Multi-point observations of reconnection signatures in the near Earth's magnetotail

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Acknowledgements:

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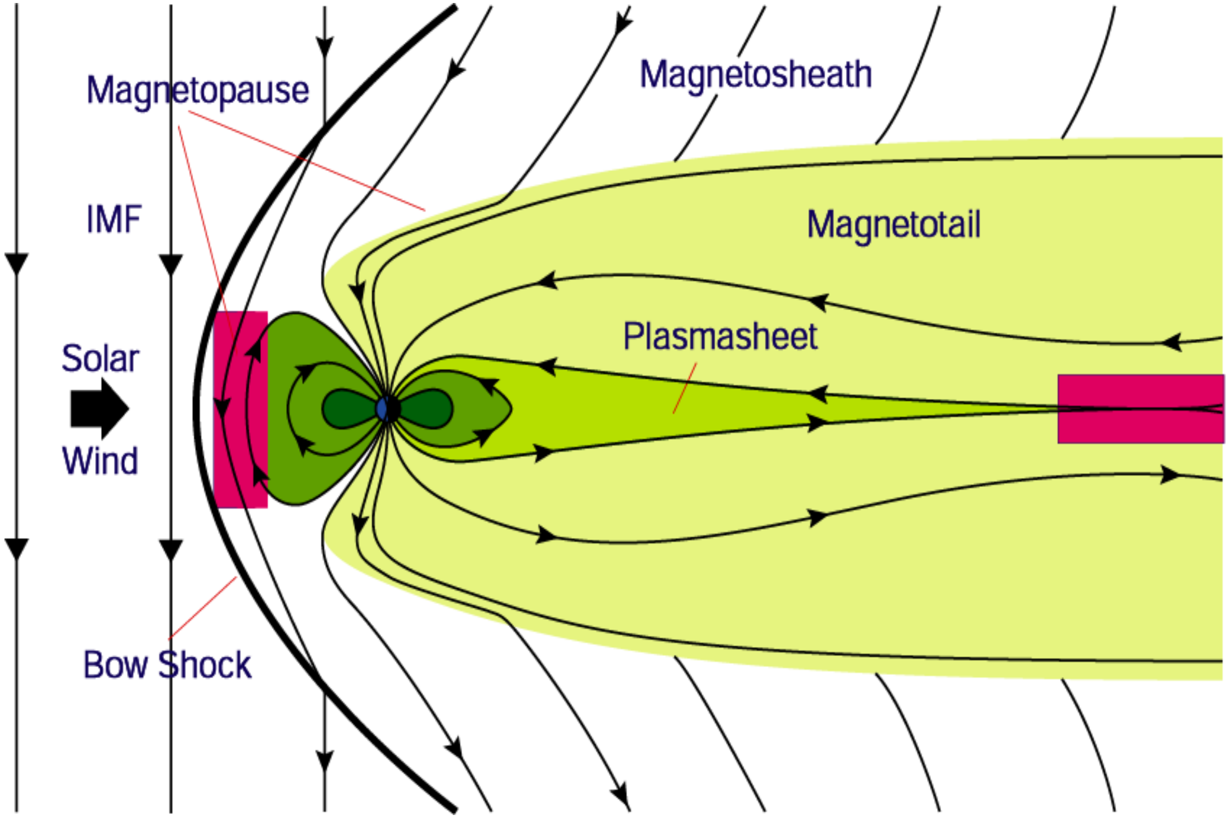
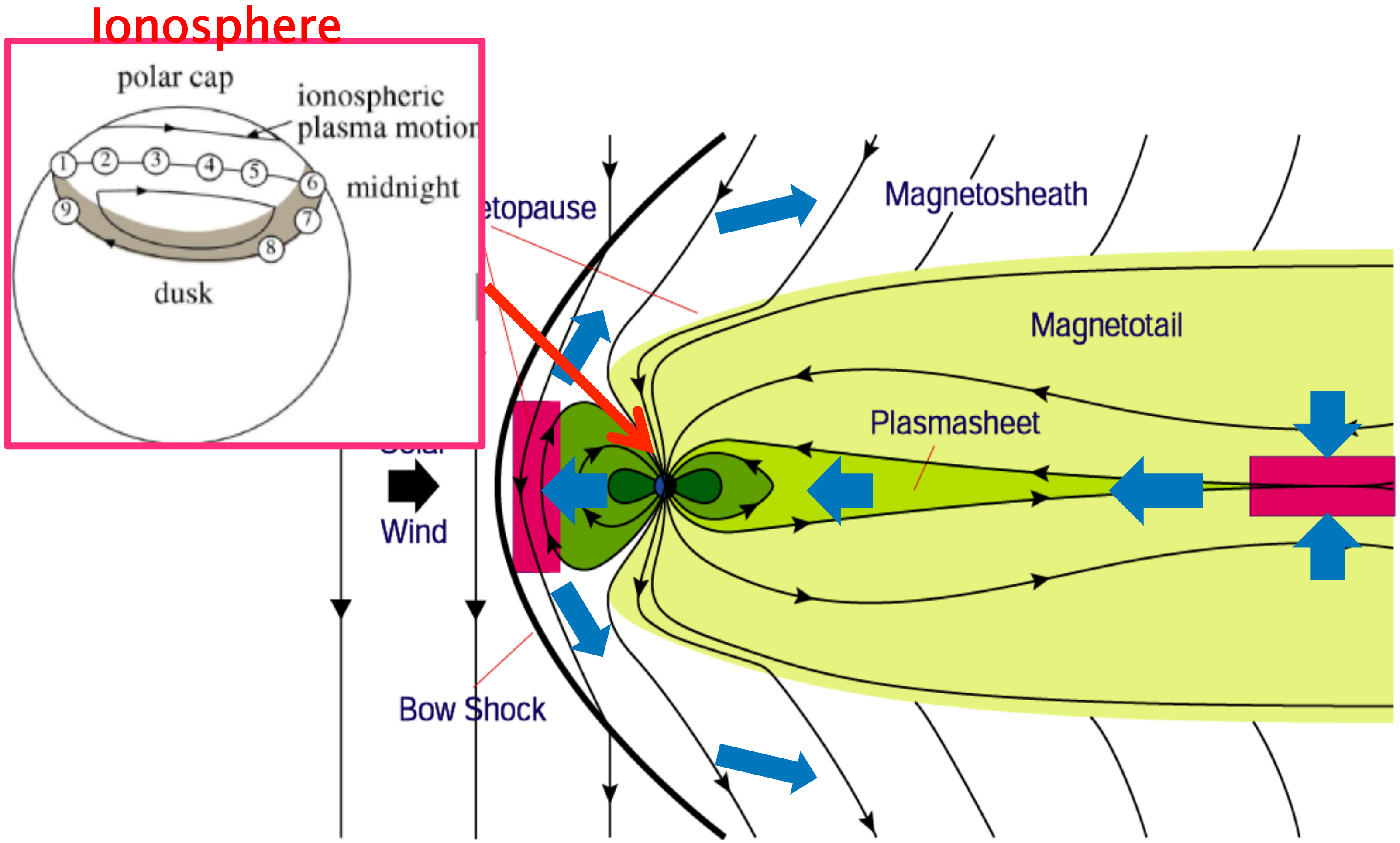
Earth's magnetosphere



- Reconnection
  - →Energy conversion, Mixing of different plasmas
  - →Solar wind energy dissipated in magnetosphere & ionosphere

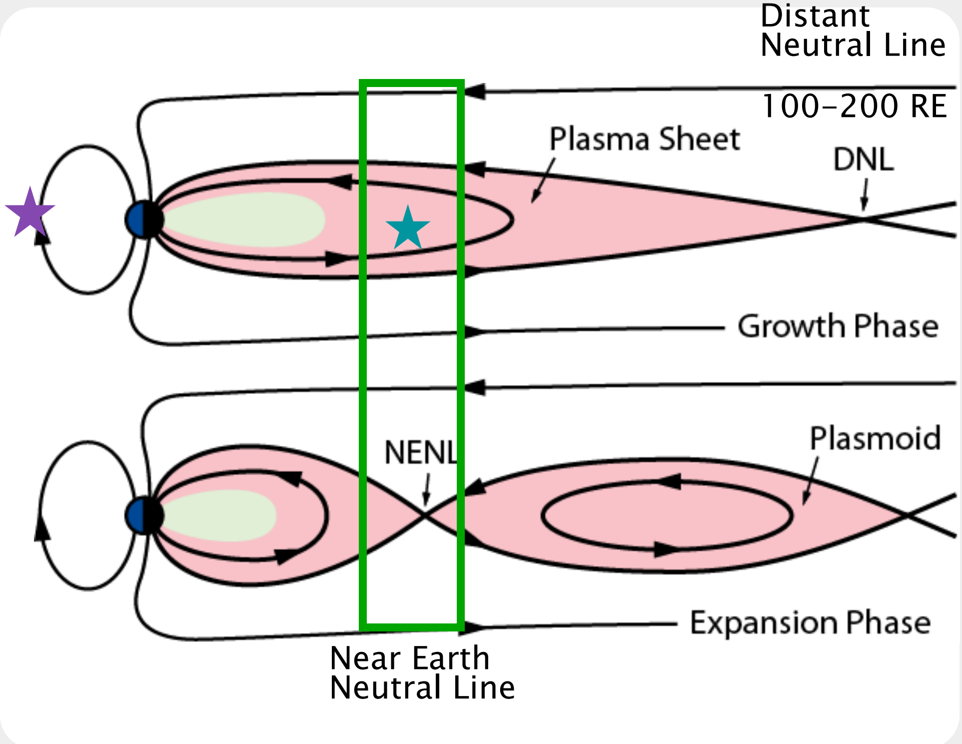
Earth's magnetosphere

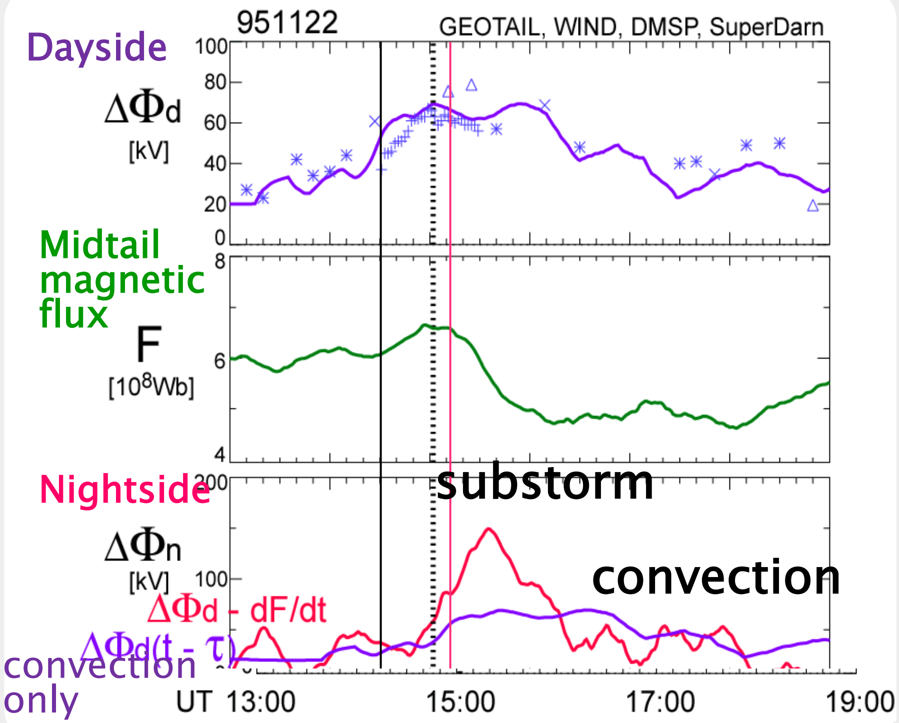


- Reconnection → **Magnetospheric Convection**
  - →Energy conversion, Mixing of different plasmas
  - →Solar wind energy dissipated in magnetosphere & ionosphere

Near-Earth magnetotail reconnection

Dayside, nightside reconnection are unbalanced → substorm





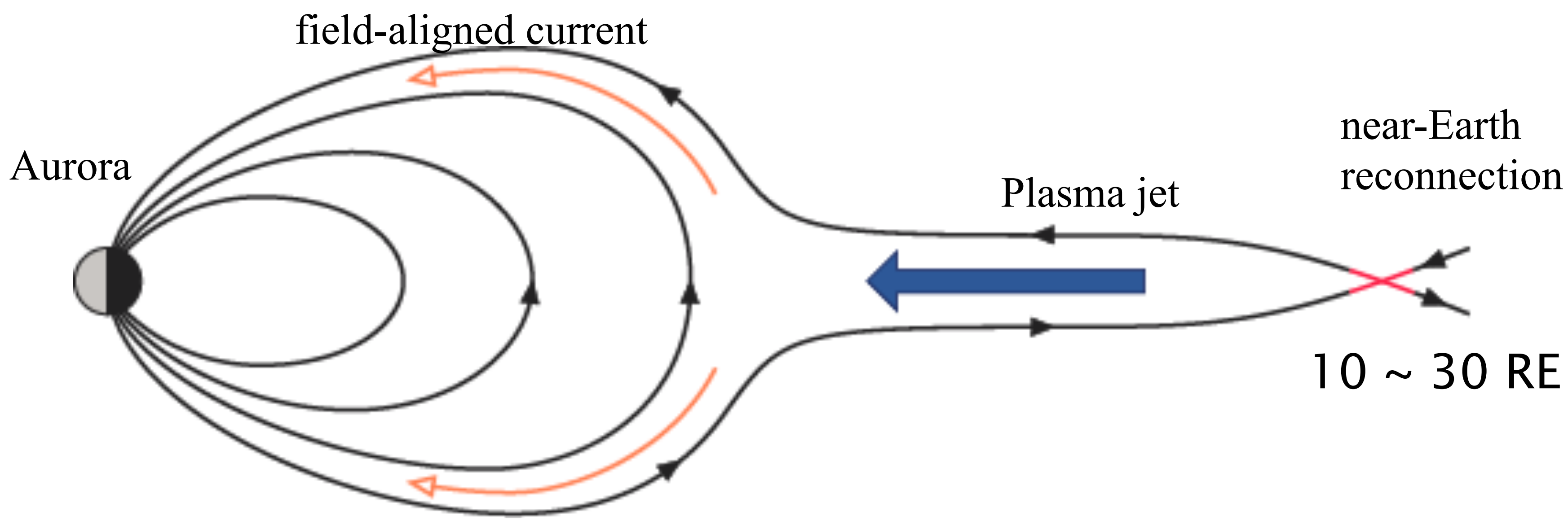
[Nakamura et al., 1999]

