A possible mechanism of a strong guide B_Y field formation in a thin current sheet of the Earth magnetotail.

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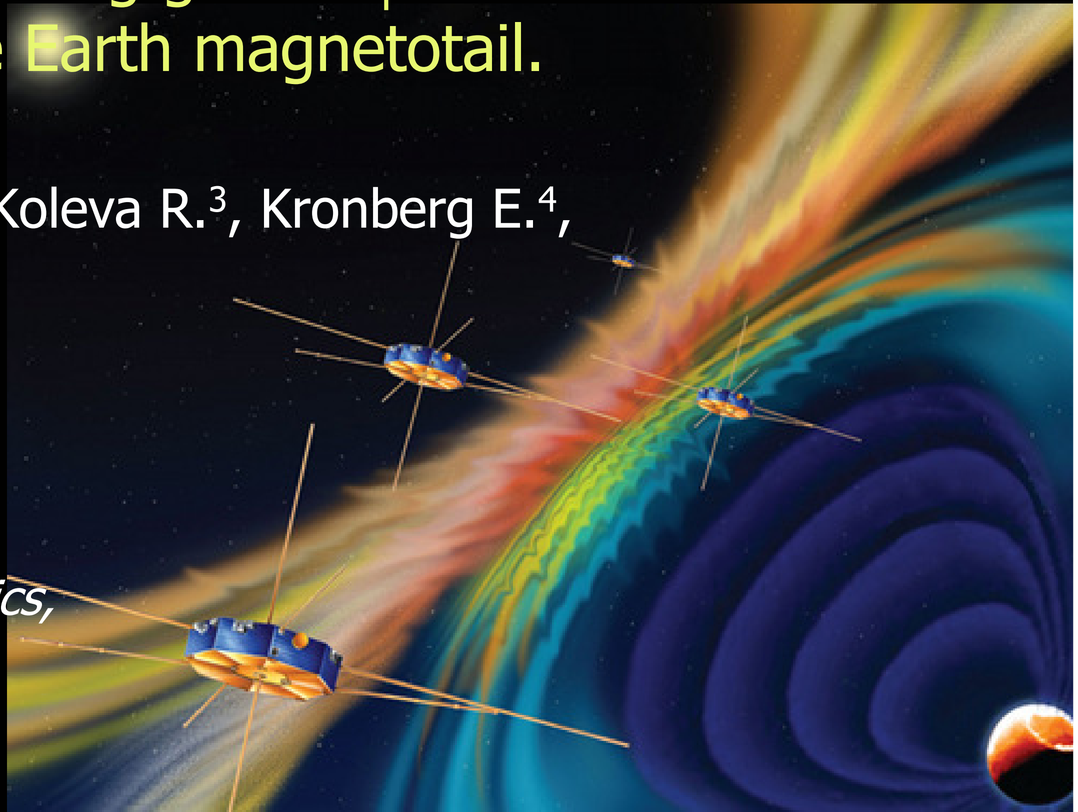
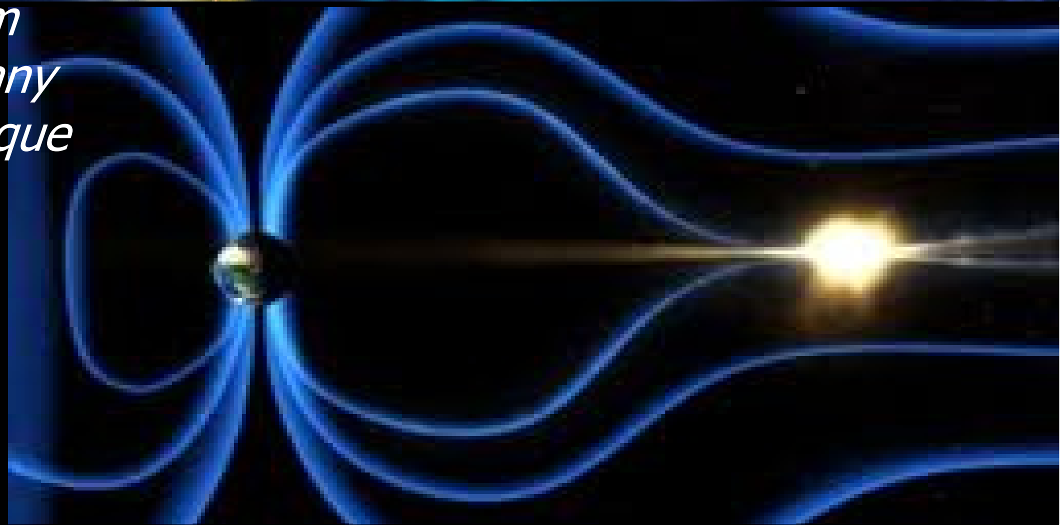
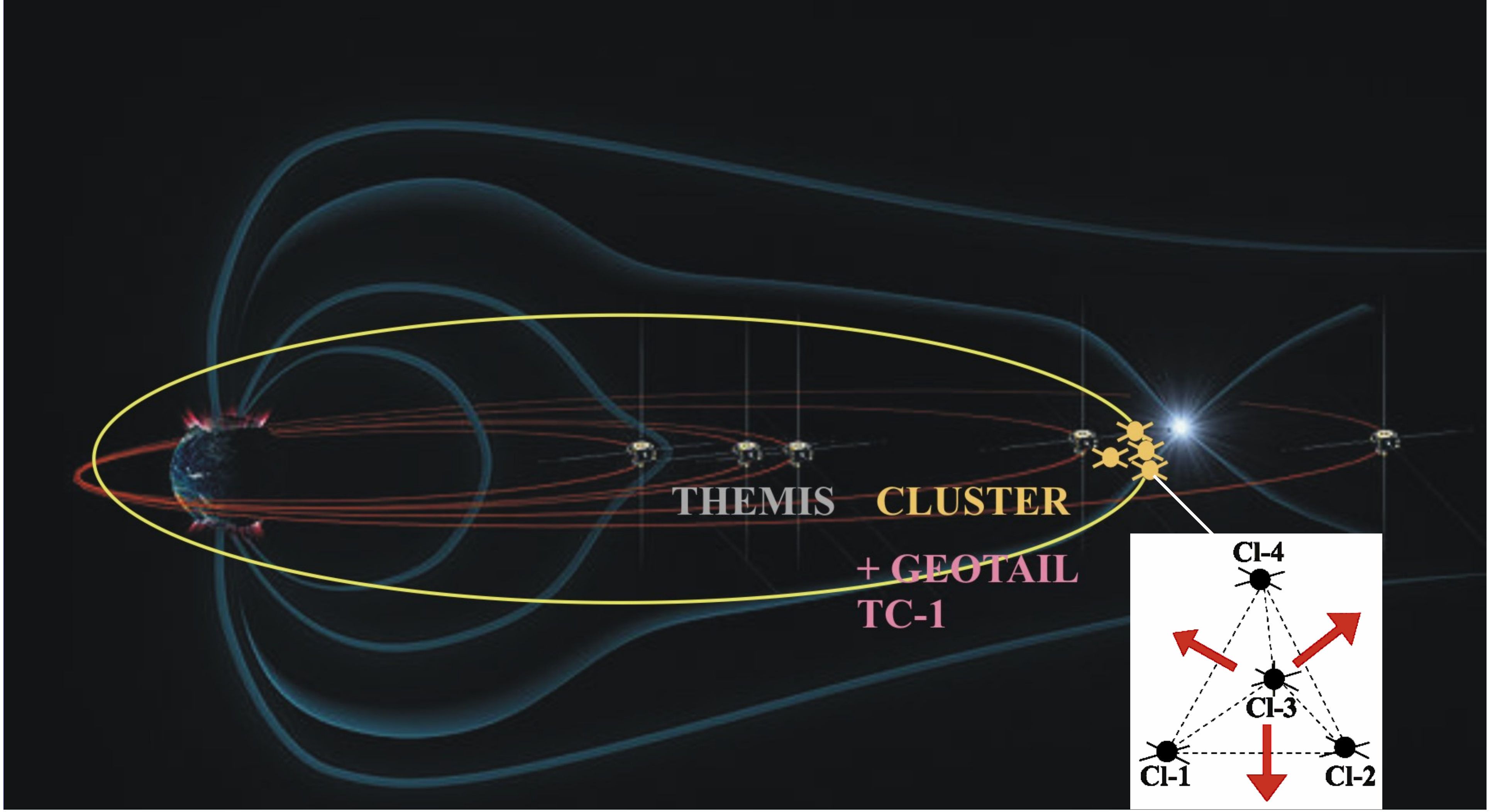




