Discrete Plasma-Sheet like Structures in the Magnetotail Lobes and in the Plasma Sheet Boundary Layer

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Plasma structures of various durations with quasi-isotropic velocity distributions, resembling the plasma of the plasma sheet (PS), are often observed in the magnetotail lobes. Previous studies performed on the basis of Interball-1 observations revealed that the spatial distribution of such structures along the south-north direction depends on the direction of the interplanetary magnetic field (IMF). These transient observations of PS-like plasma may be caused by the large-scale disturbances of the boundary of already expanded PS. Multipoint CLUSTER observations allow to study spatial geometry of these structures. Such analysis gives us the opportunity to reveal whether the observation of PS-like plasma in the lobe is related with stable plasma filaments drifting towards the NS or it is associated with a sudden disturbance of PS boundary, possibly a result of the development of PS boundary instability.

Introduction

Despite the common view that magnetotail lobes are void of plasma, various discreet plasma structures are encountered in them [1]. Based on INTERBALL-1 (IB-1) data Grigorienko et al. [2] investigated the transient plasma structures in the plasma sheet boundary layer (PSBL) and the lobes. They found two types of structures: (i) Observed for a short time-less than 2 min- ion beams with bursty appearance (beamlets), in majority of cases moving earthward with high velocity parallel the magnetic field. An isolated beamlet has a characteristic ”lima-bean” distribution function [3]. Sometimes a combination of earthward and tailward streaming (reflected) beamlets is observed and the distribution function has a ring-like shape; (ii) plasma structures, resembling ”scraps” of plasma sheet (PS) material and having no pronounced bulk velocities – plasma clouds. The complexity of the distribution function could be due to transient effects or to low statistics. Beamlets and plasma filaments are clearly distinguished by their bulk velocity directions. While the beamlet bulk velocity is mostly parallel to the magnetic field, plasma clouds may have rather high velocities across the magnetic field (in Y and/or Z direction).

The aim of the present work is to investigate the properties of plasma clouds and using the multi-point CLUSTER observations to study their spatial geometry.

One-point measurements: INTERBALL-1 statistics

A statistical study of plasma clouds observed aboard IB-1 was performed in [2]. In Fig.1 (Fig. 9 from [2]) the probability to observed plasma clouds at different distances *ΔZ* from the plasma sheet is shown. The spatial distribution of these structures along the south-north direction depends on the direction of the interplanetary magnetic field (IMF). When IMF is northward, PS-like plasma fills the lobe region, which may be related with the PS expansion. For southward IMF the probability of observing PS-like structures of long duration sharply decreases with the distance from the nominal neutral sheet (NS), but PS-like structures of short duration (<500 s) are distributed almost uniformly up to 12 R_E above the NS. Such transient observations of PS-like plasma may be caused by the flapping motions of the PS or by plasma structures (filaments) detached from the main body of the PS.

The weak points of this study are: 1) the position of the NS was obtained from the TS-96 model so ΔZ is some “average” distance for a fixed magnetic field model of the magnetotail. Thus flapping motions of the PS, which sometimes may have considerable amplitude, are not taken into account. 2) one-point Interball-1 observations do not let us understand the spatial/temporal characteristics of plasma clouds.