Flux balance

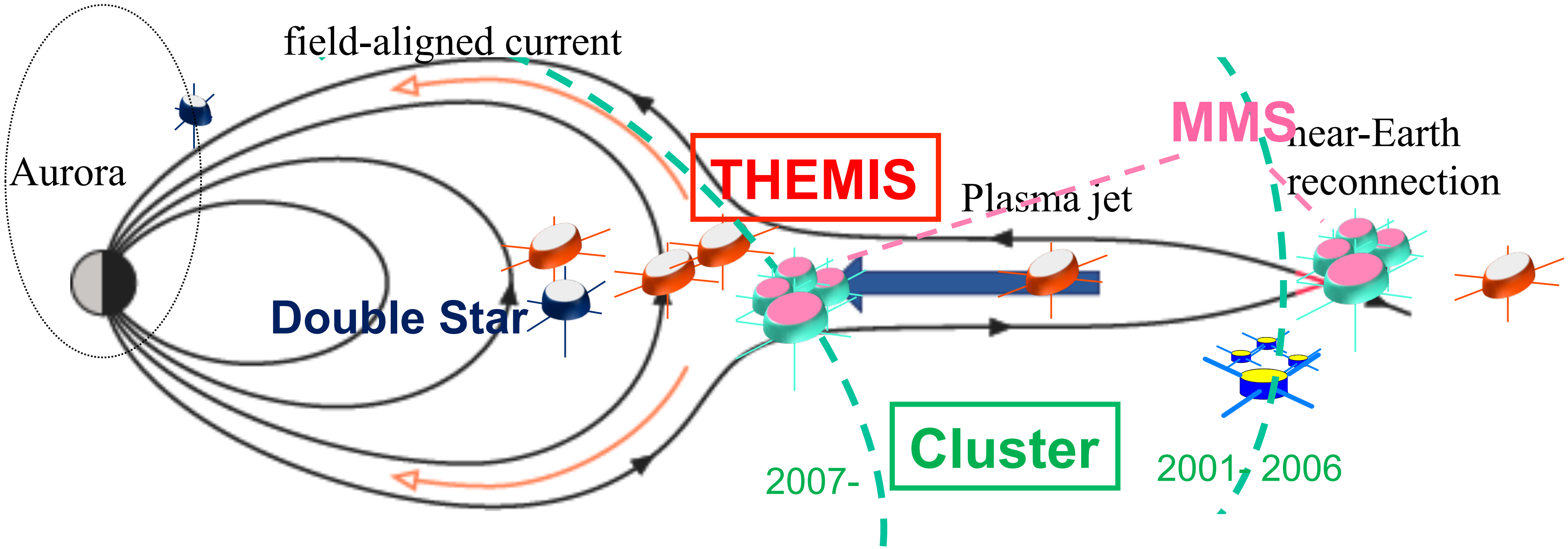
$$\Delta\Phi_n = \Delta\Phi_d - dF/dt$$

➢ Internal processes important for near-Earth magnetotail reconnection

Near-Earth tail dynamics



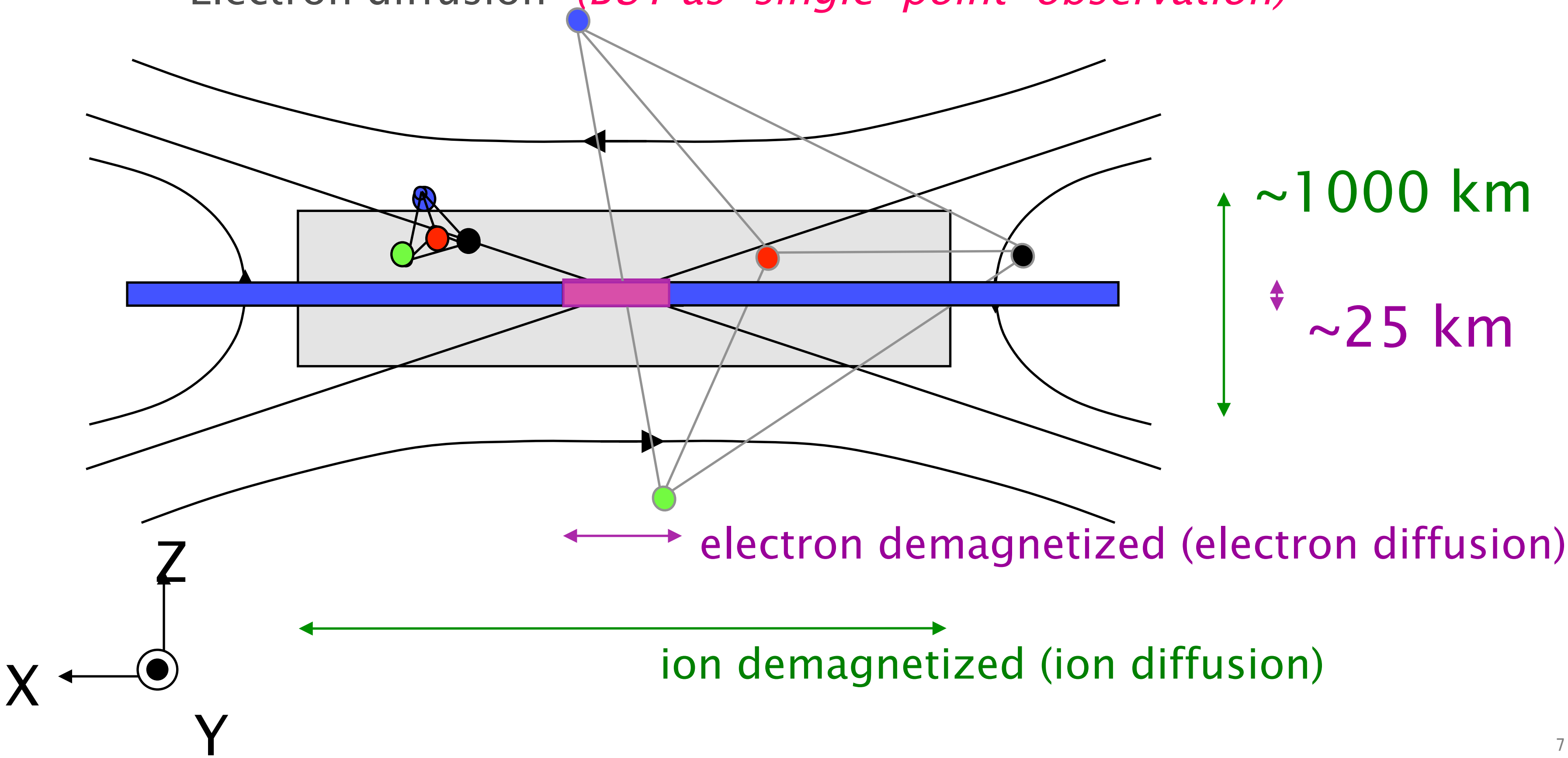
Multipoint observations in near-tail



- Cluster (2001- 4-sc separation 200 ~10000km
- Double Star (2004-2007) 1-equator, 1-polar
- THEMIS/ARTEMIS (2007- 5-sc separation > a few 1000km
- MMS (2015- 4-sc separation few10s~1000km

Reconnection region & Cluster

- Cluster "multi-point observation" can resolve:
  - Fast ion flows outside ion diffusion region
  - Ion and electron decoupling → Hall electric current
- Cluster may resolve:
  - Electron diffusion *(BUT as "single" point" observation)*



This talk

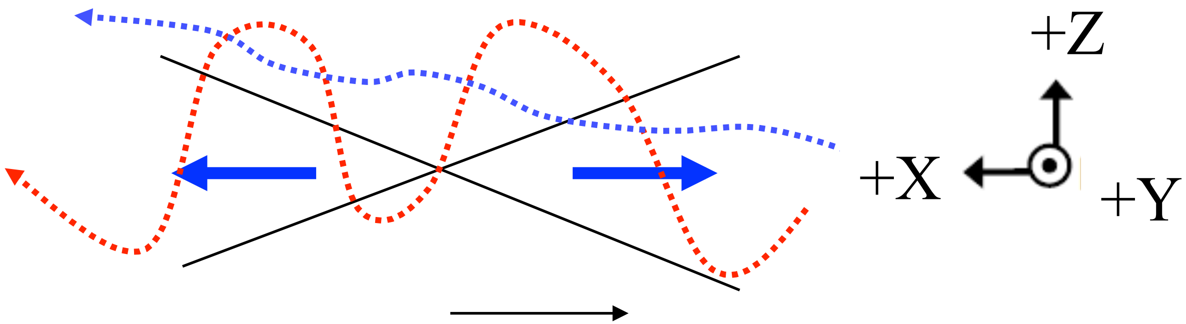
Cluster and THEMIS observation in near-Earth's tail during signatures relevant to "magnetic reconnection"

1. Crossing of thin current sheet
   - Motion of X-line
   - Ion-scale current sheet
   - Electron-scale structures

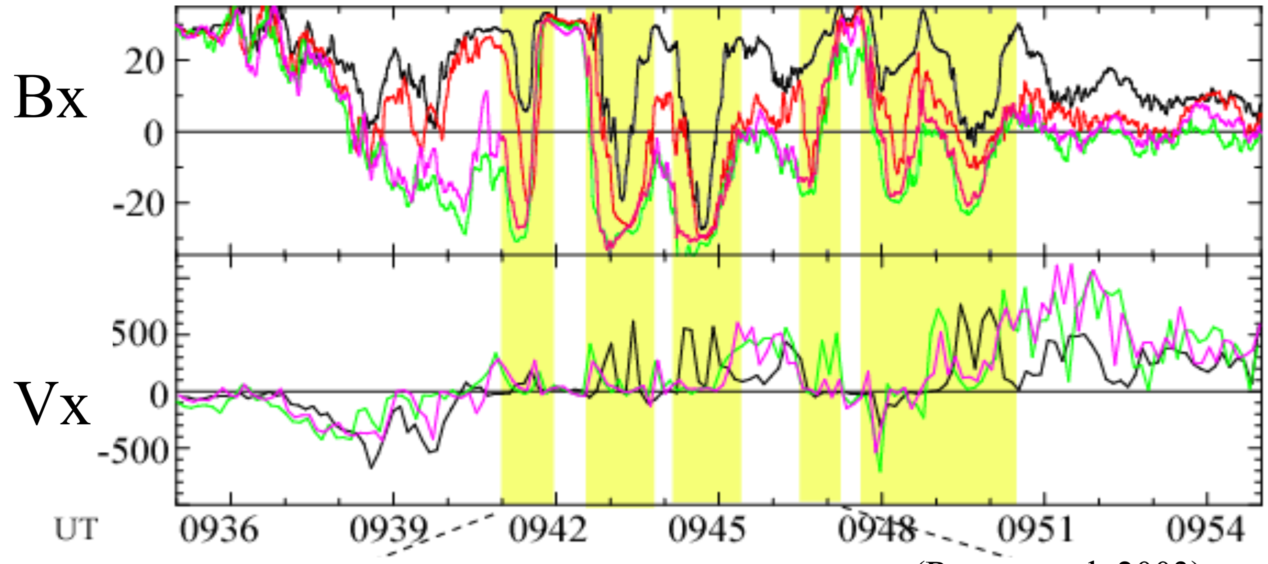
2. Fast flows (reconnection exhaust), interaction with ambient field
   - Bursty bulk flow/dipolarization front
   - Flow bouncing/braking

Crossing of tail reconnection region

- Motion of current sheet and X-line enable to obtain the current sheet structure



- Vertical motion
- X line motion



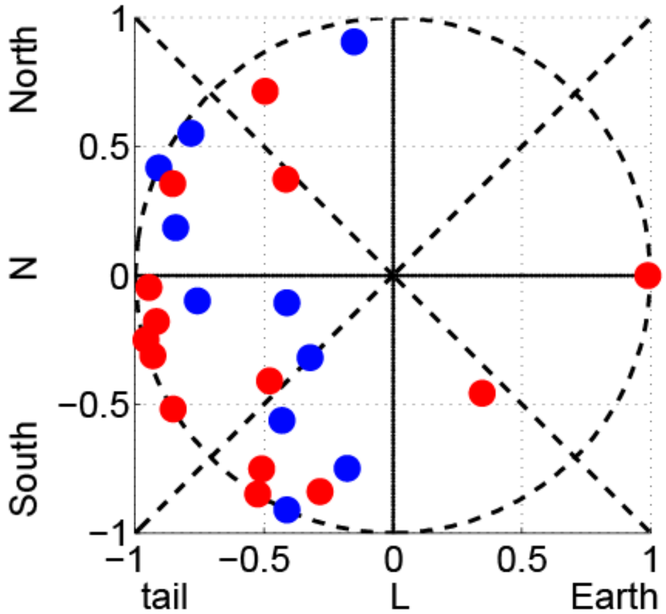
(Runov et al, 2003)

