Acceleration at the Earth's Bow Shock: Spatial Depencence of Acceleration Efficiency

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Abstract

We present GEOTAIL observations of diffuse protons ($\lesssim$40 keV) in the bow shock upstream region, covering from the nominal nose upstream region to the predawn upstream region ($X_{gse} \gtrsim$-70 Re). Our results give conclusive evidence for the earlier suggestion on the acceleration/transport process in the predawn region, which was based on the ISEE-3 observations in 1983.

1. Introduction

Extensive studies of the nature of diffuse ions and related low frequency waves have been made mainly in the upstream region ahead of the terminator ($X \gtrsim$ 0Re, e.g., [1], also see the earlier references cited in [2]), but there have been only a few studies of the 'predawn' upstream and bow shock region ($X \ll$0Re) [2-5]. Earlier in its mission phase, the GEOTAIL spacecraft made observations in the predawn part of the foreshock region, from which we can make detailed studies of this 'last frontier' of the bow shock/upstream research.

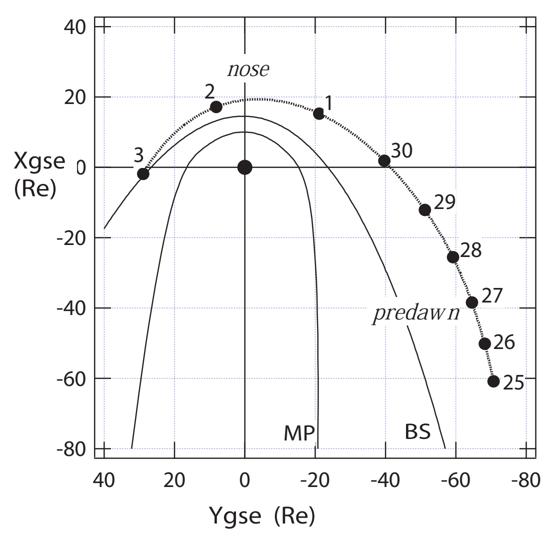

Fig. 1. The GEOTAIL orbit (25 June - 2 July 1994). Throughout the interval, the satellite was near the ecliptic plane ($0 \leq Z_{gse} \leq 5$ Re). The nominal positions of the bow shock (BS) and the magnetopause (MP) are also shown.

2. Observation

Figure 1 shows the GEOTAIL orbit when GEOTAIL moved from the predawn region, $(X, Y)_{gse} \sim (-60, -70)$ Re, to the nose upstream region ($Y_{gse} \sim$ 0). Figure 2 (a) shows the solar wind

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velocity, which was relatively steady except in the region $Y_{\rm gse} \lesssim$-50 Re). Figure 2 (b) shows the longitudinal angles of the IMF (ϕ_B) which were clustering around the spiral direction ($-45^{\rm o}$ or $135^{\rm o}$). In Figure 2 (c) it is seen that the proton counting rates were maximized around the nose upstream region and decreased toward the predawn direction.

