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The existence and properties of the distant magnetotail during 32 hours of strongly northward interplanetary magnetic field

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[1] We report observations made by the Wind spacecraft in the distant magnetotail on 22–24 October 2003 when the interplanetary magnetic field (IMF) was strongly northward for more than 32 h. A well-defined magnetotail was observed down to at least $X_{GSM} = -125\ R_E$ even after 32 h of strongly northward IMF conditions. However, the observed tail properties were strikingly different from the typical magnetotail. Although the closed field line plasma sheet was observed throughout the northward IMF interval, the usual mantle/lobe disappeared one hour after the northward IMF front reached the frontside magnetopause. Instead, open field lines were observed populated by field-aligned solar wind strahl electrons as well as plasma sheet electrons predominantly at 90° pitch angle. In essence, these observations provide evidence for reconnection between the IMF and a previously closed nightside cold dense plasma sheet during long periods of northward IMF, after poleward-of-the-cusp reconnection has depleted all open lobe field lines.

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1. Introduction

[2] The length and properties of the magnetotail during prolonged intervals of northward interplanetary magnetic field (IMF) has long been a subject of debate [see *Walker et al.*, 1998, for an overview]. When the IMF is northward-directed, draped interplanetary magnetic fields could merge with lobe fields poleward of both cusps to produce closed dayside field lines which are then subsequently transported back into the tail and become closed tail fields [*Dungey*, 1963; *Cowley*, 1981; *Song and Russell*, 1992; *Raeder et al.*, 1995; *Onsager et al.*, 2001].

[3] Some global MHD simulations have indeed produced closed magnetotails, extending to distances as short as 65 R_E [*Usadi et al.*, 1993; *Gombosi et al.*, 1998] or as long as 165 R_E [*Fedder and Lyon*, 1995]. *Raeder et al.* [1995], however, found that an open magnetotail is present down to at least 100 R_E even when the IMF is strongly northward for an extended period of time.

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[4] Although some observations have indicated that a spacecraft is much less likely to encounter the magnetotail when the IMF is northward [*Fairfield*, 1992, 1993; *Fairfield et al.*, 1996], the scarcity of prolonged intervals of strongly northward IMF has made it difficult to resolve this issue. The interplanetary coronal mass ejection (ICME) event on 22–24 October 2003, in which the IMF was strongly northward for more than 32 h, provides an unprecedented opportunity to study the effects on the magnetosphere during long duration, strongly northward IMF. During this event the Wind spacecraft passed behind the Earth at $X_{GSM} = -125\ R_E$, in an ideal position to investigate the extent and properties of the distant magnetotail.

[5] The near-Earth magnetotail during this same northward IMF interval has previously been studied in detail [*Øieroset et al.*, 2005; *Li et al.*, 2005]. Cluster and DMSP observations showed that the entire near-Earth tail was filled with cold and dense plasma sheet (CDPS), with a density five times higher and an ion temperature five times lower than what is normally observed in the plasma sheet. Comparisons with a global MHD simulation suggest that poleward-of-cusp reconnection captured dayside magnetosheath plasma and convected it into the tail to form the CDPS.

[6] Here we focus on the distant tail properties during this event. We show that a well-defined, albeit unusual, magnetotail on both open and closed magnetic field lines was present down to at least $X_{GSM} = -125\ R_E$ even during these strongly northward IMF conditions. The observed electron distributions indicate that poleward-of-cusp reconnection

