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Magnetotail reconnection and plasma sheet fast flows

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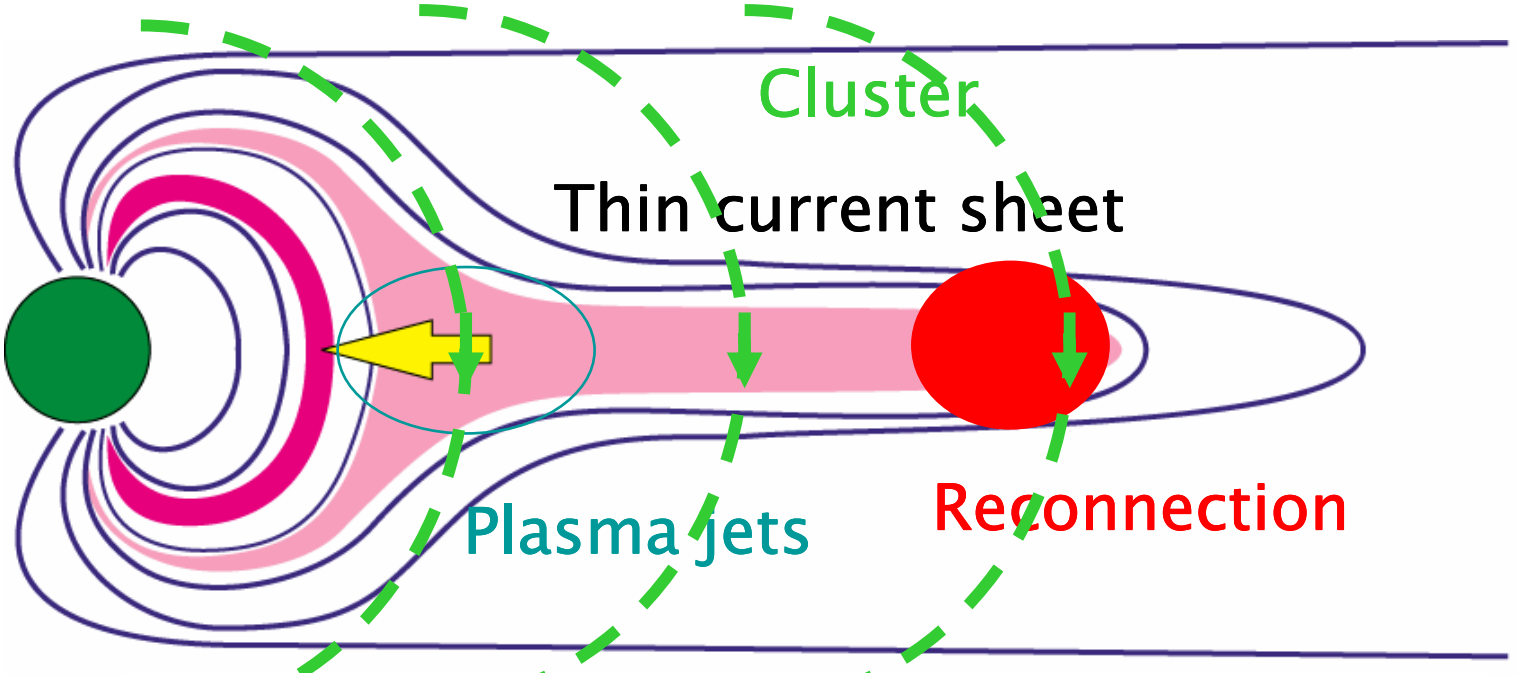
Cluster traversed key region