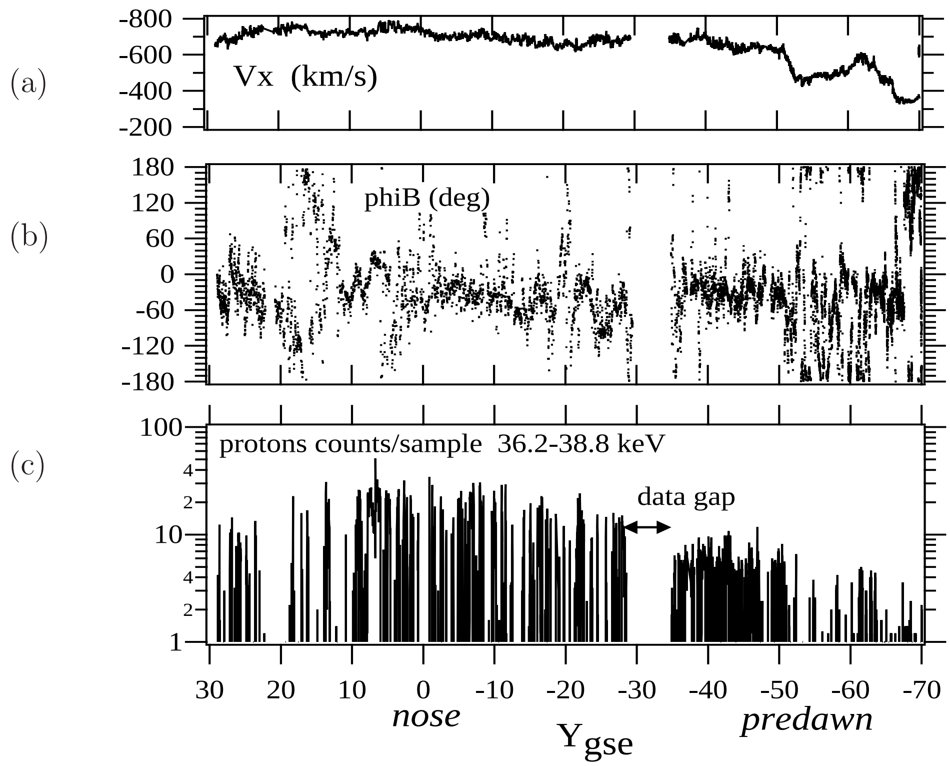

Fig. 2. In panels (a)-(c), the following quantities are plotted against the Y coordinate of the GEOTAIL position ($Y_{\rm gse}$, Re): (a) The X component of the solar wind velocity ($V_{\rm sw,x}$, km/s); (b) The longitudinal angle of the IMF (ϕ_B, deg); and (c) Counting rates of sunward-flowing protons ($\sim$ 36 keV).

We observe that the proton counting rates were controlled by the IMF direction and maximized when $\theta_{\rm B}$ (latitudinal angle) was $\sim 0^{\rm o}$ in the whole upstream region (not shown). The dependence of the counting rates on $\phi_{\rm B}$ (longitudinal angle), on the other hand, changed according to the observers' position. In Figure 3 counting rates of 37 keV protons are plotted in the $\phi_{\rm B}$-$Y_{\rm gse}$ plane: While the counting rates were maximized under the radial field condition ($\phi_{\rm B} \sim 0^{\rm o}$) in the nose upstream region ($Y_{\rm gse} \sim 0$), they were maximized when the IMF was close to the spiral direction ($\phi_{\rm B} \sim -45^{\rm o}$) in the region of $Y_{\rm gse} \lesssim -10$ Re. Note that these features of the spatial variation and the IMF dependence of proton counting rates were shown in the previous ISEE-3 observation [2]. What is new in the present observation is that the full angular and energy coverage for proton phase space distribution has been obtained. Figure 4 (a)-(c) show the ecliptic cuts of

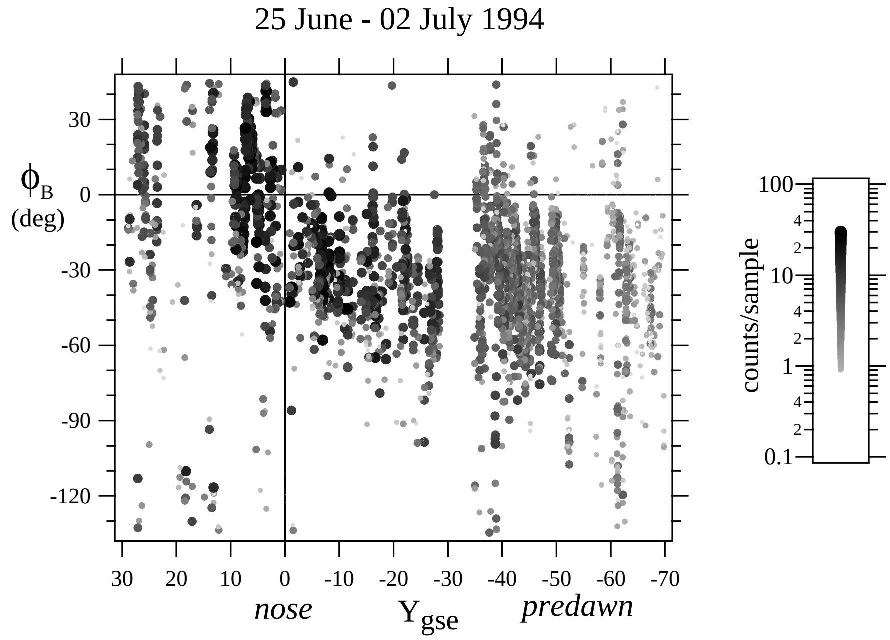

Fig. 3. Dots are plotted according to the spontaneous magnetic field direction (ϕ_{B}) and the satellite position (Y_{gse}, Re). The size and darkness of the dots represent counting rates of sunward-flowing 37 keV protons. If $\phi_{\mathrm{B}} > 45^{\mathrm{o}}$ or $< -135^{\mathrm{o}}$, the value either $\phi_{\mathrm{B}} - 180^{\mathrm{o}}$ or $\phi_{\mathrm{B}} + 180^{\mathrm{o}}$ is used in the figure.

