IMF B_y-controlled field-aligned currents in the magnetotail during northward interplanetary magnetic field

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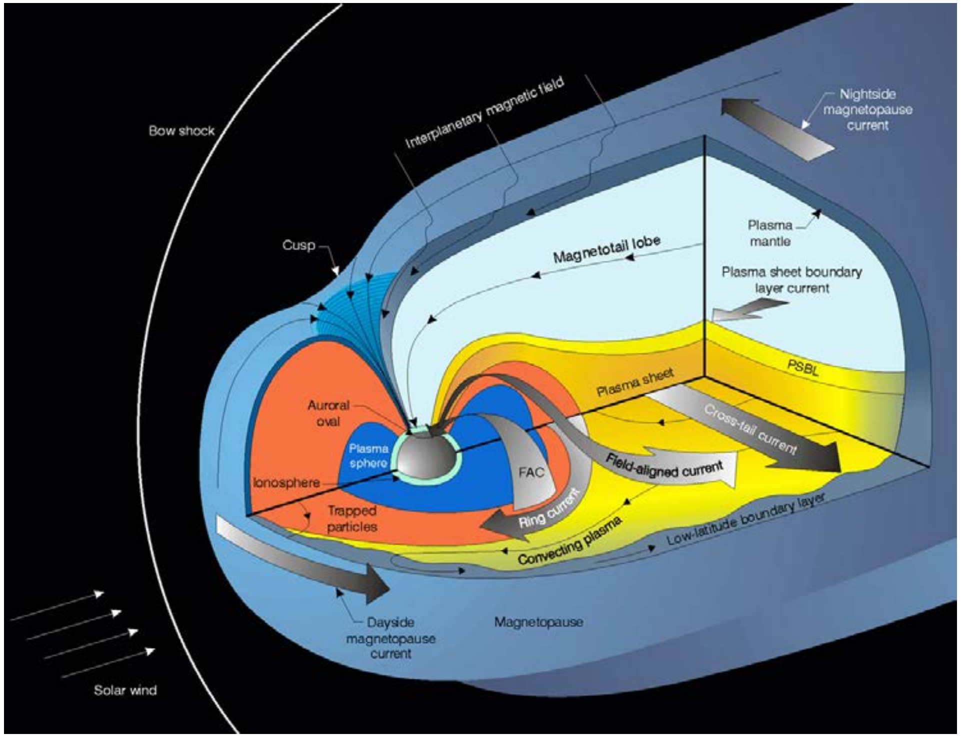
1. Introduction

FACs play an important role in the solar wind-magnetosphere- ionosphere coupling by transferring electric field, magnetic tangential stress, and energy.



Knowledge of the FACs structure and dynamics is a key to understanding solar wind energy transfer to the magnetosphere and ionosphere.

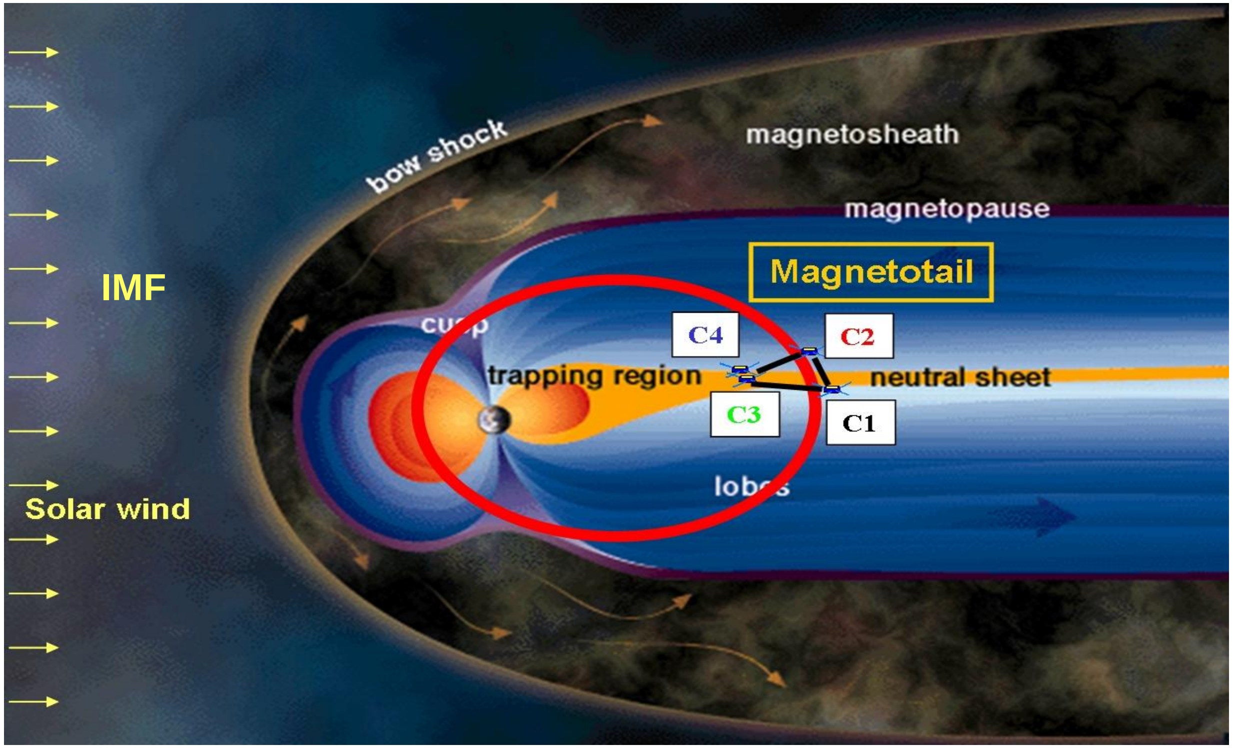
The dependence of FACs pattern and density on IMF have been well studied.

