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Simultaneous low energy particle enhancements detected upstream of the Earth's Bow Shock on SOHO and Interball

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Abstract

Multiple particle enhancements (primarily proton signatures) in the energy range (E = 44-750 keV) were detected by the LION instrument aboard SOHO in that period following launch (December 1995) until at least the end of the first two months after spacecraft injection into a Halo Orbit about the L1 point (February 1996). A sequence of two such proton enhancements recorded simultaneously by LION and by the DOK-2 detector aboard Interball (range 20-800 keV) on March 27, 1996 between 0200 and 1200 UT when Interball was, like SOHO, upstream of the Earth's Bow Shock and when the magnetic field was nearly radial, are presented in this paper. It is suggested on the basis of their similar characteristics that the particle events recorded at the two spacecraft had, in each case, a common origin.

1 Introduction:

One of the intriguing characteristics of the Earth’s Bow Shock is its capability to reflect a fraction of incident Solar Wind ions back towards the Sun, thereby energizing them so that they move counter to the Solar Wind flow along the interplanetary magnetic field. Rapid enhancements due to such particles are commonly observed in the intensity of ~100 keV energy protons upstream of the Earth’s Bow Shock on near Earth spacecraft (Asbridge et al., 1968). They are usually recorded when the interplanetary magnetic field (IMF) lines connected to the Bow Shock intercept the point of spacecraft observation - which can be as far from the Earth as 1.5 million km. The frequency of occurrence may reach several events/day (ACE News 21), and the chance to detect such events is higher when the IMF is nearly radial. The origin of these phenomena, which are named *upstream events,* is still under debate: they are either attributed to the acceleration of particles in the vicinity of the Bow Shock due to the first order Fermi mechanism (e.g. Terasawa, 1981) or to the Shock Drift process (Decker, 1983). An alternative earlier explanation is that they represent a leakage of particles from the magnetosphere (Sarris et al., 1978).

The present study describes observations made, simultaneously, during the recent solar activity minimum by two low-energy particle detectors: the LION instrument aboard SOHO when it was located far upstream of the Earth, and the DOK-2 instrument aboard Interball, an Earth orbiting satellite.

2 Instrumentation and data analysis:

The SOHO spacecraft, which was launched in December 1995, arrived four months later at its final destination, a Halo Orbit around the L1 Lagrangian point. On board SOHO the 3-component CEPAC complex (COSTEP-ERNE Particle Analyser Collaboration) serves for the registration of energetic particles. COSTEP itself *(Comprehensive Supra Thermal and Energetic Particle Analyser*) comprises two instruments: LION and EPHIN (Müller-Mellin et al., 1995)

LION (Low Energy Ion and Electron Experiment) measures particle energy spectra in the range 44 keV to 6 MeV for protons and 44 keV to 300 keV for electrons. The instrument employs two double telescopes, one (T2) with a deflection magnet to sweep away electrons with energies up to ~300 keV and another without a magnet (designated T1). A pair of front detectors (D1 and D2) are mounted in both telescopes on a common anticoincidence back detector, and have average look directions of 33° and 57° respectively to the westward of the sun direction in the ecliptic plane. The total field of view of each pair of detectors is 40° × 60°, and the total geometric factor is 0.35 cm^2 sr (for a detailed account and diagrams see McKenna-Lawlor et al., 1997). The counting rates of each of the pairs of detectors are recorded in 8 energy channels (7 for protons and heavier ions, and 1 for He and heavier) with a time resolution of 15 s.

The Interball Project represents two circumterrestrial probes: the Tail Probe and the Auroral Probe. The Tail Probe was injected into a highly elliptical orbit around the Earth in August 1995 with an apogee of 2×10^5 km and a revolution time of 4 days. The DOK-2 instrument uses two pairs of energetic particle telescopes, one of each pair employing a foil to absorb protons, the other supplied with a broom magnet that deflects electrons up to 1500 keV (for details see Lutsenko et al., 1995). DOK-2 is able to measure ions of energies from 20-850 keV and electrons from 20 to 420 keV in 57 energy channels. The electron telescopes have a full aperture angle of 27° and a geometric factor of 0.066 cm^2 sr, while the complementary parameters for the proton telescope are 12.7° and 0.015 cm^2 sr. The telescope used to provide data for the present study is fixed in the antisun direction.

In the absence of magnetic field measurements aboard SOHO (which are required for the analysis of low-energy particle events), magnetic field data recorded by the WIND spacecraft or, alternatively, aboard Earth-orbiting spacecraft IMP-8 and Interball, may be used. However, such usage is limited to time periods when SOHO was located close to the magnetic field line crossing the point of observation of that spacecraft making the magnetic field measurements (in an ideal case, a field line would directly connect these locations). In the present case a time interval was selected which fulfilled this criterion. Then, a pair of short-duration particle increases simultaneously observed at SOHO and Interball but not associated with solar events and/or with interplanetary disturbances, was selected for analysis (within the periods from 0100-04.00 UT and from 11.00-12.30 UT on March 27, 1996). Considering the large spatial separation of the two spacecraft, it is important to be convinced that the two spacecraft observed the same events in each case.

