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Wind observations of mixed magnetosheath-plasma sheet ions deep inside the magnetosphere

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Abstract. We have analyzed in detail a Wind spacecraft crossing of the high-latitude magnetosheath, magnetopause, lobe, and the high- and low-latitude plasma sheet on November 27, 1998. The crossing occurred during the first perigee pass of Wind's (new) high-inclination (45°) petal orbit. Between the lobe and the hot plasma sheet on the duskside, an extended region (x_{GSM}~ -2.8 to -7.8 R_E, y_{GSM}~ 7.8 R_E, z_{GSM}~ -11.6 to -4.3 R_E) of mixed low-energy magnetosheath and high-energy plasma sheet ion populations was detected. This region was detected in a region of strong (~ 40 nT) and steady lobe-like magnetic field and ceased to exist when the spacecraft approached the neutral sheet. The mixed ion populations are remarkably similar (in their thermal properties) to the distributions detected in the adjacent magnetosheath and plasma sheet proper, except that the mixed ions are nearly stagnant. As the neutral sheet is approached, the low-energy component of the mixed ions is gradually heated, while the high-energy component is unmodified. Near the neutral sheet the ion distributions are dominated by a single, high-energy population. The electron behavior is significantly different from that of the ions. In the mixed ion region the electrons consist of a single population with energy between those of the magnetosheath and the plasma sheet proper. Electron pitch angle information suggests that the entire mixed region is on closed field lines. However, the large reduction of high-energy plasma sheet electrons in this region may indicate that the field lines threading this regions were once open. The exact path of plasma entry to form the mixed region cannot be discerned with single-point observations, especially since the mixed ions are stagnant. However, it is possible (for this event) to rule out the mantle as a source for the low-energy component of the mixed ions. The similarity between the thermal property of the low-energy component of the mixed ions and the magnetosheath population suggests that the magnetosheath plasma had direct access to this region without significant heating along its path. The presence of nearly unmodified magnetosheath plasma deep inside the magnetosphere raises questions concerning the processes of plasma entry across the magnetopause. Finally, the mixed region in this event was detected during an extended period of persistent northward and duskward interplanetary magnetic field, which makes this event ideal for model comparisons.

1. Introduction

The processes responsible for transferring the mass, momentum, and energy of the shocked solar wind into the magnetosphere are of great interest. Previous investigations have found evidence for plasma entry across the dayside magnetopause in the form of a boundary layer at low latitudes along the magnetopause. This layer contained an admixture of magnetosheath and plasma sheet or ionospheric plasmas [e.g., *Thomsen et al.*, 1987; *Song et al.*, 1989; *Paschmann et al.*, 1993]. Of the possible entry processes, magnetic field reconnection is believed to be one of the more dominant process, especially when the magnetic shear across the magnetopause is high [e.g., *Paschmann et al.*, 1979; *Sonnerup et al.*, 1981; *Gosling et al.*, 1982]. There is also some evidence that reconnection is still important at low latitudes even when the magnetic shear is low [*Fuselier et al.*, 1997]. Diffusive plasma entry may also play a role when the magnetic shear is low and the external magnetosheath flow speed becomes substantial [e.g., *Mitchell et al.*, 1987]. The relative importance of these mechanisms is still under debate.

The mechanisms responsible for creating the low-latitude boundary layer (LLBL) can be revealed by studying the magnetic field topology of the layer itself. On the basis of in situ particle measurements, *Ogilvie et al.* [1984], *Mitchell et al.* [1987], *Hall et al.* [1991], and *Fujimoto et al.* [1996] suggested that the boundary layer is located partly on open and partly on closed field lines. Mitchell et al. found that the openness of the LLBL depends on the external magnetosheath magnetic field orientation. For northward interplanetary magnetic field (IMF) the entire LLBL may be on closed field lines (see also *Traver et al.* [1991] and *Phan et al.* [1997]). *Fuselier et al.* [1995, 1997], on the other hand, showed evidence in terms of electrons distributions in the magnetosheath boundary layer which could suggest that the LLBL is on open field lines for all magnetosheath magnetic field orientations.

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An open-field boundary layer which contains a mixture of magnetosheath and magnetospheric plasmas would be a natural consequence of merging (or reconnection) between magnetosheath and magnetospheric field lines. However, closing of field lines that were once open due to reconnection could also result in a LLBL on closed field lines [e.g., *Song and Russell*, 1992]. An alternative process to create a boundary layer on closed field lines along the magnetopause is diffusive plasma entry from the two neighboring regions by wave-particle interactions [e.g., *Tsurutani and Thorne*, 1982; *Johnson and Cheng*, 1997]. In fact, close coupling between LLBL flows and magnetosheath flows, in terms of flow direction and magnitude, has been observed for low-shear magnetopause which would be consistent with diffusive entry [e.g., *Mitchell et al.*, 1987; *Phan et al.*, 1997].

Irrespective of the mechanism of plasma transfer, an important question is how far the magnetosheath plasma can penetrate into the magnetosphere as a result of processes at the dayside magnetopause, and how it depends on the IMF or other factors. Theoretically, the plasma transfer as a result of dayside reconnection is expected to be confined to the reconnection layer itself, which is typically a fraction of an Earth radius at the dayside magnetopause. For diffusive entry the present theoretical models could account for LLBL thicknesses of up to 0.5 R_E [e.g., *Treumann et al.*, 1995].