（Iijima and Potemra, 1982; Potemra et al., 1984; Rich et a., 1990; Taguchi et al., 1993; Guo et al., 2010）.

Some studies revealed that the IMF B_y is important to determine the distribution of the FACs near the dayside cusp or the dayside polar cap at low altitudes.

（Erlandson et al., 1988; Yamauchi et al., 1989; Iijima and Shibaji, 1987; Taguchi et al.,1992 and1994）.

The field lines along which the nightside field-aligned currents flow are mapped to the magnetospheric tail (including the plasma sheet), where some observations showing By dependence have been made. **These observations showed that the influence of IMF B_y exists not only in near-Earth region where field lines are closed** (Nagai, 1987), **but also in the near-Earth magnetotail** (Lui, 1984) **and distant magnetotail** (Tsurutani et al., 1984a; Sibeck et al., 1985).



In the study, analyzing the Cluster data obtained during northward IMF, we pay special attention to the dependence of FACs in the PSBL in the magnetotail on IMF B_y.

2. Data and method

- Data: 2001 and 2004

  ACE data：solar wind and IMF data

  Cluster data：magnetic field，electron， ion (FGM, PEACE,CIS)

- FACs density can be calculated from the magnetic field measurements obtained by the four satellites, using the "curlometer" technique [Dunlop et al., 2002, JGR]
- PSBL Confirmation

  PSBL is given by the condition 0.01≤ß≤1,

  the lob region with a condition ß<0.01,

  the plasma sheet with ß>1 [Ueno et al., 2002,JGR]

- FAC cases chose [Shi et al., 2010, JGR] [Cheng et al., 2013, GRL]

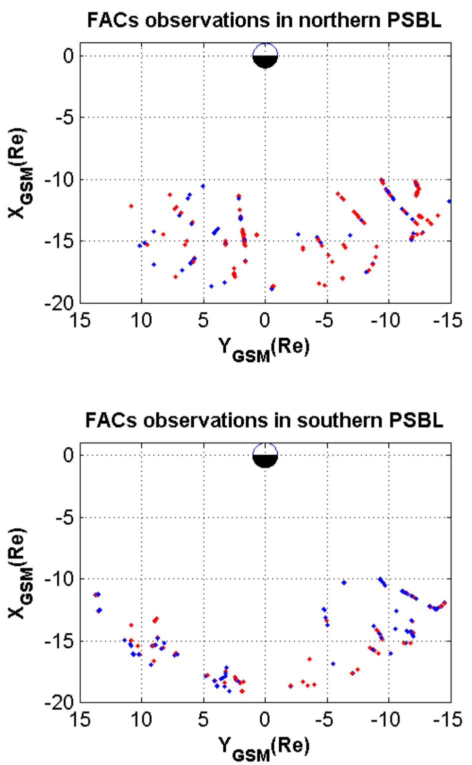
  The density of the FACs exceeds 3 pT / km (It is about 2.4 nAm^{-2} because 1.2566 pT/km = 1 nAm^{-2}).