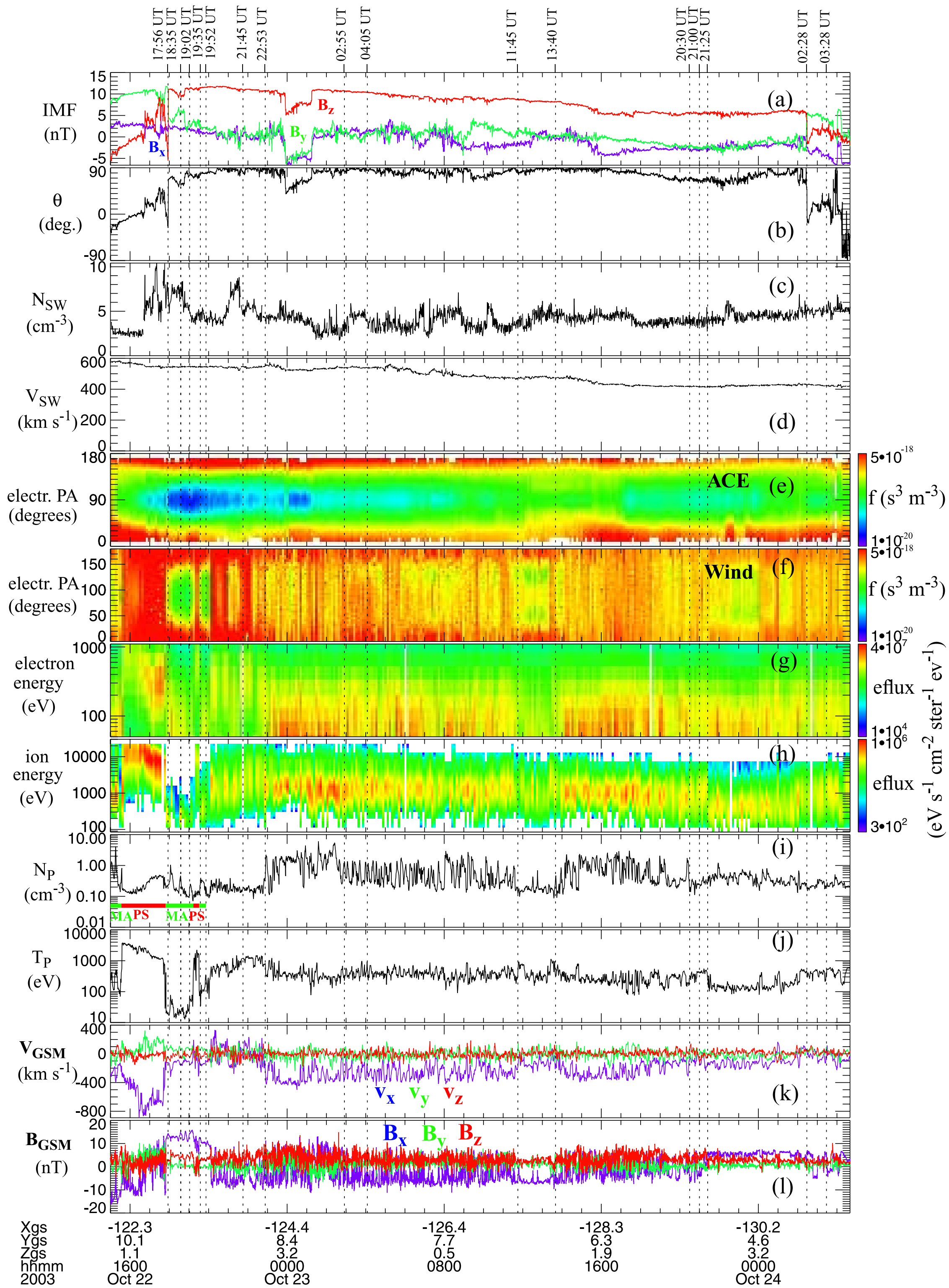

Figure 1. ACE (a–e) and Wind (f–l) observations from 22 October 2003, 15:00 UT to 24 October 2003, 09:00 UT. (a) ACE IMF (GSM), (b) ACE IMF θ angle ($\theta = arctan(B_Z/|B_Y|)$), (c) ACE solar wind density, (d) ACE solar wind speed, (e) ACE solar wind 370 eV electron pitch angle distribution, (f) Wind 430 eV electron pitch angle distribution, (g) Wind electron spectrogram, (h) Wind ion spectrogram, (i) Wind plasma density, (j) Wind ion temperature, (k) Wind plasma velocity (GSM), (l) Wind magnetic field (GSM). The southward/B_Y-dominated plasma sheet and mantle intervals described in section 3.2 are marked with red and green horizontal line segments in panel (i). Other times referred to in the text are indicated on top of the vertical dashed lines.

