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LOW ENERGY PROTON BIDIRECTIONAL ANISOTROPIES AND THEIR RELATION TO TRANSIENT INTERPLANETARY MAGNETIC STRUCTURES : ISEE-3 OBSERVATIONS

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1. Introduction. It is known that the interplanetary medium in the period approaching solar maximum is characterized by an enhancement in the occurrence of transient solar wind streams and shocks [1, 2] and that such systems are often associated with looplike magnetic structures or clouds [3, 4]. There is observational evidence that bidirectional, field-aligned flows of low-energy particles could be a signature of such looplike structures [5, 6, 11], although detailed models for the magnetic field configuration and injection mechanisms do not exist at the current time. In this paper we present preliminary results of a survey of low-energy proton bidirectional anisotropies measured on ISEE-3 in the interplanetary medium between August 1978 and May 1982, together with magnetic field data from the same spacecraft.

2. Instrumentation and Analysis. The particle measurements used in this analysis were obtained with the low-energy proton instrument on ISEE-3 [7], comprising three identical solid state detector telescopes oriented at 30°, 60° and 135° with respect to the spacecraft spin axis. Particles are counted in 8 logarithmically-spaced energy channels in the range 35 - 1600 keV, and with the exception of the highest energy channel (1000 - 1600 keV), data accumulated during each spacecraft revolution are sorted into 8 equal azimuthal sectors. Magnetic field measurements were obtained using the vector helium magnetometer [8] onboard ISEE-3.

In order to determine the anisotropy characteristics, the particle data in two channels (35-56 and 620-1000 keV) were first transformed into a frame of reference moving with the instantaneous solar wind velocity. These transformed data were then subjected to a spherical harmonic analysis in order to derive a series expansion of the 3-dimensional spatial distribution [9] from which the instantaneous particle intensity at 0°, 90°, and 180° relative to the positive B-field direction was calculated for each energy channel. The ratios of the harmonic components A_{10}'/A_0' and A_{20}'/A_0' where primed quantities refer to the solar wind frame, were used to define 1st and 2nd order anisotropies, respectively. A bidirectional flow (BDF) is seen as a reduction in the flux at 90° as compared to the fluxes at 0° and 180°, which remain approximately equal; in terms of the anisotropies, a BDF is characterised by a positive 2nd-order anisotropy, together with a 1st-order anisotropy which is close to zero. For the purpose of this study, since we are interested in relatively large scale phenomena, we have not considered BDFs of less than 3 hours duration.

We have examined plots of the magnetic field magnitude and direction for the same period for evidence of isolated, large-scale ($\gtrsim$ 0.1 AU) structures convecting past the spacecraft, in particular for signatures of magnetic clouds as defined in [3]. For those candidate structures having a rotational signature whereby the magnetic field vector rotates progressively in a plane, a minimum variance analysis has been performed to determine the degree of planarity.

3. Results and Discussion. From the 45-month data set used for this study, it was possible to identify 66 periods during which BDFs were present. In all cases, effects due to the bow shock have been excluded. By examining the magnetic field data corresponding to these periods, we have been able to group these BDF events into 5 classes as follows:

I. 19 events associated with a transient magnetic structure having a rotational signature characteristic of a magnetic cloud, which are also related to the passage of an interplanetary shock.

II. 12 events associated with a transient magnetic structure (non-rotational), which are also shock-related.

III. 8 events associated with a transient magnetic structure having a rotational signature, but no shock-association.

IV. 9 events associated with a transient magnetic structure having a non-rotational signature, but no shock-association.

V. 18 events for which no clear transient magnetic structure could be identified.

From the above it is apparent that the majority of the observed BDFs are associated with transient features in the magnetic field, although not all events are related to classical, shock-associated magnetic clouds. In addition, it should be noted that we have identified a number of examples of classical magnetic clouds which have no related BDF signature in the energy range covered by our instrument.

It is beyond the scope of this paper to present examples of all the above event classes in detail; however, in Figs. 1 and 2 we show the combined particle and magnetic field data for two 3-day periods containing a class I and a class III event, respectively. In the upper panels we have plotted the intensity of the 620 - 1000 keV channel (Fig. 1) and the 35 - 56 keV channel (Fig. 2) at 0°, 90° and 180° with respect to the magnetic field direction; the second panel shows the ratio of the second harmonic components A_{20}'/A_0' in the solar wind frame. The three lower panels show the magnitude, elevation and azimuth (in GSE coordinates) of the magnetic field, respectively.

The period containing the class I event starts at 0000 UT on Sep. 28, 1978. At this time, the fluxes seen in all channels are still elevated as a result of the large solar particle event which started 5 days earlier. The intensity in the 620 - 1000 keV channel shows an increase starting at 0700 UT, probably associated with a 2B flare, located at N27, W19 [10] with H_α maximum on Sep. 27, 1442 UT. An interplanetary shock was observed at the spacecraft at 2040 UT on Sep. 28; a second shock passed the earth at 0301 UT on Sep. 29, but was not seen at ISEE-3 due to a data gap. The particle intensity decreased sharply at 0830 UT, coincident with the arrival (presumably) of driver gas and an isolated magnetic structure possessing a clear rotational signature, which persisted until 0330 UT on Sep.30. Throughout this period, bidirectional particle fluxes were observed, as evidenced by the large positive 2nd harmonic