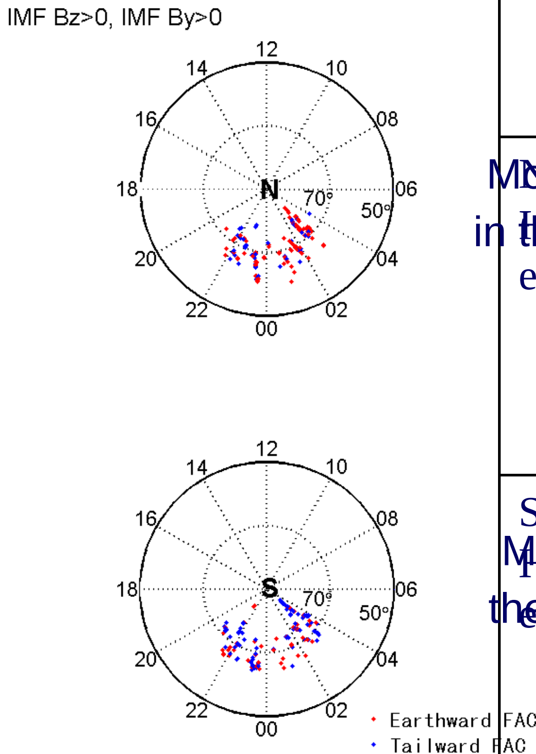
  The time interval between consecutive cases is more than 5 minutes.

- Model: T96

3. Statistics and Analysis

（1）The flow direction of FACs in the PSBL and IMF B_y



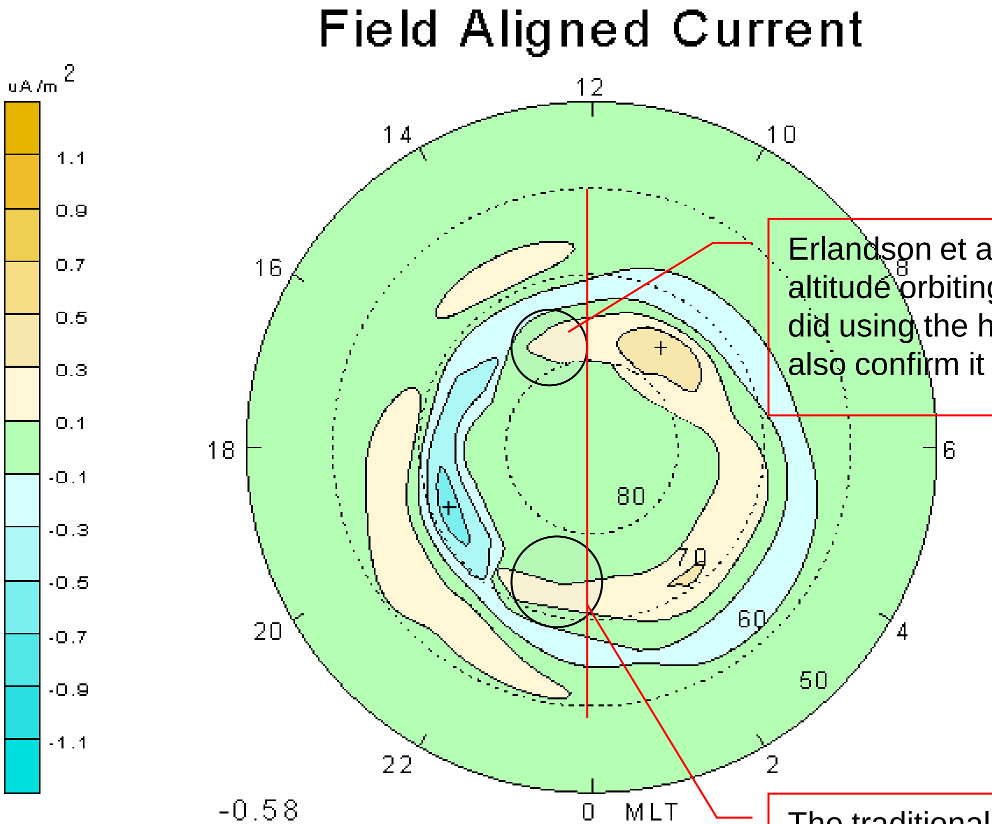


		Earth ward FAC	Tail ward FAC
Northern Hemisphere	Dawn side	85	31
	Dusk side	41	31
	Total	126	62
Southern Hemisphere	Dawn side	28	56
	Dusk side	32	49
	Total	60	105

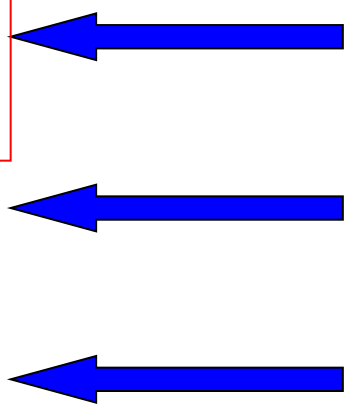
Most of the FACs cases are Earthward in the northern hemisphere.