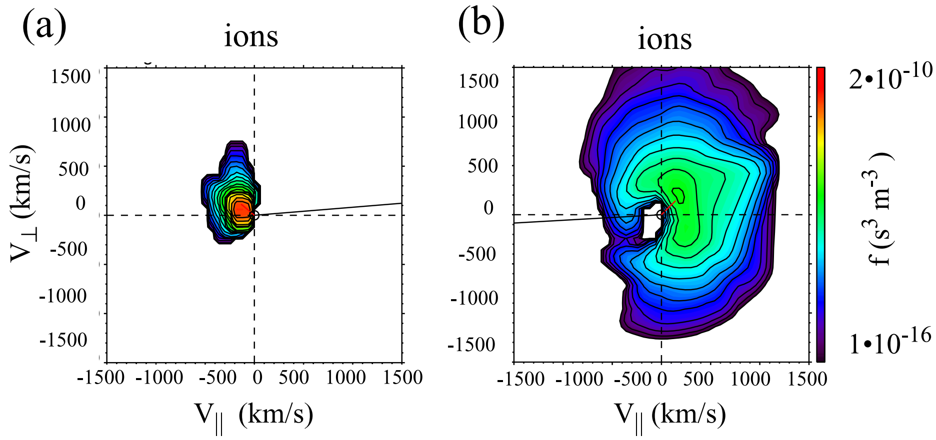

Figure 2. Two-dimensional cuts of the three-dimensional ion distributions observed by Wind (a) in the plasma mantle at 17:56:50 UT on 22 October prior to the northward IMF turning and (b) in the open plasma sheet at 11:58:20 UT on 23 October during the northward IMF interval. The black line denotes the direction to the Sun.

was responsible not only for the depletion of open lobe fields, but also for opening up the newly created closed cold dense plasma sheet.

2. Orbit and Instrumentation

[7] The Wind observations presented here were obtained in the deep tail on 22–24 October 2003, when Wind was on its way to the L2 Lagrangian point. Wind plasma and magnetic field parameters were obtained from the 3DP [*Lin et al.*, 1995] and MFI [*Lepping et al.*, 1995] instruments. 3DP detects protons with energies from 80 eV to 27 keV and electrons from a few eV to 27 keV. During the interval presented here full 3D particle distributions were transmitted every 97 s. Spin (3s) resolution magnetic field data is used in this study. The ACE spacecraft monitored the solar wind 235 R_E upstream of the Earth.

3. Observations

[8] In this section we first describe ACE observations of the exceptionally long interval of strongly northward IMF. We then contrast the properties of the distant tail observed by Wind before and after the northward turning of the IMF.

3.1. Solar Wind Observations

[9] Figures 1a–1e show the ACE observations from 22 October, 15:00 UT to 24 October 2003, 09:00 UT. The IMF was southward-directed or B_Y-dominated until 17:56 UT on 22 October (Figures 1a, 1b) when the leading edge of an extended interval of strongly northward IMF ($\theta = arctan(B_Z/|B_Y|)$ close to 90°) was observed by ACE (Figures 1a, 1b). The strongly northward IMF interval lasted more than 32 h, until 02:28 UT on 24 October. Following the northward IMF turning the solar wind density (Figure 1c) increased a factor of 4 from 2.5 cm^{-3} to more than 10 cm^{-3}, but settled between 2.5 cm^{-3} and 6 cm^{-3} after 21:45 UT on 22 October. The solar wind speed (Figure 1d) decreased steadily from 550 km s^{-1} to 400 km s^{-1} during the strongly northward IMF interval. ACE observed counter-streaming field-aligned strahl electrons (in the 70–1400 eV range) throughout the interval (Figure 1e), indicating closed interplanetary magnetic field lines with both foot points connected to the Sun [e.g., *Gosling et al.*, 1987]. The strahl electrons provide an important tool for diagnosing the magnetic topology of the magnetotail. The presence of strahl electrons on magnetotail field lines indicates open field lines (connecting magnetospheric field lines to the IMF) [e.g., *Baker et al.*, 1986], while the absence of strahl electrons indicates closed plasma sheet. With a solar wind speed of 550 km s^{-1} the strongly northward IMF front reached the dayside magnetopause at ~18:35 UT and the Wind location ($X_{GSM} = -125\ R_E$) in the distant tail at ~19:02 UT.

3.2. Southward or B_y-Dominated Magnetotail

[10] Before 19:35 UT on 22 October the Wind spacecraft, located 125 R_E behind the Earth, observed the typical structure of the distant tail (usually associated with southward IMF), with a hot (1–4 keV) and tenuous (0.2–0.4 cm^{-3}) plasma sheet at lower magnetic latitudes as inferred from the small $|B_X|$ (15:33–17:49 UT and 19:13–19:31 UT) and a cold lobe/mantle at higher latitudes (large $|B_X|$) in both hemispheres (15:00–15:33 UT, 17:49–19:13 UT, and 19:31–19:52 UT). The mantle ion distributions are characterized by a narrow field-aligned anti-sunward ion beam (Figure 2a). The mantle electrons were counterstreaming and field-aligned (Figure 3a). The observed energies (100 eV–4 keV) of these electrons were similar to the solar wind strahl electron energies observed by the ACE spacecraft (Figure 1e), indicating that the mantle field lines were connected to the IMF, and the counterstreaming electrons were the strahl electrons streaming earthward and mirroring near Earth [*Baker et al.*, 1986]. Consistent with this scenario, counterstreaming electrons were observed in both the northern (as inferred from the large positive B_X) and southern (as inferred from the large negative B_X) mantle due to the electron source (the solar wind strahl electrons) being bidirectional [e.g., *Gosling et al.*, 1986]. A clear distinction between the closed plasma sheet and the open mantle is the absence or presence of strahl electrons. Figure 1g shows that the strahl electrons (100 eV–4 keV) that are present in the mantle (e.g., 17:49–19:13 UT) are absent in the hot plasma sheet (e.g., 15:33–17:49 UT), indicating that the latter is on closed field lines.