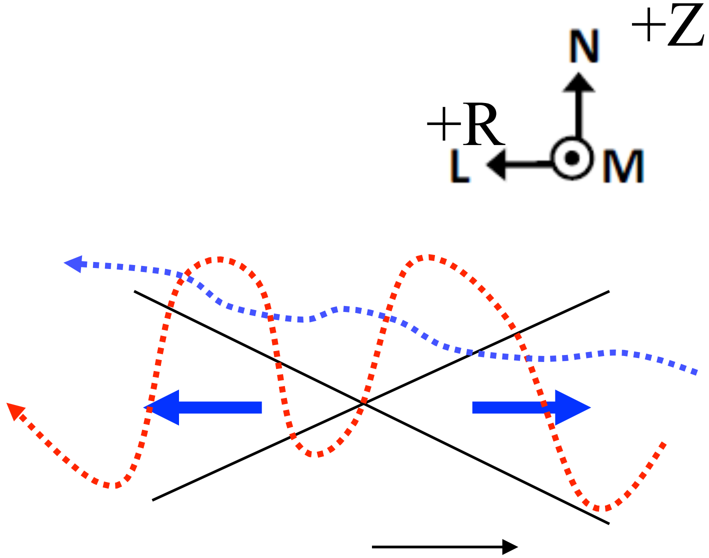
- Cluster 2-point statistics: majority tailward (Eastwood et al., 2010)

Motion of X–line

- Cluster four point measurements of reversal of normal component (Bz)

multiple
single





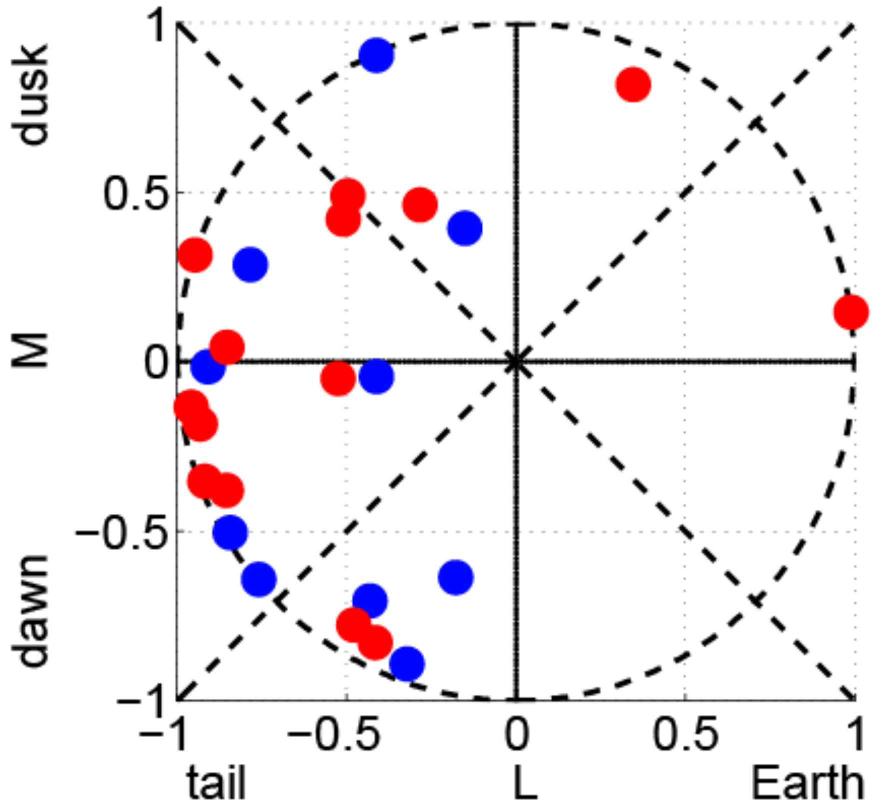
(Alexandrova et al., 2015)

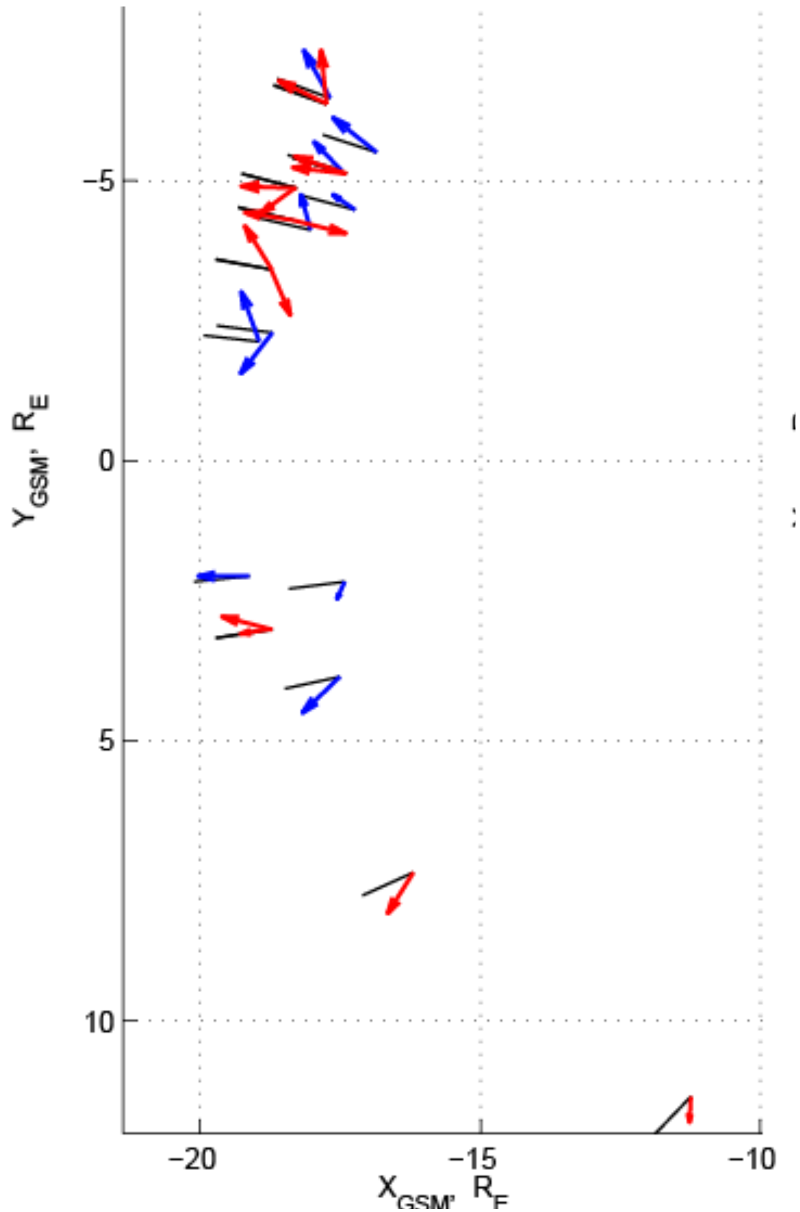
- X–line crossing mainly tailward (radial outward)
  median Vx: −60 km/s tailward motion

accompanied by currrent sheet flapping motion |Vn|: 30 km/s confirmed by direction of current sheet motion Vcs = (dBx/dz)/(dBx/dt)

Motion of „localized“ X-line

- Outward propagation of X-line in radial, as well as from midnight to flank (effect from pressure gradient direction i the near-Earth tail..)



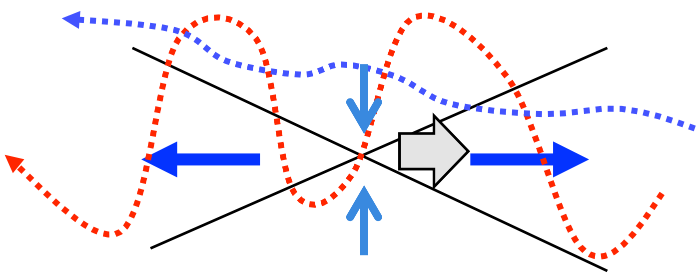


(Alexandrova et al., 2015)

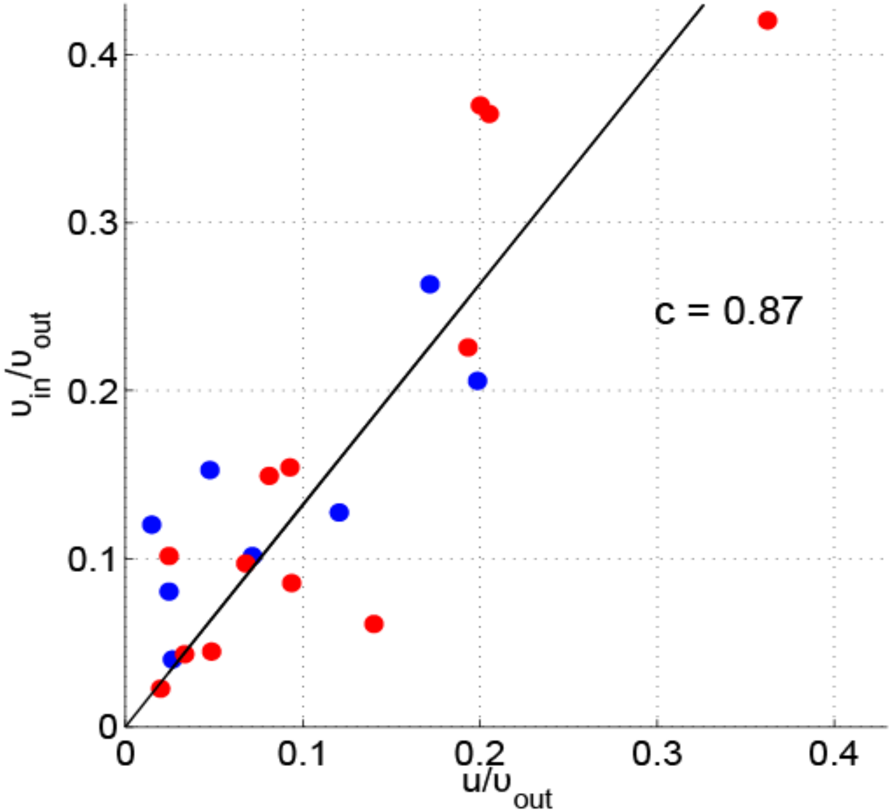
Speed of X-line motion

- Speed of outward motion of X-line is comparable to speed of inflow (normalized to outflow speed)

→ Local reconnection properties relevant to motion

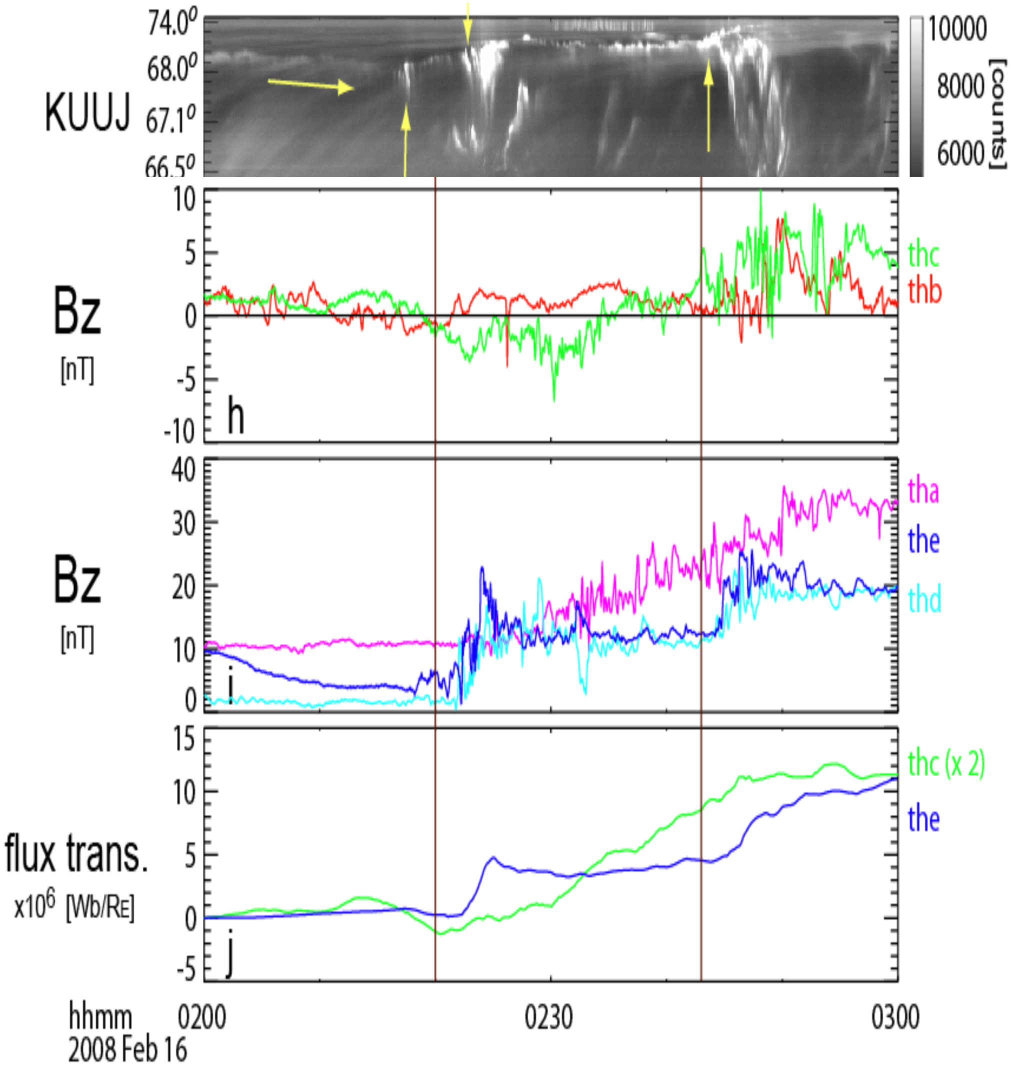


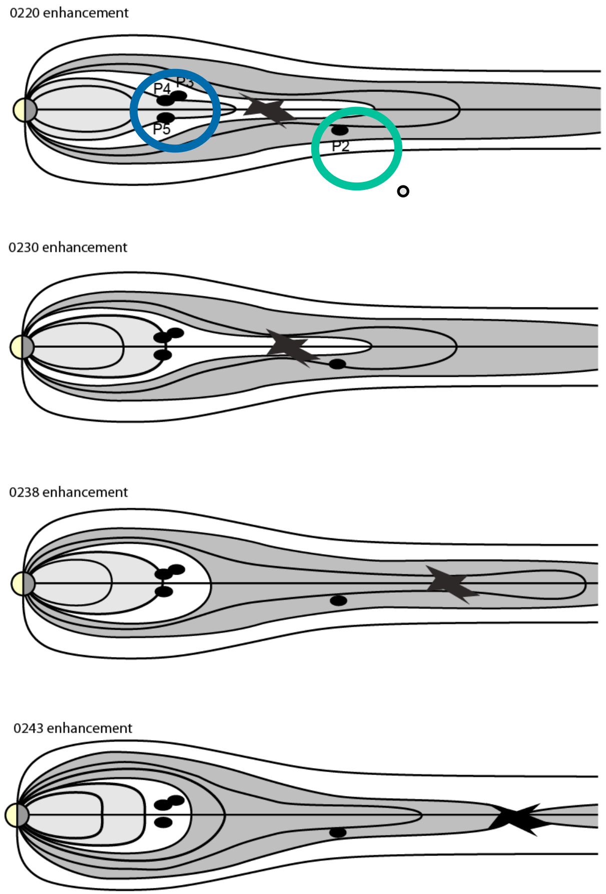
- Flow asymmetry indicating assymmetric flux pileup not found



