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Particle acceleration at the interplanetary shock on 15 July 2000

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Abstract. GEOTAIL observations of an interplanetary shock caused by the Bastille day solar event in 2000 are discussed in several aspects: (1) possibility of diffusive shock acceleration of electrons, (2) shock geometry determination, and (3) self-excitation of shock-upstream waves by protons.

1 Introduction

The particle acceleration at shocks created by coronal mass ejection (CME) from the solar corona is now considered as the major acceleration process in the inner heliosphere (e.g., Reames, 1999). A fairly strong interplanetary shock (IPS) was observed on 15 July 2000, $\sim$ 28 hours after the solar flare and the (CME) near the disk center (N22W07) occurred on the 'Bastille day'. This shock (we call it 'Bastille IPS', hereafter) had fairly high average propagation velocity of $\sim$ 1500 km/s from the sun to 1 AU. According to the GOES record of solar protons, this solar event provided the strongest proton flux above 10 MeV in the 8-year interval between 1992 and 2000. Decker et al. (2000) reported that the Bastille IPS had a feature of local shock acceleration of lower energy particles (protons>0.3 MeV and electrons>0.22 MeV). It is quite interesting to see what the plasma and field conditions existed for the acceleration process at the Bastille shock to work. In this report we present a preliminary summary of the GEOTAIL observations at the passage the Bastille IPS for magnetic field and thermal-nonthermal particles of the lowermost energy (ions <=8 keV/q and electrons <=40 keV).

2 Observation

When the Bastille IPS arrived the GEOTAIL spacecraft was at $(X, Y, Z)_{\mathrm{GSE}}$= $(25.03, 6.80, -1.64)$ $\mathrm{R_E}$ about 10 $\mathrm{R_E}$ upstream from the nominal bow shock surface. What we utilize here are datasets of energetic electrons and solar wind ions from LEP/EAE and LEP/SWI experiments on GEOTAIL (Mukai et al., 1994) and magnetic field data from MGF experiment (Kokubun et al., 1994).

The top panel of Figure 1 shows the magnitude of the interplanetary magnetic field $|B|$. The IPS arrived at GEOTAIL at 14:35:45 UT when we observed a factor of 3-4 jump of $|B|$. In the middle and bottom panels of Figure 1 show an energy-versus-time (E-t) plot for solar wind ions (0.3-8 keV/q), and an E-t plot for thermal-nonthermal electrons (0.06-40 keV). In the middle panel, solar wind protons and alphas were seen as lower and upper 'bands' separated by factor 2 in the upstream region before the shock arrival (Their bulk flow velocities were $\sim$ 630 km/s at 14:00 UT). In this panel the shock arrival was seen as the sudden widening of the proton and alpha distributions.

It is noted that observations of nonthermal ions (5-40 keV/q) were not available owing to the severe background contamination of solar particles of much higher energy, which were also related to the same solar event as the Bastille IPS. The effects of background contamination also existed for both solar wind ions and energetic electrons but with much less severe levels ($\sim$ 10 and $\sim$ 40 counts/sample for them near the IPS, respectively.). For the solar wind ions this contamination was minor. For electrons, however, we need a careful elimination of the contamination to obtain a reliable energy spectrum. The E-t plots in Figure 1 are the results of our preliminary trial of the elimination of these contaminations.

2.1 Diffusive Shock Acceleration of Electrons

In the bottom panel of Figure 1, it is seen that ahead of the shock front there was an enhancement of electrons of several tens of keV lasting for $\sim$10 hours (3 UT - the IPS arrival). After the shock passage, dense heated electrons up to $\sim$ 1 keV were seen till 19:50 UT when the upstream edge of the CME proper arrived at GEOTAIL.

The upstream enhancement of electrons stated above is likely attributable to the diffusive shock acceleration of electrons. While there have been many reports on the diffu-