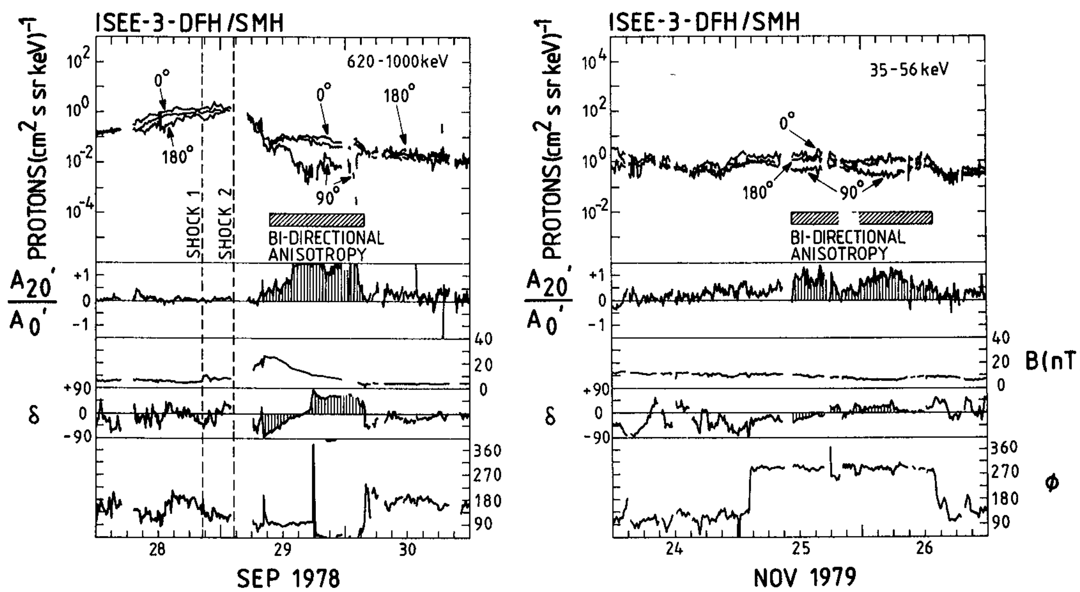

Fig.1. *(left) Proton intensity and anisotropy parameters, and magnetic data for the BDF event of 29 Sept. 1978.*
Fig.2 *(right) As for Fig. 1, for the BDF event of 25,26 Nov. 1979.*

which dominated the anisotropy signature, and the prominent decrease in the flux at 90° relative to the field-aligned component. The particle data at lower energies (not here) show evidence for two separate populations bounded by the discontinuity in the magnetic cloud signature occurring at 1720 UT on Sep. 29.

The 3-day period shown in Figure 2 starting at 0000 UT on Nov. 24, 1979 is characterised by the appearance of an isolated, stable magnetic structure at 0230 UT on Nov. 25, accompanied by bidirectional fluxes. In this example of a class III event, the magnetic signature is less rotational than in the class I event described above. As in the previous case, the bidirectional flow is not continuous at the same level throughout the event, but is interrupted, presumably by the passage of a flux tube separated from the cloud.

In addition to the classification described above, we have examined the statistical characteristics of the complete BDF event set, with the following results:

a) 48 events are associated with isolated, transient magnetic structures, of which 27 show a rotational signature and 10 show a constant field orientation normal to the nominal spiral direction; the remaining 11, while clearly separated from the ambient medium, show no specific directional features. In general, the r.m.s. noise in the field seems to be smaller when bidirectional fluxes are present.

b) The distribution of BDF event durations is presented in Fig. 3, the average duration being 15 hours. In 20% of the cases, the BDF persisted for more than 24 hours, and the longest event observed had a duration of 50 hours. In terms of the spatial extent of the structures supporting the flows, the above data imply an average scale size of ~0·15 AU, with a maximum of 0·5 AU if we assume a nominal solar wind velocity of 400 km/s.

c) 37 events followed the passage of an interplanetary shock, with a separation in time of, on average, 19 hours. This statistic should be treated with caution, however, since in several other events, the observed BDF may have been related to a shock which passed the spacecraft more than 40 hours previously.

d) For 41 events, the amplitude of the 2nd harmonic at 35 keV is comparable to, or greater than, that at 620 keV.

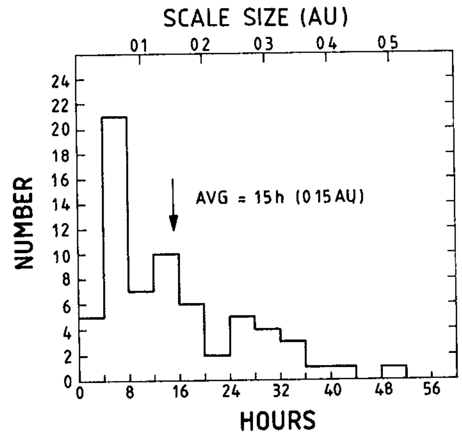

***Fig.3.** Distribution of BDF event durations. Scale size shown for solar wind vel. = 400 km/s.*

Taking into account the relative propagation times for 35 and 620 keV particles together with point d) above, we suggest that, while undoubtedly fitting the data for a number of (in particular) class I events, the commonly proposed model (e.g. [11]) in which particles are confined in a simple, large-scale magnetic loop with mirroring occurring in the high-field regions close to the Sun cannot explain all our BDF observations. Given the uncertainty in the 3-dimensional field geometry within magnetic clouds which still exists, we cannot rule out effects of a more localised nature giving rise to the observed anisotropies, particularly for events having relatively short duration. The qualitative correlation between the degree of quietness of the magnetic field and the presence of bidirectional flows is clearly of importance, and will be addressed in a future paper.

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