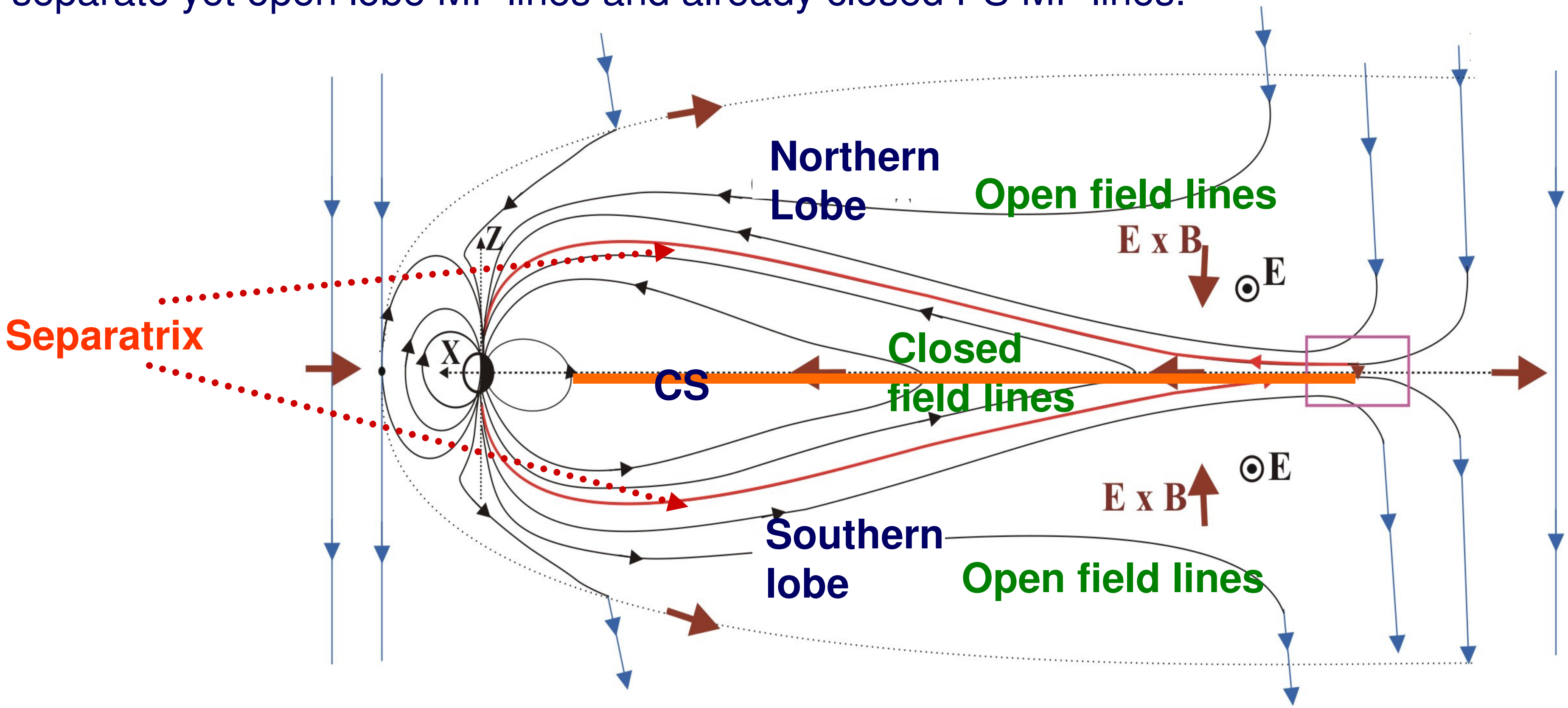
Outline:

- Observational signatures of a near-Earth magnetic reconnection
- Brief introduction to particle dynamics in a thin CS
- Reconnection under the presence of a guide B_Y field: features of particle dynamics



The magnetotail is an important region in which the energy coming in the magnetosphere from the solar wind accumulates and dissipates.

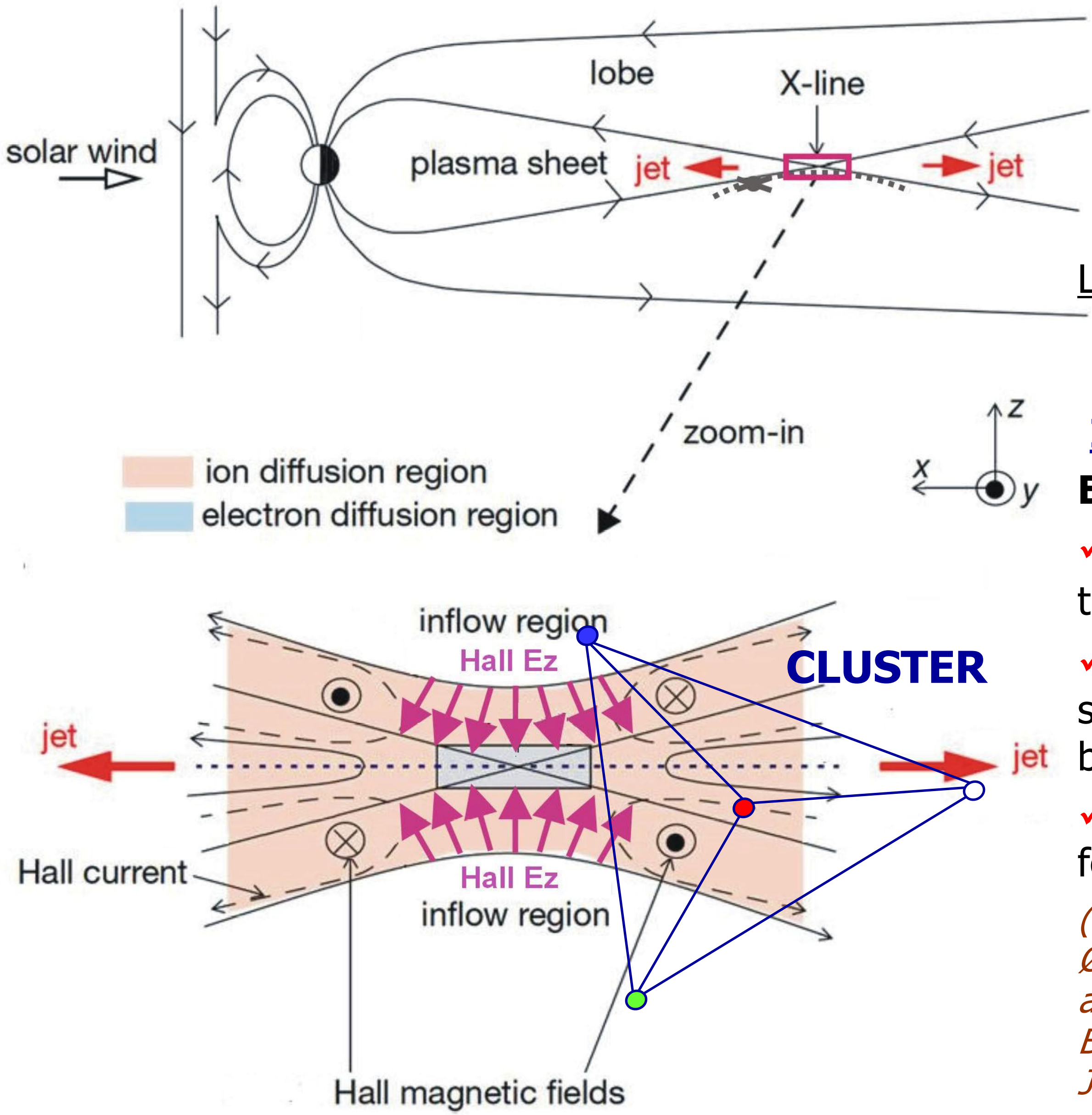
The magnetotail has two separatrix in the northern and southern lobes which separate yet open lobe MF lines and already closed PS MF lines.



In order to support the stretched magnetic configuration of the magnetotail the electric current flows in the neutral plane across the tail (along Y).

This current is localized within a layer – Current Sheet of finite thickness which varies from a few thousands km to a few hundreds km (ion scale).

1. Observational signatures of magnetic reconnection in the magnetotail.



Signatures observed at meso-scales: Earthward/tailward flows; energetic particle bursts; earthward propagating dipolarization fronts (THEMIS observations, *e.g. Runov et al.,JGR, 2009*); plasmoid/magnetic islands *(e.g. Drake et al.GRL,2006; Lin et al., JGR,2008)*

Location: X~ -10 - -30 Re *(e.g. Nagai, SSR, 2006; Sergeev et al., JGR,2008)*

Ion diffusion region:

$E+(V_i \times B)\neq 0$; $E+(V_e \times B)=0$

✓Thin and often bifurcated CS (CS thickness ~2λi, $\lambda i=c/\omega_{pi}$)

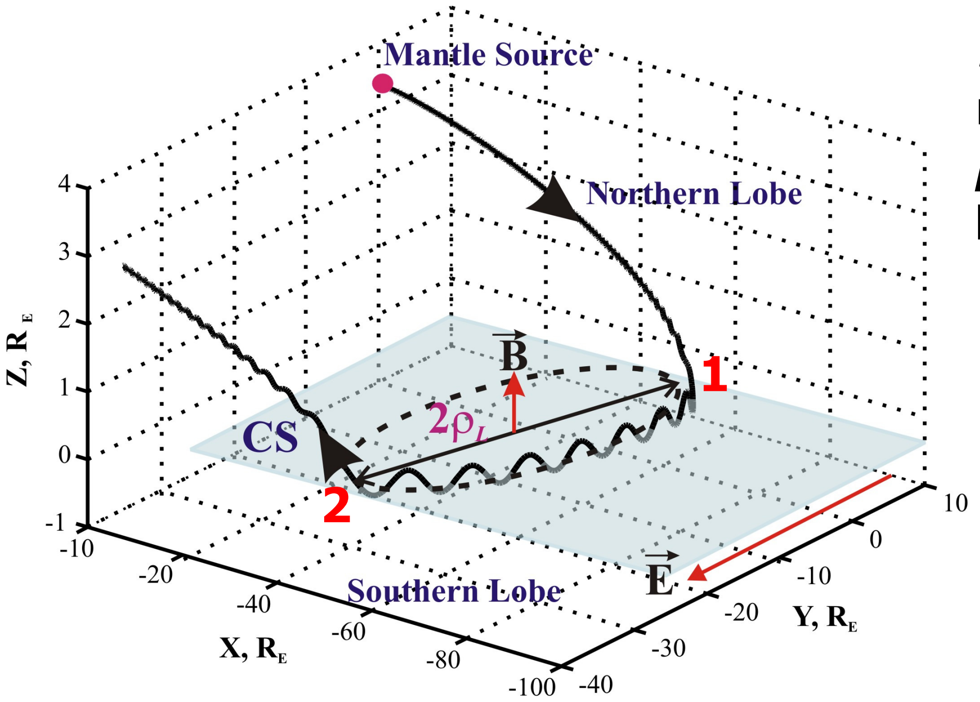
✓ Hall currents: quadrupole B_Y structure; electron beams; strong bipolar electric fields normal to the CS