Most of the FACs cases are tailward in the southern hemisphere.

The possible explain, for northern hemisphere:



IMF B_y>0

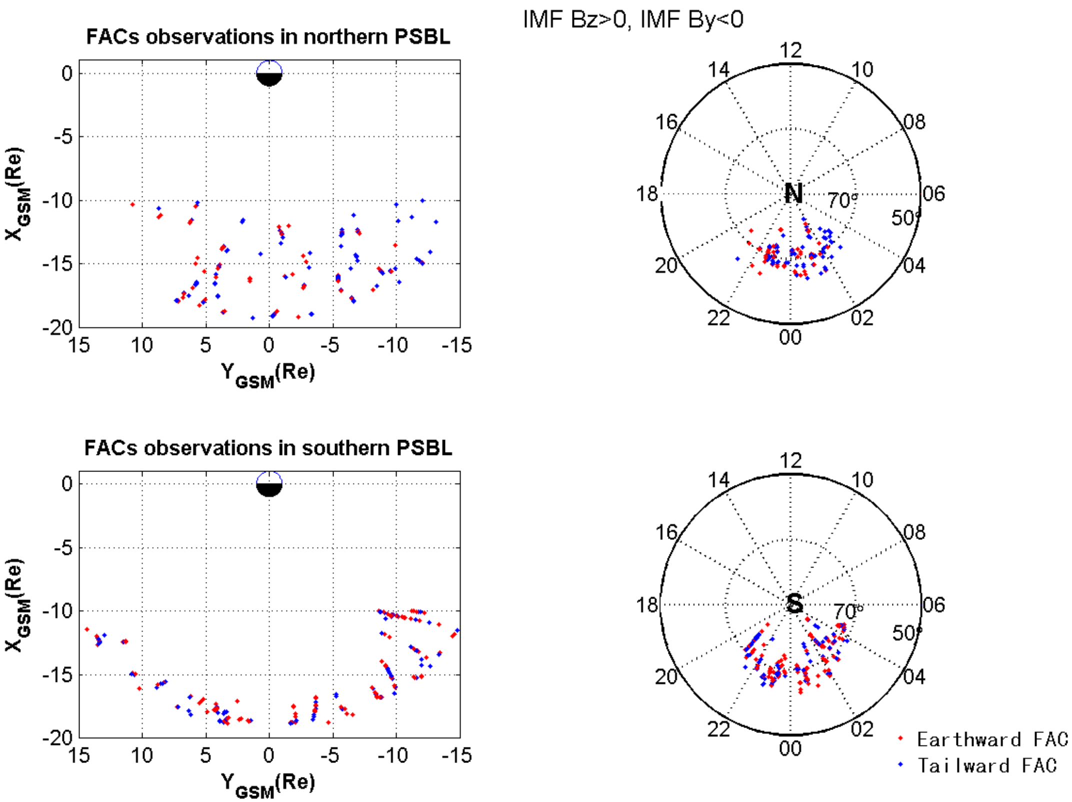


Erlandson et al. (1988) did using the low-altitude orbiting Viking and Zhou et al. (2000) did using the high-altitude orbiting Polar data also confirm it near the noon.

The traditional tailward FACs on the duskside are flowing earthward.

It indicates that when IMF B_y is positive, the earthward FACs on the postmidnight shifts to the premidnight.

