



**HAL**  
open science

# Continuum emission and broadband electrostatic noise at the low latitude boundary layer: A diagnostic of boundary layer dynamics

William M. Farrell, R. J. Fitzenreiter, Michael L. Kaiser, Keith Goetz, Milan  
Maksimovic, M. J. Reiner

► **To cite this version:**

William M. Farrell, R. J. Fitzenreiter, Michael L. Kaiser, Keith Goetz, Milan Maksimovic, et al.. Continuum emission and broadband electrostatic noise at the low latitude boundary layer: A diagnostic of boundary layer dynamics. *Geophysical Research Letters*, 2002, 29, pp.21-1. 10.1029/2000GL01279 . hal-03801698

**HAL Id: hal-03801698**

**<https://hal.science/hal-03801698>**

Submitted on 8 Oct 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Copyright

## Continuum emission and broadband electrostatic noise at the low latitude boundary layer: A diagnostic of boundary layer dynamics

W. M. Farrell,<sup>1</sup> R. J. Fitzenreiter,<sup>1</sup> M. L. Kaiser,<sup>1</sup> K. Goetz,<sup>2</sup> M. Maksimovic,<sup>3</sup>  
and M. J. Reiner<sup>4</sup>

Received 21 December 2000; revised 27 August 2001; accepted 27 September 2001; published 25 June 2002.

[1] We examine the plasma and radio waves near the inner edge of the low latitude boundary layer (LLBL) during a period of time when the layer is in a “pulsed” oscillating configuration. Previous work suggests there are numerous possible explanations for such oscillations including a Kelvin-Helmholtz instability, flux transfer events, and a boundary response to solar wind pressure oscillations. We demonstrate that the inner edge of the LLBL is indeed in motion, based upon the influence this motion has on the incident freely-propagating continuum emission. We also demonstrate that the inner boundary contains impulsive broadband events that appear, in high resolution, as a series of bipolar solitary pulses. These are the result of a kinetic electron beam instability occurring in association with the boundary fluid motion. We suggest that the large-scale fluid motion drives the kinetic instability via particle evacuation near the oscillating boundary. *INDEX TERMS:* 2724 Magnetopause, cusp, and boundary layers; 2728 Magnetosheath; 2772 Plasma waves and instabilities; 2784 Solar wind/magnetosphere interactions

### 1. Introduction

[2] Quasi-periodic motion of the magnetopause has been reported for decades (see the review by *Fitzenreiter and Ogilvie* [1995]). However, the interpretation of this motion is still the subject of considerable debate. Essentially, three different scenarios have been presented to explain the movement, including a Kelvin-Helmholtz surface instability (see *Fairfield et al.* [2000] and references therein), boundary response to solar wind pressure variations [*Sibeck et al.*, 1990] and/or boundary variation associated with patchy reconnection at the surface [*Russell and Elphic*, 1978].

[3] *Skopke et al.* [1981] observed an interesting situation called a “pulse” boundary layer where density and temperature oscillations are observed in the adjacent LLBL located just inside of the magnetopause. They suggested that the Kelvin-Helmholtz instability is active along the inner edge of the LLBL, mixing a colder, high-density boundary plasma with a hot, low density halo plasma. Stability analysis [*Ogilvie and Fitzenreiter*, 1989] and simulation [*Lee et al.*, 1981] analytically demonstrate that the K-H instability is operating at this inner edge. However, these measurements from the same period of time have been interpreted as the passage of flux transfer events (FTEs) by the spacecraft [*Cowley*, 1982]. *Sibeck et al.* [1990] examined these same events and concluded that solar wind pressure pulses could drive the observed impulsive LLBL motion described by *Skopke et al.* [1981]. In all

interpretations, the “pulsed” LLBL has density irregularities, but their causes differ.