✓A scale of ion diffusion region ~ a few λi

(e.g. Nagai et al., JGR, 2001;2003;2011; Øieroset et al., Nature,2001; Runov et al.,GRL,2003; Wygant et al., JGR,2005; Borg et al., GRL, 2005; Nakamura et al., JGR, 2006 ets)

2. Nonadiabatic particle dynamics in a thin CS

(Shabansky, 1971; Lyons and Speiser, 1982)



If CS is thin, so that a radius of curvature $\boldsymbol{R_{curv}}$ of the magnetic field line crossing the neutral plane is smaller than Larmor radius $\boldsymbol{\rho_L}$ of charged particles, then particles become **non-adiabatic**.

$$\kappa = \sqrt{\frac{R_{curv}^{\min}}{\rho_L^{\max}}} \leq 1.0$$

(Buchner and Zelenyi, 1989)

Particle non-adiabatic motion:

slow rotation around **finite B_Z**

+

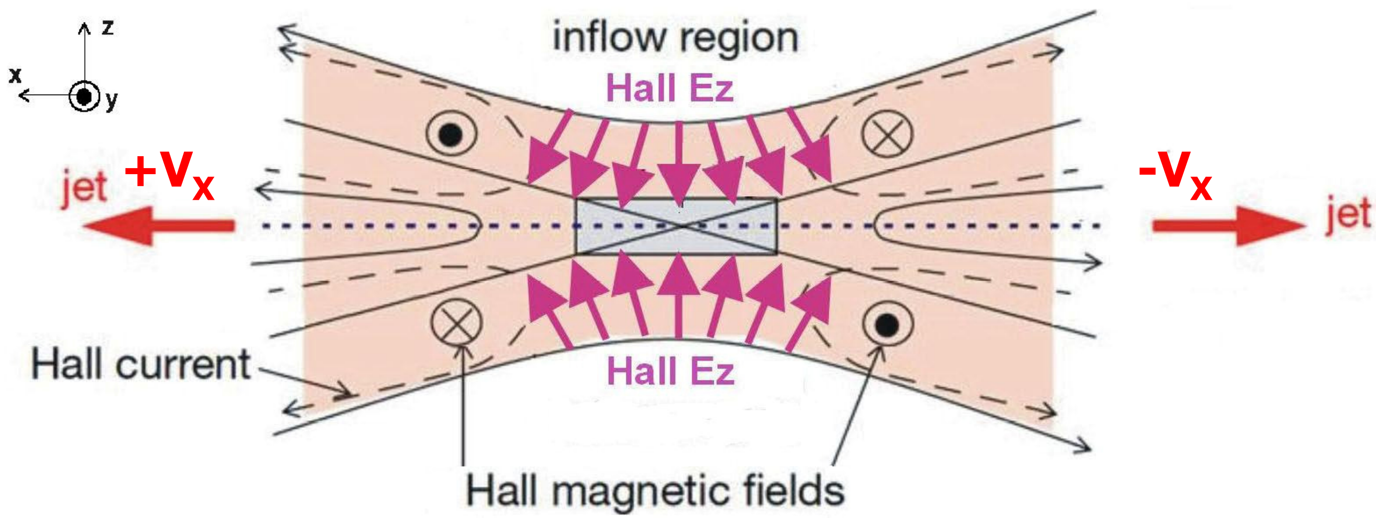
fast oscillations in the plane **perpendicular** to CS.

$$\Delta W(X) = E_Y \cdot 2\rho_L = 2m\left(\frac{E_Y}{B_Z(X)}\right)^2$$

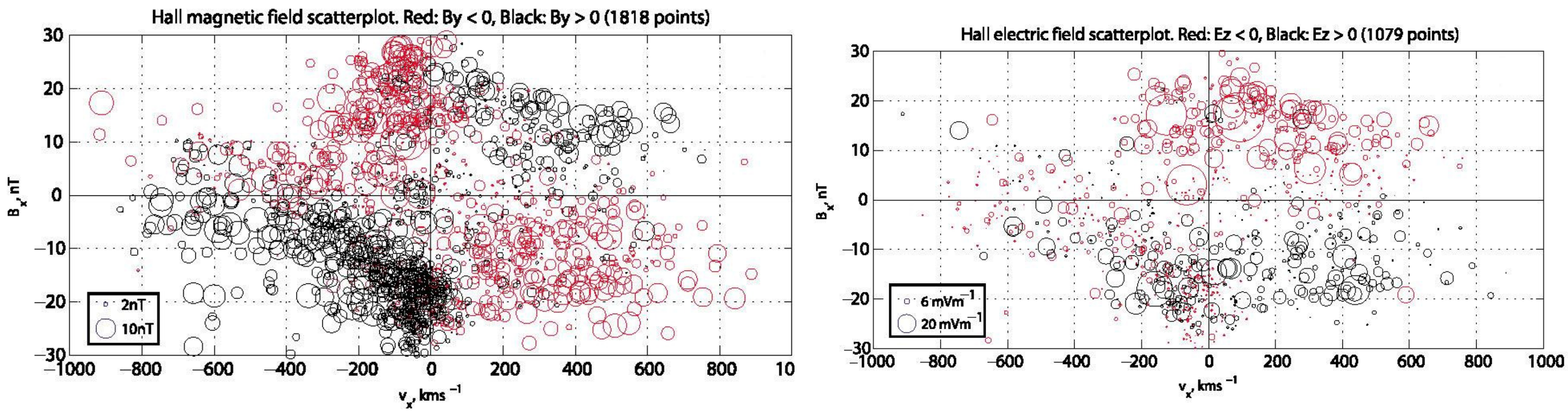
Ion energy gain ΔW → Thermal form (trapped orbits)

Ion energy gain ΔW → Kinetic energy of field-aligned motion (flyby orbits)

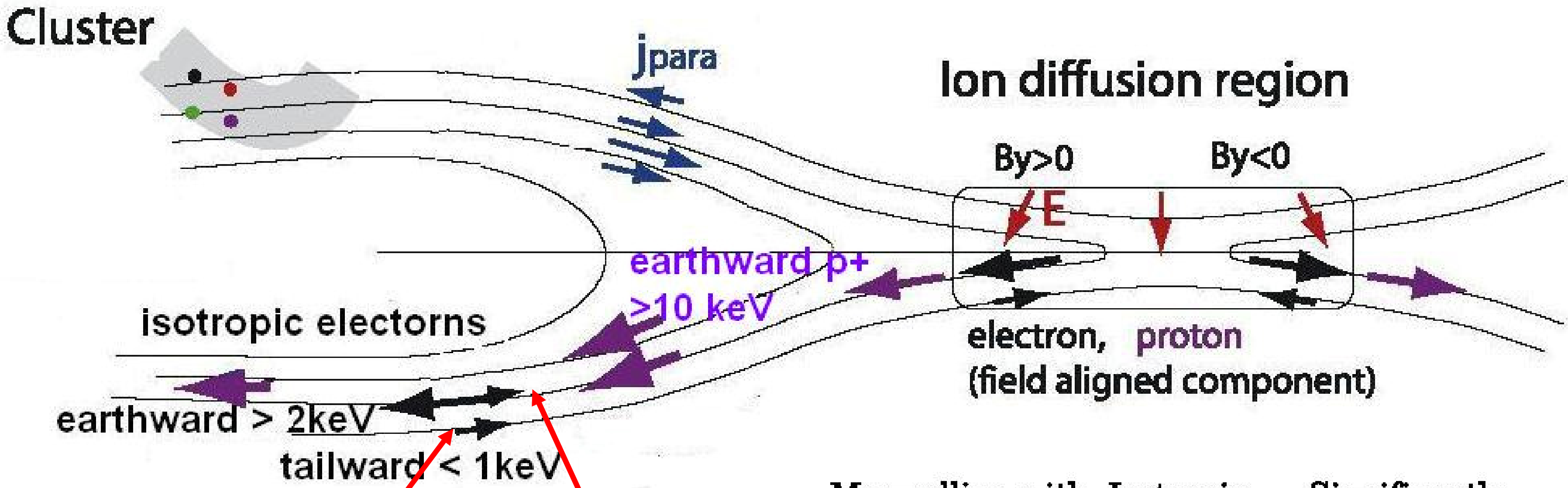
3. Advantages of multipoint observations in studies of reconnection fields.