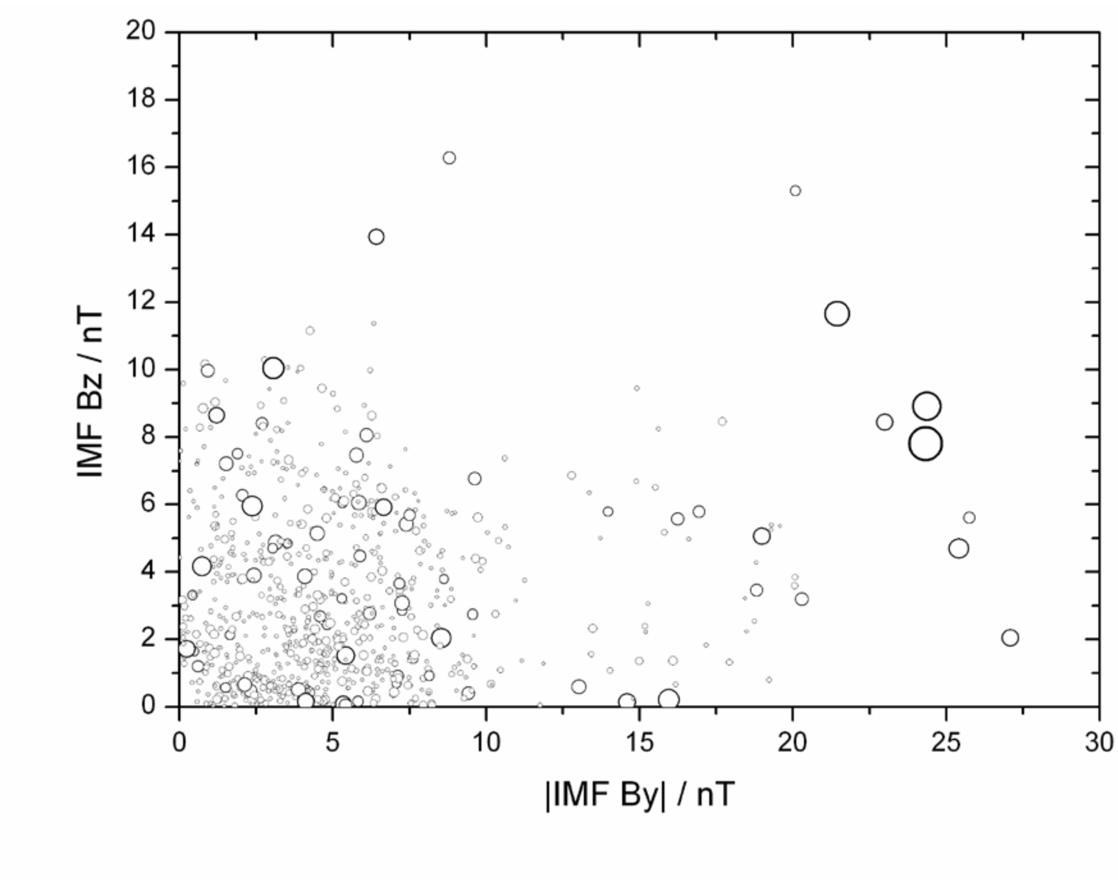
For the FACs in the PSBL, the polarity (earthward / tailward) asymmetry are different in the two hemispheres. To the contrary, in the southern hemisphere, the effect of the positive IMF B_y is a tailward FACs.



		Earthward FAC	Tailward FAC
Northern Hemisphere	Dawn side	40	56
	Dusk side	26	34
	Total	46	90
Southern Hemisphere	Dawn side	80	51
	Dusk side	54	54
	Total	134	105

The effect of the negative IMF B_y is a tailward FACs in the northern hemisphere. To the contrary, in the southern hemisphere, the effect of the negative IMF B_y is an earthward FACs.

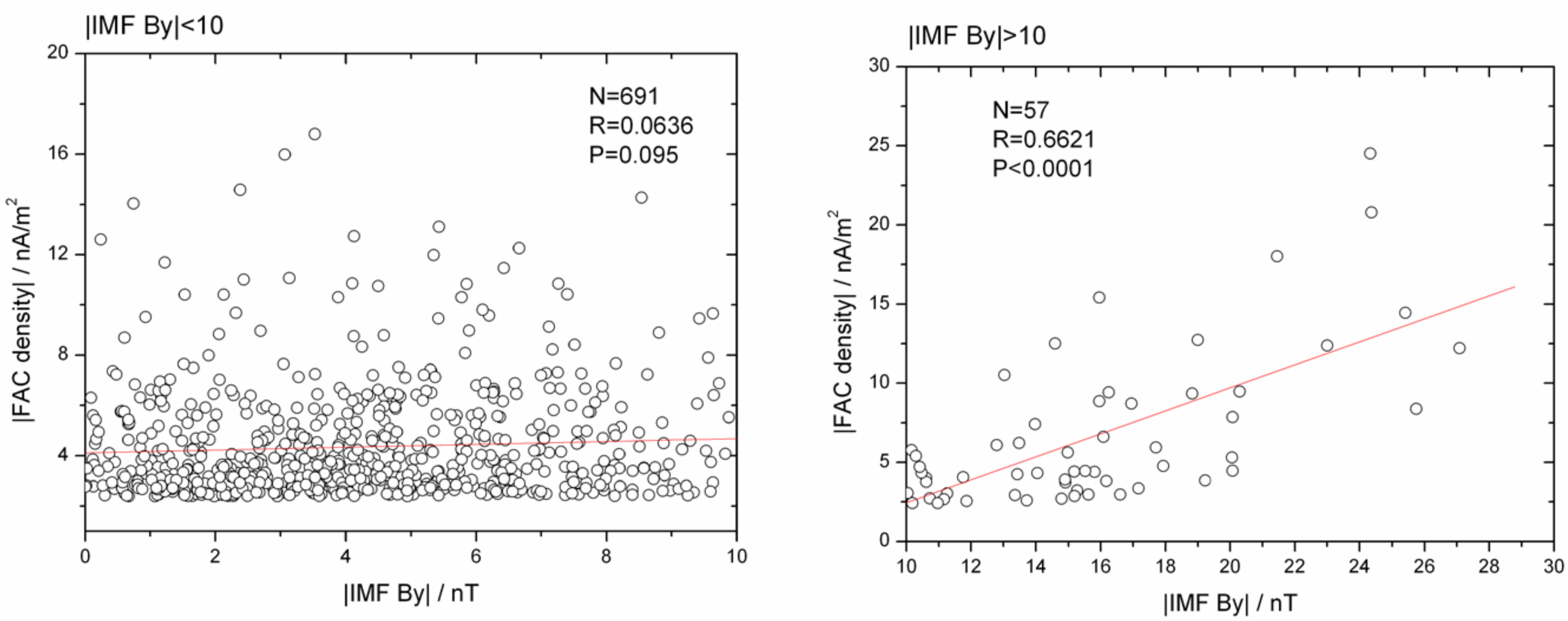
（2）The FAC density in the PSBL and IMF B_y