Observationally, the majority of the studies of the dayside low-latitude magnetopause have revealed only a thin boundary layer adjacent to the magnetopause. The thickness of the LLBL may depend on the IMF [*Mitchell et al.*, 1987]. There are examples where a mixed magnetosheath-plasma sheet ion region is confined to the magnetopause itself, which has a thickness of a few hundred kilometers [e.g., *Gosling et al.*, 1986]. These cases tend to occur when the magnetic shear across the magnetopause is large. Even for reports of thick LLBL the thickness rarely exceeds 1.5 R_E, irrespective of the magnetic shear across the magnetopause [*Phan and Paschmann*, 1996].

Recently, however, there have been reports of a mixed magnetosheath-plasma sheet plasma region deep inside the magnetosphere at x_{GSM}~ -20 R_E [*Fujimoto et al.*, 1996, 1998]. Surveys of ISEE midlatitude flank (x_{GSM}~ 0 R_E) magnetopause crossings have also revealed several occurrences of an extended mixed ion region adjacent to the magnetopause [*Williams et al.*, 1985; *Le et al.*, 1996; *Fuselier et al.*, 1999]. On the basis of ion composition information, Fuselier et al. concluded that the low-energy component of the flank mixed ions is of solar wind origin. In contrast to the tailward flowing LLBL and mantle plasmas the mixed ions reported by Fujimoto et al. and Fuselier et al. are stagnant, as are the ions detected in a region identified by Williams et al. as the stagnation region, and by Le et al. as the inner LLBL.

For the mixed region deep inside the magnetosphere, Fujimoto et al. showed evidence for counterstreaming electrons which they interpreted as indications for closed field lines. Fuselier et al. reported that the mixed region adjacent to the flank magnetopause is absent of high-energy plasma sheet electrons, and concluded that the topology of the region cannot be deduced from the behavior of magnetosheath electrons alone. Irrespective of the topology of the mixed region, the observations by *Fujimoto et al.* [1996] and *Fuselier et al.* [1999] are significant since they seem to indicate deeper penetration of magnetosheath plasma, up to tens of Earth radii, than can be accounted for by direct entry of plasma via reconnection or diffusion along the low-latitude dayside and flank magnetopause.

In this paper we report observations of an extended (~8 R_E) mixed magnetosheath-plasma sheet ion region by the Wind spacecraft. This region was observed just after Wind entered its new, high inclination (45°) petal orbit (on November 27, 1998). The new Wind trajectory provides a latitude profile of a region of the near-Earth magnetotail that has not been extensively explored by previous spacecraft. The mixed ion region was detected at high magnetic latitude between the mantle/lobe and the hot plasma sheet, in the near-Earth tail region (x_{GSM}~ -2.8 to -7.4 R_E), and far from the dusk flank magnetopause (y_{GSM}~ 7.8 R_E). Comparisons between particle distributions detected in the consecutive regions of the magnetosheath, magnetopause, mantle/lobe, mixed ions, and the plasma sheet provide some indications of the source for the mixed ions. Detailed electron distributions provide additional information on the topology of the field lines and on the history of the region. Finally, the traversal of the mixed region occurred during an extended period of northward and duskward IMF, which makes this event ideal for comparisons with theoretical and simulation models.

The paper is organized as follows. In sections 2 and 3 the instrumentation and data selection are briefly described. The observations are presented in section 4, and in section 5 the observations of the mixed region are discussed versus the mantle and the LLBL and in terms of magnetic field topology, plasma entry site, and entry mechanisms. We summarize the findings in section 6.

2. Instrumentation

The present analysis uses data from the Wind spacecraft. The full three-dimensional (3-D) ion and electron distributions were obtained from "top-hat" electrostatic analyzers, in a mode to detect ions with energies from 80 eV to 30 keV and electrons with energies from a few eV to 30 keV [*Lin et al.*, 1995]. Although a full 3-D distribution is obtained every spacecraft spin (3 s), the distributions are transmitted at a rate of one sample every 96 s, owing to limited telemetry capacity. The low sample rate of the data does not pose a problem for this event since the region of interest is rather wide. The magnetic field was measured at a rate of 10.9 samples/s [*Lepping et al.*, 1995], but for our analysis the magnetic field data are averaged over 3 s.

3. Wind Petal Orbit and Data Selection

During the first 4 years of the Wind mission the orbit was confined to the ecliptic plane. In November 1998, Wind entered its new petal orbit, shown in Plates 1a-1c, with an inclination of 45 deg and apogee and perigee distances of 80 R_E and 5.9 - 10.5 R_E, respectively. The orbital period is ~17.5 days, and the orbit precesses from the dayside to the nightside. Thus this orbit is ideal for studies of the high-latitude magnetosphere at various distances from the Earth.

The event reported in this paper occurred during the very first pass of the new petal orbit. During this event the ACE spacecraft was in solar wind at L1 point, ~200 R_E upstream of the Earth, providing measurements of the solar wind plasma parameters [*McComas et al.*, 1998] and the IMF [*Smith et al.*, 1998]. Level 2 solar wind plasma moments and the magnetic field data were obtained from the ACE science center website.