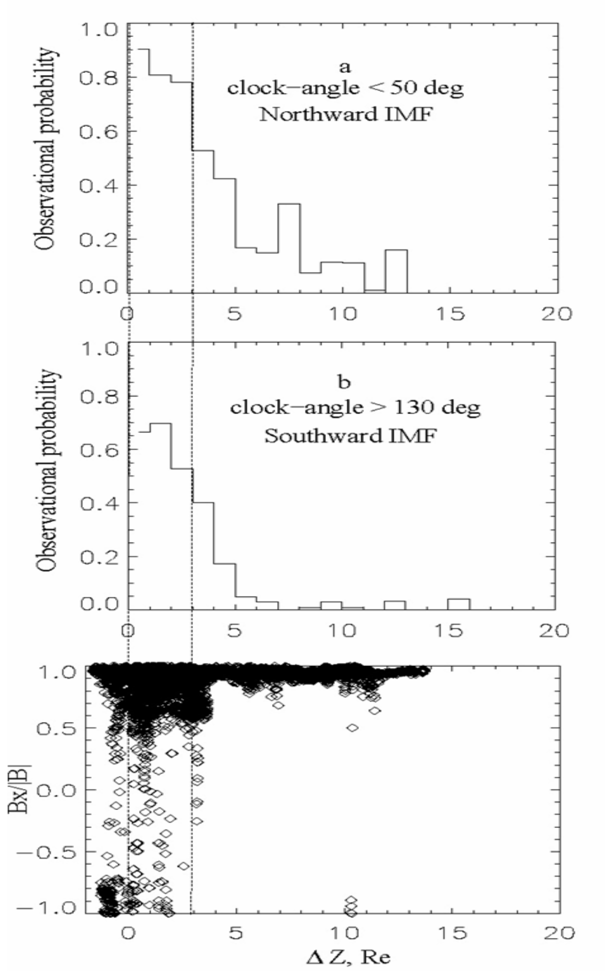

Fig. 1. Probability to observe plasma clouds versus ΔZ for northward IMF (a) and for southward IMF (b). Low panel shows the scatter plot of Bx/\B\| to demarcate the PS boundary which is shown by dashed vertical line (Fig.9 from [2]).

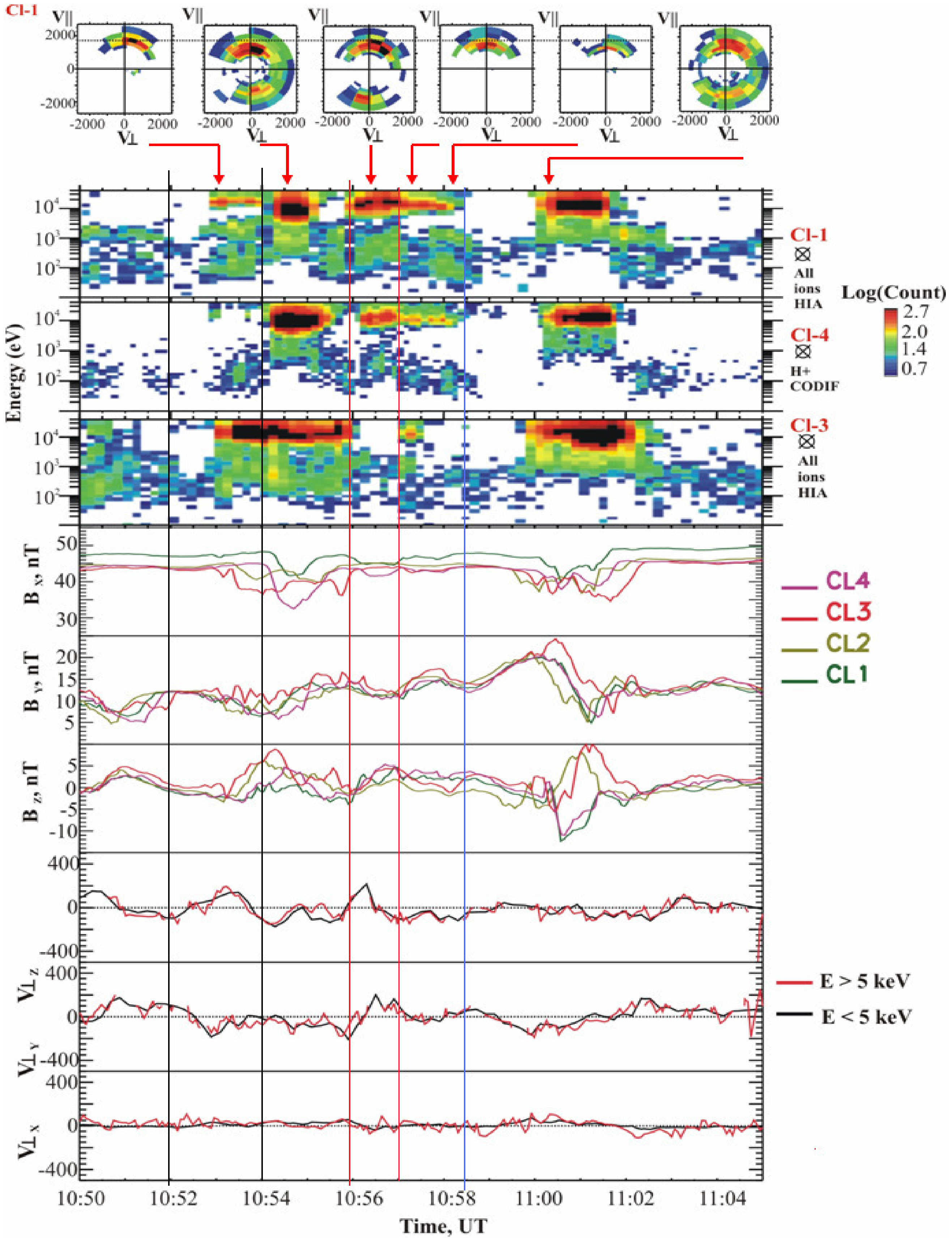

Fig.2. Successive observations of plasma clouds and field-aligned ion beams in several PSBL encounters observed by CLUSTER on 11.08.02. From top to bottom: 2D ion velocity distribution functions obtained from CLUSTER-1 for 12s (HIA spectrometer); E-T ion omni-directional spectrograms from CLUSTER-1, -4 and -3; three components of the magnetic field; three components of the perpendicular velocities of low-energy ions (E < 5 keV) and high-energy PSBL ions (E > 5 keV)