(Alexandrova et al., 2015)

Tailward retreat of onset regions





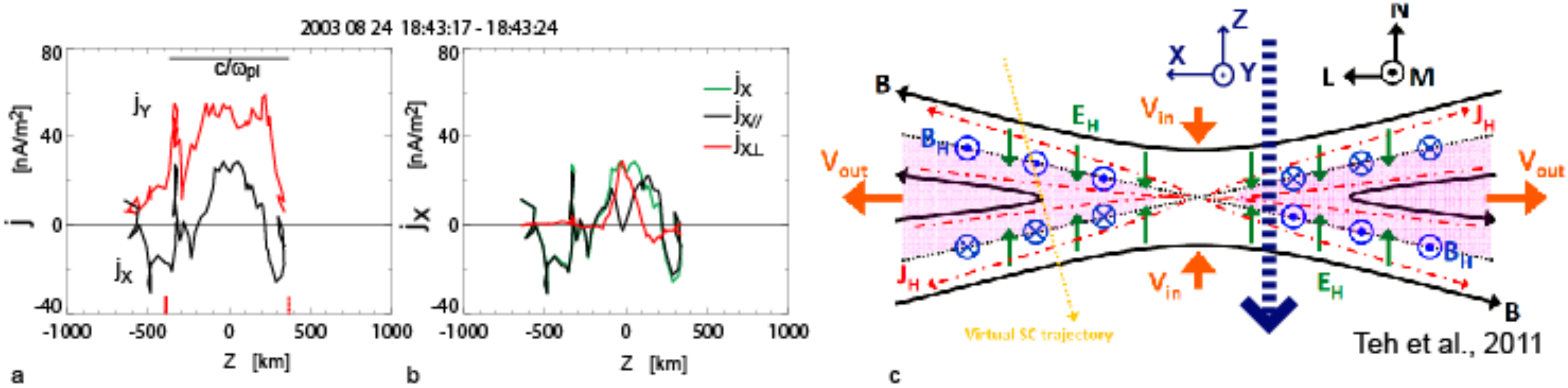
(Nakamura et al., 2012)

- Tailward retreat of „reconnection region“ → new activation of reconnection tailward.

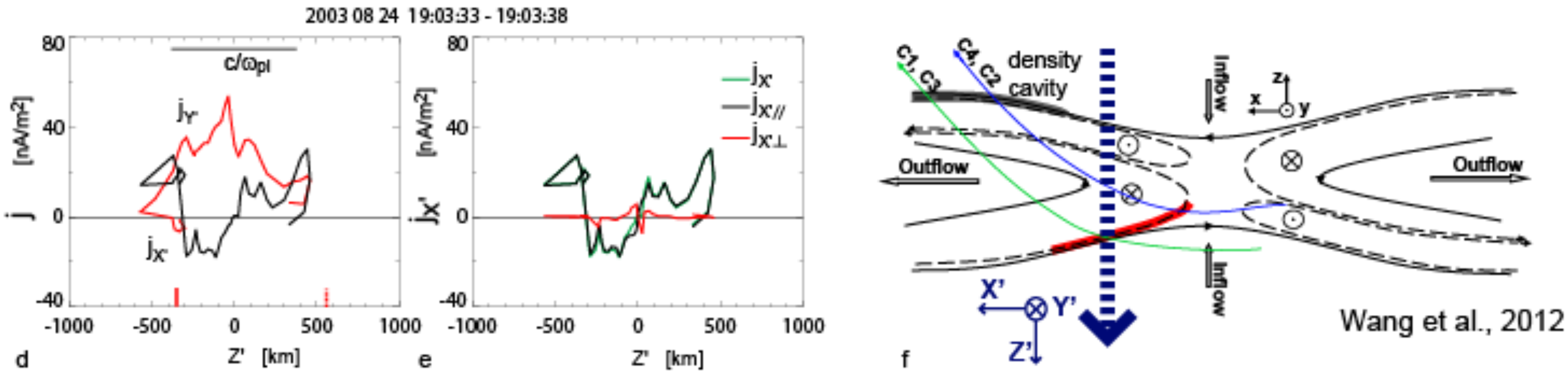
Rapid crossing of thin current sheets

- Hall current & its closure current at ion scale (0.9–1.1) c/ω_{pi} resolved

2D reconnection configuration



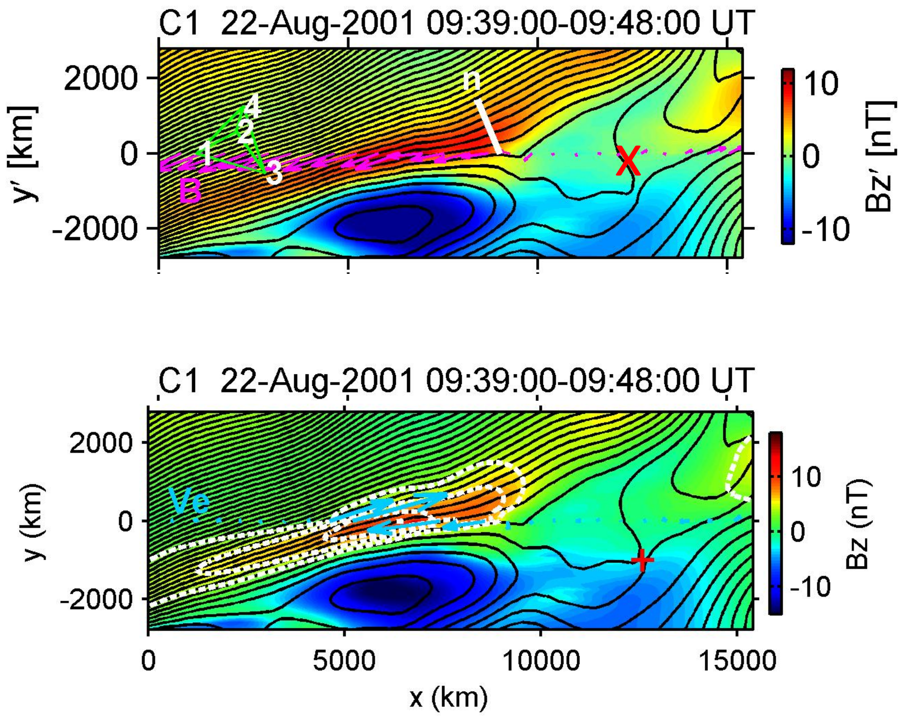
Current sheet with weak guid field



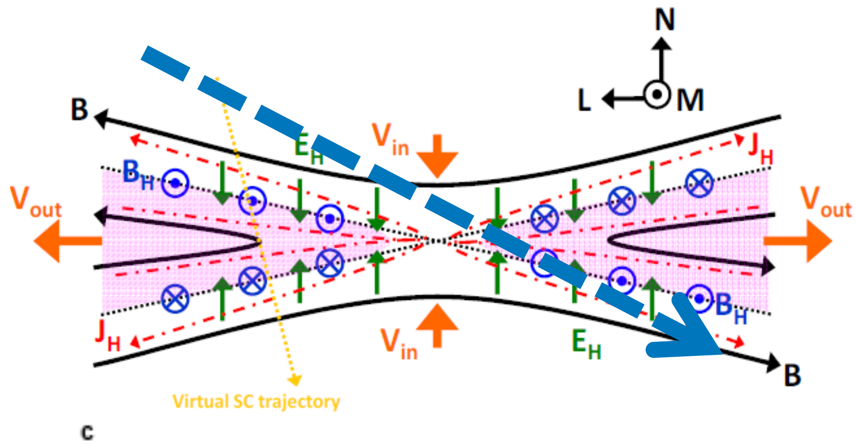
(Nakamura et al., 2006)

Current sheet reconstructed

- Reconstruction of the current sheet by assuming steady state, 2D Hall-MHD equation valid during each SC crossings (Sonnerup and Teh, 2009)



(Teh et al., 2011)

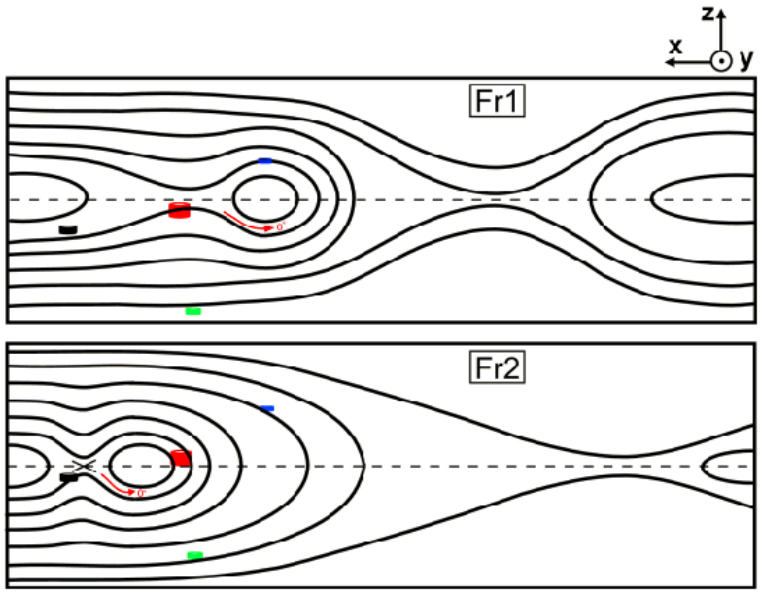


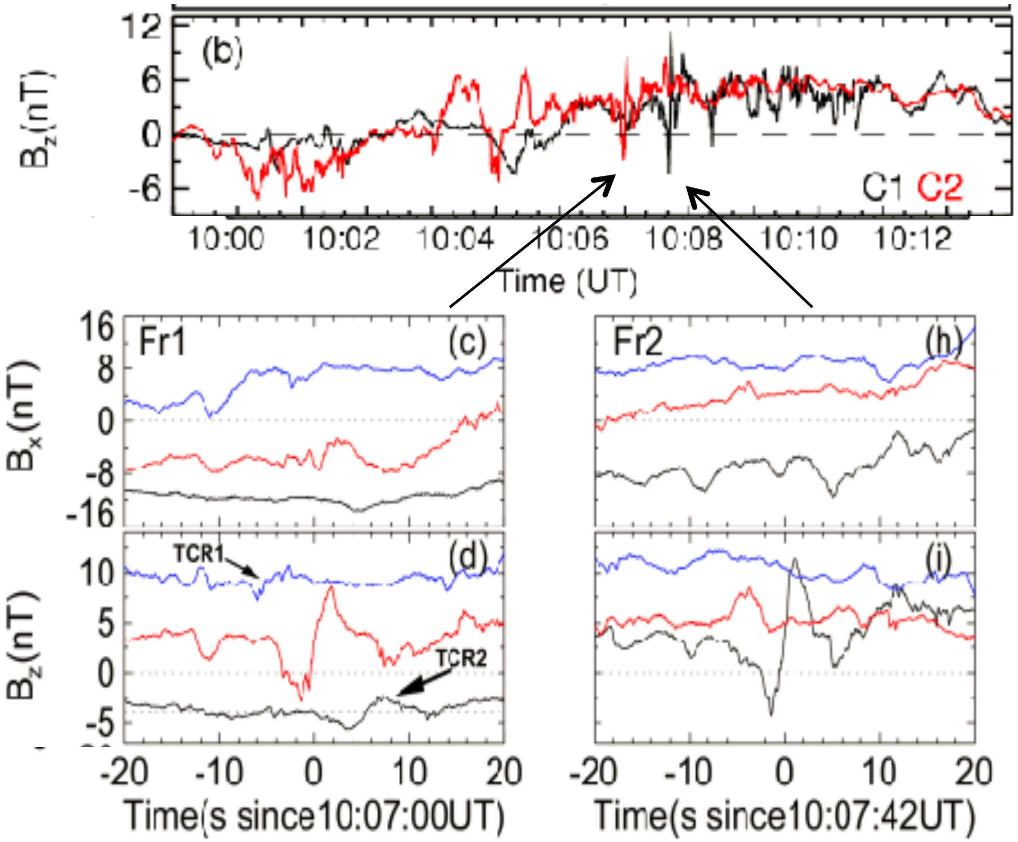
Regions of counter-streaming electrons contributing to Hall current loop identified using reconstruction map

→ 3D reconstruction from multi SC (Hasegawa et al., 2015)

Transient/localized features

- Transient, internal structures (flux rope, TCRs) identified that are created in the outflow region