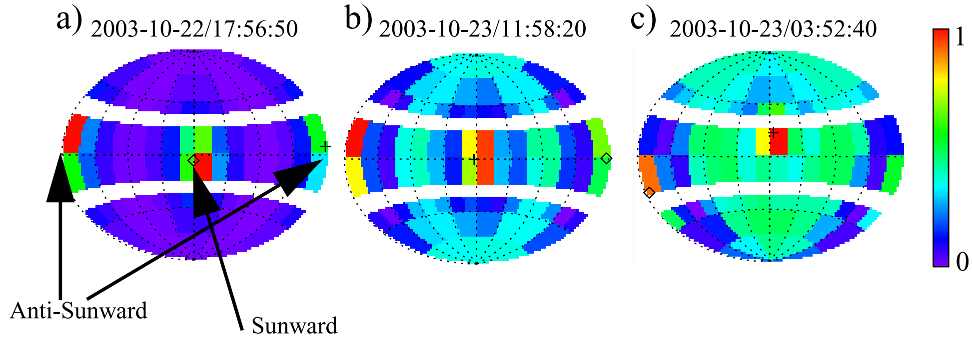

Figure 3. Three-dimensional 430 eV electron distributions observed by Wind (a) in the plasma mantle at 17:56:50 UT on 22 October prior to the northward IMF turning, (b) in the open plasma sheet at 11:58:20 UT on 23 October during the northward IMF interval showing a ring distribution, and (c) also in the open plasma sheet during northward IMF at 03:52:40 UT on 23 October showing a distribution that is more filled inside the ring. The center of each plot shows electrons arriving from the Sunward direction and the magnetic field aligned and anti-field aligned directions are marked by the "plus" and "diamond" signs, respectively. Enhanced electron counts along the "plus" and "diamond" signs indicate counterstreaming field-aligned and anti-field-aligned electrons, respectively. The electron counts in each plot are normalized to the peak electron count.

[11] The last mantle distribution after the northward turning of the IMF was observed by Wind at 19:35 UT on 22 October only ~ one hour after the northward IMF front reached the dayside magnetopause.

3.3. Strongly Northward IMF Magnetotail

[12] When the last mantle distribution was observed at 19:35 UT Wind remained inside the magnetotail, characterized by large $|B_X|$ (~10 nT) and relatively high ion temperatures (~1 keV) until ~22:53 UT on 22 October After ~22:53 UT on 22 October Wind began making brief excursions into the magnetosheath, observing densities between 1 and 2 cm^{-3} and ion temperatures less than 200 eV, with an anti-sunward flow of 300–400 km s^{-1}. The magnetosheath encounters were quite regular and occurred every 5–10 min, indicating that the tail was flapping with a frequency of 1–3 mHz. These rather regular fluctuations were observed until 21:25 UT on 23 October except for the 11:45–13:40 UT interval on 23 October when Wind observed predominantly magnetotail plasma. After 21:25 UT on 23 October Wind again observed only magnetotail plasma (no magnetosheath) until the northward IMF tail was gradually replaced by the usual active southward IMF tail after ~03:30 UT on 24 October 2003.

[13] Figure 4 shows a zoom-in of the Wind observations from 02:55 to 04:05 UT on 23 October 2003. The properties of the distant tail in this interval are qualitatively representative of this region during the prolonged period of northward IMF. In addition to the cold, dense, and fast-flowing magnetosheath two other distinct plasma regions were observed. Both regions were more tenuous and much hotter than the magnetosheath. However, the two regions had distinctly different plasma properties.