Multi point measurements: CLUSTER, a case study

Multi point CLUSTER measurements allow us to deconvolute the spatial from time dependences. In our study we use measurements of the ion three-dimensional velocity distribution functions collected every 12 s by the hot ion analysers (HIA) onboard CLUSTER-1 (Cl-1) and Cl-3 and the H^+ velocity distribution functions compiled for 8 s by composition and distribution function analyser (CODIF) onboard Cl-4 [4]. The magnetic field data were obtained with a 4 s resolution by the fluxgate magnetometer FGM [5].

We analyse one case observed on 11.08.2002 in the interval 10:50 – 11:05 UT when the four CLUSTER satellites several times crossed the plasma sheet–lobe interface. The dynamic spectrograms of the event, the measured magnetic field and the computed velocities and distribution functions are shown in Fig. 2. Fig 3 represents the position of CLUSTER satellites during this interval.

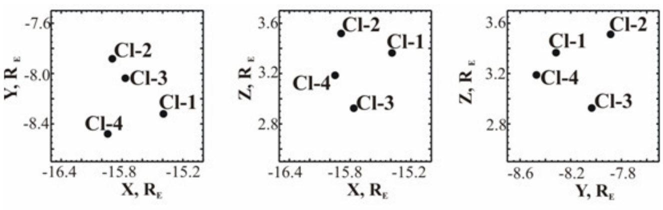

Fig. 3. CLUSTER positions in the interval of interest

We will look closer into the interval 10:52 – 10:58 UT. Plasma and magnetic field data look like the satellites were 'touching' the boundary between the PS and the lobes – the PSBL, going in and out the boundary layer consecutively. The sequence is the following:

<u>At 10:52-10:54 UT,</u> on entry from the lobe to the PS, Cl-1, Cl-3 (and possibly Cl-2) observe high energy plasma with typical distribution of a beamlet with velocity ~ 1750 km/s, while Cl-4, located between them in Z direction, observes PS-like plasma with a significant delay.

<u>At 10:54 – 10:56 UT</u> all three satellites are deeper in PSBL and already observe more isotropic hot ion population, which causes depletion in the magnetic field. As expected from their Z displacement, Cl-1 first exits into the lobe at 10:55 UT, then Cl-4, Cl-3 stays in till 10:56. On exit Cl-1 and Cl-4 register beamlets (distribution not shown).

<u>At 10:56-10:57</u> UT Cl-1 and Cl-4 observed PS-like plasma while Cl-3 (and Cl-2) did not observe it. Cl-3 and Cl-2, being strongly separated along Z, had close Y locations.

<u>At 10:57 – 10:58</u> all three CLUSTER observed field-aligned ion beam but its observation by Cl-3, though lower in Z, was the shortest.

These features indicate on complicated motion of PSBL boundary, not only upward-downward flapping, but also oscillation along Y direction.

Discussion and conclusions

CLUSTER satellites, in course of their crossing the lobe-PS interface, depending on their position may simultaneously observe either beamlet or PS-like plasma without beamlet, due to the spatial localization of magnetic tubes, containing field-aligned or already isotropic ions.

In order to analyse plasma motion near the lobe/PS boundary in the case of no PSBL observed by Cl-1 we use the flapping motion of the plasma sheet and apply the procedure described in [6]. We introduce a new coordinate system X'Y'Z' obtained by the following way: X' axis is directed along the nondisturbed lobe magnetic field which was observed when all CLUSTER spacecraft were located in the lobe before they encountered the PSBL; Z' is directed along the normal to the PSBL boundary obtained from a timing analysis (so it coincides with the direction of the motion of PSBL boundary); and Y' completes the orthogonal system. Fig. 4 presents a scatterplot of $\delta E_{Z'}$ versus $-V_A*\delta B_{Y'}$ measured by the three CLUSTER satellites. $E_{Z'}$ was deduced as $-(V \times B)_{Z'}$. The Alfven velocity V_A was calculated from plasma and magnetic field parameters observed in the lobe-PS interface during this interval.