[4] As we demonstrate, the signatures of fluctuations in the LLBL are also manifested in plasma/radio wave activity. Specifically, trapped within the magnetospheric density cavity (the low-density region defined by the plasmopause and magnetopause) is terrestrial “continuum” emission [*Gurnett and Shaw*, 1973; *Gurnett*, 1975]. The low frequency portion of this emission undergoes reflections from density gradients at the magnetosphere’s walls, and hence is contained in the magnetosphere. Consequently, the emission is detected quasi-continually from about 1–30 kHz throughout the entire magnetospheric cavity. The emission essentially fills up the cavity from its plasmopause source, much like water filling a swimming pool (see reviews by *Kurth* [1992] and *Matsumoto et al.* [2000] and references therein).

[5] Given that the inner cavity walls are often in oscillatory motion, the associated cavity wall oscillation ought to affect the local propagation of the incident continuum emission. In this work, we will examine the wave/boundary interface during “pulsed” boundary layer conditions. In particular, we will use the continuum emission as a diagnostic to demonstrate that the inner edge of the LLBL is in oscillatory motion. Besides the fluid motion, we demonstrate that electrostatic impulsive events are also observed near this boundary, indicating the presence of an associated kinetic instability.

### 2. Observations

[6] Figure 1 shows a Wind/WAVES spectrogram from 28 November 1995, during an interval when the spacecraft traversed the dusk magnetopause. For a description of Wind/WAVES, see *Bougeret et al.* [1995]. The spacecraft was located at approximately  $-6.5$  Re, 19.6 Re, and 1.7 Re in GSE X, Y, and Z coordinates, respectively, just nightside of the dusk terminator. Prior to 0840 UT, the spacecraft was in the solar wind, but at that time crossed the bow shock. As evident in Figure 1, the change in plasma frequency at this time is indicative of a substantial and abrupt shock-related density increase. The plasma frequency is identified as the intense narrow tone labeled “ $f_{pe}$ ”. From 0840 UT to approximately 1620 UT, the spacecraft remained in the magnetosheath, where plasma frequencies are above 30 kHz and electron densities remain above 10 el/cc.

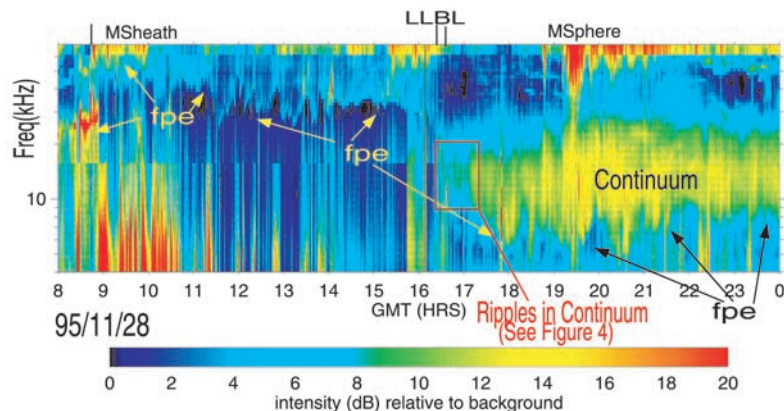
[7] At 1620 UT, the spacecraft entered a rather different medium. Specifically, for the next 22 minutes, the spacecraft remained in a region where there appeared to be “pulses” of high-temperature, low density plasma, similar to the LLBL defined previously by *Skopke et al.* [1981]. An energy-versus-time spectrogram of the Wind solar wind experiment (SWE) electrons is shown in Figure 2 (see *Ogilvie et al.* [1995]). As evident in the figure, low-energy sheath-like plasma is observed until 1620 UT. At that time a series of impulsive density depletions are observed, that appear much like the “halo” regions described by *Skopke et al.* [1981]. These density depletions are identifiable by their reduction in color intensity (from red to blue) and their temperature enhancement is indicated by electron measurements (blue regions extending) up to 400 eV. They are

<sup>1</sup>NASA/Goddard Space Flight Center, Greenbelt, MD, USA.