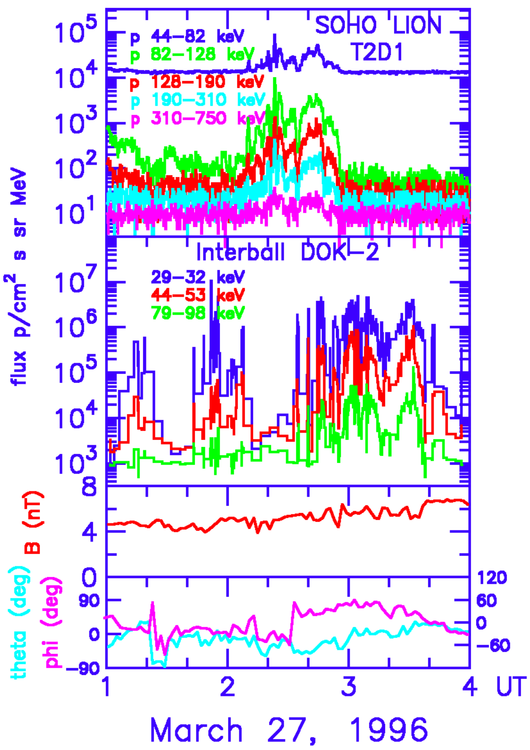

Figure 1: Time history of ion fluxes observed by LION, DOK-2, Interball magnetic field (GSE) |B|, θ, φ between 0100 and 0400 UT on March 27, 1996.

3 The 27 March 1996 events:

3.1 The increase between 0100-0400 UT**,** March 1996 occurred in a very quiet period without any significant solar energetic particle events and with little interplanetary activity, thereby providing an opportunity to study upstream ion populations against a low particle background.

Fig. 1 depicts the time variation of ion fluxes observed by Telescope 1, Detector D1 of LION (5 channels in the energy range 44-750 keV) as well as fluxes recorded by Proton Telescope #2 of DOK-2 (29-98 keV) between 0100 and 0400 UT on 27 March 1996, with contemporary magnetic field data from Interball. (The high plateau of the lowest energy of LION is instrumental background.) On this day SOHO was located at $(1.26, 0.30, 0.09)\times10^6$ km or (198, 47, 14) R_e (Earth radii) in GSE coordinates, while

Interball was at (17, 23, 8) R_e.

The background was quiet with some indication of an earlier increase in LION data (there was a data gap on 26 March). However, no evidence for any solar or interplanetary events was recorded during the whole day. The Solar Wind record on both SOHO and IMP-8 (then also outside the magnetosphere) was quiet, and the wind velocity gradually declined during the interval concerned, showing an average value of 440 km/s. It is therefore plausible to assume that the ion increases recorded originated from the terrestrial environment. The magnetic field measurements on Interball and on IMP-8 exhibit very similar profiles, indicating that both spacecraft were in the interplanetary medium. WIND, however, was close to, and later on the day even within, the magnetosheath. Therefore data from this latter spacecraft are not used here. While the LION profiles exhibit only one well-defined increase between 0205 and 0255 UT, DOK-2 recorded many small peaks - of which the one between 0235 and 0345 UT seems to correspond with the LION peak. The DOK-2 data are easier to interpret:. The fluxes exhibited a clear correlation with the direction of the locally measured magnetic field. In general, elevated intensities of energetic ions are expected when the interplanetary magnetic field lines, extrapolated to Earth, intersect the Bow Shock. After about 0140 UT, with a short interruption between 0210 and 0230 UT, the direction of B was favorable to provide a connection to the Bow Shock, and indeed, higher particle fluxes were seen. After about 0340 UT, the polar angle became negative (eastward B), and the particle intensities fell off. In accordance with a statistical study by Kudela et al. (1999), between energies of 20 and 100 keV, energetic ion fluxes are higher when B approaches the radial direction. The connection points of the magnetic field lines with the Bow Shock based on a model by Formisano (1979) were calculated for the present case assuming B to be a straight line, and the distance of the spacecraft from the intersection, as well as the angle between B and the nominal shock normal, were determined. The distances obtained along the magnetic field were between 12 and 13 R_e, while the angles were in the range approximately 20 to 40 degrees. It is noted that the energy spectrum of ions observed by DOK-2 was relatively hard, and the increase above the background attained a factor of ~30 at 90 keV.