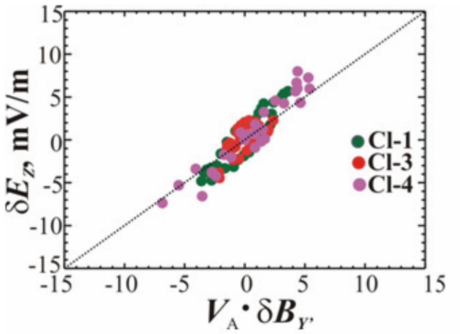

Fig.4. A scatterplot of δEZ variations versus VA·δBY variations observed within 10:5 2- 10:57 UT by three CLUSTER spacecraft.

The good corelation gives us ground to conclude, that the magnetic disturbance that causes transient observation of PSBL structures and the increasing of energy of cold lobe ions, is propagating earthward with Alfven velocity. The successive observations of lobe, beamlet and PS-like plasma regions by the three CLUSTER may be caused by simultaneous south-north and dawn-dusk oscillations of the magnetic tubes, as illustrated in Fig. 5. Magnetic tubes should be localized in *Y* direction (which is perpendicular to the non-disturbed lobe magnetic field) and have size ~0.5 R_E.

The conventional view of the plasma sheet–lobe interface, the PSBL, which arose from one-point (single satellite) measurements, assumes that PSBL is a temporally variable transition region [7]. Characteristic feature of PSBL are the fast field aligned (> 400 km/s) flows - beamlets. When satellite transverses PSBL from the lobe to the PS, according to the classical picture, first it encounters hot electrons, then fast earthward ion beams appear. Further inside the PSBL bidirectional ion beams with higher densities but lower velocity are observed. The part of the PSBL consisting of unidirectional and bidirectional flows evolves into hot isotropic central PS component [8, 9]. In this picture the discrete PS-like structures – plasma clouds, are interpreted as isolated islands of plasma – Fig. 6(a).

In a previous work based on CLUSTER measurements [6] it was revealed that beamlets represent long-living (~ 5–15 min) plasma filaments elongated along the lobe magnetic field (~ 60–100R_E) and strongly localized in direction perpendicular to the PSBL-lobe boundary (~ 0.2–0.7R_E). Beamlets experience not only the PSBL flapping motions but also an earthward propagation of kink-like perturbations along the beamlet filaments. Phase velocity of these

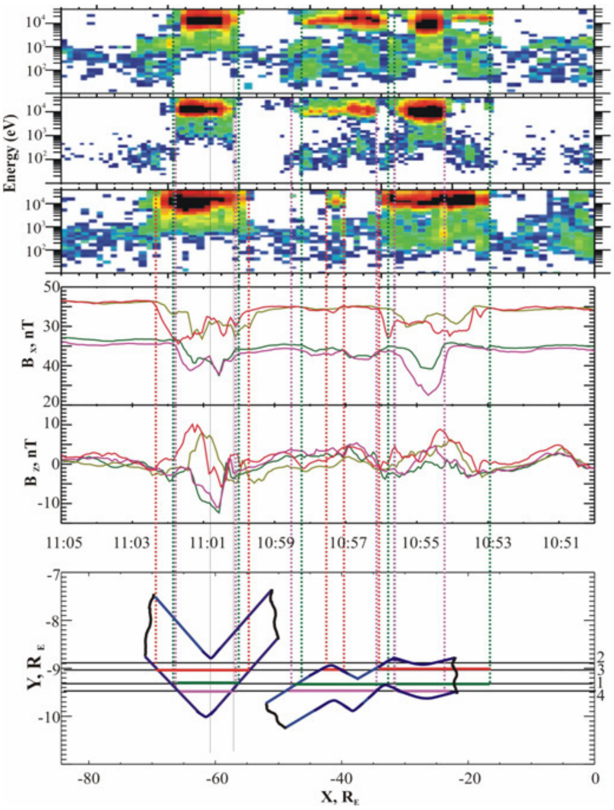

Fig.5. E-T spectrograms of omni-directional ions observed by Cl -1, -4 and -3; B_X and B_Z magnetic field variations.
Bottom panel: a cartoon of the spatial structure (in XY plane) of the magnetic tubes containing beamlet ions at the lobeward edge of PSBL and more isotropic plasma inside the PSBL. The CLUSTER positions along Y are shown by the straight lines.