- Island speed 400~500 km/s (scale >2000 km)
- Secondary X-line at 15000 km
- ($38\ c/\omega_{pi}$) Earthward of main X-line

(~2 ω_{gi})

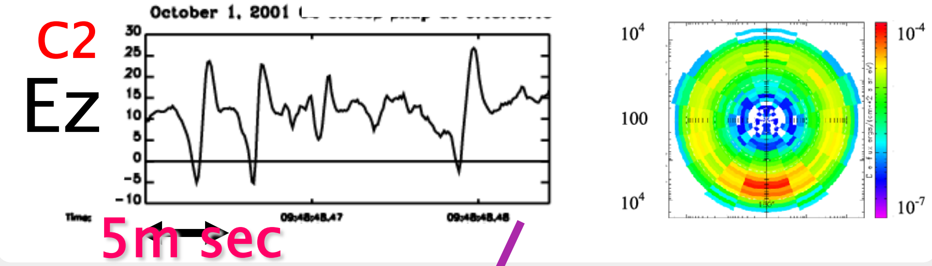
(Wang et al., 2014)

- Temporal evolution:
  flux pileup [Imada et al., 2009], DP front [Fu et al.,2013]

Different electron acceleration sites

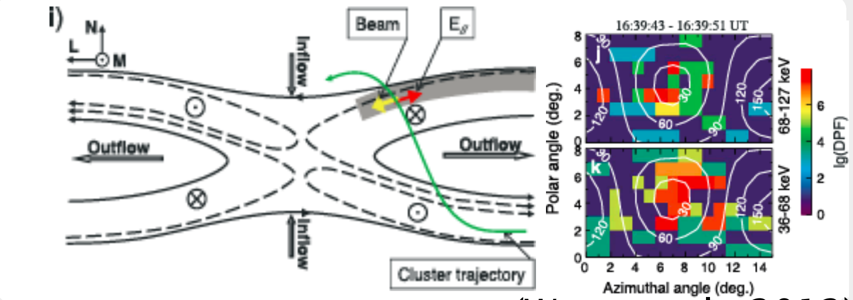
Inflow region — Solitary waves

E-field and <5 keV electron



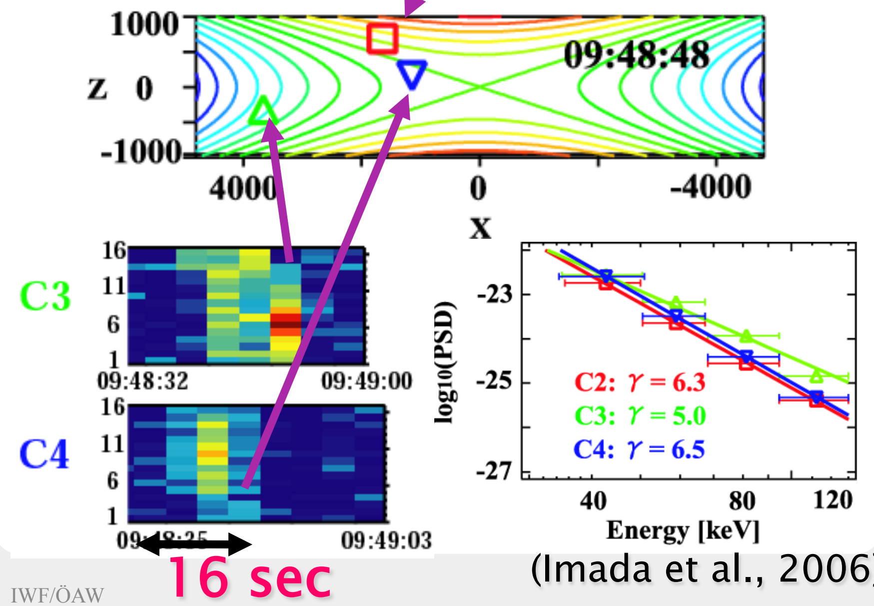
(Cattell et al., 2005)

>36 keV electron



(Wang et al., 2012)

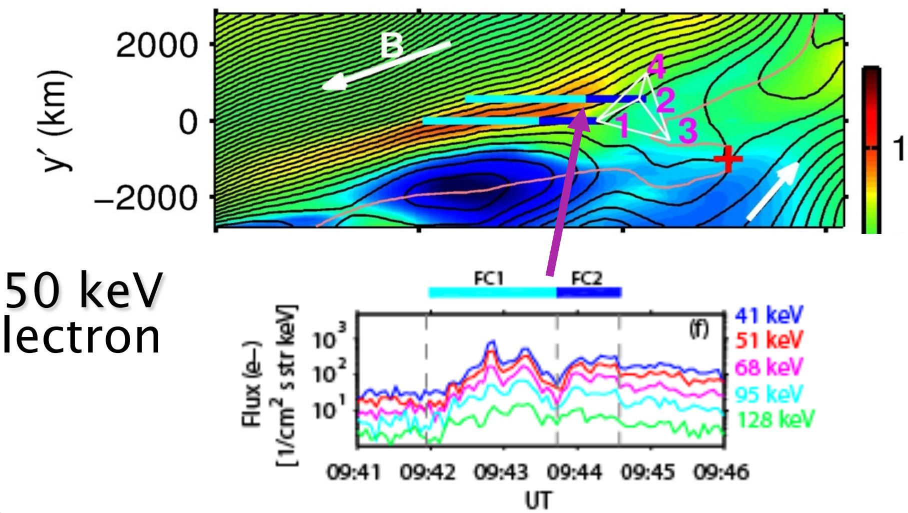
Outflow region — Flux pileup



(Imada et al., 2006)

Wave particle interaction

>50 keV electron



(Teh et al., 2012)

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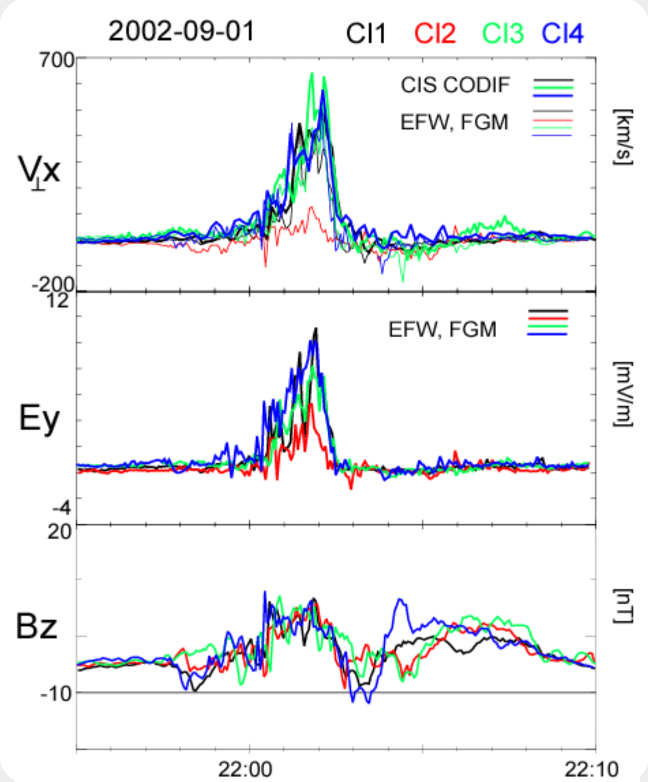
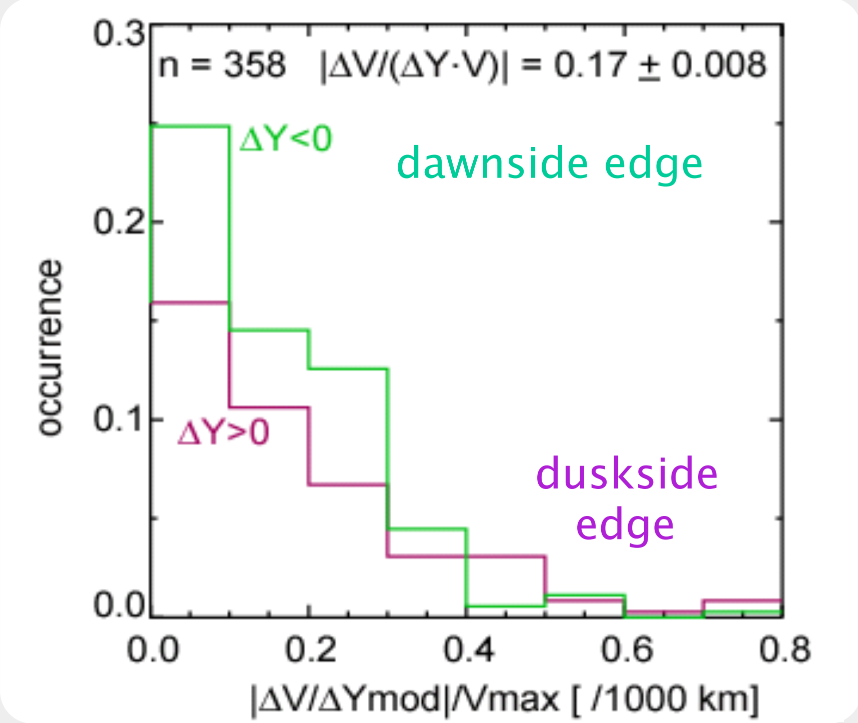
Bursty bulk flows (BBFs)

5-20 min in total duration; Consists of a few min long flow bursts;

Essential for flux transport. (Baumjohann et al. 1990; Angelopoulos et al. 1992)



[Nakamura et al., 2005]



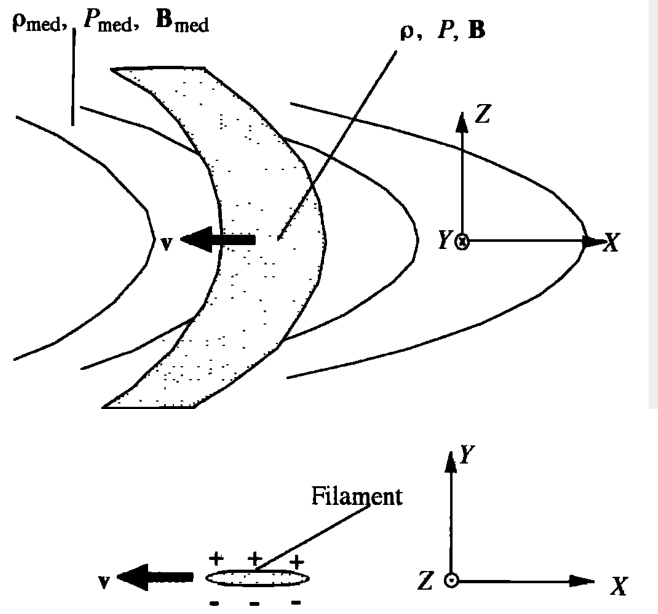
rate of change in velocity along Y

[Nakamura et al., 2004]

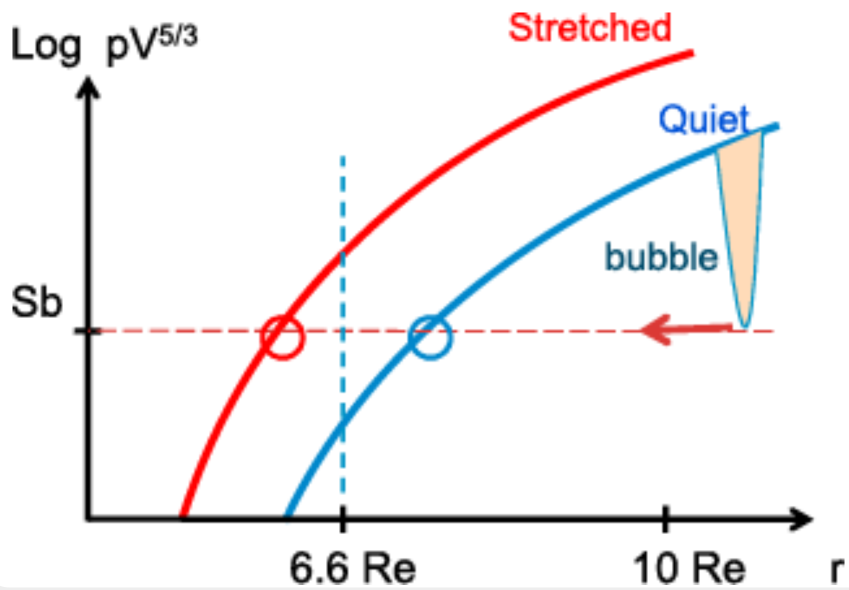
- Spatial scale from multi point observations: 2-3 RE in dawn-dusk (dawn-dusk asymmetry) → Size of reconnection region

What controls BBF penetration ?