<sup>2</sup>School of Physics and Astronomy, University of Minnesota, Minneapolis, USA.

<sup>3</sup>Observatoire de Paris, Meudon, France.

<sup>4</sup>The Catholic University of America, Washington, D.C., USA.



**Figure 1.** A Wind/Waves spectrogram during the dusk transit of the magnetopause region. The plasma frequency,  $f_{pe}$ , is labeled and identified by Langmuir emission at the local plasma frequency (prior to 1642 UT) and the low frequency o-mode cutoff at the local plasma frequency of the continuum radiation (after 1642 UT).

labeled as D1, D2, and D3, and are approximately 2 minutes each in duration and  $\sim 5$  minutes in separation.

[8] At around 1642 UT, the spacecraft exited the LLBL and entered the magnetosphere and remained there for the remainder of the day. In Figure 2, the magnetospheric region is identifiable by the presence of a high energy electron component extending  $>1$  keV. Returning to Figure 1, the magnetospheric region is easily identified by the copious continuum emission found between 5–25 kHz. Note that the low frequency limit of the emission is the local plasma frequency. The nominal value of this low frequency cutoff is about 6 kHz, giving an estimate of the magnetospheric density as less than 1 el/cc. However, there is substantial variation in this density, and even some suggestion of quasi-periodic wave structures in the magnetospheric plasma, based upon this density variation.

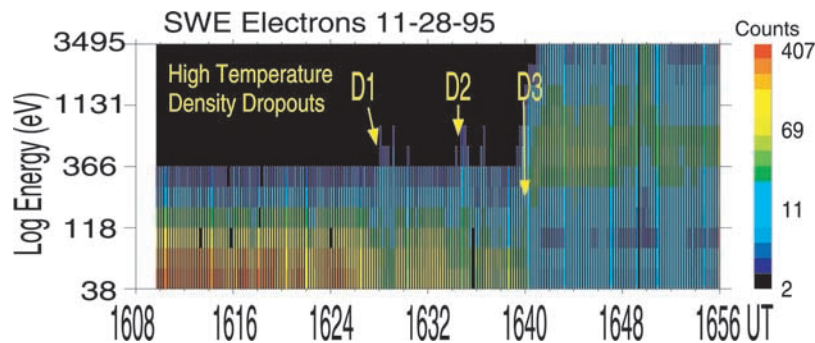
[9] We find this Wind/magnetopause transit to be particularly interesting for three specific reasons: First, Wind enters a LLBL that appears as a “pulsed” boundary layer, as previously defined by *Scopke et al.* [1981]. Second, the continuum emission is ubiquitous within the magnetosphere, and is contained by the density gradient at the magnetospheric edge. The common paradigm for continuum emission propagation has this reflection point at the magnetopause. However, as evident in Figure 1, the continuum is really contained at the inner edge of the LLBL, and for the most part, its lower frequencies do not propagate into the higher density LLBL region. The emission containment at the inner edge of the LLBL has not been previously reported. Finally, at the inner edge of the LLBL, a series of impulsive broadband electrostatic noise (BEN) events are observed which, as we demonstrate below, consist of a series of bipolar solitary pulses. This observation of such solitary waves is the first made along the disturbed inner edge of the LLBL.

[10] We note that there is no apparent magnetic field signature of a flux transfer event, the bipolar field changes like that defined in *Russell and Elphic* [1978], coincident with the passages of D1, D2, and D3. Thus, these density dropouts do not appear to be associated with FTE’s. However, a possible FTE event may be present near 1632 UT (between D1 and D2).