[14] The first region had a density of 0.3 cm^{-3}, an ion temperature of 0.7–1.5 keV, a tailward flow speed of 100–200 km s^{-1}, low $|B_X|$ (<6.5 nT), and nearly isotropic electrons. The isotropy of the electrons is similar to the closed plasma sheet observed during southward and B_Y-dominated IMF (e.g., at 15:33–17:49 UT, see Figure 1f) which suggests that this region is also the closed plasma sheet, although the ion temperature of this plasma sheet during northward IMF is cooler (0.7–1.5 keV versus 1–4 keV) while the density remains similar (~0.3 cm^{-3}). The lack of solar wind strahl electrons in this region (e.g., at 03:45–03:51 UT on 23 October 2003, see Figure 4b) provides additional evidence that this region is the plasma sheet on closed field lines.

[15] While the first region (the closed plasma sheet under northward IMF) is similar to the closed plasma sheet under southward or B_Y-dominated IMF, the second region (located at larger $|B_X|$) is quite different from the mantle. The electron distributions in this region consist of two populations: Counterstreaming field-aligned electrons and electrons near 90° pitch angle (Figure 3b). The counterstreaming electrons at solar wind strahl energies in this region are similar to those observed in the southward/B_Y-dominated IMF mantle and indicate that this is a "mantle-like" region which is on open field lines. However, the additional population at 90° pitch angle was not seen on mantle field lines. The energy of this population is between 400 eV and 2 keV, resulting in a total electron temperature of ~500 eV, a factor of five higher than the conventional mantle. Sometimes the "ring" population is broader, filling in the "ring" (Figure 3c).

[16] The presence of the hotter electrons near 90° pitch angle suggests that these are plasma sheet electrons on field lines that were originally closed plasma sheet field lines. Once the plasma sheet field lines are open, field-aligned plasma sheet electrons are rapidly lost to the solar wind while the perpendicular electrons could remain longer. Ring distributions that are more filled could indicate newly open field lines. The observed ion distributions in this region show much hotter tailward flowing ions (Figure 2b) compared to the narrow field-aligned cold ion beams seen in the conventional mantle (Figure 2a), consistent with the region being the open plasma sheet. The first clear "open plasma sheet distribution" appeared at 19:52 UT on 22 October 2003, just a few minutes after the last mantle distribution was observed and 1 h 17 min after the northward IMF reached the dayside magnetopause. The open plasma sheet region was observed more commonly as the northward IMF interval