Plasma bubble model (Pontius and Wolf, 1990; Chen and Wolf, 1993): Earthward BBF is a plasma entropy depleted flux tube



[Chen and Wolf, 1999]

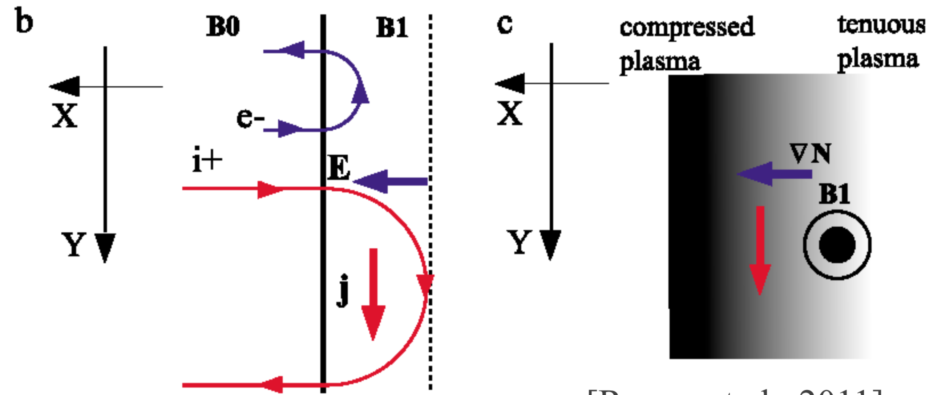


[Sergeev et al., 2012]

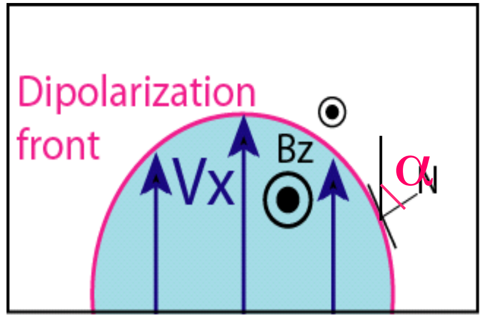
- BBF(bubble) penetrates to the distance where its plasma tube entropy pV^g (derived from Bz, Br, p; Wolf et al., 2006) equals that of ambient plasma (more important than Vx or Bz) (Dubyagin et al., 2011, Sergeev et al., 2012)

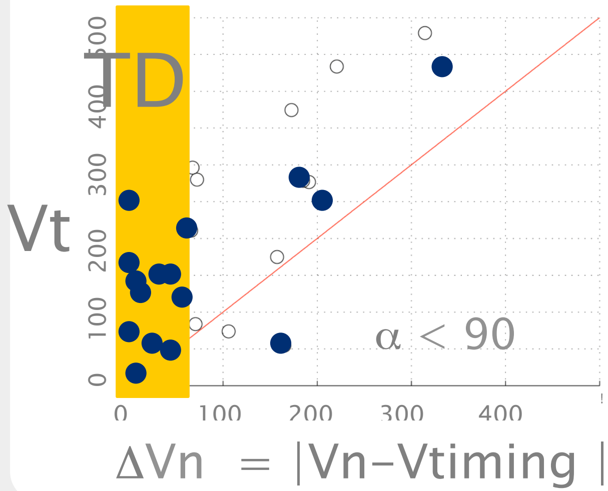
Dipolarization front (DP)

- BBF led by a thin layer of enhanced Bz (or l_B)
- Thickness:<5 ion-inertia & <3 gyro scale
- Often tangential discontinuity (but not always…)
- Localized flux tube bundle (Liu et al., 2013)



[Runov et al., 2011]





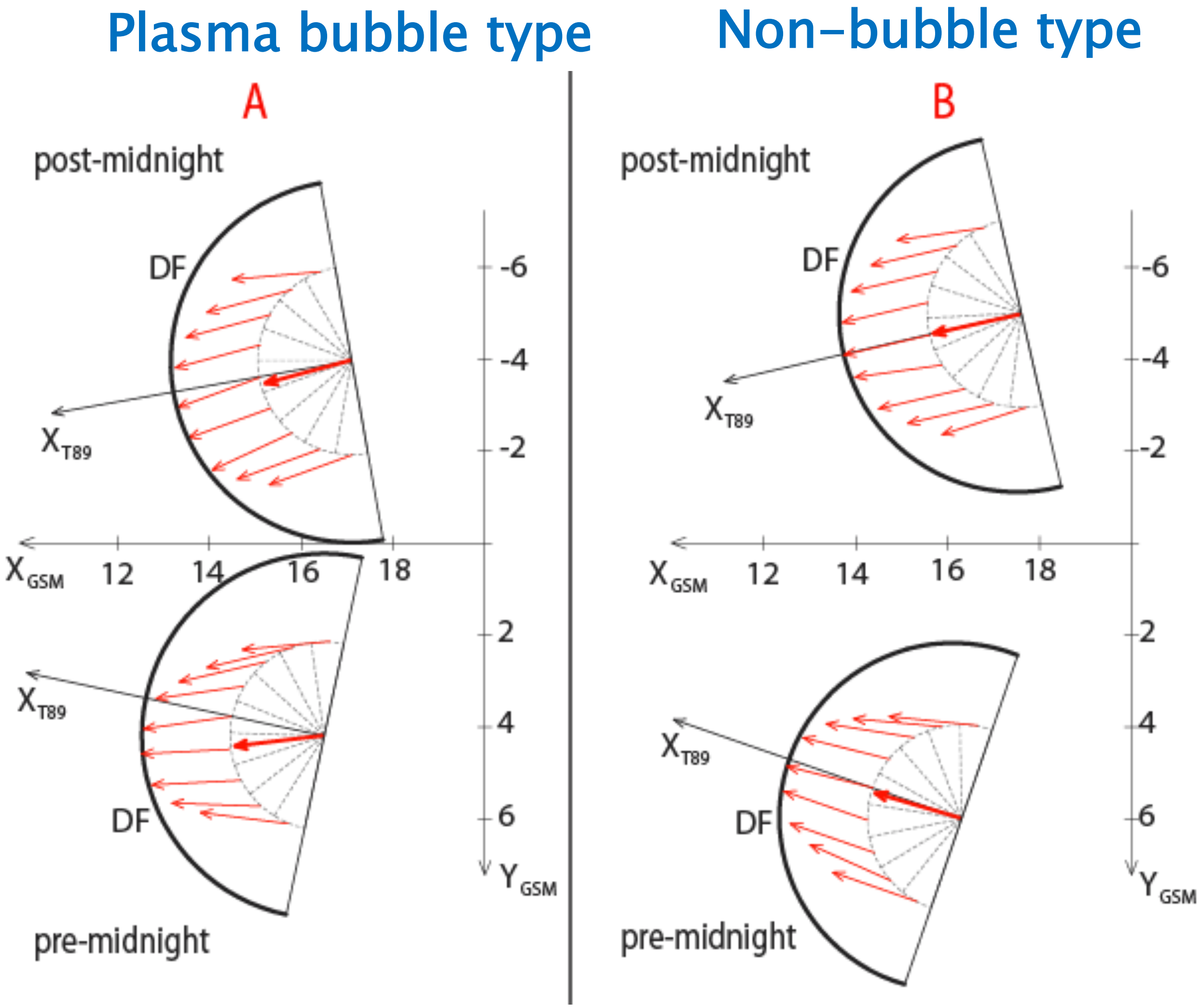
[Schmid et al., 2011]

- Ion acceleration (Sergeev et al., 2010; Zhou et al., 2011; Eastwood et al., 2014)
- Hall & diamagnetic current (Runov et al., 2011)
- Electron pressure gradient (Fu et al., 2012)
- Major energy conversion (Hamrin et al., 2011; Angelopoulos et al., 2013)

➢ Further kinetics waited to be resolved by MMS

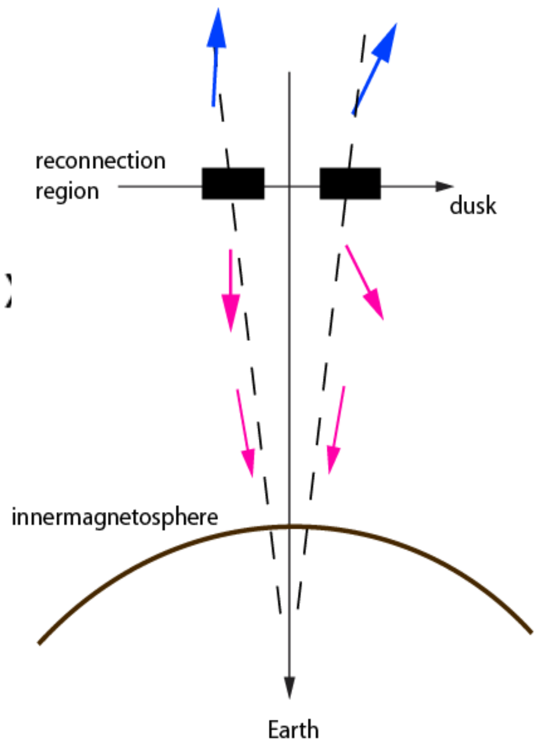
Flow direction v.s. DF

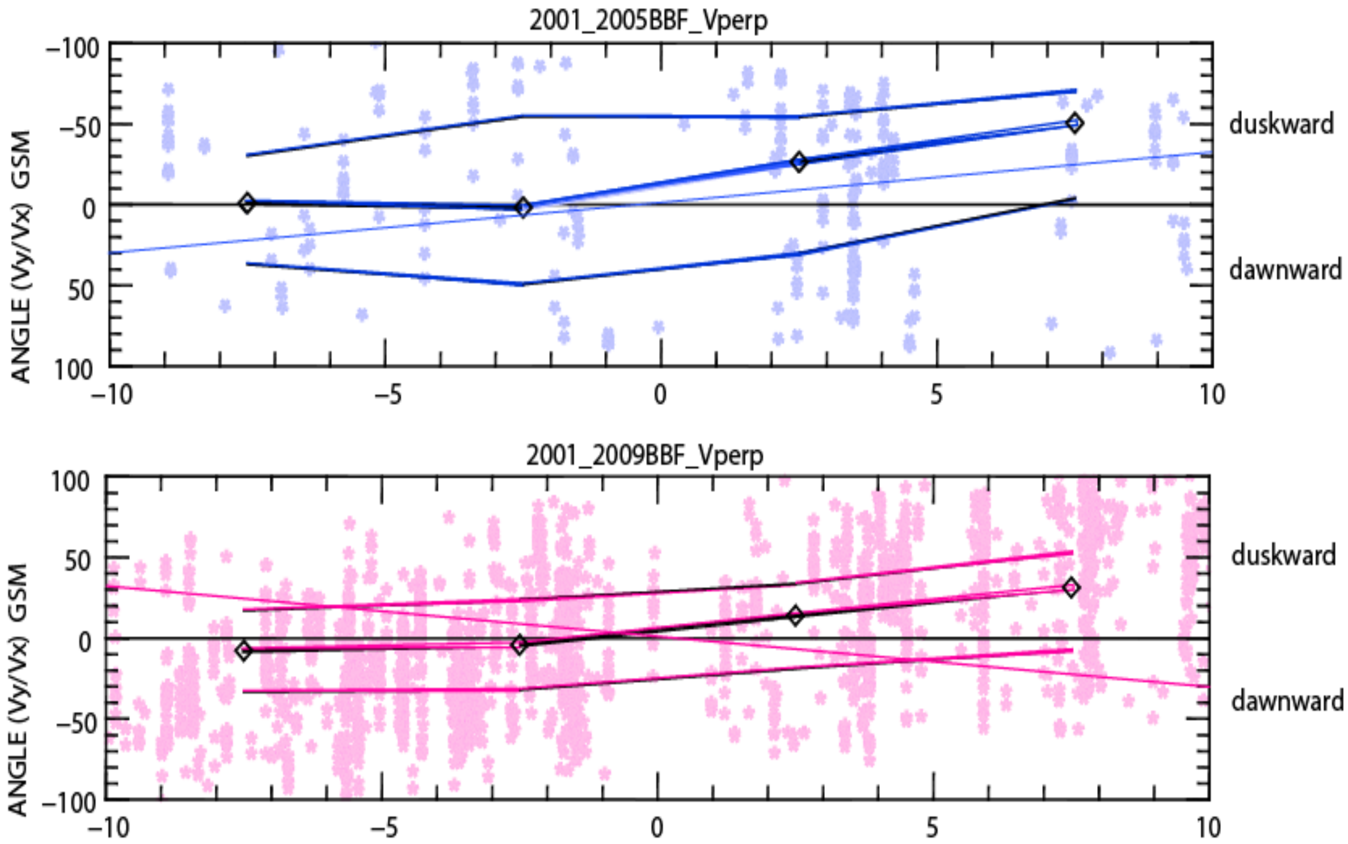
- A: small Bz before DF duskward deflected flows from direction of magnetic tension (T89 Bmodel)
- B: large Bz before DF flow along magnetic tension
- flows in different current sheet configuration. Evolution A → B ?



(Schmid et al., 2015)

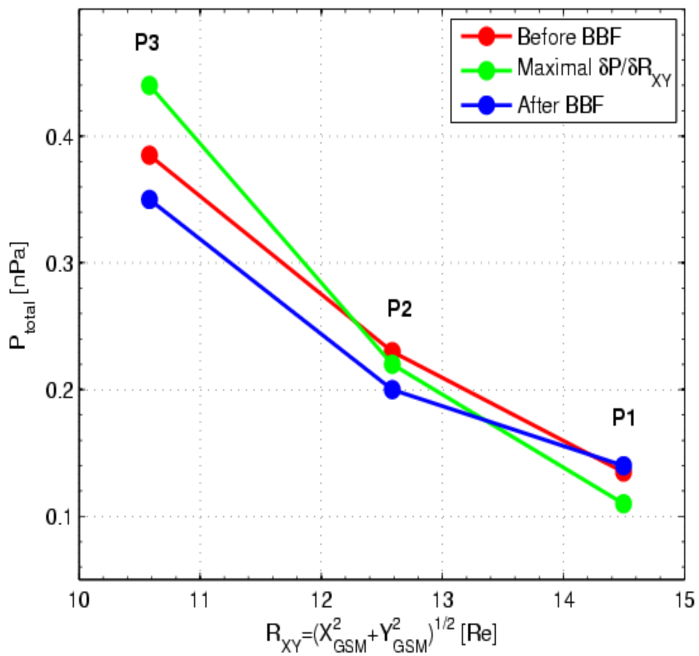
BBF duskward deflection (<−15 RE)