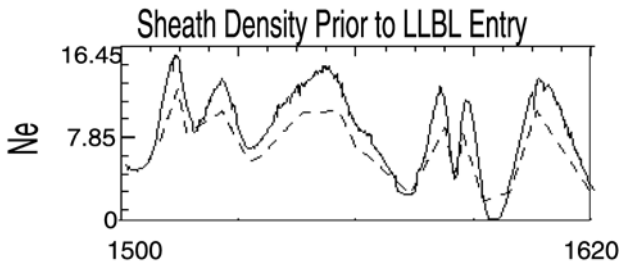
[11] Unfortunately, no spacecraft was directly upstream in the solar wind for a unique determination of incoming pressure pulses that might stimulate D1–D3. IMP-8 was located in the dawn magnetosheath and GEOTAIL was directly tailward during this Wind passage. However, Figure 3 is an examination of the density as measured by Wind SWE during the hour preceding the LLBL crossing (unbroken line = electrons, broken line = ions), while the spacecraft was located in the magnetosheath. During this period the flow in the sheath was nearly constant, but the density displayed a distinct modulation with a 6 minute periodicity. We conclude that during the hour preceding the LLBL passage, the sheath was undergoing an AC pressure variation with a 6–17 minute periodicity, and this may account for the corresponding LLBL pulses D1–D3 of approximately the same temporal cycle. Both sheath-located Wind and IMP-8 registered a northward turning magnetic field starting near 1540 UT; this assumed to be associated with a northward directed IMF. As Wind entered the magnetosphere, IMP-8 continued to monitor a northward IMF until  $\sim 1710$  UT.

### 3. Oscillations in the Continuum Emission at the LLBL

[12] As described, the ubiquitous continuum emission is incident upon the inner edge of the LLBL. At this location, the local



**Figure 2.** A SWE energy-time electron spectrogram in the LLBL, showing a number of periods where the core electron flux dropped out and temperatures rose (D1–D3), appearing as the “halo” events previously described by *Scopke et al.* [1981].



**Figure 3.** The electron (solid line) and ion (dashed line) density measured the hour before the LLBL crossing (Note the 6–17 minute periodicity in the density).

plasma frequency quickly increases from about 5 kHz to nearly 30 kHz. Continuum emission below about 30 kHz is incident upon the inner edge of the LLBL, and reflected back into the medium. If the inner edge of the LLBL is oscillating, one might expect an effect on the incident continuum emission. In fact, for most of this Wind magnetospheric passage, the continuum emission has a fairly consistent appearance, like that shown in Figure 1 after about 1700 UT.

[13] However, between 1640 UT and 1700 UT, near the inner edge of the LLBL, the continuum emission has a very different character. First, the overall emission intensity appears to fade during this time, and in proximity to the inner edge of the LLBL (e.g., the weaker emission levels in the boxed region of Figure 1). Of further interest, between 1640 UT and 1700 UT, there are a series of oscillations or “ripples” in the continuum emission intensity. These oscillations are shown in a blowup Figure 4, and are labeled as oscillation A, B, C and D. Note that they also possess an approximate seven minute variation, and would be an expected occurrence if the inner edge of the LLBL is oscillating at a 6–17 minute time scale. In essence, as the boundary wall oscillates, it