4. Observations

4.1. Overview

Plates 1d-1f and 2 show the spacecraft trajectory and an overview of the inbound pass from the solar wind to the magnetosphere

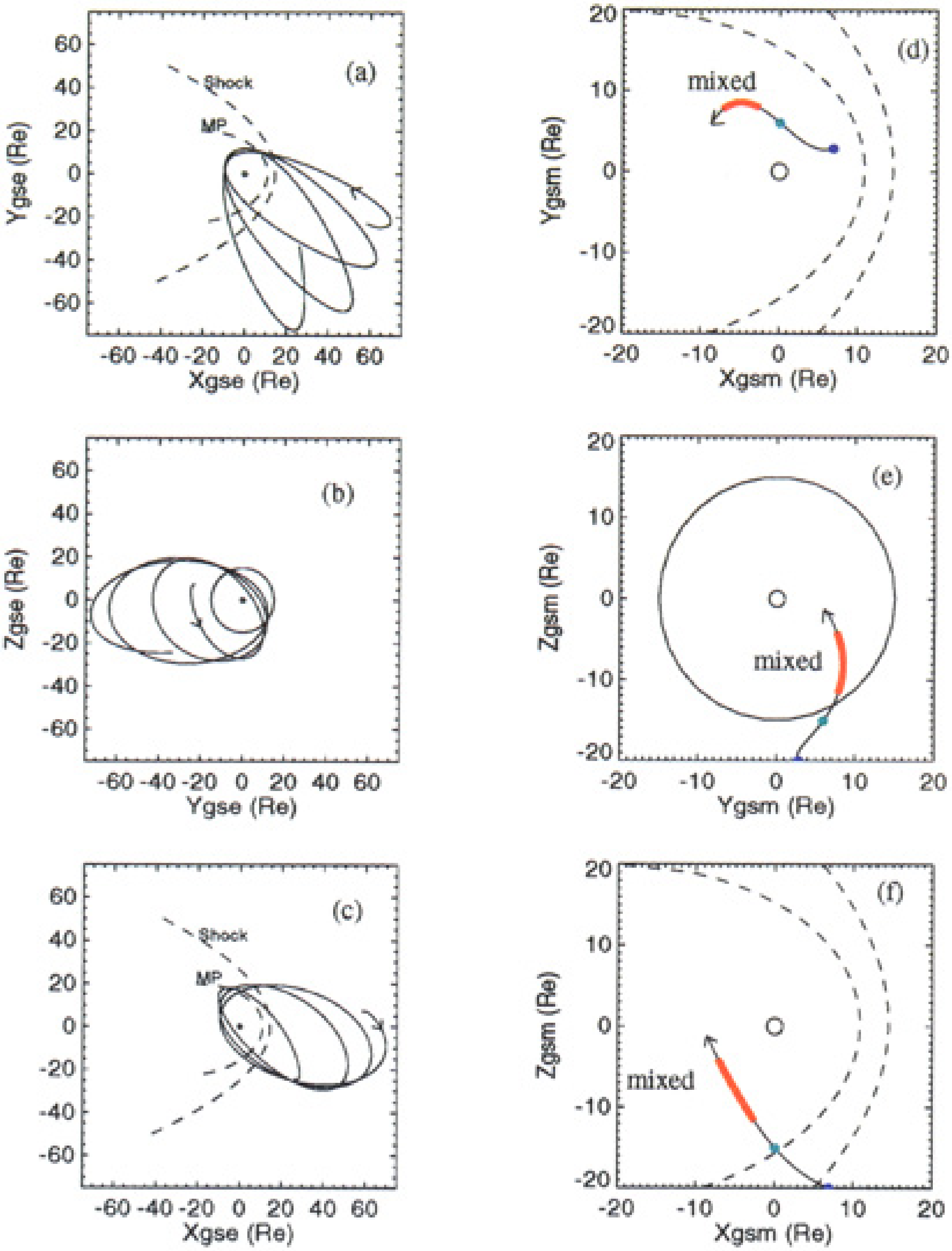

Plate 1. (a-c) Wind high-inclination (45°) petal orbit in GSE; (d-f) Wind trajectory on November 27, 1998, in GSM. The dark and light blue dots denote the crossings of the bow shock and the magnetopause, respectively. The red interval is the mixed-ion region. The 15 R_E circle is drawn in Plates 1b and 1e for reference.

