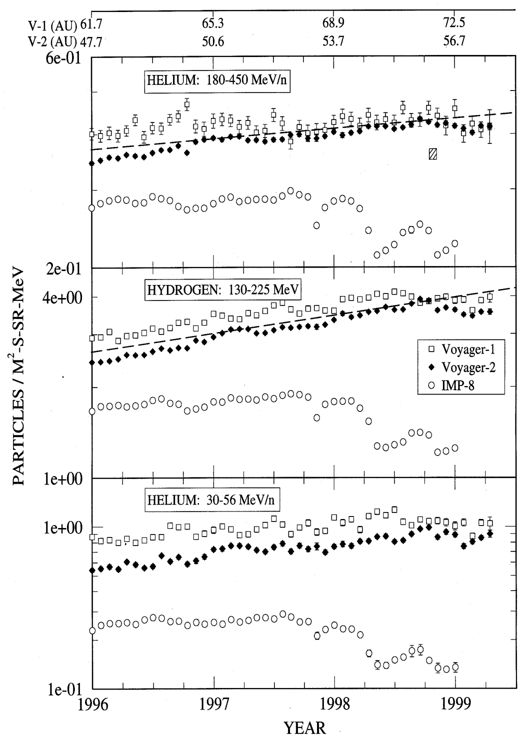

Figure 2: Time histories of 180-450 MeV He, 130-225 MeV He (26 day AVG) for IMP-8, V1 and V2. Dashed-line in upper 2 panels provides a means of estimating the V-2 intensity near 1998.75 in the absence of any interplanetary disturbance.

dominant role over the 1985-1989.0 period but are relatively unimportant for the ion component at similar times in the qA>0 epochs (McDonald et al. 1993). What is also interesting is that the step-like decrease in 1998 is approximately the same magnitude as the 1st step decrease of cycle 21 in 1978. This probably reflects the general pattern of solar activity starting at a low level at the onset of the new cycle.

An expanded plot of this step decrease (Fig. 2) shows that at 1 AU it starts at ~1998.26 with a decrease of 36% in GCR He and 43% in GCR H compared to the 3.6% decrease observed at mid-latitude neutron monitors. In the outer heliosphere there is no corresponding decrease over the expected time interval of 1998.75-1999.0. However there is a flattening in the recovery of the GCR He and of the 130-225 MeV H component (in the outer heliosphere this H component has a substantial contribution from ACR hydrogen). Extrapolation of the observed rate of increase of these two V-2 components from 1996.5-1998.0 provides an upper upper limit of the expected intensity near 1998.75 in the absence of any interplanetary disturbances. This procedure gives an upper limit of the decrease of 10% for GCR 180-450 MeV/n He and 16% for 130-225 MeV H at V-2– substantially smaller than that observed at 1 AU.

However, the low energy 1.8-2.8 MeV H data at V-2 (Fig. 3) shows a well-defined increase at the expected time in association with a small increase in the solar wind velocity (Fig. 3) and with a significant increase in the magnitude of the interplanetary magnetic field (Burlaga et al., SH 3.2.06). There are also similar increases at approximately the same time in the Pen L rate (Protons: 70-200 MeV, He > 70 MeV) and 4-8 MeV/n ACR He. However there is one very

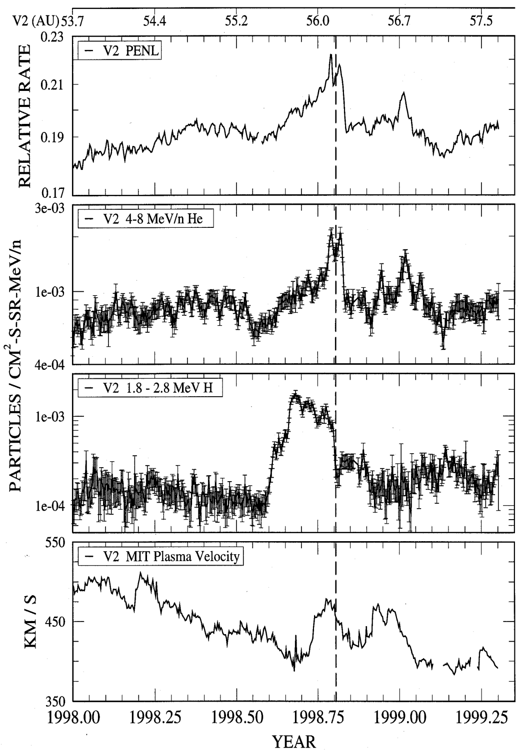

Figure 3: V-2 H and He spectra for peak period (10/06/98-10/30/98) and for an earlier "quiet time".