the phase space distribution (PSD) functions of diffuse protons: These protons were more or less isotropic in the nose upstream region (a), but had anisotropic pancake distributions (perpendicular > parallel) around the IMF in the predawn upstream region (b)-(c). (The pancake shape of PSDs in this region was first suggested in [2] from the ISEE-3 observation. However, this suggestion has been unconfirmed: Angular distributions of protons ($\sim$30 keV) were obtained, but their energy spectra were not measured. The energy spectra of alpha particles (30-60 keV/q) were obtained, but the angular coverage was incomplete because of the contamination of solar UV photons.) We also observe that diffuse protons generally had the exponential-type energy spectrum with a characteristic e-folding energy, E_c, $\sim$10-30 keV in the nose upstream region, and $\sim$10-15 keV or less in the predawn upstream region.

3. Concluding Remarks

From GEOTAIL observations, we have shown that the diffuse protons have higher counting rates and harder spectra in the nose upstream region than in the predawn upstream region. While these protons are more or less isotropic in the nose upstream region, they have anisotropic pancake distributions around the interplanetary magnetic field (IMF) direction in the predawn upstream region. The counting rates of the diffuse protons in the predawn region are maximized

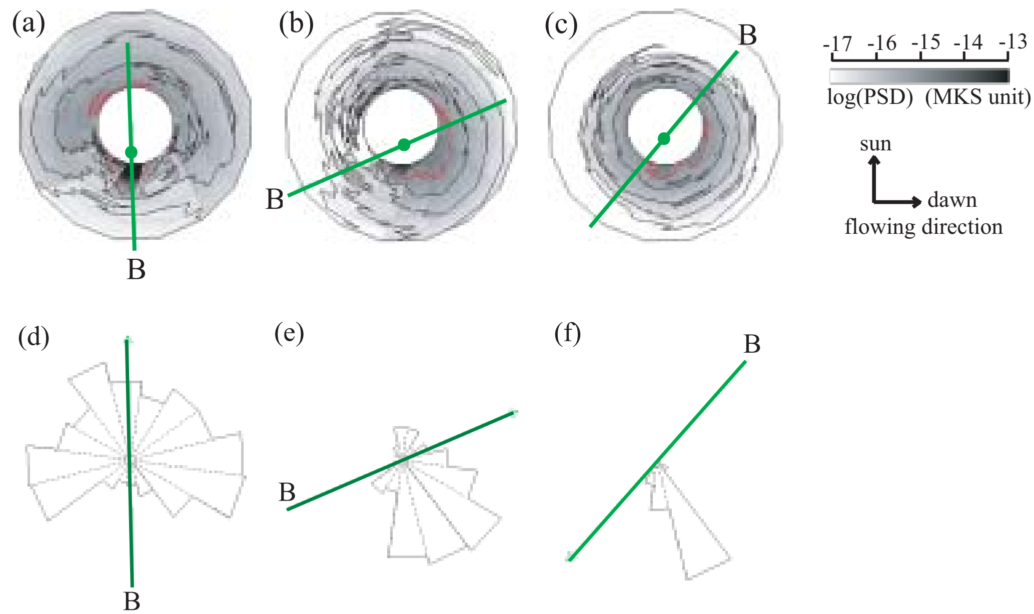

Fig. 4. Panels (a) and (b) show the ecliptic cuts of the phase space distributions (PSD) of diffuse protons, $f(\vec{V})$, in the velocity range of 1000-2869 km/s (5.2-43 keV) for (a) 00:51-00:54 UT on 2 July 1994 (in the nose upstream region), (b) 20:14-20:17 UT on 28 June 1994 and (c) 19:35-19:38 UT on 25 June 1994 (in the predawn upstream region). The gray scale and directions are given in the right of the figure. Directions of the IMF are shown by straight lines (marked 'B'), which are drawn to pass through $\vec{V}_{\rm sw}$ (solid circles). Panels (d)-(f) show the traditional anisotropy plots of 37 keV protons for the same intervals as (a)-(c). A dark spot (or tongue) below the center of panel (a) represents a contamination of solar wind heavy ions.

when the IMF was around the spiral direction. These observations are consistent with the model that diffuse protons in the predawn upstream region have their origin in the nose upstream region, from where they are transported by the solar wind perpendicular to the magnetic field (namely, with the $\mathbf{E} \times \mathbf{B}$ motion.) Protons with small pitch angles would eventually escape out parallel to the IMF and we are left with a pancake distribution. The implications of this model are that the diffuse protons are predominantly produced around the nose bow shock, and that the acceleration at the predawn bow shock is much weaker.

4. References

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