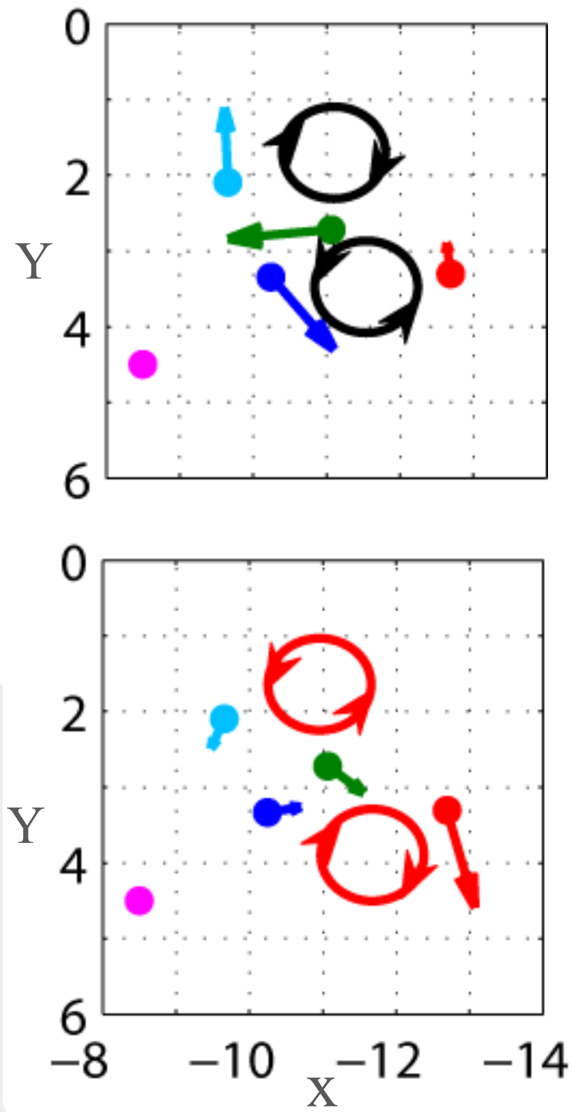
- Cluster 1, Vperp_xy > 300 km/s , Beta_xy > 2 (tailward flow: X < −15 RE)
- Duskward deflection → jet braking in thin current sheet
  (Hall effect, Ex <0, due to non-adiabatic ion leading adiabatic electrons)
- Dawn-dusk asymmetry

Flow patterns during bouncing

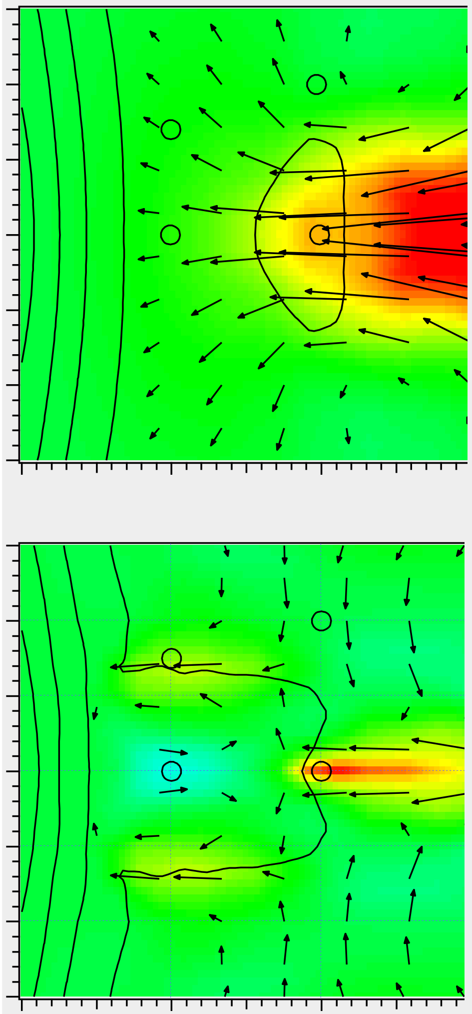


[Panov et al., 2010]

THEMIS observation



Simulation

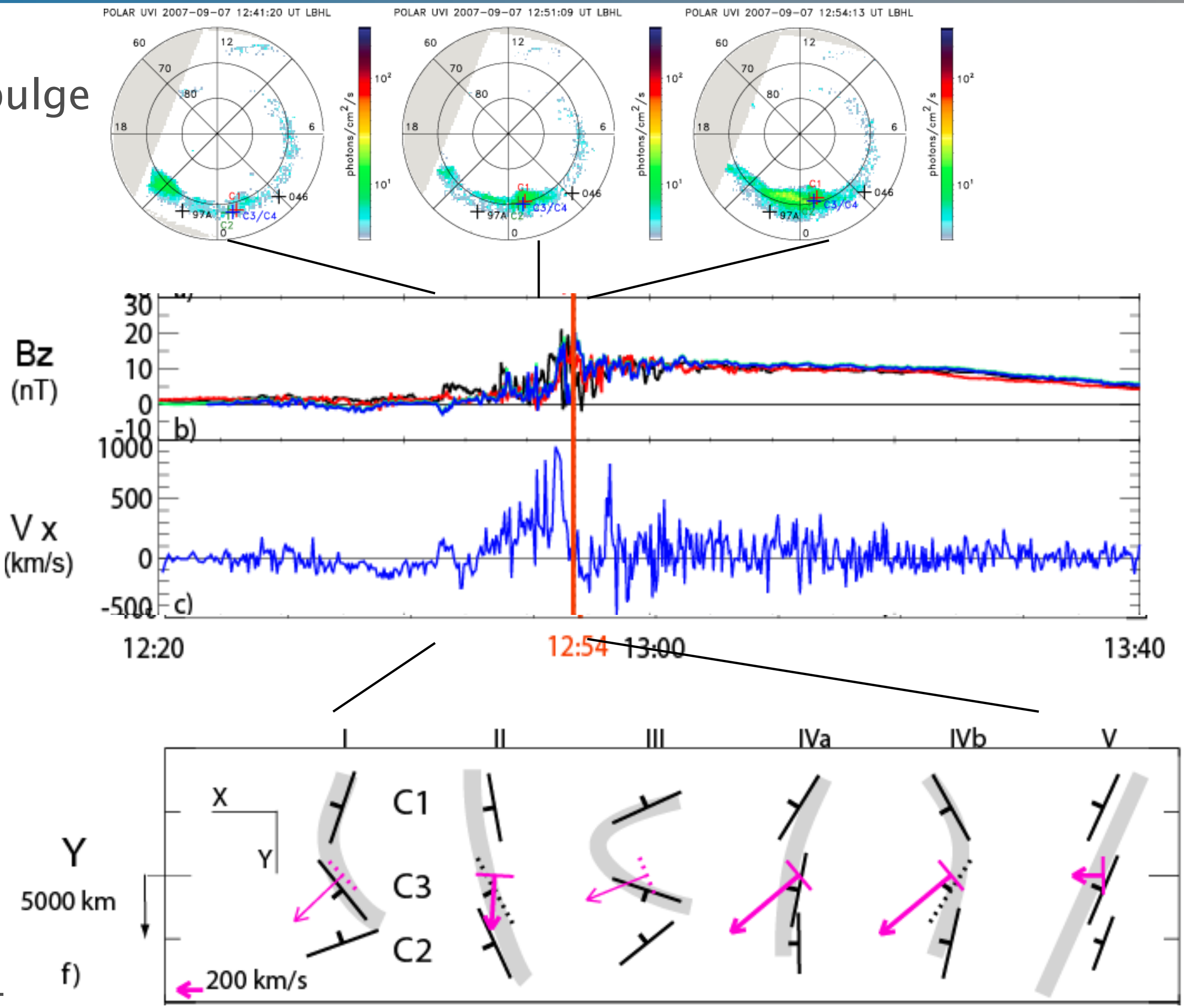


[Birn et al., 2011]

- ➢ Pressure gradient → pushing plasma back toward tail
- ➢ Vortex pattern reverses for Earthward & tailward flow

Multi-scale, multi-step intensification

- Stepwise, auroral bulge development
- Multiple dipolarization (Bz enhancements)
- Flow bouncing (due to tailward $-\nabla p$ and JxB force)
- Different front shape for each BBF
- >10 Re-scale front before flow bouncing



(Nakamura et al., 2013)

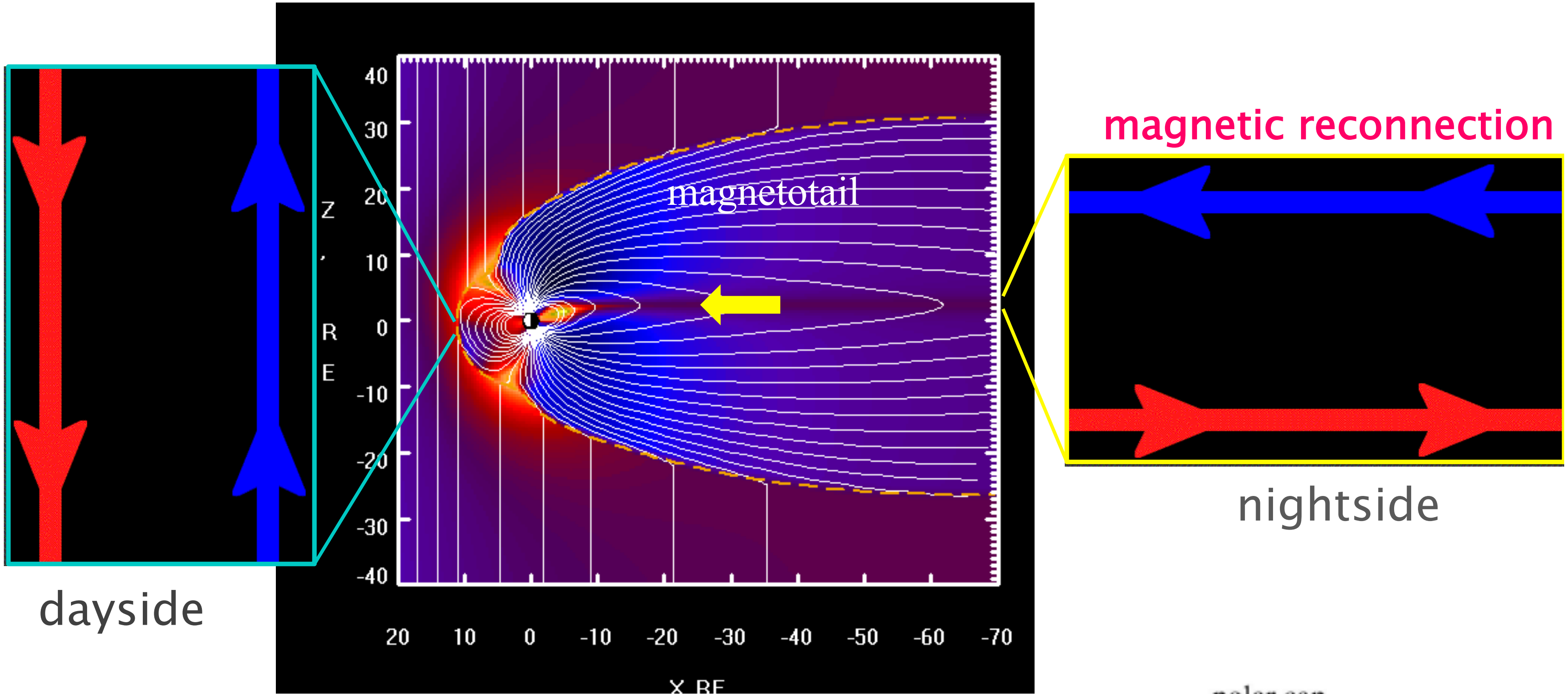
Summary

- Multi-point observations from Cluster and THEMIS enabled to resolve temporal and spatial scales of disturbances associated with near-Earth magnetotail reconnection:
    - Overall motion of reconnection region: mostly tailward (radial) and flankward with speed comparable to inflow speed in a flapping CS
    - Ion-scale current sheet with 2D reconnection geometry as well as that with guide field resolved, containing transient/internal features (ex. flux ropes)
    - Localized Earthward plasma jet interacts with ambient fields leading to: Flow braking/ bouncing, coupling to ionosphere
- Observed signatures are likely mixtures of reconnection properties as well as consequence of ambient magnetotail dynamics

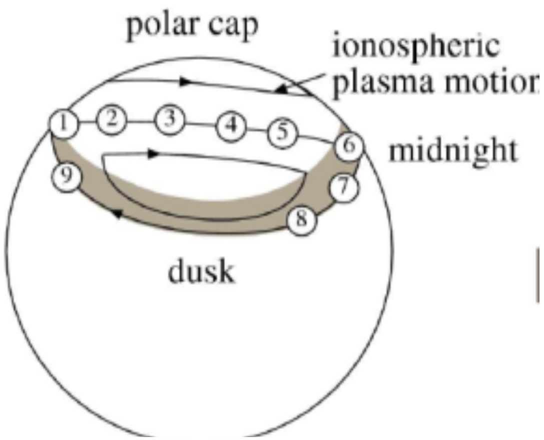
→ Relevance between local and global scale (substorm) processes to be understood, i.e. Multiplicity? and/or Evolution?