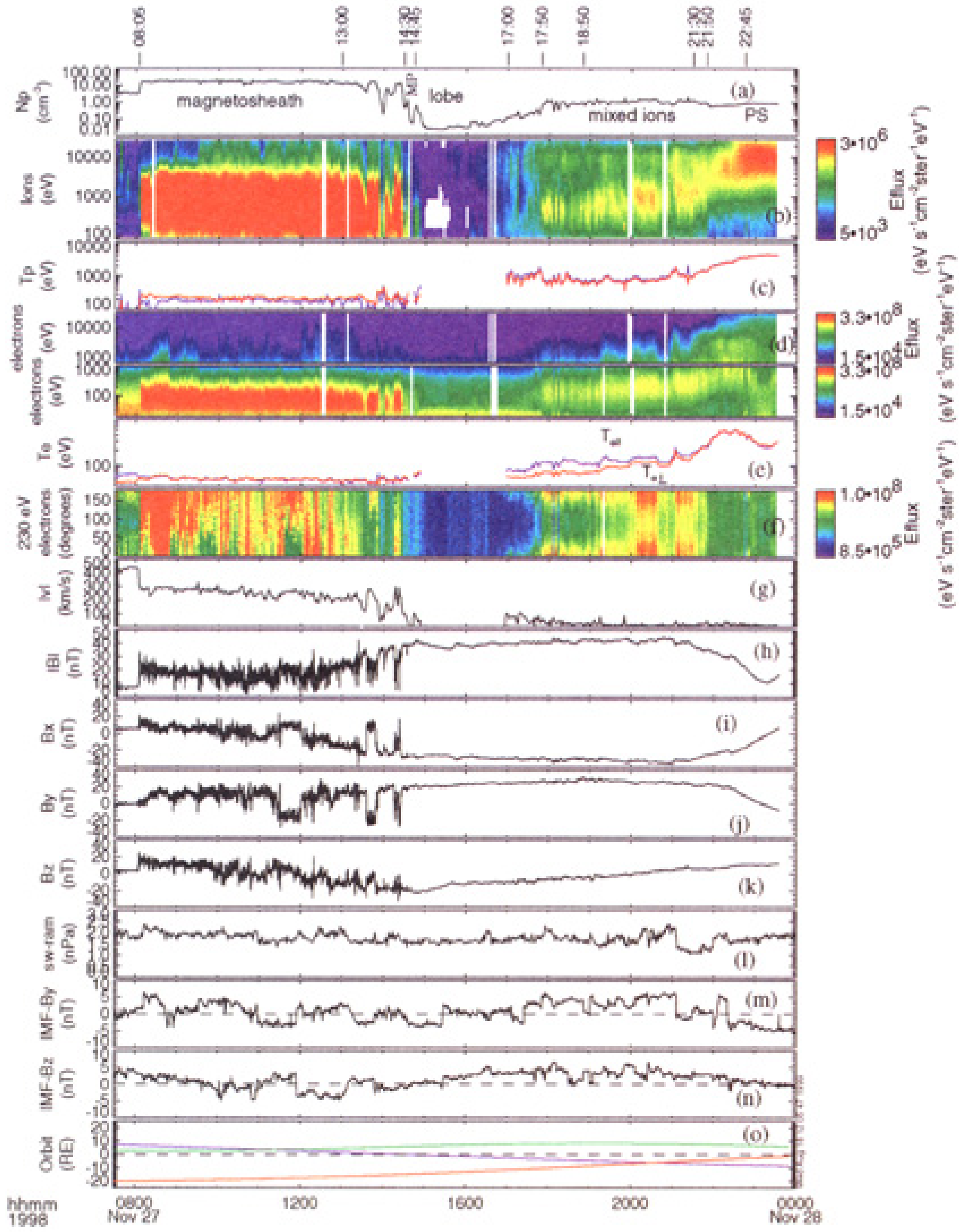

Plate 2. Wind inbound pass on November 27, 1998, extending from the solar wind, across the high-latitude magnetosheath, the magnetopause (MP), the mantle/lobe, the mixed ion region, and the low-latitude plasma sheet (PS). (a) The total ion density, (b) ion energy-time spectrogram, (c) the parallel (blue) and perpendicular (red) ion temperatures, (d) the electron energy-time spectrogram (data below and above 1.2 keV are from two separate "top-hat" analyzers), (e) the parallel (blue) and perpendicular (red) electron temperatures, (f) the pitch angle of 230 eV electrons, (g) the bulk flow speed, (h) the magnetic field magnitude, the magnetic field components in GSM (i) B_x, (j) B_y, and (k) B_z, (l) the solar wind ram pressure (from ACE), the IMF components (m) IMF-B_y and (n) IMF-B_z, and (o) the orbit of the Wind spacecraft in GSM (*x*, blue; *y*, green; *z*, red). Plasma temperature and velocity moments are not well measured in the lobe due to low flux level.

on November 27, 1998, respectively. At 0805 UT (at a radial distance of 21 R_E and a GSM latitude of -70 deg), the satellite crossed the bow shock and moved into the magnetosheath. At 1430 UT the satellite crossed the high-latitude magnetopause (at $[x, y, z]_{GSM}$= [0, 5.9, -15.0] R_E) and entered the mantle/lobe where the plasma density was < 0.1 cm^{-3}. The mantle/lobe encounter lasted until shortly before 1700 UT when Wind entered a region of mixed low-energy (peaked at 700 eV) and high-energy (peaked at 10 keV) ions (Plate 1b). Wind remained in the mixed ion region, indicated in red in Plates 1d-1f, for more than 5 hours. The single ion population plasma sheet was finally encountered at 2150 UT, at a GSM latitude of -17 deg. The spatial distance of the mixed ion region along the spacecraft trajectory is ~8 R_E, spanning distances of x_{GSM}= -2.8 -> -7.4 R_E, y_{GSM}= 7.6 -> 7.8 R_E, and z_{GSM}= -11.6 -> -4.3 R_E. The spacecraft moved from a radial distance of 14.2 R_E to 11 R_E during this interval. At these y_{GSM} and z_{GSM} distances, and with a solar wind ram pressure of ~2 nPa, the mixed region was several Earth radii away from the magnetopause [e.g., *Roelof and Sibeck*, 1993].

The density of the mixed ions increased from 0.1 cm^{-3} at 1700 UT to ~1 cm^{-3} at 1750 UT and remained at that level until 2150 UT. The bulk temperature was ~0.75 keV throughout most of the mixed ion region, except near the end of the mixed region, starting at 2130 UT, when the temperature started to increase until the plasma sheet value (~4.5 keV) was reached. Thus the ion density and temperature in the mixed ion region are intermediate between those of the magnetosheath and plasma sheet. The intermediate temperature, however, is due largely to the interpenetrations of the high- and low-energy populations.

The mixed ions are observed in a region of strong and lobe-like magnetic field, with field magnitudes in the 40 nT range. The magnetic field in this region is rather steady, in contrast to the highly fluctuating fields detected in the magnetosheath or in the magnetopause boundary layer, say at 1445 UT.