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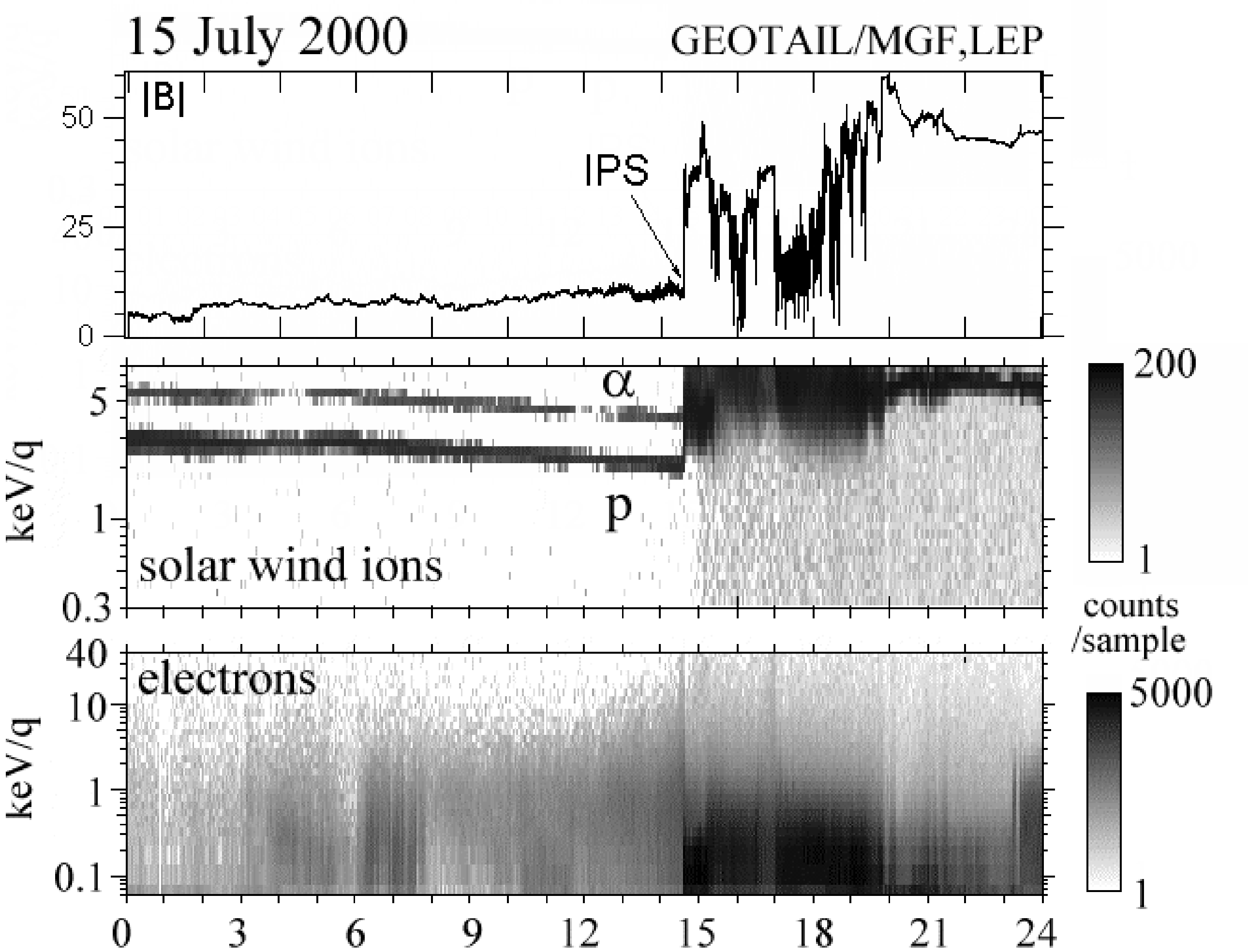

Fig. 1. The GEOTAIL observation of the Bastille IPS. (Top panel) the magnitude of the magnetic field $|B|$. (Middle panel) the energy-versus-time (E-t) plot of the solar wind ions, where the gray scale shows the count rate of ions. (Bottom panel) the same as the middle panel, but for electrons.

sive shock acceleration of ions at interplanetary shocks, there have been only a few reports on the corresponding observation of electrons: Shimada et al. (1999) reported a diffusive shock acceleration event of electrons accompanying with an IPS observed on 21 Feb 1994, which had the average propagation velocity of $\sim$ 1300 km/s from the sun and 1 AU, which is almost comparable to the Bastille IPS. To confirm the shock origin of upstream electrons it is crucial to see their energy spectrum. In the Shimada's case, a power law energy spectrum of the upstream electrons was a key to conclude that they were accelerated diffusively at the shock. In the present case, we should postpone the final conclusion about the origin of these electrons after the determination of the reliable energy spectrum.