- Context will also be essential for MMS, when studying electron kinetic processes for studies of near-Earth magnetotail reconnection

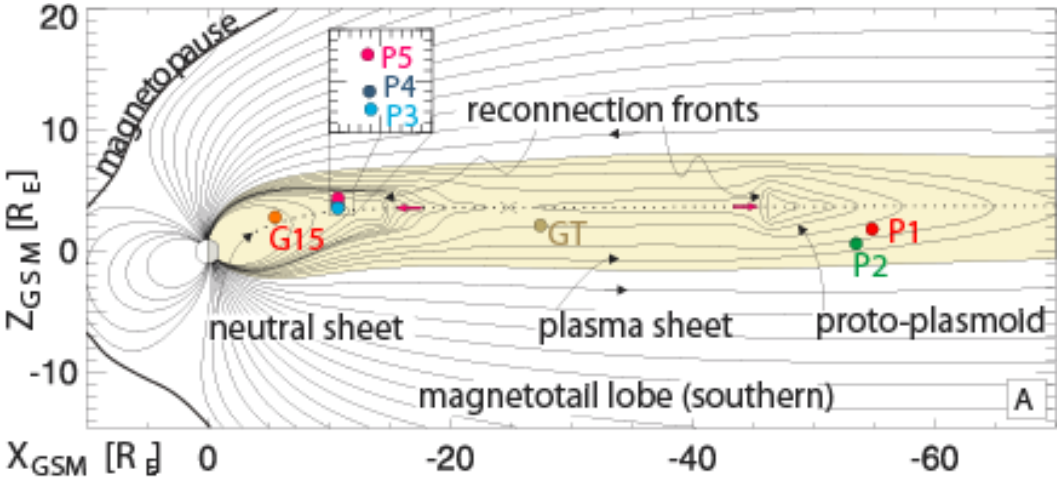
Magnetospheric convection



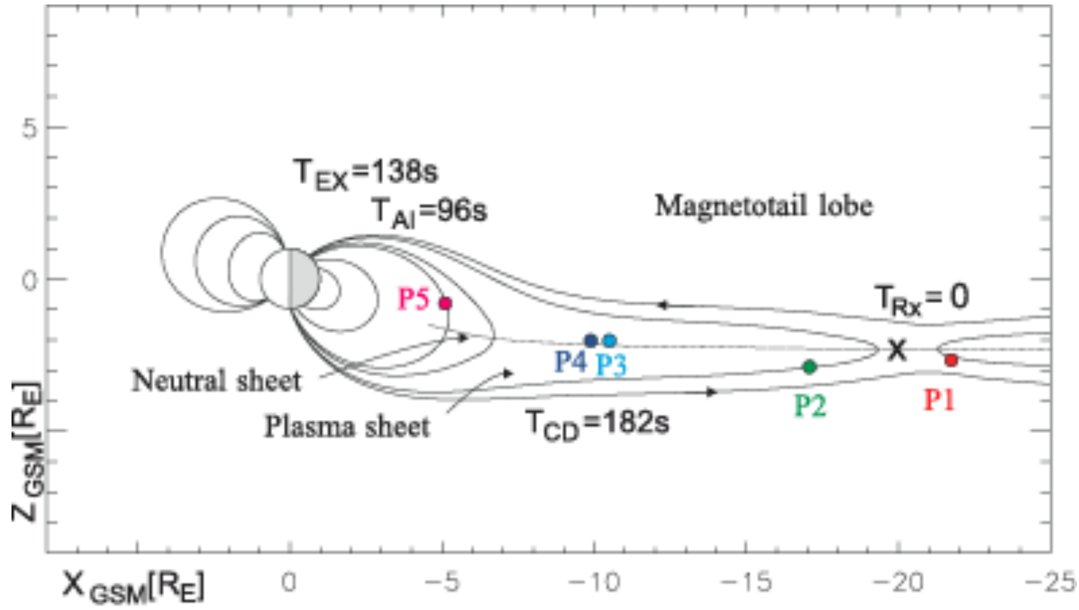
- About 10% of solar wind energy enters magnetosphere due to dayside **magnetic reconnection.**
- Open field lines move tailward over polar cap
- Nightside reconnection jets plasma toward Earth and back to dayside



Large-scale multi-point studies



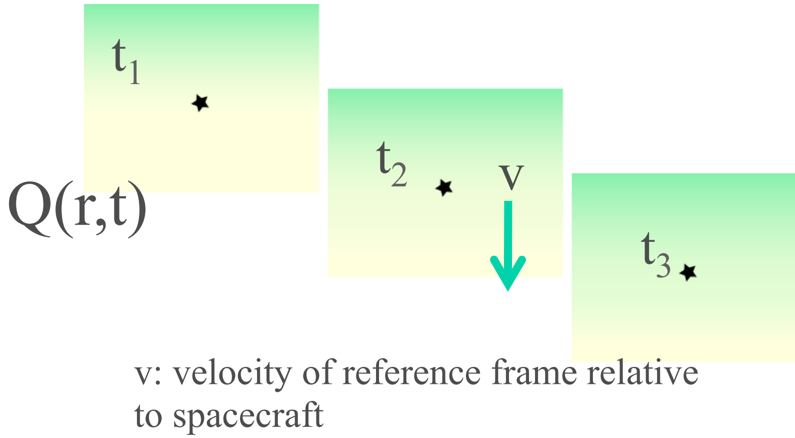
(Angelopoulos et al., 2013)



(Angelopoulos et al., 2009)

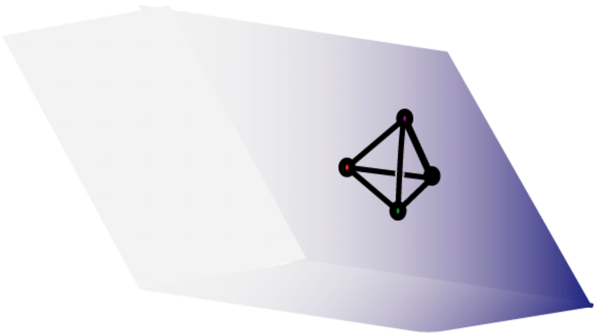
Why multi-spacecraft ?

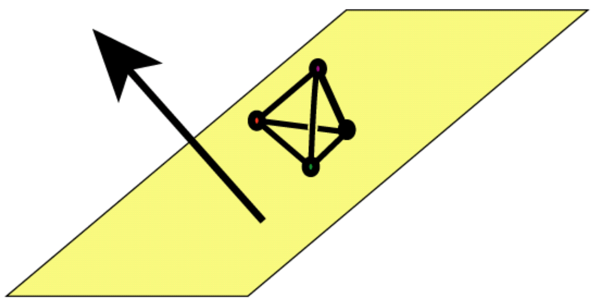
- Observation in space requires to detect temporal & spatial changes by taking into account the motion of the frame of reference



$$\frac{DQ}{Dt} = \frac{\partial Q}{\partial t} - (v \cdot \nabla)Q$$

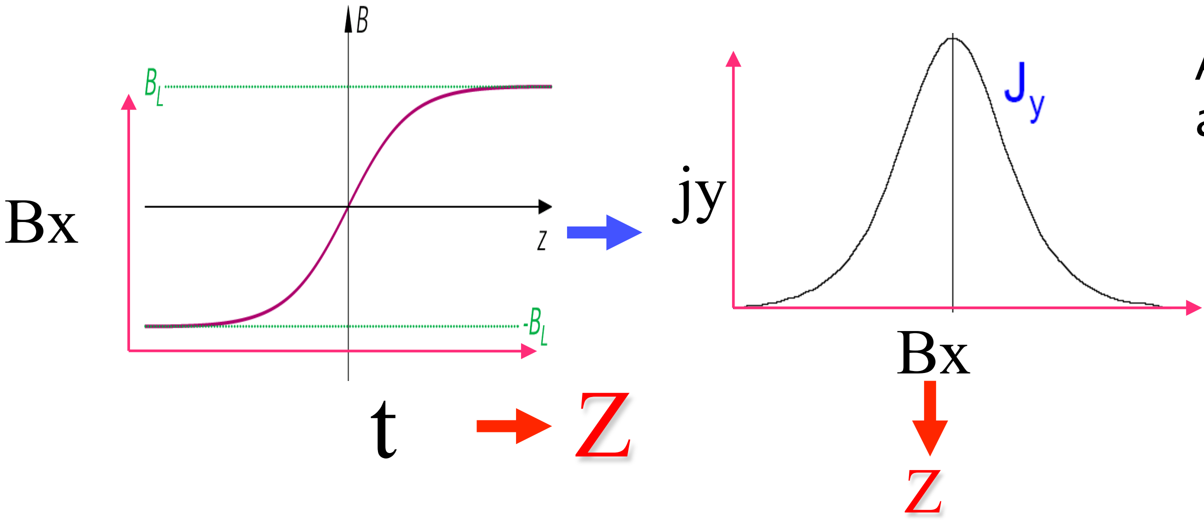
- 4sc: Minimum number of spacecraft to determine spatial gradient or velocity vector of a planar structure in 3D space





How to obtain current sheet scales

- *Rapid motion of the current sheet allows to resolved vertical profile of current density ($\nabla \times$ B) in magnetotail current sheet and its orientation*



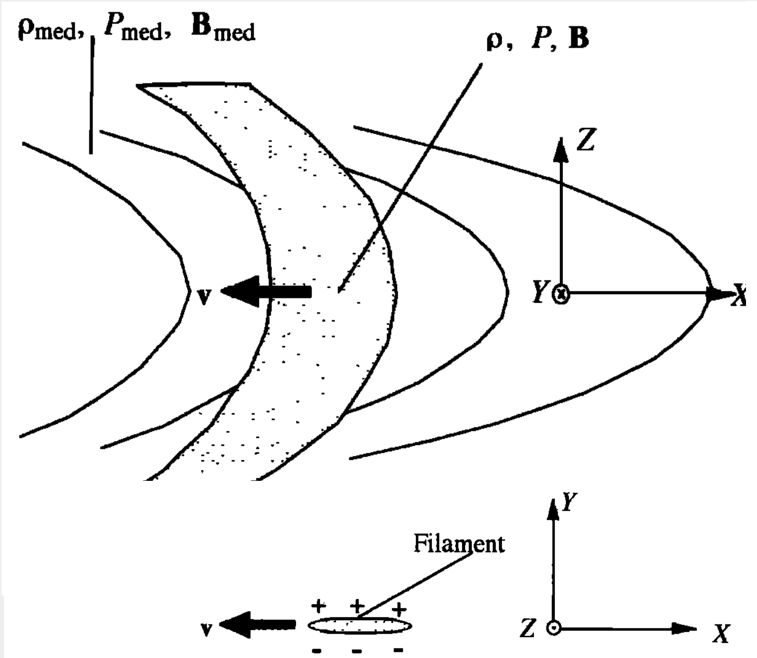
Assume rapid crossing of a pure spatial structure

$$\frac{\delta B_X}{\delta t} = j_Y \frac{\delta z}{\delta t}$$

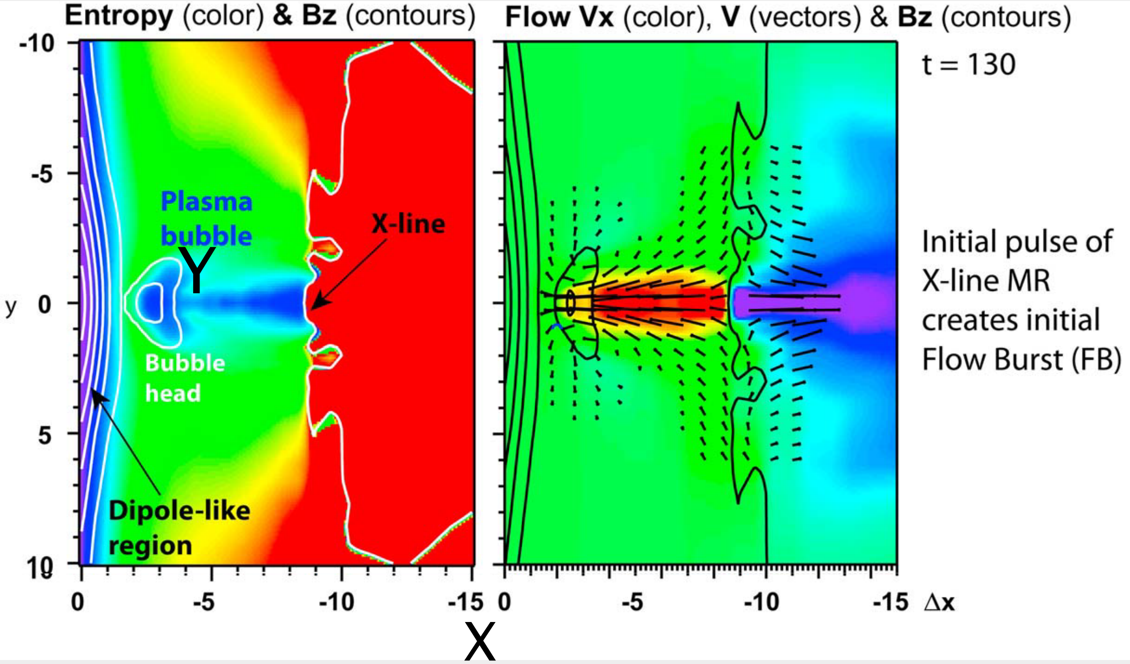
Velocity determination from multi-point measurement is essential to obtain current sheet thickness because of

(1) Velocity changes during the crossings
(2) Limited accuracy of ion measurement in Z direction

Plasma bubble model



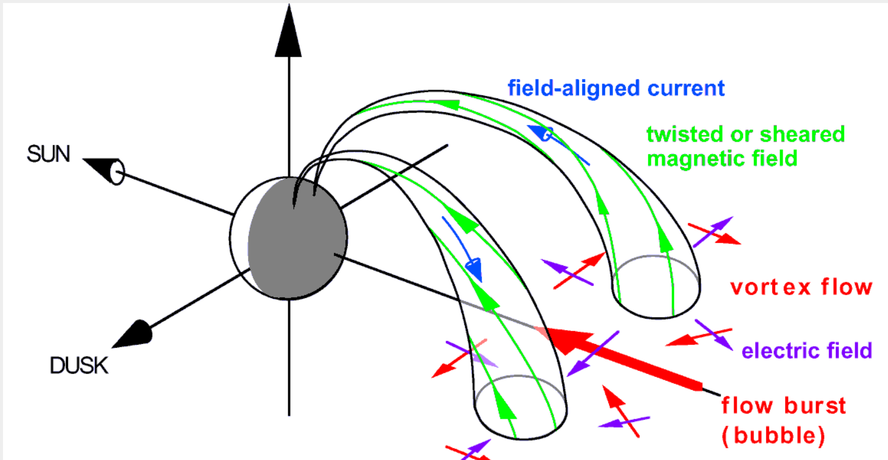
[Chen et al., 1999]



From Birn et al. 2011 [Sergeev et al., 2012]

Bursty bulk flow (BBF) considered as plasma bubble: entropy depleted flux tube (Pontius and Wolf, 1990)

Many observational characteristics found to be consistent with the plasma bubble model



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