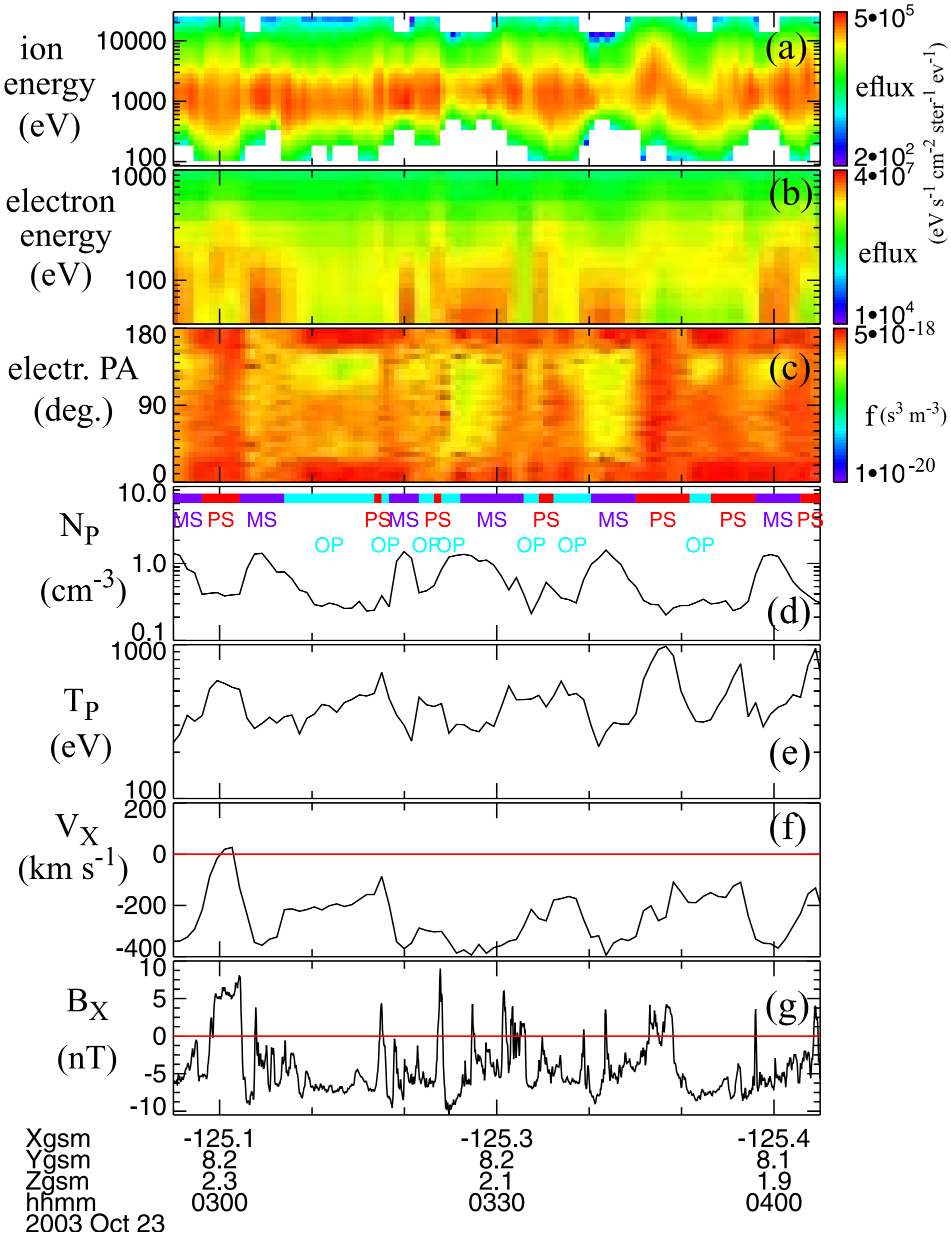

Figure 4. Zoom-in of Figure 1 showing Wind observations from 02:55 UT to 04:05 UT on 22 October 2003. (a) Ion spectrogram, (b) electron spectrogram, (c) 430 eV electron pitch angle, (d) plasma density, (e) ion temperature, (f) velocity along X_{GSM}, (g) magnetic field along X_{GSM}. The closed plasma sheet (PS), the open plasma sheet (OP), and the magnetosheath (MS) intervals are marked by color bars in Panel d.

progressed. Between 20:30 UT on 23 October and 03:28 UT on 24 October during the end of the northward IMF interval, the two-population distributions were observed 87% of the time. The remaining 13% were closed plasma sheet.

[17] During the interval shown in Figure 4 the open plasma sheet region had a density of $\sim$0.3 cm^{-3} which is comparable to the closed plasma sheet (the first region) but a slightly lower ion temperature of 0.5–1.2 keV, a tailward ion flow speed of $\sim$200 km s^{-1}, and large and stable $|B_X|$ (>6.5 nT).

[18] Overall both the closed and open plasma sheet became cooler and denser as time progressed. After 21:00 on 23 October 2003 the ion temperature of the open plasma sheet region had dropped to 100–200 eV and the density had increased slightly to $\sim$0.3–0.5 cm^{-3}. The tailward flow speed and $|B_X|$ range remained the same, but the magnetic field in the open plasma sheet region was no longer as stable and was more variable than in the beginning of the northward IMF interval. Toward the end of the northward IMF interval the density in the closed plasma sheet region had increased to $\sim$0.3–1.0 cm^{-3} and the ion temperature dropped to 100–500 eV. In general the closed plasma sheet was slightly hotter and slower-moving than the open plasma sheet throughout the northward IMF interval. The cooler

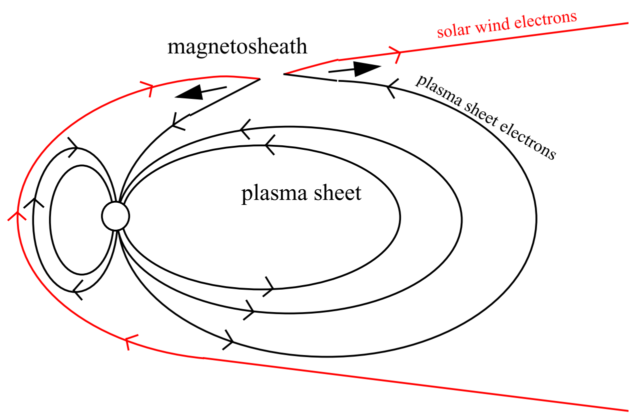

Figure 5. A sketch illustrating the creation of the open plasma sheet by tailward-of-cusp reconnection between the draped northward-directed IMF (red) and closed plasma sheet field lines (black). This sketch is similar to one by *Dungey* [1963] except that reconnection is not simultaneous in the two hemispheres in the present open tail case.

(and less dense) open plasma sheet may be due to the fact that hotter particles escape (into the solar wind) before the colder particles.