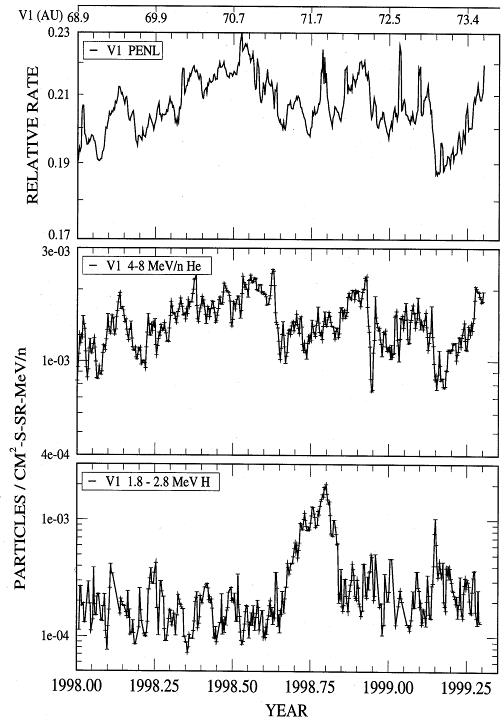

Figure 4: Time history of V-1 Pen L (H 70-200 MeV, He>70 MeV/n) 4-8 MeV ACR He, 1.8-2.8 MeV H and the Solar Wind speed (from the MIT V-2 Solar Wind Experiment

striking difference: the sharp decrease in the 1.8-2.8 MeV H intensity starts some 11 days before that of 6 MeV/n ACR He and the Pen L rate.

A comparison of the detailed H and He spectra (Fig. 5) over the peak period with those of an earlier time in 1998 shows that the He increase is dominated by contributions from ACR He with no significant increase of low energy He (1.8-2.8 MeV) of solar interplanetary origin. There are negligible changes in the higher energy GCR He. The low-energy H spectra is that expected for ions of solar/interplanetary origin and there is a substantial increase in ACR H at higher energies.

At V-1 (34^{o}N) near 72 AU there is also a very similar increase in 1.8-2.8 MeV H (Fig. 4). Using the sharp decrease at the trailing edge of this peak as a timing marker reveals that the interplanetary disturbance passed V-1 some 13 days after V-2 – indicating an average transit time to the distant heliosphere some 25% faster at 34^{o}N than at 22^{o}S. There are no increases in the Pen L and 6 MeV ACR He at V-1 (Fig. 4) corresponding to those present in the V-2 data.

3 Discussion:

The step decreases for cycle 21 and 22 were some 25-50% larger at P-10 than at 1 AU (McDonald et al. 1993). The relatively small decrease at 1 AU and the subsequent significant recovery at all energies (Fig. 2) and the absence of a step decrease in the outer heliosphere is probably a reflection of the relatively weak solar activity over the April-May period which did not lead to the formation of a complete GMIR. Most of the events at the Sun occurred in the southern hemisphere which may account for the difference between the V-1 and V-2 Pen L and 6 MeV/n ACR He increases but does not explain the close similarity of the 1.8-2.8 MeV H increase. From the H and He spectral plots (Fig. 4) it is seen that ACR H and He are the main constituents of the increases in the V-2 Pen L rates and in the 4-8 MeV/n He. These components and the low energy H are being swept out by the interplanetary disturbance as it moves through the outer heliosphere. Further studies are underway to study this process in greater detail.

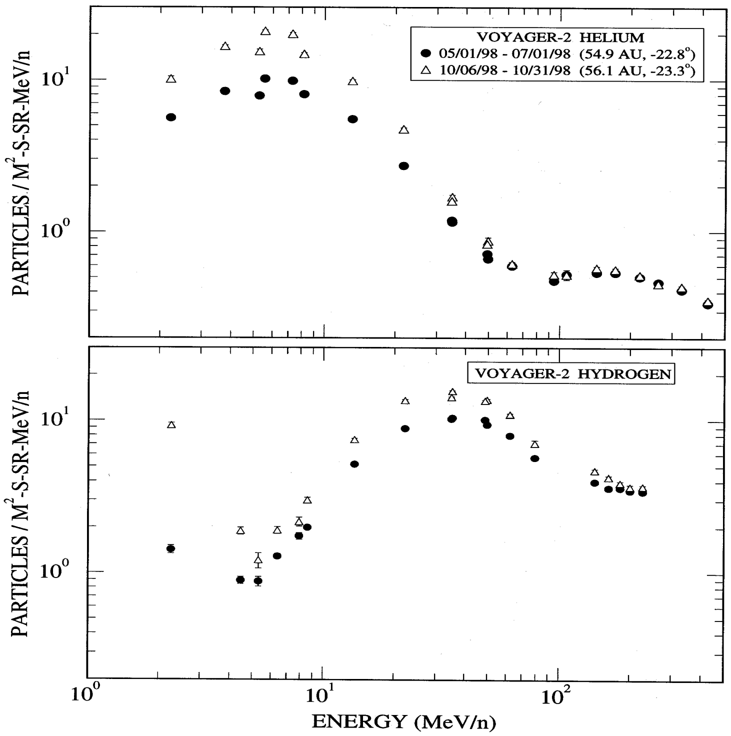

Figure 5: V-2 Time history (24 hr AVG) of Pen L rate, 4-8 MeV/n He and 1.8-2.8 MeV H

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