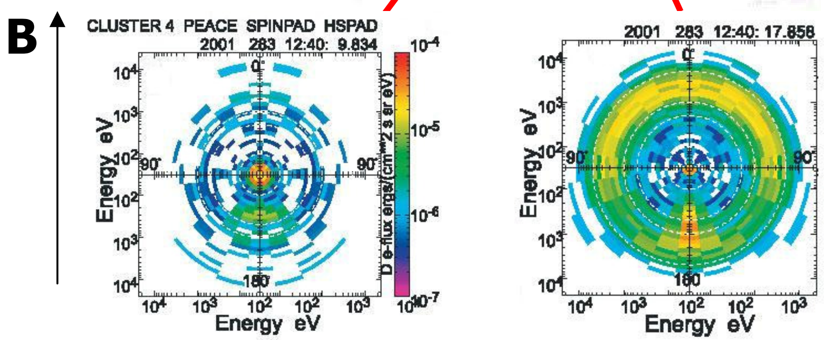


Cluster observations confirm the spatial structure of Hall magnetic and electric fields.

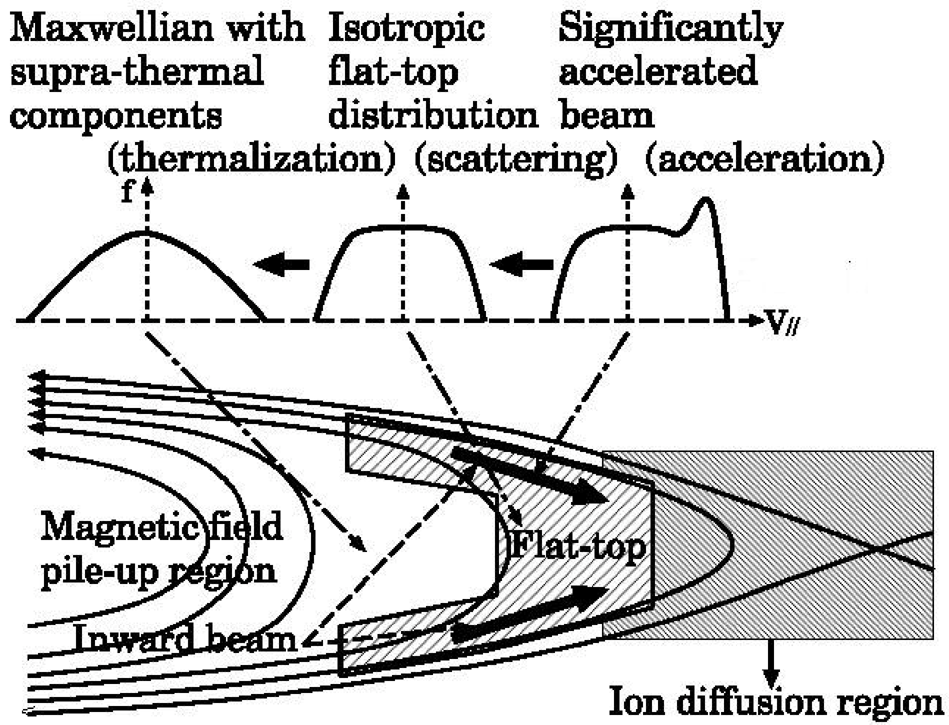


(Eastwood et al., JGR, 2010)





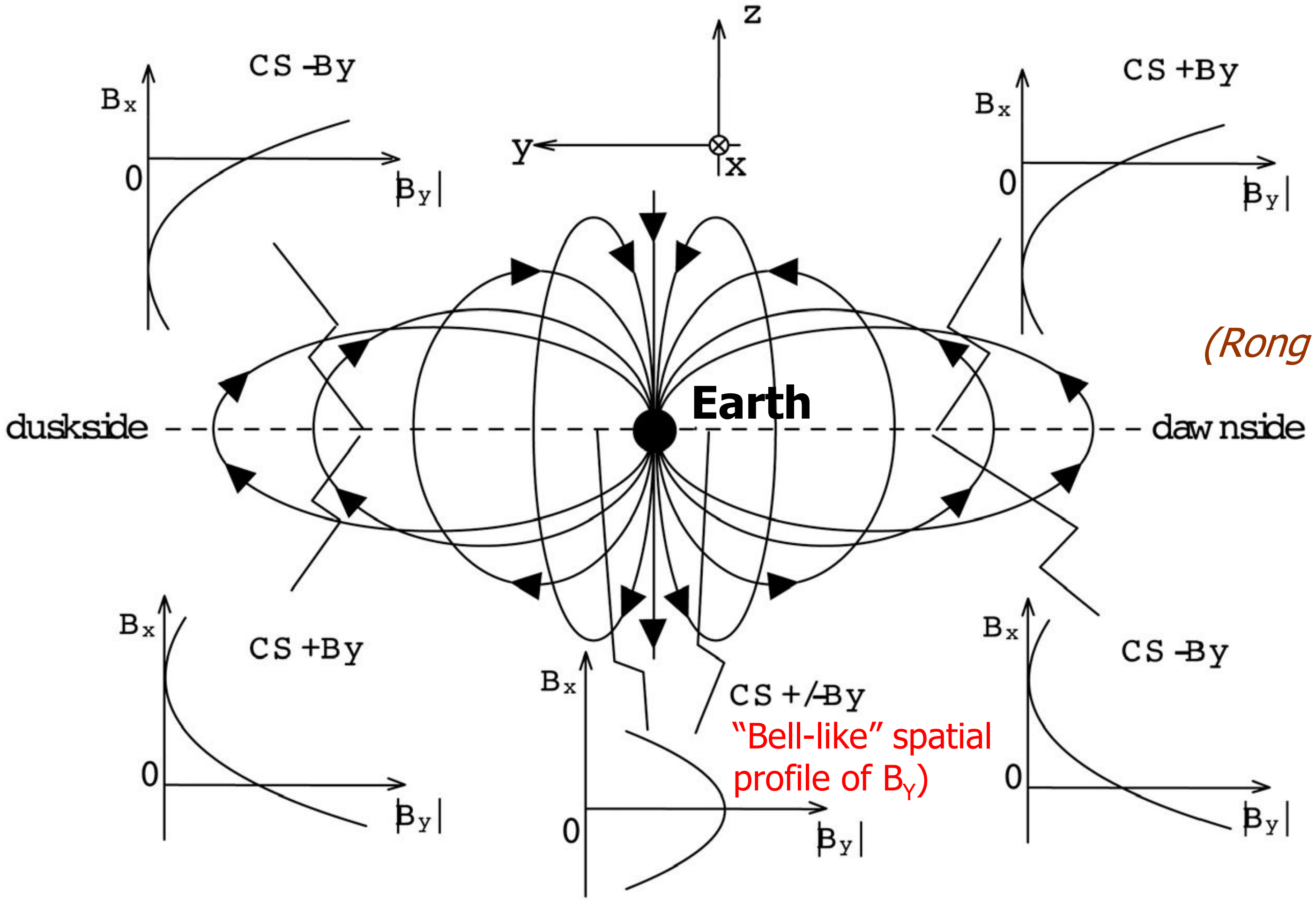
(Geotail observations: e.g. *Nagai et al.,JGR, 2001*;
Fujimoto et al., JGR, 2001;
Cluster observations*: e.g. Nakamura et al., JGR,2004)*



(Asano et al., JGR, 2004)

Generally reconnection in the magnetotail is anti-parallel (no guide field) and symmetric (similar plasma conditions on the two sides of the CS).

However, sometimes a strong guide B_Y field exists in the magnetotail CS.



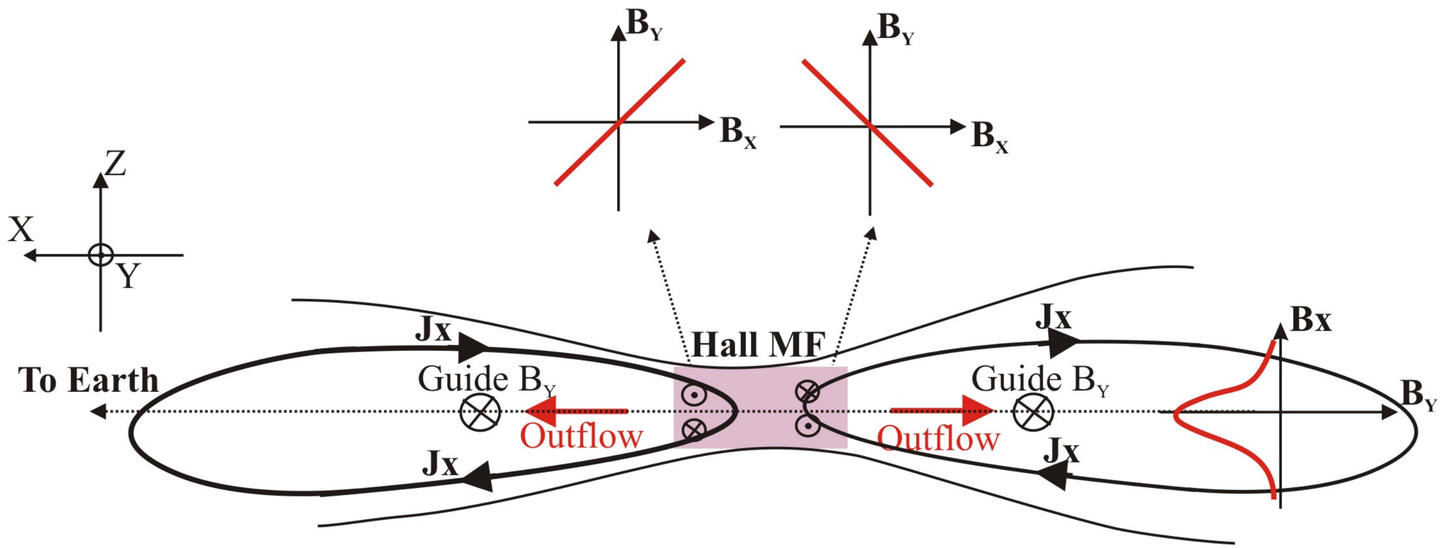
(Rong et al., JGR, 2012)