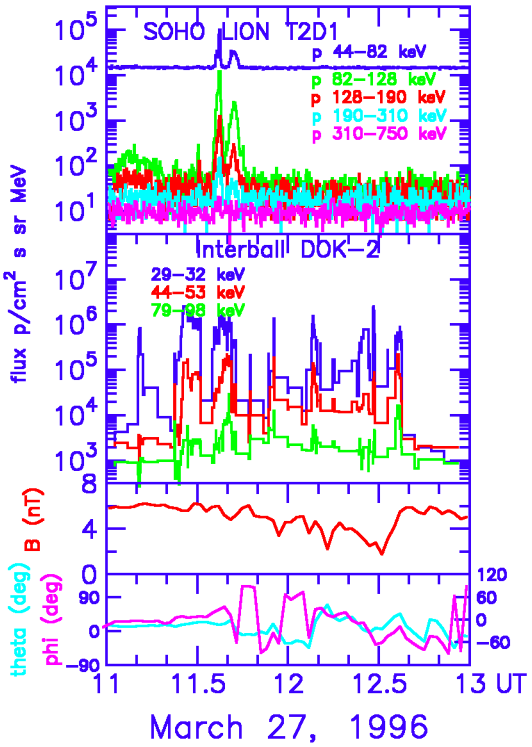

Figure 2: Time variation of the same parameters as in Fig. 1 between 1100 and 1300 UT.

The energy spectrum of LION particles was similarly hard: and the fluxes recorded appreciable above 300 keV. The absolute fluxes were lower by a factor of about 10 to 30 than those observed at DOK-2, a fact that suggests a common origin for the particles. To interpret the flux variations, magnetic field values were sourced from Interball and from IMP-8, taking into account the time needed for interplanetary structures to move from SOHO to the vicinity of the Earth (about 45 min). One can then interpret the variations seen in the flux profiles, for example when φ became negative between 0230-0330 UT (Earth), this corresponds with the dip at 0140-0240 UT (SOHO). Also, the return of B to a nearly radial direction around 0320 appears to be related to the increase of flux at 0220 recorded at SOHO. The end of the event at LION at 0255 corresponds with the time when φ became negative again (unfavorable for connection). Bearing in mind that SOHO was about 200 R_e upstream, one can realize that, in order to connect SOHO's position to the Bow Shock, the interplanetary magnetic field had to be very close to radial. Of course, such an extrapolation is very crude. However, it seems to work reasonably well in our case. A comparison with fluxes observed by detector T1,D1 indicates little contribution from electrons. The ion profiles recorded by D2 of Telescope 2 (not shown) were somewhat different:. First, the fluxes before and after the first peak were higher below 200 keV (probably due to background), while the second peak (near 0240 UT) was significantly higher than the first one (at 0220 UT), a fact that might be attributed to a real anisotropy.

3.2 The increase between 1100-1230 UT: The IMP-8 and Interball magnetic field data indicate a directional change from $\varphi = -60^\circ$ to $+10^\circ$ starting at 1030 UT. The DOK-2 fluxes (see Fig. 2) remained high for more than an hour and were again found to be in correlation, although not so closely as in the previous case, with the locally measured magnetic field direction. The calculated distance from the Bow Shock along B was 10-15 R_e and the angle between B and the shock normal at the location of the intersection was between 30° to 60° with, however, a much larger spread of points than pertained during the earlier event. Moreover, the spectrum was softer, and the increase at 90 keV rather small. The LION flux profile was almost flat for about 7 hours prior to this event, which exhibited two peaks of overall short duration (12 min). The LION ion spectrum showed no increase above ~200 keV. The correlation with B when extrapolated back 45 min is less obvious than before, and it seems that a short lived connection occurred when B swept through the radial direction. The flux profiles of the other detectors were nearly identical, thereby suggesting a nearly isotropic distribution. Again, there was no special contribution from electrons.

The similarities observed suggest a common origin for the LION and DOK-2 enhancements. Moreover, a close similarity of the energy spectra to those observed at WIND during another upstream event (Sanderson et al., 1996) in the spectral shapes as well as in the flux levels observed by SOHO indicates that the present events are rather typical. It is important to note that, after about 1530 UT when the magnetic field became nearly radial, DOK-2 recorded high, relatively constant fluxes.

4 Discussion:

Simultaneous records of 40-750 keV ions made far upstream from and near the Earth during March 27, 1996 have been compared (above). A plausible interpretation of these observations is that particle populations from the same source were in each case recorded at the two observation points. The arguments in favor of this idea include: (1) the energy spectra recorded are similar; (2) near-Earth fluxes were 10 to 30 times higher than the upstream values; (3) far upstream enhancements were shorter, possibly due to the smaller inherent chance of having a magnetic field configuration favorable for connection, (4) there was a positive correlation with the magnetic field direction measured (later) near the Earth.

The present work constitutes a first step in attempting to compare proton fluxes relatively close to but upstream of the Earth's Bow Shock (<20 R_e) with those at the SOHO orbit (beyond about 200 R_e). In a more general context it can be inferred that such comparisons can elucidate the contribution made to the populations of medium energy particles present in interplanetary space upstream of planetary magnetospheres (including that of the Earth) during periods of low solar activity.

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