Finally, it should be pointed out that unfortunately, for this Wind pass, no data exists for the northern hemisphere (i.e., beyond 2300 UT).

4.2. Ion Distributions

Plate 3 displays the ion distributions typical of the magnetosheath (1300 UT), of the early part of the mixed region (1850 UT) and of the plasma sheet proper (2245 UT). These distributions are taken in the bulk plasma frame. It is seen that the distributions detected in the mixed region is a simple superposition of the magnetosheath (at velocities < 800 km/s) and plasma sheet (at velocities > 800 km/s) populations, without noticeable modifications (such as heating) to either population. As the plasma sheet proper is approached, however, the peak energy (thus temperature) of the low-energy component of the mixed ions increases (Plate 2b), while the high-energy component remains at the same energy. The double population distributions changes to hot single-population distributions at ~2150 UT when the plasma sheet is reached. The change from double to single population seems gradual and may be a consequence of continuous heating of the low-energy ions while the high-energy component remains unmodified. The low-energy component eventually merges with (and becomes) the plasma sheet population. Finally, Plate 2i shows that the mixed region was located at high (southern) magnetic latitudes (large negative B_x), while the single population plasma sheet was encountered closer to the neutral sheet (smaller negative B_x).

Another characteristic of the mixed region is that both the low- and the high-energy ion components are nearly stagnant, resulting in flow magnitudes typically less than 50 km/s throughout the region (Plate 2g). The average (standard deviation) of the x and y components of the flow velocity, v_x and v_y, are -6.9 km/s (37 km/s) and +1.5 km/s (17 km/s), respectively, for the entire mixed ion interval of 1700-2150 UT. This is in contrast to the mixed magnetosheath-plasma sheet ions found in the LLBL which typically convect tailward [e.g., *Eastman et al.*, 1976]. In comparison, the average (standard deviation) of v_x and v_y are +1.8 km/s (8.2 km/s) and +14.3 km/s (9.7 km/s), respectively, for the plasma sheet interval of 2150-2330 UT. Thus, for this event at least, the plasma flow in the mixed ion region is somewhat more turbulent than that in the plasm sheet, while the only clear bulk motion is the duskward flow of the plasma sheet ions.

Finally, it should also be pointed out that although the mixed ion region is located immediately adjacent to the mantle/lobe, we find no evidence in this region for field-aligned ion beams usually associated with the plasma sheet boundary layer [e.g., *Takahashi and Hones*, 1988].

4.3. Electron Distributions

The electron energy spectrogram is shown in Plate 2d. Unlike the ions which consist of two components in the mixed region, the electrons in this region consist of a single population with energy intermediate between the magnetosheath and plasma sheet populations. As the plasma sheet proper is approached, the electron temperature increases.

Plate 2f shows pitch angle of 230 eV electrons as a function of time. Balanced counterstreaming fluxes are seen throughout the mixed region. Plate 4a shows energy flux as a function of energy for pitch angles of 0°, 90°, and 180°, taken in the mixed ion region at 1850 UT. It is noted that the 0° and 180° fluxes are remarkably balanced at all energies (20 eV to 10 keV). This feature will be used in section 5.2 to argue that the mixed region is on closed magnetic field lines. Plate 4b shows that these field-aligned fluxes are not beams: They represent simply a field-aligned temperature anisotropy $T_{e\|} > T_{e\perp}$. The large temperature anisotropy is evident throughout the mixed region (Plate 2e). The temperature anisotropy is similar to that observed in the LLBL [*Paschmann et al.*, 1993] but is opposite to the electron distributions in the magnetosheath which typically are isotropic [*Paschmann et al.*, 1993] or display $T_{e\perp} > T_{e\|}$ [*Phan et al.*, 1996].

Finally, it is noted that the electron spectra in the plasma sheet proper (after 2150 UT) display multiple peaks at 60 eV, 400 eV, and 3 keV (Plate 5), with $T_{e\|} > T_{e\perp}$ below 200 eV and $T_{e\perp} > T_{e\|}$ at higher energies. The $T_{e\perp} > T_{e\|}$ anisotropy at high energies is in contrast to the electron distributions in the mixed region which display field-aligned anisotropy at all energies.

4.4. Solar Wind Conditions

Plates 2m and 2n show that the IMF was persistently northward (B_z> 0) and mostly duskward (B_y> 0) during the Wind traversal of the mixed region. The solar wind ram pressure was rather constant, at its typical value of ~2 nPa, throughout the event (Plate 2l).

5. Discussion

We have investigated a Wind crossing of the near-Earth high-latitude magnetopause, mantle/lobe and the plasma sheet when the IMF was northward and duskward over an extended period of time (more than 3.5 hours). The focus of our study is on the presence of a region with mixed magnetosheath/plasma sheet ions located in a

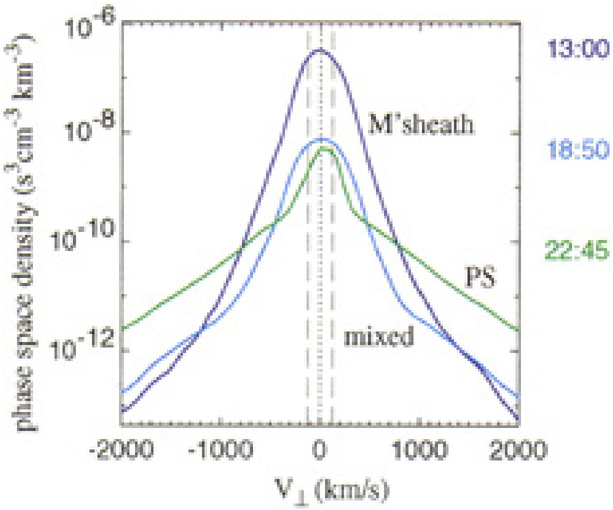

Plate 3. Proton distributions perpendicular to the magnetic field measured in the magnetosheath (at 1300 UT), mixed-ion region (at 1850 UT), and the plasma sheet (PS) (2245 UT). The mixed-ion distribution is a simple superposition of the magnetosheath and plasma sheet distributions.