A guide B_Y field may affect the properties of reconnection fields and particle dynamics. *(Pritchett and Coroniti, JGR, 2004; Mozer et al., GRL, 2008)*

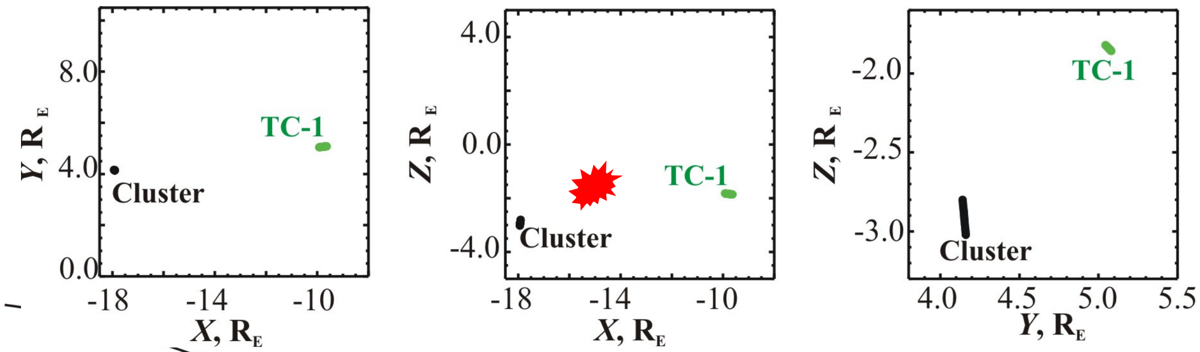
What is the origin of a guide B_Y?

- IMF B_Y penetration into the magnetotail (e.g. *Fairfield*, 1979; *Lui, 1*984; *Sergeev* 1987; *Kaumaz et al.*, 1994, *Shen et al.*, 2008)

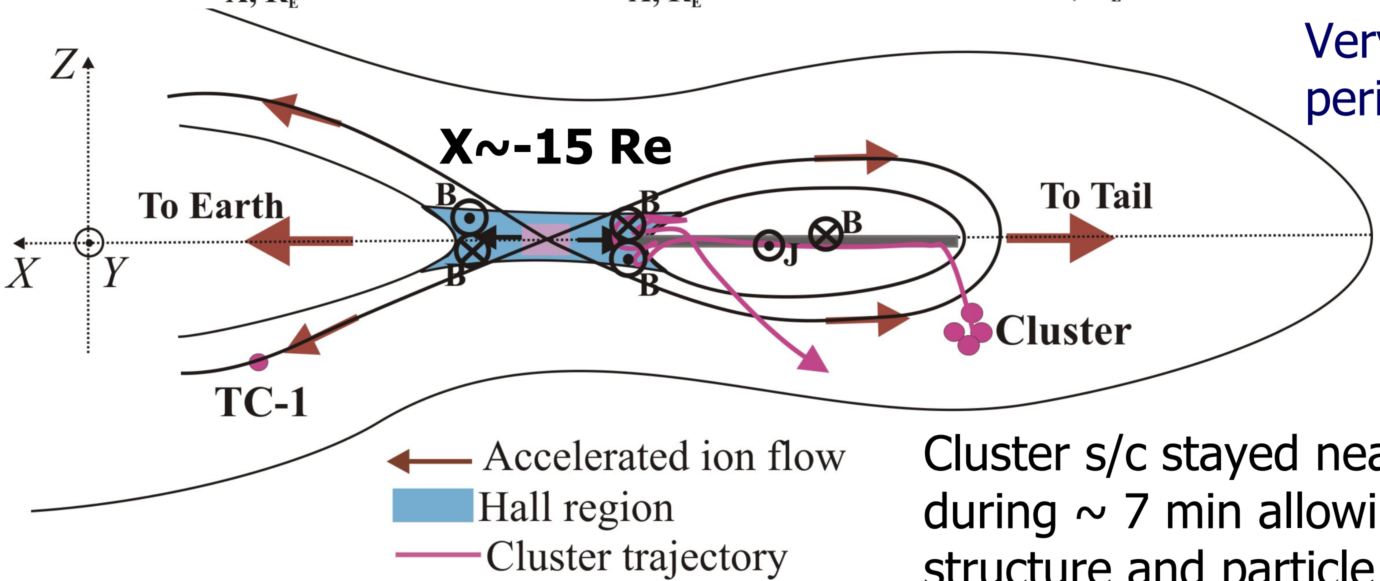
- Internal CS dynamics (*Nakamura et al., 2008; Petrukovich et al.,JGR,2011;*
- *Rong et al.,JGR,2012; Grigorenko et al.,JGR,2013)*



4. Near-Earth reconnection between TC-1 and Cluster s/c (on 22.09.2004)



Cluster and TC-1 separation in Y: **ΔY ≤ 1 Re,** so that manifestations of the same phenomenon were observed by both s/c



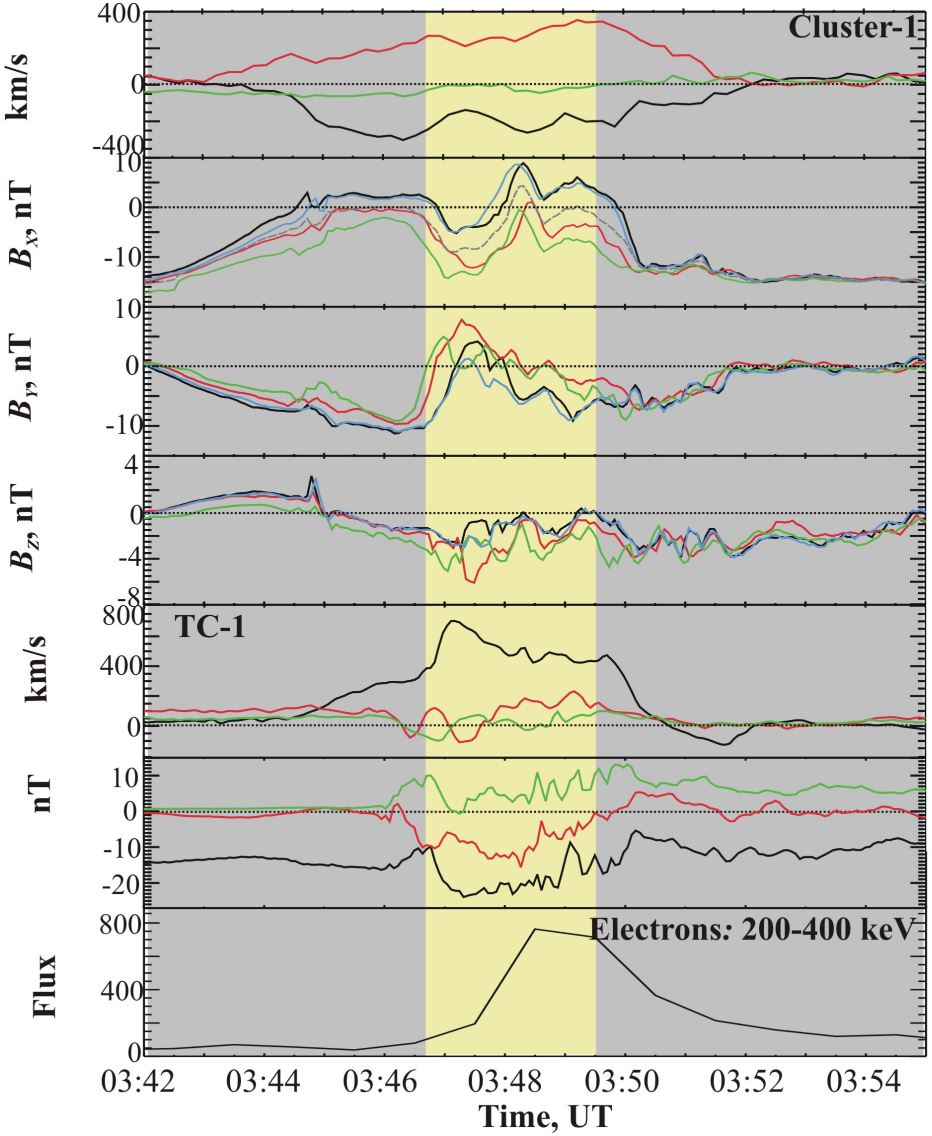
Very quiet geomagnetic period |AL| < 50 nT

Cluster s/c stayed near the neutral plane during ~ 7 min allowing to study the CS structure and particle dynamics.