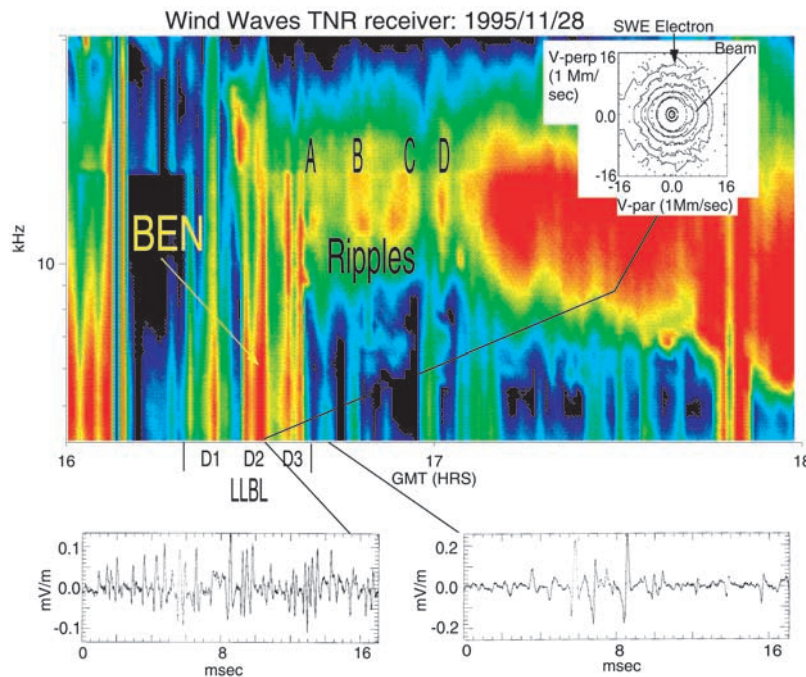
acts to modulate the local continuum emission. Their relative intensity above the background continuum emission is 4–6 dB. Other cases of continuum “ripple” events are apparent in the Wind measurements including an occurrence on 13 December 1994 between 0040–0100 UT.

#### 4. Impulsive Broadband Events

[14] As indicated in Figure 4, a set of impulsive broadband events was observed between 1620 UT–1640 UT, in conjunction with the spacecraft passage through the inner edge of the LLBL. In fact, these events occur in exact coincidence with the density depletions D1–D3 [shown in Figure 2], suggesting that the “halo” like events previously described in *Sckopke et al.* [1981] are sites of kinetic activity.

[15] In the past, such impulsive broadband events were found at magnetospheric boundary layers and were identified as broadband electrostatic noise (BEN) [Gurnett *et al.*, 1976]. Such events were indicative of instabilities occurring on the boundary layers [Grabbe and Eastman, 1984]. Recent studies of the detailed waveform of such magnetotail events found that the BEN consists of a single (or set of) bipolar electrostatic solitary wave structures [Matsumoto *et al.*, 1994; Kojima *et al.*, 1997] and are similar to those found in the auroral region [Ergun *et al.*, 1998; Franz *et al.*, 1998]. Comparisons of the two (plasma sheet vs. auroral comparisons) have been made [Cattell *et al.*, 2000]. We note that the events reported here do not generate similar magnetic activity (i.e., impulsive VLF broadband event) in the Wind search coil and thus conclude the emission is primarily electrostatic in nature, and not an Alfvénic disturbance.

[16] Figure 4 displays a set of waveform snapshots from the Wind/WAVES Time Domain Sampler [Bougeret *et al.*, 1995]. This instrument is a burst memory system designed to return 120 kilosamples per second between 0.03 Hz and 50 kHz. The waveform snapshots occur during the BEN event near 1638 UT and 1643 UT. Note that the events consist of a series of bipolar pulses similar to those found in the deep tail and auroral region. Such an



**Figure 4.** An enlarged spectrogram of the wave activity near the inner edge of the LLBL. Waveform measurements were obtained during some of the BEN event, and these are indicative of solitary waves. Such waveforms are shown in the bottom panels. SWE electron distribution (inset figure) shows the presence of electron beams in the same region as the BEN.

observation is consistent with the spacecraft passage through a series of solitary electrostatic wave structures like those expected in an unstable electron-beaming situation [Omura *et al.*, 1996; Krasovsky *et al.*, 1997].

[17] In fact, electron beams were detected by SWE (e.g., see inset of Figure 4) in association with D1–D3, consistent with the Omura *et al.* [1996] concept. The SWE distributions are resolved at 3-second intervals, but clearly show the presence of energetic field-aligned electron flows in concurrence with the solitary electric field structures, these with energies near a few hundred eV's. Theory suggests that magnetic compressions on the edges of the magnetosphere will create currents (and beams) [Southwood and Kivelson, 1990; Glassmeier and Heppner, 1992], and observations of ~100 eV beams at the inner edge of the LLBL have been previously reported [Ogilvie *et al.*, 1984].