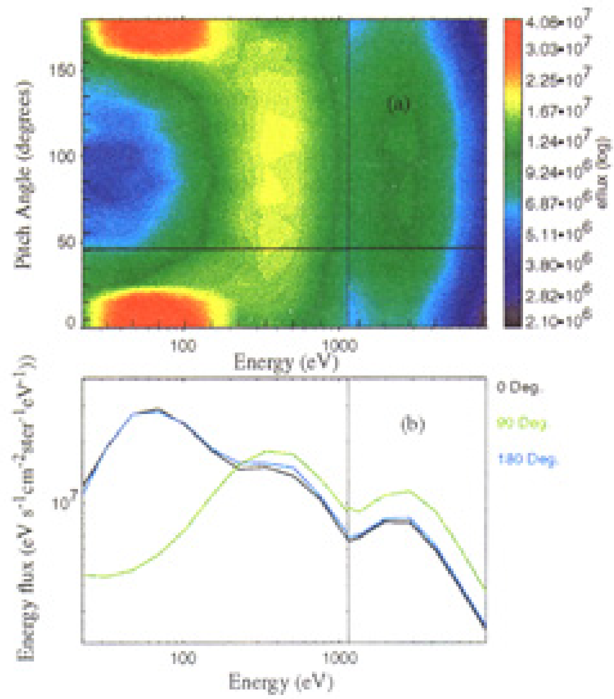

Plate 5. (a) Electron pitch angle versus energy and (b) energy spectra in the plasma sheet at 2255 UT. Note the multiple peaks in the energy flux at 60 eV, 400 eV, and 3 keV. Data below and above 1 keV are from two separate "top-hat" analyzers.

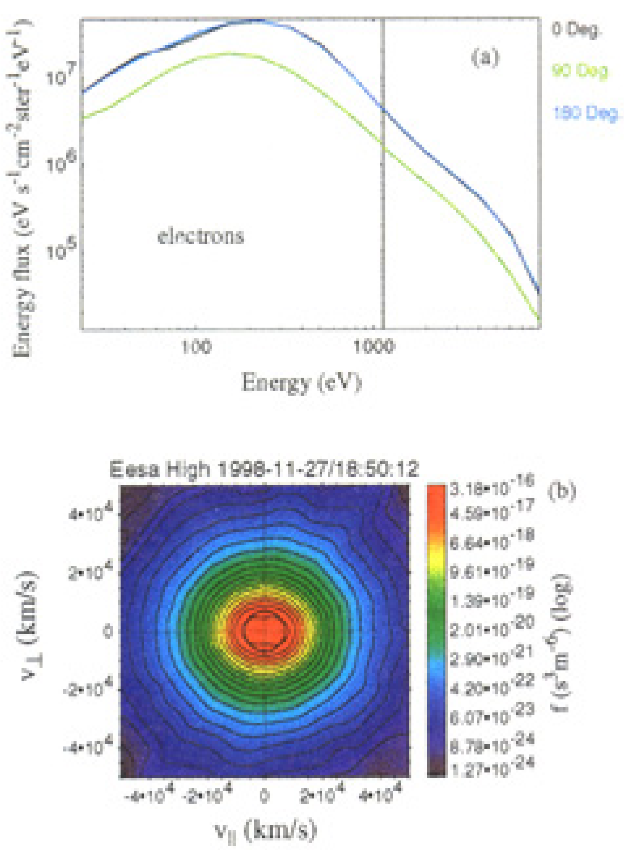

Plate 4. (a) Electron energy spectra for 0^{o}, 90^{o}, and 180^{o} pitch angle in the mixed-ion region. The distribution is dominated by a single population with 200 eV peak energy. Note the remarkable balance of field-aligned (0^{o}) and anti-field-aligned (180^{o}) fluxes in the entire energy range; (b) two-dimensional cut of electron distribution function showing field-aligned temperature anisotropy ($T_{e\parallel}$ > $T_{e\perp}$) in the mixed region.

strong and lobe-like magnetic field region between the mantle/lobe and the plasma sheet. The mixed ions are stagnant and are detected deep inside the magnetosphere, far inward of the dusk flank magnetopause. Although this region is situated between the lobe and the plasma sheet, there is no evidence for ion beams usually associated with the plasma sheet boundary layer. Below we first point out the similarities and differences between the present mixed ions and the LLBL and mantle plasmas. We then discuss the topology and the possible entry paths of the mixed ions.

5.1. Mixed Ion Region Versus Mantle and LLBL

The observed location of the mixed ion region, at high latitude and on lobe-like field, may suggest that this region could be the plasma mantle. However, unlike the mantle plasma which typically flows tailward and contains only the low-energy magnetosheath plasma, the mixed ions consist of two distinct (magnetosheath and plasma sheet) populations that are stagnant. Furthermore, the encounter of the mixed region at lower magnetic latitudes than the lobe is inconsistent with the mantle identification.