A strong **negative guide B_Y field** (~ $2|B_0|$ - MF field value at the edges of the CS) was observed at Cluster location (tailward of the X-line).

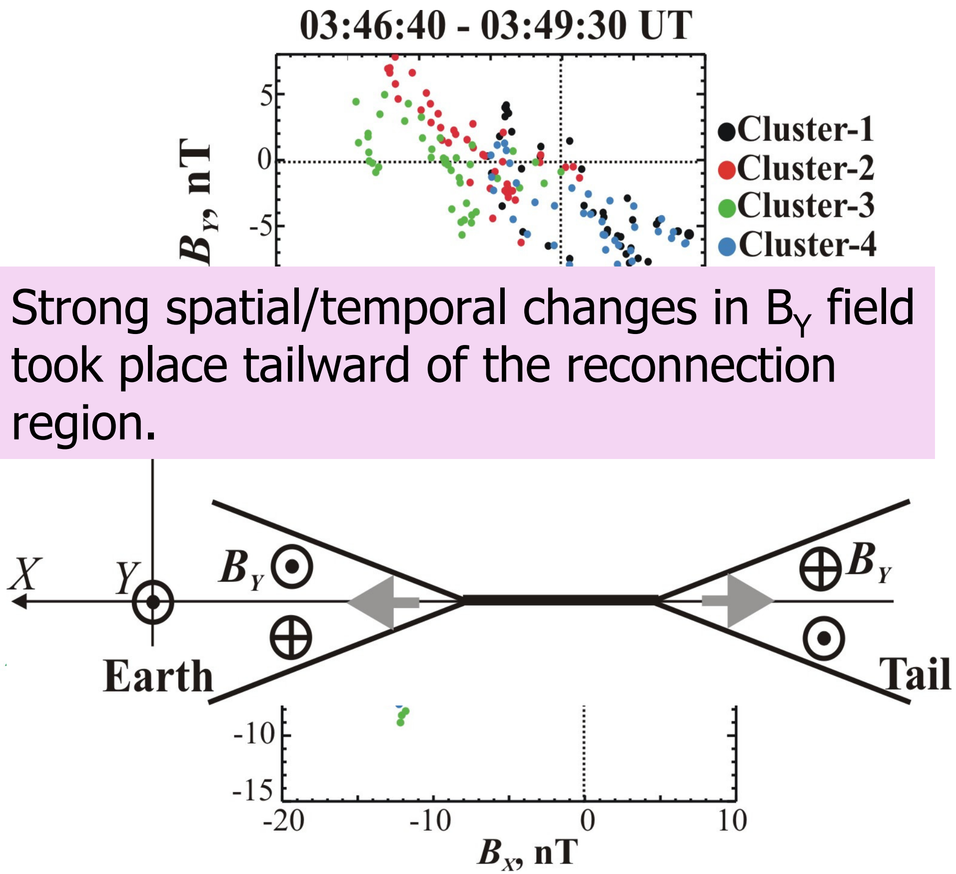
(Grigorenko et al.,JGR, 2013)

The zoom of Cluster and TC-1 observations



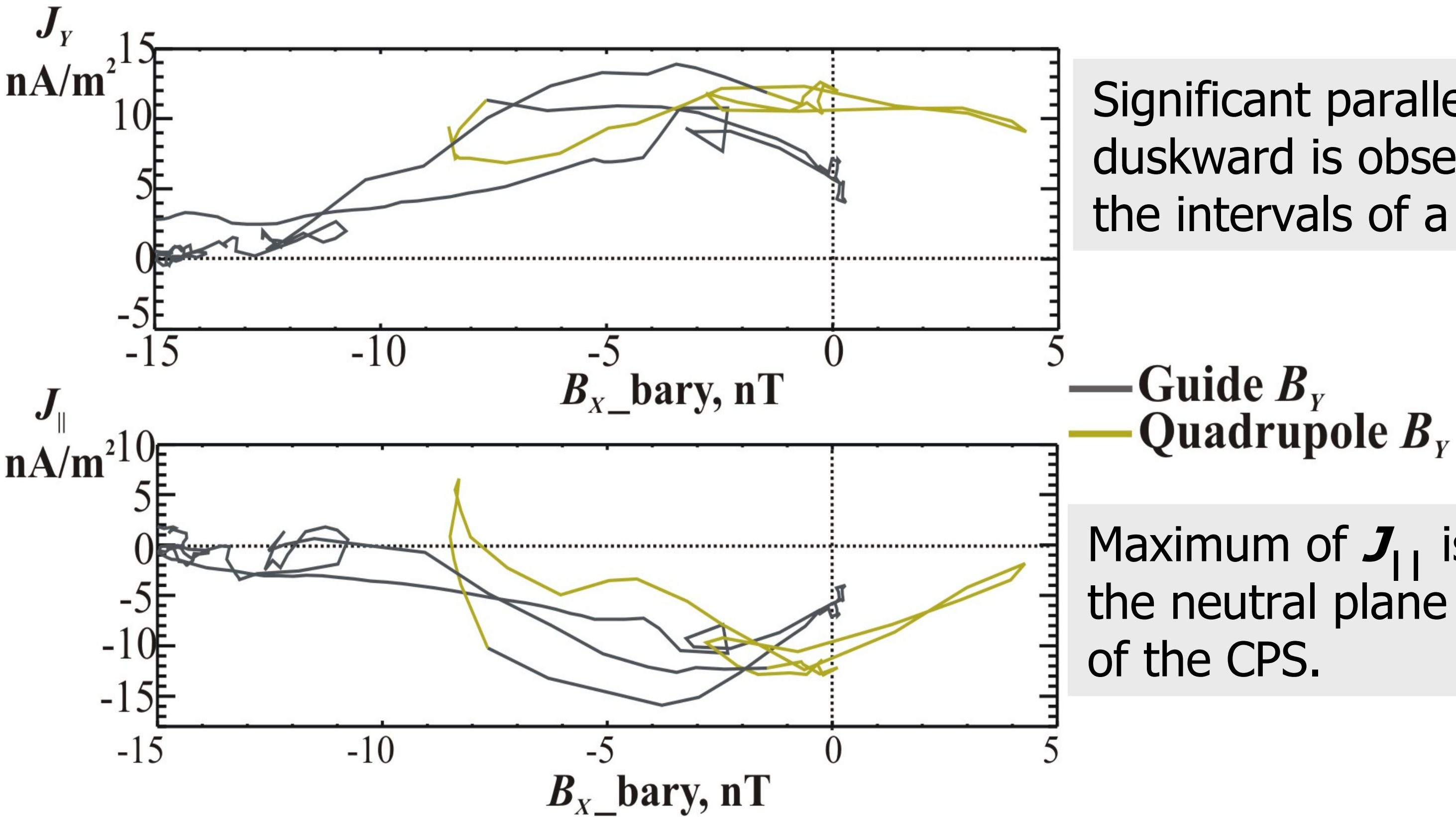
Guide B_Y with a maximum near the neutral plane ("bell-like" spatial profile)

Quadrupole B_Y variation



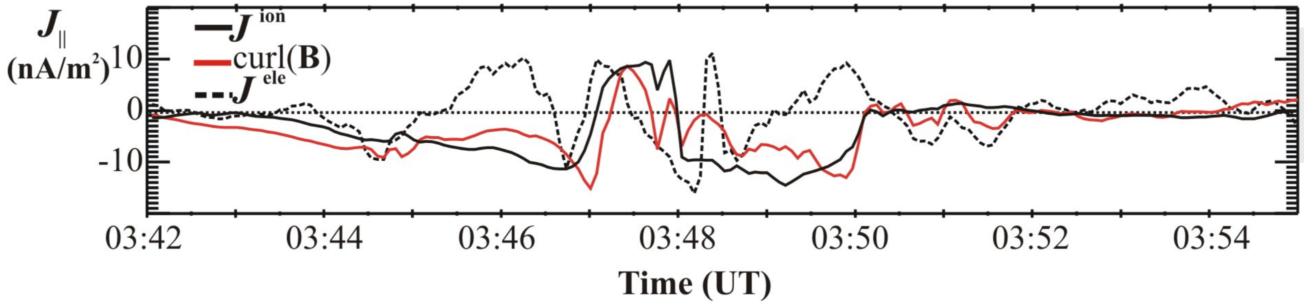
Strong spatial/temporal changes in B_Y field took place tailward of the reconnection region.

CS structure tailward of reconnection region. Cluster observations.