2.2 Shock Velocity and Geometry

For a quantitative discussion of the shock acceleration of particles, detailed information on the shock velocity as well as its geometry (e.g., the shock angle, θ_{Bn1}, the angle between the shock normal and the upstream magnetic field direction) is needed. From the minimum variance analysis of the magnetic field data around the shock front, we obtain the shock normal vector of $\boldsymbol{n}_S$= (-0.82,+0.41,+0.40) or ϕ_{n_S}= 153^o and θ_{n_S}= +24^o (the longitudinal and latitudinal angles of $\boldsymbol{n}_S$ respectively), which then gives the shock angle θ_{Bn1} = 48^o, namely in the quasi-perpendicular regime. That the Bastille IPS belonged to the quasi-perpendicular regime, although not far away from the border between quasi-perpendicular and quasi-parallel regimes, is consistent with the observed structure of field and plasma across the shock front: the shock transition in both the magnetic field and plasma was abrupt as expected for quasi-perpendicular shocks.

A unique feature of the Bastille IPS is that its arrival time was recorded at least by 5 spacecraft, namely ACE, SOHO, GEOTAIL, IMP8, and WIND. Figure 2 shows their constellation, from which we can obtain the shock geometry simply based on the triangulation assuming that the shock is planar. We have tried to use 2 sets of 4-spacecraft constellation, ACE-SOHO-GEOTAIL-WIND (*'asgw'*) and ACE-SOHO-IMP8-WIND (*'asiw'*), and seen that resultant direc-

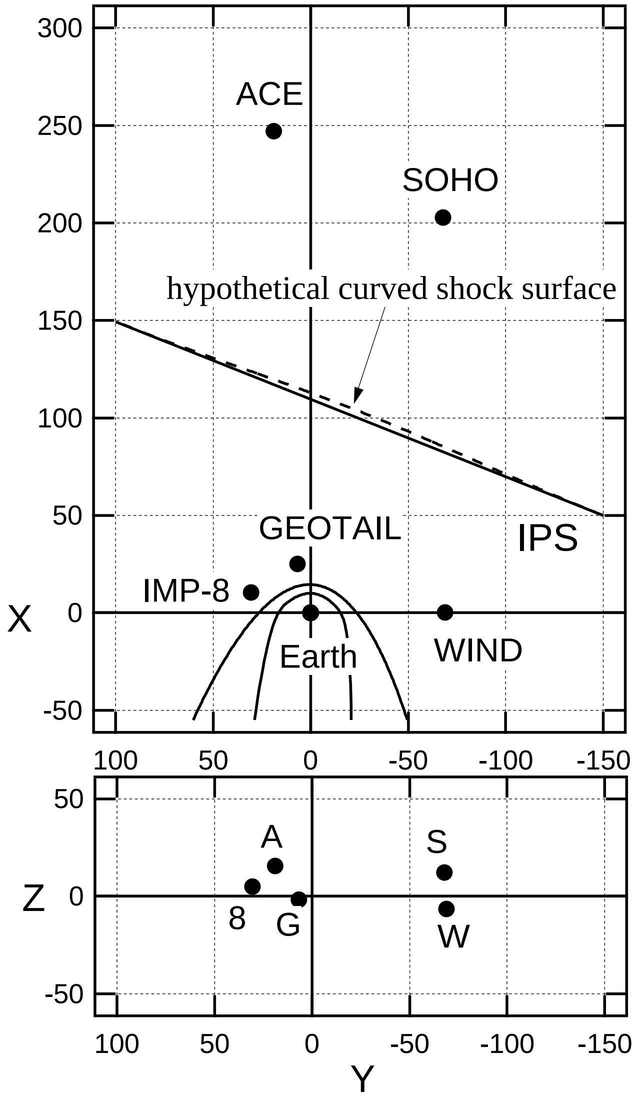

Fig. 2. The spacecraft constellation at the arrival of the Bastille IPS. The upper and lower panels show the X-Y and Z-Y planes, respectively.

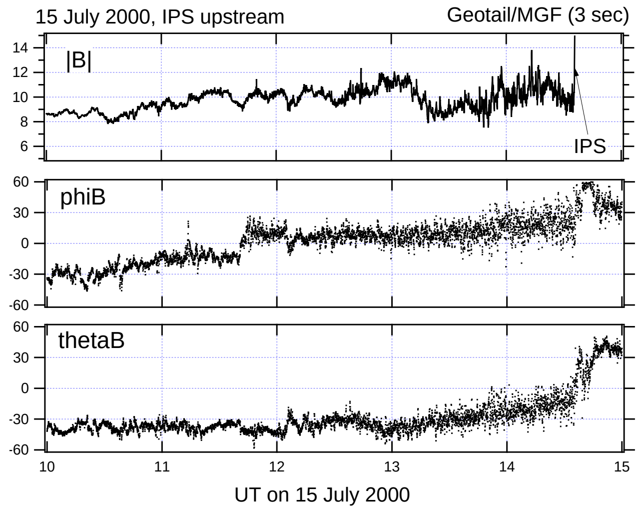

Fig. 3. 3 sec averaged magnetic field data from the MGF experiment on GEOTAIL. (Top panel) the magnitude of the magnetic field $|B|$. (Middle panel) the longitudinal angle ϕ_B. (Bottom panel) the latitudinal angle θ_B.