Mixed magnetosheath/plasma sheet ions are commonly observed in the dayside LLBL. The process which leads to the plasma mixing, however, is still under debate, with reconnection and diffusive entry being the leading candidates. Several features of the LLBL are similar to the mixed ion region reported here. However, significant differences also exist which make the link between the LLBL and the mixed ion region difficult.

5.1.1. Similarities In addition to the mixed ion feature, the LLBL is also characterized by a lack of high-energy plasma sheet electrons and the presence of field-aligned temperature anisotropy [*Ogilvie et al.*, 1984; *Song et al.*, 1993; *Phan and Paschmann*, 1996]. Balanced counterstreaming field-aligned electron fluxes of the type observed in the mixed region have also been reported in the inner (low density) portion of the LLBL under large magnetic shear condition at the magnetopause [e.g., *Mitchell et al.*, 1987; *Fujimoto et al.*, 1996] and in the entire LLBL for low-shear conditions [*Traver et al.*, 1991; *Phan et al.*, 1997].

5.1.2. Differences (1) The mixed ions in this event are stagnant. This is unlike the tailward flowing plasma in the outer part of the LLBL, but it is somewhat similar to the inner LLBL plasma which also tends to be stagnant [*Le et al.*, 1996; *Fujimoto et al.*, 1996; *Phan et al.*, 1997] (2) The magnetic field threading the LLBL tends to be highly turbulent [*Phan and Paschmann*, 1996], whereas the field in the present case is remarkably steady and tail-like, with field strength similar to that of the lobe. (3) The extent of the mixed region, 8 R_E along the spacecraft trajectory, has not been reported for the LLBL, especially with a significant width in the radial direction from the Earth of 3.2 R_E (from 14.2 to 11 R_E).

5.2. Topology and History of the Mixed Ion Region

To conclusively establish the magnetic topology of the mixed region requires examination of electron pitch angle behavior over a wide energy range which covers both magnetosheath (tens to hundreds of eV) and plasma sheet (keV) populations. Counterstreaming electrons of magnetosheath origin alone cannot be used as conclusive evidence for closed-field topology because low-altitude mirroring of magnetosheath electrons entering along open field lines would also result in bidirectional streaming [*Fuselier et al.*, 1997]. The escape of higher-energy magnetospheric electrons along open field lines, on the other hand, should produce heat flux pointing outward (toward the magnetosheath). In the present mixed ion region, well-balanced counterstreaming electron fluxes at all energies (20 eV - 10 keV) are observed (Plate 4a). We take this as a strong indication that the mixed-ion region is located on closed field lines. However, this does not preclude the possibility that the field lines threading this region were once open. In fact, the large reduction of high-energy plasma sheet electrons in this region could indicate that most of the energetic electrons have escaped during the time when the field lines were open. In this scenario, the plasma sheet ions are present because (1) they are much slower than the electrons and the field lines were not open long enough for them to escape, or (2) they have large enough gyroradii to drift onto the field lines before, during, or after the field lines are closed.

Finally, if the electrons in this region are of magnetosheath origin, their intermediate temperature and field-aligned anisotropy implies significant heating of the source population, especially in the field-aligned direction.

5.3. Plasma Entry Site

The close resemblance of the mixed ion distributions to the magnetosheath and plasma sheet distributions suggests that these regions provide the plasma sources for the mixed region. With single spacecraft measurements the exact path of the ions leading to the creation of the mixed region plasma cannot be identified, although it is possible in this event to narrow down the possibilities. For example, Wind observations of the consecutive regions of the magnetopause, mantle/lobe, and the mixed region allow one to rule out the plasma mantle as the main path of magnetosheath plasma to the mixed region; the reason being the mantle/lobe (at 1500 - 1630 UT) contains even fewer magnetosheath ions than in the mixed region. Other possibilities for entry sites include entry across the midlatitude flank magnetopause, between the lobe and the plasma sheet, and entry further down the magnetotail with subsequent earthward convection. In the latter case, the similarity between the energy spectra of the mixed ions and the magnetosheath and plasma sheet spectra implies that the reconnection site could not be too far down the magnetotail, since Earthward convection would have heated the ions significantly.

The importance of midlatitude magnetopause entry cannot be assessed (in this case) unless the spacecraft trajectory were along the lobe-plasma sheet boundary (and transverse to the magnetopause). Such a trajectory would reveal whether the present mixed ion region extends all the way to the dusk flank magnetopause.

5.4. Entry Mechanisms

A central question is how plasmas from two clearly different sources can get onto the same field lines. For the case of the dayside magnetopause/LLBL, reconnection and diffusive entry have been invoked as the possible mechanisms. It is more difficult to account for the present mixed ion region because of (1) the large extent of the mixed region and (2) the steadiness of the magnetic field threading this region. The latter feature seems to rule out anomalous transport by wave-particle interactions. Dayside reconnection, on the other hand, can account for a mixed-ion boundary layer of no thicker than the width of the reconnection layer itself, which is typically a fraction of an Earth radius. Our observations also do not seem to be related to the cusp reconnection models for the creation of closed field LLBL on the dayside under northward IMF of *Song and Russell* [1992] and *Le et al.* [1996]. This is because the present mixed ion region is located in tail-like field. Below, we point out two additional models which predict plasma entry along the mid/high-latitude flank magnetopause. Our observations, however, do not seem to be related to either proposed mechanism.