4. Summary and Discussion

[19] The 32 h interval of strongly northward IMF that occurred on 22–24 October 2003 has provided an unprecedented opportunity to address the long standing question concerning the length and properties of the magnetotail during such conditions. The Wind observations presented here demonstrate that the magnetotail was indeed present and extended to at least $X_{GSM} = -125$ R_E throughout the northward IMF interval.

[20] The observed northward IMF tail consisted of two distinct regions: (1) Plasma sheet on closed magnetic field lines, and (2) plasma sheet on open magnetic field lines. The open plasma sheet is identified by the presence of mirroring solar wind strahl electrons and plasma sheet electrons on the same field line while solar wind strahl electrons are not present in the closed plasma sheet. Thus the tail during strongly northward IMF does not become completely closed as in some global MHD models [*Usadi et al.*, 1993; *Gombosi et al.*, 1998; *Fedder and Lyon*, 1995], but rather stays long and consists of regions of open and closed field lines [*Raeder et al.*, 1995]. However, the properties of the magnetotail are drastically different from the distant tail structure during southward or B_Y-dominated IMF.

[21] The plasma mantle/lobe region, which is an integral part of the magnetotail during southward or B_Y-dominated IMF, ceased to be observed one hour after the northward IMF reached the frontside magnetopause. Instead a relatively hot region on open magnetic field lines (as indicated by the presence of solar wind strahl electrons) was observed at high latitudes. The ion temperature in this region was a factor of five higher than in the mantle due to the presence of plasma sheet ions and electrons. The plasma sheet-like electrons appeared predominantly at 90° pitch angle while the plasma sheet-like unidirectional ions streamed tailward at $\sim$200 km s^{-1}.

[22] The presence of both solar wind and plasma sheet electrons indicate that this hot and open region is the open plasma sheet created by poleward-of-cusp reconnection between the IMF and the closed plasma sheet (Figure 5), a scenario that was first proposed by *Dungey* [1963], but rarely reported. The more common situation during northward IMF is to have reconnection between the IMF and the open mantle/lobe field lines. However, if the IMF stays strongly northward long enough the mantle/lobe can be eroded away and the IMF can start reconnecting with closed plasma sheet field lines tailward of the cusps [*Cowley*, 1981; *Onsager et al.*, 2001; *Li et al.*, 2007]. In a realistic magnetosphere where the Earth's dipole tilt is taken into account a reconnected field line will be temporarily open before being reconnected again in the other hemisphere [*Cowley*, 1981]. This scenario leads to a magnetotail that is always partially open also during strongly northward IMF, as observed here.

[23] During the 32 h of northward IMF Wind traveled a distance of $\sim$6 R_E in the Y_{GSM} direction while the tail was flapping in Z_{GSM}, as indicated by the many B_X reversals. It is likely that the tail was flapping in Y_{GSM} as well. Thus Wind must have sampled a large cross section of the tail. The fact that no lobe/mantle plasma was detected after 19:35 UT on 22 October one hour after the northward IMF reached the frontside magnetopause, implies that the lobe/mantle was eroded over a large dawn-dusk portion (if not all) of the tail in just one hour.

[24] The one hour erosion time found here appears reasonable for the conditions at hand. The reconnection rate for a magnetosheath density of $\sim$14 cm^{-3} and a reconnecting field of 30 nT is $\sim$25 km s^{-1} [*Swisdak and Drake*, 2007] if one assumes a fast reconnection rate of 10% of the inflow Alfvén speed. Assuming that this reconnection rate is uniform across the mantle (in the dawn-dusk direction) it would take one hour to erode a 14 R_E cross section of the mantle/lobe (i.e., more than the entire mantle/lobe) in each hemisphere. Considering the fact that the Wind observations of the presence or absence of low-energy mantle ions were made at $X_{GSE} = -125$ R_E, it is likely that the mantle/lobes were depleted in even less than an hour at the reconnection site closer to the Earth.

[25] While Wind monitored a long and open distant tail during this event *Øieroset et al.* [2005] have shown that the entire near-Earth plasma sheet became filled with cold dense plasma sheet (CDPS) and stayed that way for the duration of the strongly northward IMF interval. Quantitative agreement with a global MHD simulation demonstrated that the observed CDPS was most likely formed by the capture of magnetosheath plasma on the dayside by poleward-of-cusp reconnection in both hemispheres and the subsequent transport of closed field lines into the tail [*Øieroset et al.*, 2005; *Li et al.*, 2005]. The fact that both the near-Earth cold dense plasma sheet and the distant tail exist after more than 32 h of strongly northward IMF suggests that there is a balance in the creation and destruction of the closed-field plasma sheet by poleward-of cusp reconnection. The Cluster and Wind observations of the near-Earth and distant tail thus indicate that poleward-of-cusp reconnection is responsible not only for the closure of open tail flux during strongly northward IMF, but also for opening up closed plasma sheet field lines, leading to a long

and open magnetotail even during prolonged northward IMF conditions.