tions, $(\phi_{nS},\ \theta_{nS})_{\rm asgw}$= (163°,+63°) and $(\phi_{nS},\ \theta_{nS})_{\rm asiw}$= (162°,+53°), agree reasonably well each other (by allowing the angular error of $\sim$10°). However, the large latitudinal angle as $\theta_{nS} \sim$ +50-60° obtained above looks problematic if we remember that the parent solar event was at N22W07 from which we expect that the nominal value of θ_{nS} is nearly 0° or even slightly negative. Further this shock normal vector differs from that obtained by the minimum variance method by 30-40°.

A possible (but not unique) resolution to solve the above discrepancy between the results of the minimum variance method and the triangulation is to introduce the curvature of the shock surface. In Figure 2 a dashed curve shows a hypothetical curved shock surface which has a concave shape with the maximum bend of 3 R_E at the concave center. We have shown that this seemingly tiny concave changes the results of triangulation (for both *asgw* and *asiw* constellations) by 30-40° so as to become consistent with the minimum variance result (Terasawa et al., in preparation, 2001) [1].

From the triangulation we also obtain the shock propagation velocity projected to the ecliptic plane, $V_{sn}/\cos\theta_{nS}$, $\sim$ 1100 km/s, where V_{sn} is the shock velocity toward the shock normal direction. It is noted that the result of $V_{sn}/\cos\theta_{nS}$ is almost model-independent (It only weakly depends on the concave correction stated above.).

2.3 Upstream Waves

Figure 3 from the top shows the magnitude $|B|$, the longitudinal angle ϕ_B, and the latitudinal angle θ_B of the 3-sec averaged magnetic field. Note that there was a clear enhancement of magnetic fluctuation of the periods of several tens to 10^2 sec about two hours before the arrival of the shock (or $\sim$ 0.07 AU). This enhancement is explicable in terms of wave self-excitaion by shock-accelerated protons of several hundred keV. It is noted that there is some similarity between these waves upstream of the Bastille shock and those in the well-analyzed quasi-parallel IPS by Kennel et al. (1984a, 1984b, 1986) [2]. However the wave amplitude of the Bastille shock was much larger than the latter. This amplitude difference certainly relates to the difference in shock strength: As shown in the previous subsection, the Bastille shock propagated with the velocity of $\sim$ 1100 km/s within the ecliptic

[1] Of course, assuming the concave shape as illustrated in Figure 2 is not enough to explain why we observe positive θ_{nS} from the solar event in the northern hemisphere. We should assume some global deformation of the shock surface.

[2] The Kennel's IPS had θ_{Bn1}=41°, which was not so far away from θ_{Bn1}=48° of the Bastille IPS, although they are separated by the parallel-perpendicular demarcation at 45°.

plane, which was almost twice faster than the Kennel's shock having a propagation velocity of $\sim$ 600 km/s. Further comparative study between these two different IPSs is now under way.

3 Concluding Remarks

We have presented GEOTAIL observations of the Bastille IPS. Although the analyses of the data are still in the preliminary stage, this IPS shock proved to be quite rich in the physics involved. Further results on the nature of the IPS itself as well as its properties on the particle acceleration will be reported in near future.

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References

Decker, R. B., et al., AGU 2000 Fall Meeting Abstracts, SH52B-14, 2000.
Kennel, C. F., et al., J. Geophys. Res. 89, 5419, 1984.
Kennel, C. F., et al., J. Geophys. Res. 89, 5436, 1984.
Kennel, C. F., et al., J. Geophys. Res. 91, 11917, 1986.
Kokubun, S., et al., J. Geomag. Geoelectr. 46, 7, 1994.
Mukai, T., et al., J. Geomag. Geoelectr. 46, 669, 1994.
Reames, D. V., Space Sci. Rev. 90, 413, 1999.
Shimada, N., et al., 1999, Astrophys. Space Sci. 264, 481.