The Figure display the FACs cases in the IMF $|B_y|$-B_z plane.

The position of the circle is determined by the corresponding values of the IMF $|B_y|$ and B_z. The area of the circle represents the FAC density.

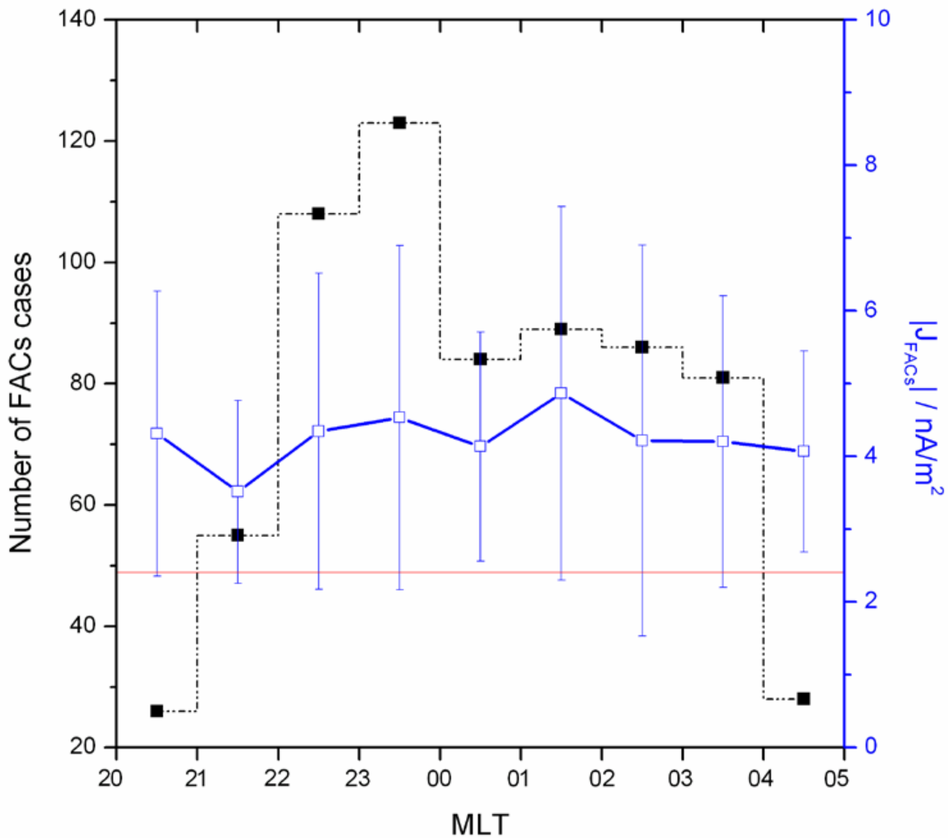
We can see that larger densities of FACs cases always occur in the large |IMF B_y| region. Indeed, the FACs with large density corresponds to the large value of IMF B_y rather than IMFB_z.



The Figures display the relationship between the absolute FAC density and absolute IMF B_y when |IMF B_y|<10 nT (left panel) and |IMF B_y|>10 nT (right panel) . The line is the result of least-mean-square fitting. N is the number of FACs cases. R stands for correlation coefficient.