## 5. Conclusion

[18] We report on intense kinetic activity within quasi-periodic density depletions (i.e., halo events [Skopke *et al.*, 1981]) of the LLBL. Further, density depletions with periodicity of 6–7 minutes appear to be driven by external pressure variations, which also create ripples in the magnetospheric continuum emission incident on the boundary. By examining wave activity at this LLBL crossing, there is evidence of dynamics occurring on scale-sizes both greater than and much less than an ion gyroradius (i.e., the MHD/kinetic spatial boundary).

[19] The question becomes: How does the large-scale fluid oscillation or pulse drive a kinetic electron beam instability at the boundary? We suggest here that the unstable beams form in association with plasma expansion at the oscillating boundary edge. As the boundary extends inward and/or outward, a set of plasma depletions form (which manifest themselves as D1, D2, and D3) which refill their plasma in a way similar to plasma expansion into a void or wake [Samir *et al.*, 1983; Ogilvie *et al.*, 1996; Farrell *et al.*, 1998]. Faster energetic electrons move into the depletions ahead of the ions, creating an ambipolar electric field that may possibly form an electrostatic solitary pulse like that observed by WAVES. Further these depletion-directed energetic electron populations appear as beams as observed by SWE, and are thus unstable to electron beaming instabilities in the depletion region plasma. The associated nonlinear beam density structures created by the instability might also account for the electrostatic solitary pulse [Omura *et al.*, 1996] as observed by WAVES. Thus, there is a conversion of large-scale motion into kinetic phenomenon at the boundary, with the sites of kinetic activity collocated with the halo density depletions.

[20] **Acknowledgments.** The authors wish to thank Don Fairfield for very helpful comments regarding the manuscript.