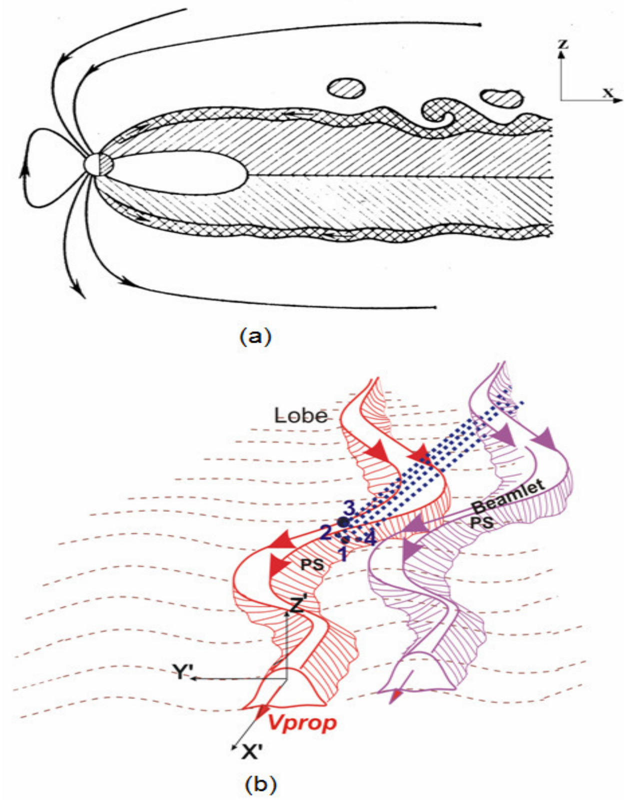

Fig. 6. (a) One-point view on the structure of PSBL. The field-aligned beamlets are temporal transients, the plasma clouds look like isolated islands of plasma sheet material.
(b) Cluster 3D point view on the structure of PSBL: in this interface coexist magnetic tubes with beamlets and magnetic tubes with PS-like plasma, subjected to wave-like disturbances

perturbations is of the order of the local Alfven velocity (V ~ 600–1400 km/s).

Multipoint CLUSTER observations discussed in this study lead to different interpretation of the complicated observational pattern of the lobe-PS interface, illustrated in Fig. 6(b). At the lobe-PS interface simultaneously exist magnetic tubes with field-aligned beamlets – a classical PSBL, and PS-like structures – classical 'absence' of PSBL. The transient appearance of the field-aligned ion beams (beamlets) or PS-like plasma without beams is a spatial, not temporal effect. The spatial localization of the magnetic tubes containing field-aligned or already isotropic ions in the direction perpendicular to the direction of the non-disturbed lobe magnetic filed. The propagating earthward wave-like disturbance of these magnetic tubes may be caused by Kelvin-Helmholtz or two-beam instability.

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REFERENCES

[1] Koleva, R., Sauvaud, J.-A., Plasmas in the near Earth magnetotail lobes: properties and sources, *J. Atmos. Solar-Terr. Phys.*, vol. 70, 2008, pp. 2118-2131.

[2] Grigorenko E. E., A. O. Fedorov and L. M. Zelenyi, Statistical study of transient plasma structures in magnetotail lobes and plasmasheet boundary layer: Interball-1 observations, *Ann. Geophys*, vol. 20, 2002, pp 329-340.

[3] DeCoster R.J. and L.A. Frank, Observations pertaining to the dynamics of the plasma sheet,*J. Geophys. Res.*, vol. 84, 1979, p 5099.

[4] Reme H. et al., First multispacecraft ion measurements in and near the Earth's magnetosphere with identical Cluster ion spectrometry (CIS) experiment, *Ann. Geophys.*, vol. 19, 10/11, 2001, pp 1303-1354.

[5] Balogh A. et al., The Cluster magnetic field investigation: Overview of in-flight performance and initial results, *Ann. Geophys.*, 19, 10/11, 2001, pp 1207-1217.

[6] Grigorenko, E., J.-A. Sauvaud, L. Zelenyi, Spatialtemporal characteristics of ion beamlets in the plasma sheet boundary layer of magnetotail,*J. Geophys. Res,* vol. 112, A05218, 2007, doi:10.1029/2006JA011986.

[7] Eastman T. E., L . A. Frank, W. K. Peterson and W. Lennartsson, The plasma sheet boundary layer, *J. Geophys. Res.*, vol. 89, 1984, 1553.

[8] Takahashi, K. and E. W. Hones Jr., ISEE 1 and 2 observations of ion distributions at the plasma sheet-tail lobe boundary *J. Geophys. Res.*, vol. 93, 1988, 8558-8582.

[9] Parks, G. et al., New observations of ion beams in the plasma sheet boundary layer, *Geophys. Res. Lett.*, vol. 25, 17, 1998, pp 3285-3288.