It indicate the absolute FAC density in the PSBL has a very weak correlation with the absolute IMF B_y when |IMF B_y|<10 nT and has an obvious positive correlation with the absolute IMF B_y when |IMF B_y|>10 nT .

（3） The MLT distribution of the density and number for FACs in the PSBL



The difference between the largest and smallest is 1.45 nA/m^2. In order to test the difference is significant or not, we perform an evaluation of significance (unpaired t-test) for the difference of FAC density between the largest (in the dawnside: 0100-0200 MLT) and the smallest (in the duskside: 2100-2200 MLT).

The result indicate that the difference is statistically significant (P=0.0004 by unpaired t-test).

4. Conclusions

(1) When |IMF B_y| >10 nT, an obvious positive correlation. When |IMF B_y| <10 nT, no correlation. (10 nT is just our setting.)

(2) The effect of the positive (negative) IMF B_y is an earthward (tailward) FACs in the PSBL in the northern hemisphere. It is opposite for the southern hemisphere.

There is a clear north-south asymmetry of the polarity of the FACs when IMF B_y is positive or negative. And when IMF B_y is positive, the asymmetry is more distinct.

(3) There is a clear dusk-dawn asymmetry in the current densities for the FACs in the PSBL, with the dawn currents appearing larger than the dusk currents.

Our results present IMF B_y component plays a very important role in controlling the flow direction and density of the FACs in the PSBL in the magnetotail. It is maybe caused by the process that the IMF B_y sinks into the mageototail. However, the detail of the physics process needs to be further studied.

THANK you！

The Cluster is with 4 satellites, the current can be calculated with its data.

The electrical current density and the magnetic flux vector are related through Ampere's law:

$$\mu_0 \vec{J} = \nabla \times \vec{B}$$

In integral form:

$$\mu_0 \int_A \vec{J} \cdot ds = \oint_C \vec{B} \cdot dl$$

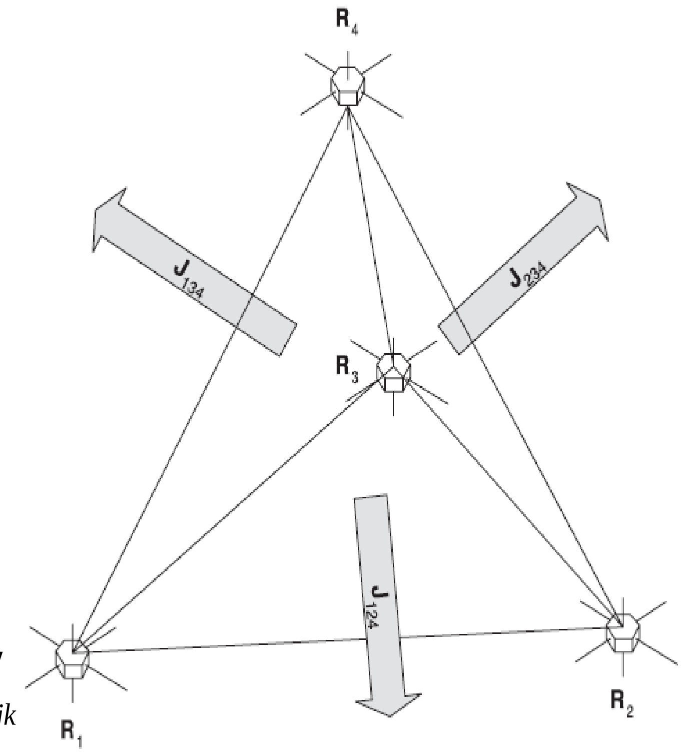
A: a face of tetrahedron, C: a triangular path around A. The area of a face with spacecraft i,j,k (=1,2,3,4) is $0.5\vec{r}_{ji} \times \vec{r}_{jk}$ **,** we can write

$$\int_A \vec{J} \cdot ds = \frac{1}{2} \vec{J}_{ijk} \cdot \left| \vec{r}_{ji} \times \vec{r}_{jk} \right|$$

The line integral can be estimated assuming that the field varies along the sides of the face linearly:

$$\oint_C \vec{B} \cdot dl = \langle \vec{B} \rangle_{ij} \cdot \vec{r}_{ij} + \langle \vec{B} \rangle_{ik} \cdot \vec{r}_{ik} + \langle \vec{B} \rangle_{jk} \cdot \vec{r}_{jk}$$

$$\langle \vec{B} \rangle_{ij} = \frac{1}{2}(\vec{B}_i + \vec{B}_j)$$



With $$\Delta\vec{r} \equiv \vec{r}_i - \vec{r}_1,\ \Delta\vec{B} \equiv \vec{B}_i - \vec{B}_1$$