## References

- Bougeret, J.-L., *et al.*, Waves: The radio and plasma wave investigation on the Wind spacecraft, *Space Sci. Rev.*, 71, 231, 1995.
- Cattell, C., *et al.*, Comparison of solitary waves and wave packets observed at plasma sheet boundary to results from the auroral zone, in press, *Physics and Chemistry of the Earth*, 2000.
- Cowley, S. W. H., The causes of convection in Earth's magnetosphere: A review of developments during the IMS, *Reviews of Geophys. and Space Phys.*, 20, 531, 1982.
- Ergun, R., *et al.*, FAST satellite observations of large amplitude solitary wave structures, *Geophys. Res. Lett.*, 25, 2041, 1998.
- Farrell, W. M., M. L. Kaiser, J. T. Steinberg, and S. D. Bale, A simple simulation of a plasma void: Applications to Wind observations of the lunar wake, *J. Geophys. Res.*, 103, 23,653, 1998.
- Fairfield, D. H., *et al.*, Geotail observations of the Kelvin-Helmholtz instability at the equatorial magnetotail boundary for parallel northward fields, *J. Geophys. Res.*, 105, 21,159, 2000.
- Fitzenreiter, R. J., and K. W. Ogilvie, Kelvin-Helmholtz instability at the magnetopause: Observations, in physics of the magnetopause, American Geophysical Union, Washington, D. C., 1995.
- Franz, J., P. Kintner, and J. Pickett, Polar observations of coherent electric field structures, *Geophys. Res. Lett.*, 25, 1277, 1998.
- Glassmeier, K.-H., and C. Heppner, Traveling magnetospheric convection twin vortices: Another case study, global characteristics, and a model, *J. Geophys. Res.*, 97, 3977, 1992.
- Grabbe, C. L., and T. E. Eastman, Generation of broadband electrostatic noise by ion beam instabilities in the magnetotail, *J. Geophys. Res.*, 89, 3865 and 3977, 1984.
- Gurnett, D. A., The Earth as a radio source: Nonthermal continuum radiation, *J. Geophys. Res.*, 80, 2751, 1975.
- Gurnett, D. A., and R. R. Shaw, Electromagnetic radiation trapped in the magnetosphere above the plasma frequency, *J. Geophys. Res.*, 78, 8136, 1973.
- Gurnett, D. A., L. A. Frank, and R. P. Lepping, Plasma waves in the distant magnetotail, *J. Geophys. Res.*, 81, 6059, 1976.
- Kojima, H., *et al.*, Geotail waveform observations of broadband/narrowband electrostatic noise in the distant tail, *J. Geophys. Res.*, 102, 14,439, 1997.
- Krasovsky, V. L., H. Matsumoto, and Y. Omura, Bernstein-Green-Kruskal analysis of electrostatic solitary waves observed by Geotail, *J. Geophys. Res.*, 102, 22,131, 1997.
- Kurth, W. S., Continuum emission in planetary magnetospheres, in *Planetary Radio Emissions III*, edited by H. O. Rucker, S. J. Bauer, and M. L. Kaiser, Verlag, Vienna, Austria, 1992.
- Lee, L. C., R. K. Albano, and J. R. Kan, Kelvin-Helmholtz instability in the magnetopause boundary layer region, *J. Geophys. Res.*, 86, 54, 1981.
- Matsumoto, H., I. Nagano, and Y. Kasaba, Terrestrial continuum radiation in the magnetotail: Geotail observations, in radio astronomy at long wavelengths, American Geophysical Union, Washington, D.C., 2000.
- Matsumoto, H., *et al.*, Electrostatic solitary waves (ESW) in the magnetotail—BEN waveforms observed by Geotail, *Geophys. Res. Lett.*, 21, 2915, 1994.
- Ogilvie, K. W., R. J. Fitzenreiter, and J. D. Scudder, Observations of electron beams in the low latitude boundary layer, *J. Geophys. Res.*, 89, 10,723, 1984.
- Ogilvie, K. W., and R. J. Fitzenreiter, The Kelvin-Helmholtz instability at the magnetopause and inner boundary layer surface, *J. Geophys. Res.*, 94, 15,113, 1989.
- Ogilvie, K. W., *et al.*, SWE: A comprehensive plasma instrument for the wind spacecraft, *Space Sci. Rev.*, 71, 55, 1995.
- Ogilvie, K. W., *et al.*, Observations of the lunar plasma wake from the Wind spacecraft on December 27, 1994, *Geophys. Res. Lett.*, 23, 1255, 1996.
- Omura, Y., *et al.*, Electron beam instabilities as generation mechanism of electrostatic solitary waves in the magnetotail, *J. Geophys. Res.*, 101, 2685, 1996.
- Russell, C. T., and R. C. Elphic, Initial ISEE magnetometer results: Magnetopause observations, *Space Sci. Rev.*, 22, 681, 1978.
- Samir, U., K. H. Wright Jr., and N. H. Stone, The expansion of plasma into a vacuum: Basic phenomena and processes and applications to space plasma physics, *Rev. Geophys.*, 21, 1631, 1983.
- Skopke, N., *et al.*, Structure of the low-latitude boundary layer, *J. Geophys. Res.*, 86, 2099, 1981.
- Sibeck, D. G., R. P. Lepping, and A. J. Lazarus, Magnetic field line draping in the plasma depletion layer, *J. Geophys. Res.*, 95, 2433, 1990.
- Southwood, D. J., and M. G. Kivelson, The magnetohydrodynamic response of the magnetospheric cavity to changes in solar wind pressure, *J. Geophys. Res.*, 95, 2301, 1990.

W. M. Farrell, R. J. Fitzenreiter, and M. L. Kaiser, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA.

K. Goetz, School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455, USA.

M. Maksimovic, Observatoire de Paris, Meudon, France.

M. J. Reiner, The Catholic University of America, Washington, D.C. 20064, USA.