In the first model, derived from global MHD simulations, a "sash" is created along a band of weak magnetic field representing the locus of points along the last open field lines. For a strong duskward IMF, the sash would run tailward along the high-latitude magnetopause flank from the northern cusp to the southern cusp, closing via the cross-tail neutral sheet [*White et al.*, 1998; *Nishikawa*, 1998]. Thus the sash represents the sites where direct access of magnetosheath plasma across the magnetopause can occur. However, our observations may not be relevant to plasma entry along the sash since (1) the mixed region is in a strong (~ 40 nT) magnetic field, and (2) the predicted location of the sash, for a duskward IMF, is on the dawnside in the southern hemisphere whereas the mixed ion region in this case was detected on the duskside.

Another entry mechanism was suggested by *Lennartsson* [1992] based on ISEE observations of ion composition in the plasma sheet. In that scenario, during times of northward IMF, solar wind plasma enters the magnetotail along the tail flank, in a region between the lobes and the central plasma sheet. These plasmas are propelled inward by **ExB** drift associated with the electric fringe field of the LLBL. The location of the mixed ions (between the lobe and the plasma sheet) observed in our event is in agreement with the Lennartsson model. However, the expected inward plasma flow (v_y< 0) is not present is our case: The mixed ions are nearly stagnant, with v_y~ +1.5 km/s on average in the mixed region. The positive value of v_y is opposite to the expected inward plasma flows from the dusk flank magnetopause, although the low value of the average velocity (with a large standard deviation of 17 km/s) may not be statistically significant.

In summary, we are not aware of any existing models that can describe the creation of an extended region on strong and steady tail-like field containing unheated mixed magnetosheath-plasma sheet ions that are stagnant.

6. Summary and Conclusion

During the first petal orbit pass by Wind of the high-latitude magnetopause and plasma sheet, an extended region of mixed magnetosheath and plasma sheet ions was observed in the near-Earth region (x_{GSM}~ -2.8 to -7.8 R_E), between the lobe and the plasma sheet, and far inward of the dusk flank magnetopause. The presence of this mixed ion region deep inside the magnetosphere raises questions concerning the plasma entry processes across the magnetopause. Here we summarize the main characteristics of the mixed region:

1. The ion distributions of the mixed region are remarkably similar to those of the magnetosheath and plasma sheet, suggesting that these two regions provide the plasma source for the mixed region and the transfer process does not alter the source populations significantly. We have not considered the ionosphere as a source for the mixed ions. However, to conclusively rule out ionospheric sources would require ion composition measurements [e.g., *Fuselier et al.*, 1999].

2. Field-aligned counterstreaming electrons with well-balanced fluxes occur for the entire energy range, suggesting that the mixed region is on closed field lines. However, the electrons in the mixed ion region consist of a single population with temperature intermediate between those of the magnetosheath and plasma sheet. The large reduction of the high-energy plasma sheet electrons in the mixed region could indicate that the region was once on open field lines.

3. As the neutral sheet is approached, the temperatures of the electrons and of the low-energy component of the mixed ions increase, while the high-energy component of the ions is unaltered. The single ion population plasma sheet is reached when the energy of the low-energy ion population reaches the plasma sheet energy. This feature of the ion distributions raises the possibility that the low-energy ions in the mixed region are the source of the plasma sheet plasma.

4. Unlike the LLBL mixed ions which convects tailward, the present mixed ions are stagnant. It should be pointed out that mixed ions reported by *Fujimoto et al.* [1996, 1998] at low latitudes further down the magnetotail (at x_{GSM}~ -20 R_E) and by *Fuselier et al.* [1999] at the midlatitude flank magnetopause are also stagnant, as are the mixed ions in the inner LLBL [e.g., *Le et al.*, 1996]. To establish the connection between the stagnant mixed ions observed in these various regions will require a more complete survey of the occurrence of mixed ions.

5. The mixed region was detected in strong and steady lobe-like magnetic field. The mixed region ceased to exist when the spacecraft approached the neutral sheet. This raises the possibility that the occurrence of the mixed ion region may be latitude dependent.

6. Although the mixed region is situated between the lobe and the plasma sheet, there is no evidence for ion beams usually associated with the plasma sheet boundary layer. This seems to imply that field-aligned ion beams are not a permanent feature in the boundary between the lobe and the plasma sheet.

7. The extended mixed ion region was detected during a period of persistent northward and duskward IMF. The location of the present mixed region for these IMF conditions is not consistent with the location of the sash seen in MHD simulations [*White et al.*, 1998]. It should be pointed out that the mixed ion events reported by *Fujimoto et al.* [1998] also occurred during periods of northward IMF.

The key particle signatures of the present mixed region are similar to the mixed ion region observed by Geotail [*Fujimoto et al.*, 1996, 1998] near the neutral sheet further down the magnetotail (at x_{GSM}< -10 R_E), and by ISEE [*Le et al.*, 1996; *Fuselier et al.*, 1999] adjacent to the midlatitude dusk flank magnetopause. This suggests that mixed ions are not uncommon in the magnetosphere.

The combined Geotail, ISEE, and future Wind petal orbit observations are expected to provide a map of the mixed ion region and its possible dependence on factors such as the IMF. It is our hope that this information will stimulate theoretical studies to investigate the origin of the mixed ion region. The success of theoretical modeling should shed light on the plasma entry processes across the magnetopause and the assimilation of solar wind plasma into the magnetosphere.

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