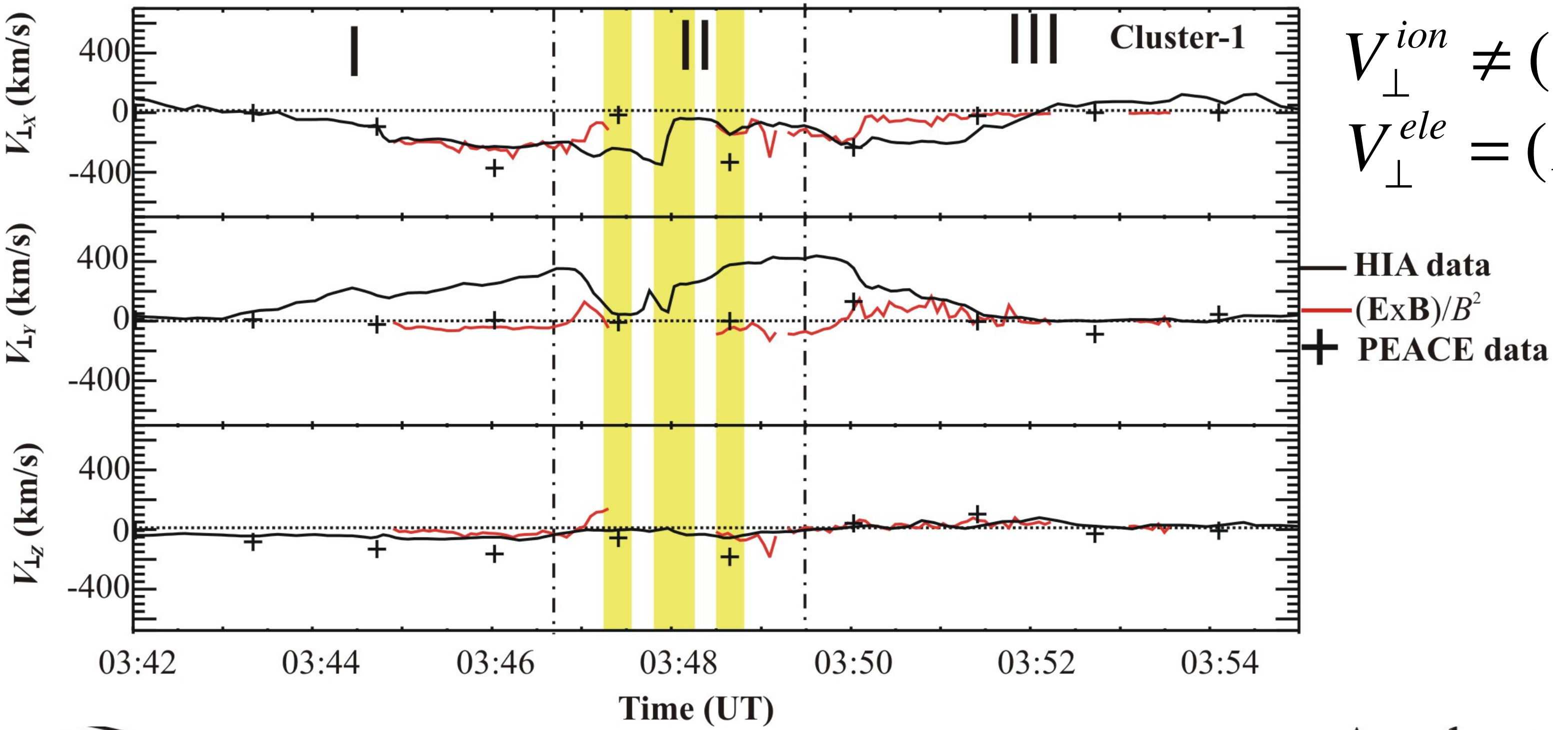
Significant parallel current directed duskward is observed during the intervals of a guide B_Y

Maximum of $\boldsymbol{J}_{||}$ is observed outside the neutral plane in the southern part of the CPS.



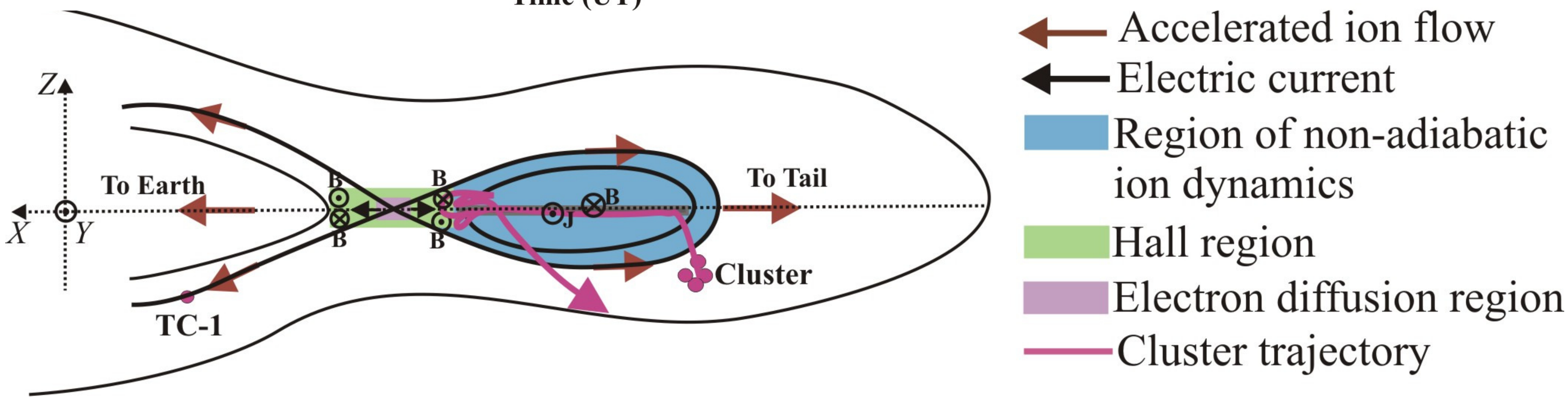
Parallel current is produced by ions

- Ions are **unmagnetized** during the main part of interval.
- Electrons are **mostly magnetized during the periods of a guide B_Y** (I and II).
- Only during short periods of quadrupole B_Y (yellow shaded intervals) the frozen-in condition is violated for electrons, indicating that Cluster-1 approaches to the electron diffusion region

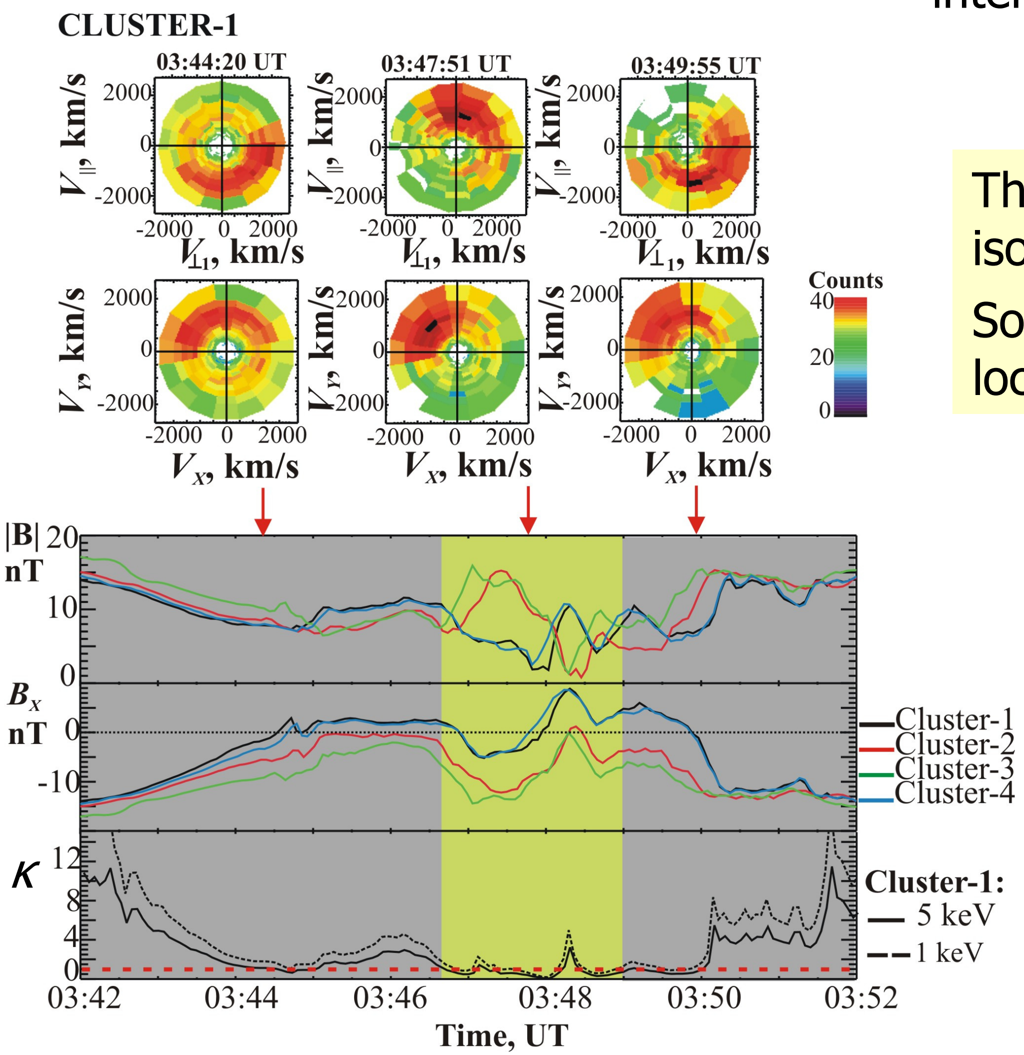


$$V_\perp^{ion} \neq (ExB)/B^2$$

$$V_\perp^{ele} = (ExB)/B^2$$



Particle dynamics in a thin CS tailward of the reconnection region. Cluster observations.