The average current density in the spacecraft volume can be estimated from:

$$\mu_0 \vec{J} \cdot (\Delta\vec{r}_i \times \vec{r}_j) = \Delta\vec{B}_i \cdot \Delta\vec{r}_j - \Delta\vec{B}_j \cdot \Delta\vec{r}_i$$

For quality of the current calculation

$$\left| \frac{\nabla \cdot \vec{B}}{\nabla \times \vec{B}} \right| << 1$$

$$\int_V div\vec{B} \cdot dv = \int_A \vec{B} \cdot ds = \sum_{faces} \frac{1}{2} \vec{B}_{av} \cdot (\Delta\vec{r}_i \times \Delta\vec{r}_j)$$

The volume : $\frac{1}{6} \Delta\vec{r}_i \cdot (\Delta\vec{r}_j \times \Delta\vec{r}_k)$

$$\langle div\vec{B} \rangle \left| \Delta\vec{r}_i \cdot (\Delta\vec{r}_j \times \Delta\vec{r}_k) \right| = \sum \Delta\vec{B}_i \cdot (\Delta\vec{r}_j \times \Delta\vec{r}_k)$$

return

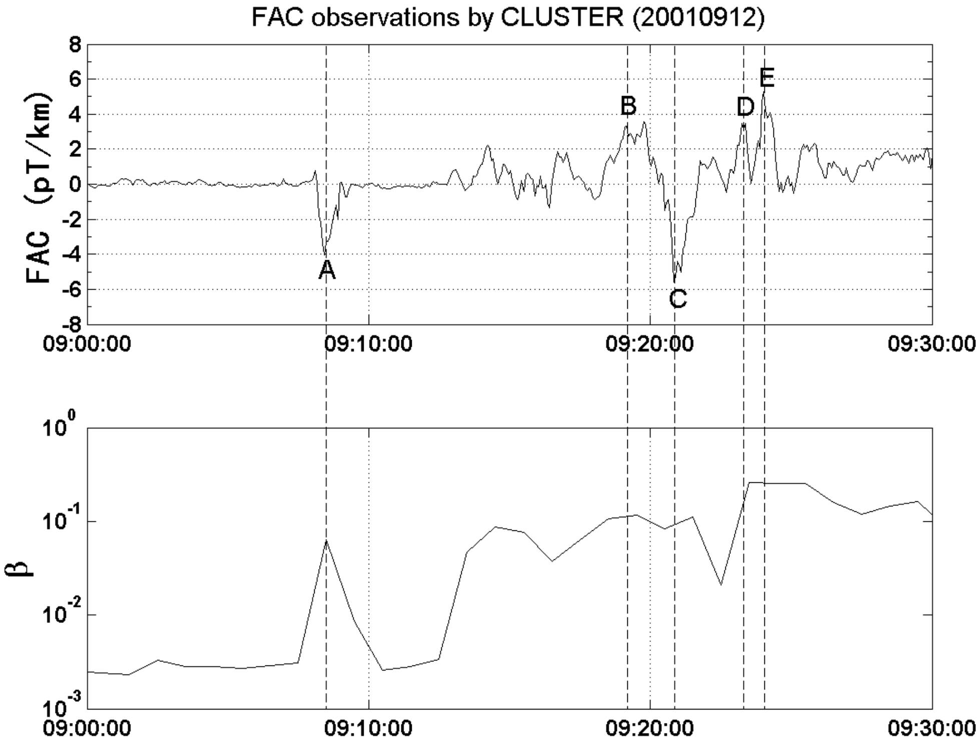


Fig.1 An example of FACs cases selection. The A and C were selected as FAC cases because they meet all of the conditions.

In this study, there are 1839 FACs cases from July to October in 2001 and 2004 were selected in the PSBL in the magnetotail. According to the corresponding IMF conditions, we chose 748 cases that during northward IMF to do analysis.

return

[return](#)

The corresponding IMF conditions:

The time delay from the ACE satellite to the magnetotail

ACE —(1)→ magnetopause —(2)→ magnetotail

(1) The time delay from the satellite to the magnetopause are about 48 to 76 minutes according to the solar wind speed.

(2) Sometimes the time-shift is uncertain in a study, e.g., Collier et al. (1998) have used the uncertainties of the time shifts (0~10 minute) in their study. We also used the uncertainties of the time shifts (0~5 minutes) in this study.