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References

Baker, D. N., et al. (1986), Strong electron bidirectional anisotropies in the distant tail - ISEE 3 observations of polar rain, *J. Geophys. Res.*, *91*, 5637.

Cowley, S. W. H. (1981), Magnetospheric and ionospheric flow and the interplanetary magnetic field, in *The Physical Basis of the Ionosphere in the Solar-Terrestrial System*, AGARD-CP-295 4/1-4/14, AGARD Conf. Publ.

Dungey, J. W. (1963), The structure of the exosphere or adventures in velocity space, in *Geophysics, The Earth's Environment*, edited by D. De Witt, J. Hieblot, and L. Le Beau, Gordon and Breach, New York, p. 503.

Fairfield, D. H. (1992), On the structure of the distant magnetotail: ISEE 3, *J. Geophys. Res.*, *97*, 1403.

Fairfield, D. H. (1993), Solar wind control of the distant magnetotail: ISEE 3, *J. Geophys. Res.*, *98*, 21,265.

Fairfield, D. H., et al. (1996), Geotail observations of an unusual magnetotail under very northward IMF conditions, *J. Geomagn. Geoelectr.*, *48*, 473.

Fedder, J. A., and J. G. Lyon (1995), The Earth's magnetosphere is 165 R_E long: Self-consistent currents, convection, magnetospheric structure and processes for northward interplanetary magnetic field, *J. Geophys. Res.*, *100*, 3623.

Gombosi, T. I., et al. (1998), The length of the magnetotail for northward IMF: Results of 3D MHD simulations, in *Phys. Space Plasmas* (1998), vol. 15, edited by T. Chang and J. R. Jasperse, p. 121, Cambridge, Mass.

Gosling, J. T., et al. (1986), Bidirectional solar wind electron heat flux and hemispherically symmetric polar rain, *J. Geophys. Res.*, *91*, 11,352.

Gosling, J. T., et al. (1987), Bidirectional solar wind electron heat flux events, *J. Geophys. Res.*, *92*, 8519.

Lepping, R. P., et al. (1995), The Wind magnetic field investigation, *Space Sci. Rev.*, *71*, 207.

Lin, R. P., et al. (1995), A three-dimensional plasma and energetic particle investigation for the wind spacecraft, *Space Sci. Rev.*, *71*, 125.

Li, W., et al. (2005), Plasma sheet formation during long period of northward IMF, *Geophys. Res. Lett.*, *32*, L12S08, doi:10.1029/2004GL021524.

Li, W., et al. (2007), Solar wind plasma entry into the magnetosphere under northward IMF conditions, *J. Geophys. Res*, in press.

Øieroset, M., et al. (2005), Global cooling and densification of the plasma sheet during an extended period of purely northward IMF on 22–24 October 2003, *Geophys. Res. Lett.*, *32*, L12S07, doi:10.1029/2004GL021523.

Onsager, T. G., et al. (2001), Reconnection at the high-latitude magnetopause during northward interplanetary magnetic field conditions, *J. Geophys. Res.*, *106*, 25,467.

Raeder, J., et al. (1995), The structure of the distant geomagnetic tail during long periods of northward IMF, *Geophys. Res. Lett.*, *22*, 349.

Swisdak, M., and J. F. Drake (2007), The orientation of the reconnection X-line, *Geophys. Res. Lett.*, *34*, L11106, doi:10.1029/2007GL029815.

Song, P., and C. T. Russell (1992), Model of the formation of the low-latitude boundary layer for strongly northward interplanetary magnetic field, *J. Geophys. Res.*, *97*, 1411.

Usadi, A., et al. (1993), A global simulation of the magnetosphere with a long tail: Southward and northward interplanetary magnetic field, *J. Geophys. Res.*, *98*, 7503.

Walker, R., et al. (1998), Source and loss processes in the magnetotail, in *Magnetospheric Plasma Sources and Losses*, edited by B. Hultqvist et al., Space Sciences Series of ISSI, Vol. 6, Kluwer Academic Publishers, Dordrecht, The Netherlands, (also in *Space Science Reviews*, 88, issues 1 and 2, 1999).

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