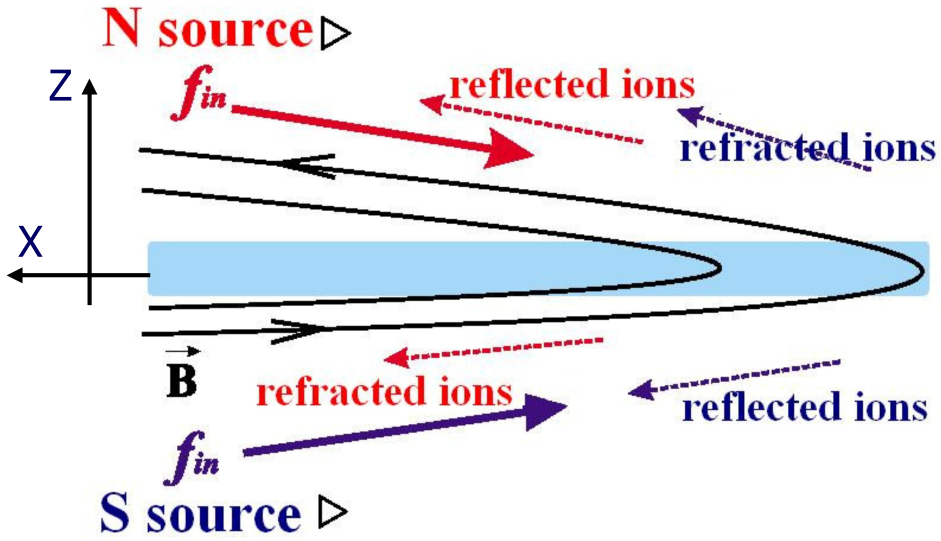


CS thickness ~ 800 km by the middle of the interval

The background ion population was mostly isotropic.

So that, energy dissipation process was localized at the closed (CPS) MF lines

Ion nonadiabatic dynamics under the presence of a guide B_Y field

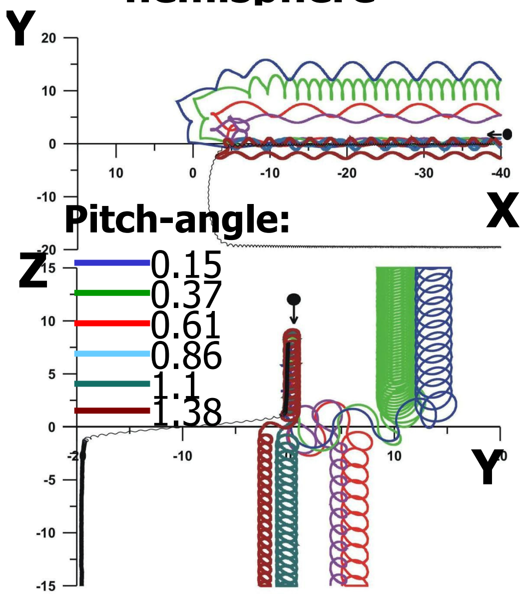


Symmetric case:

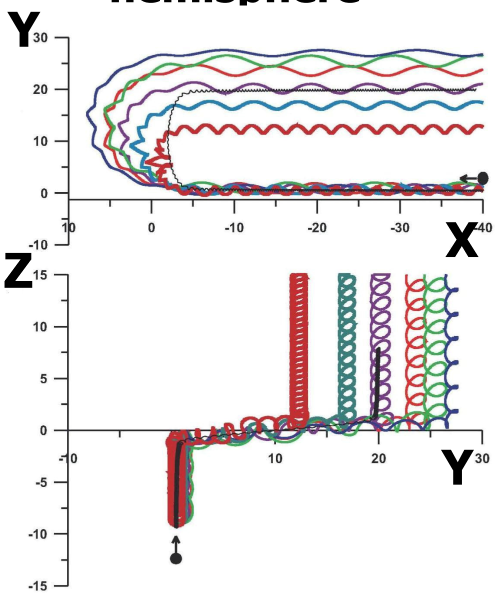
$\boldsymbol{B_Y = 0}$

There is no north-south asymmetry in the ejections of nonadiabatic ions after their interaction with the CS.

Source in the northern hemisphere



Source in the southern hemisphere



Asymmetric case:

$$B_Y = B_{Y0}\cos(Z\pi/2L), |Z| \le L$$

$$B_Y = 0, |Z| > L$$

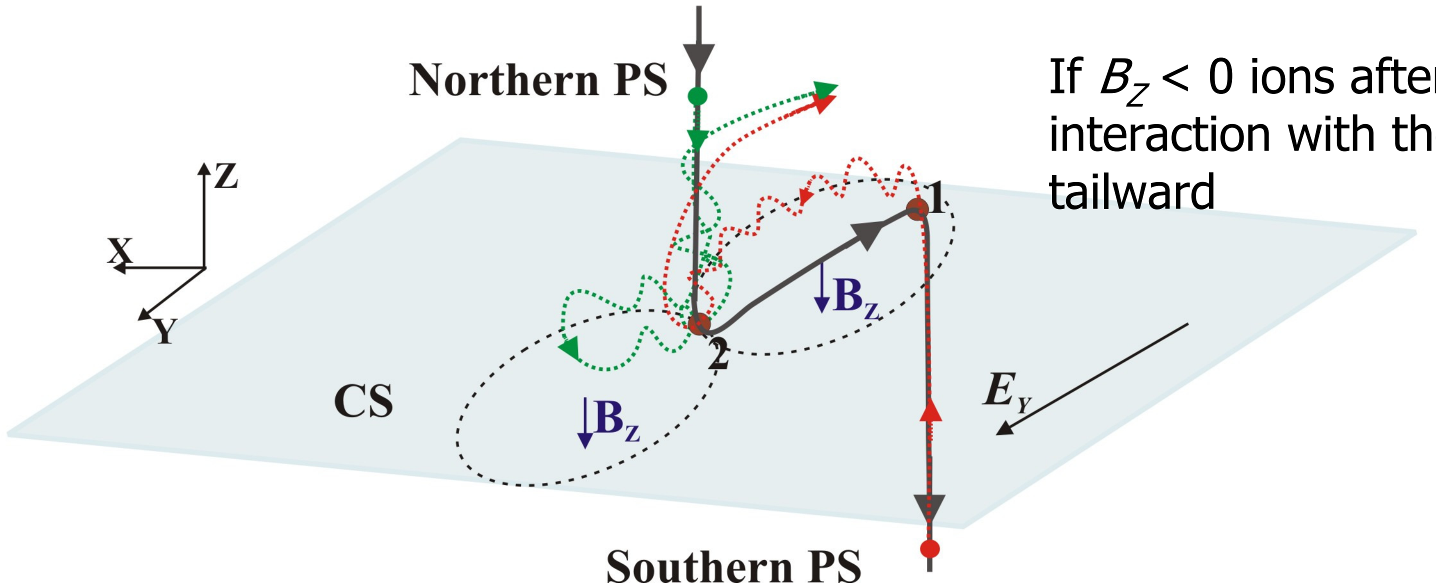
$\boldsymbol{B_{Y0} \sim -2|B_0|\ ,\ B_Z = -0.1|B_0|,}$

B_0 is the MF at the edges of the CS

All ions coming to the CS from the **southern** hemisphere are ejected to the **northern PS** after the nonadiabatic interaction with the CS

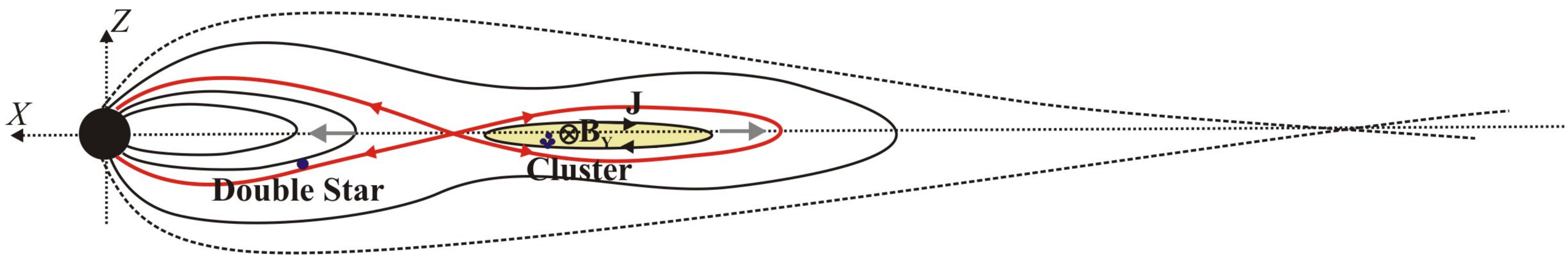
North-south asymmetry in keV-ions distribution appears.

Peculiarities of ion nonadiabatic interaction with the CS under the presence of **B_Y<0** at the neutral plane.



If $B_Z < 0$ ions after the nonadiabatic interaction with the CS are ejected tailward

North-south asymmetry in keV-ions ejected tailward is observed. These ions could produce a **tailward current** in the **northern PS**



The tailward current in the northern PS produces a negative B_Y near the neutral plane

Summary.

Cluster observations show that the presence of a strong B_Y field near the neutral plane affects CS structure and particle dynamics:

- significant parallel current with asymmetric density profile, which is carried by nonadiabatic ions;
- north-south asymmetry in the refraction/reflection of the nonadiabatic ions from the thin CS

A strong enhancement of a B_Y field near the neutral plane could be caused by the electric current carried by nonadiabatic ions. This current arises due to the north-south asymmetry in the reflection/refraction of nonadiabatic ions from the CS.