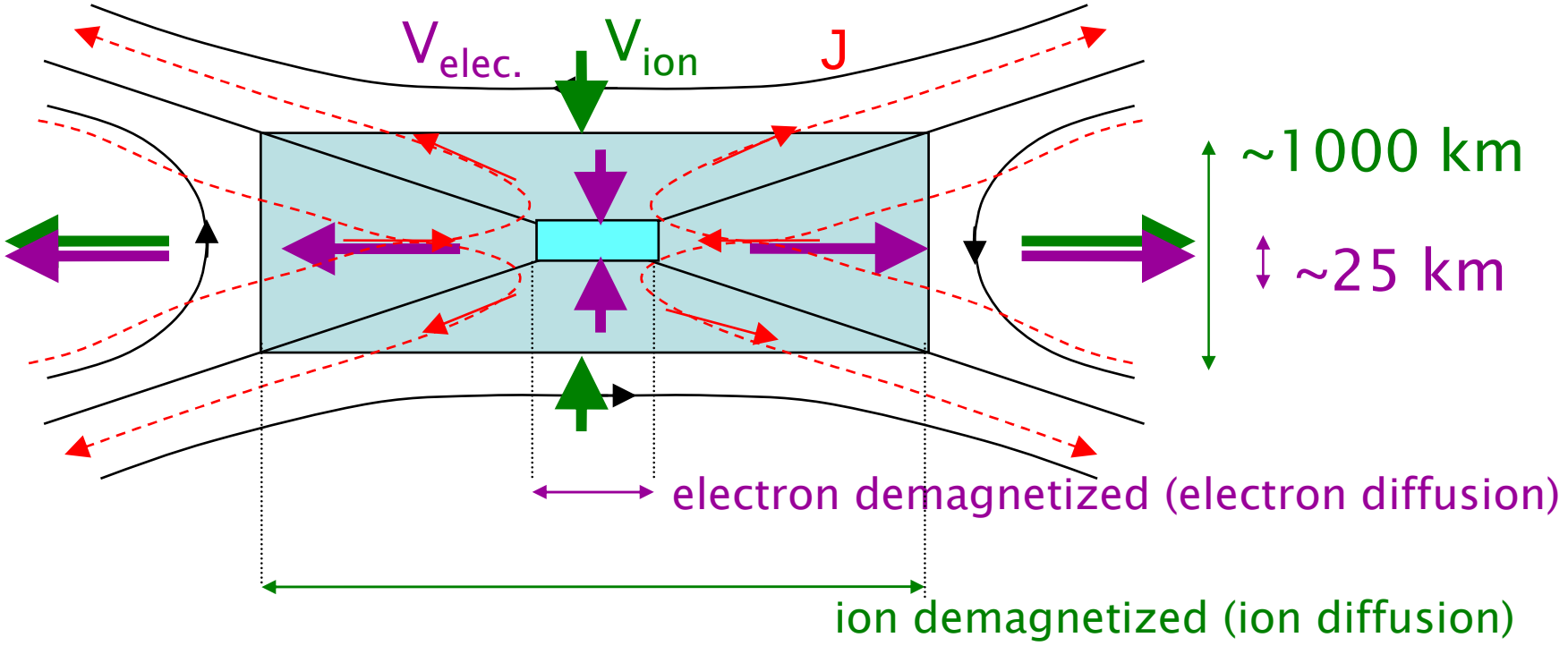
Magnetotail reconnection
- Current sheet structure
- Hall-current and its closure
- Remote effect of X-line(s)

Plasma sheet fast flows
- Spatial scale and 3-D shape
- Interaction with ambient plasma/field

Magnetotail Reconnection

Multi-scale process involved

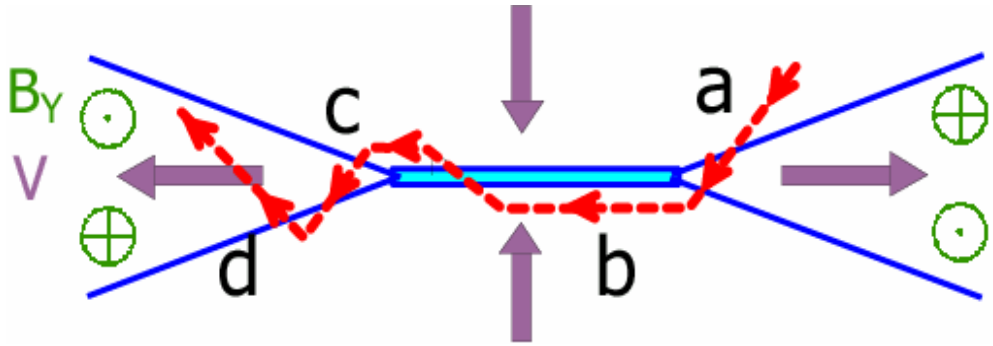
- Fast ion flows outside ion diffusion region
- Ion and electron decoupling → Hall electric current
- Electron diffusion (Cluster cannot resolve)



Current sheet structure

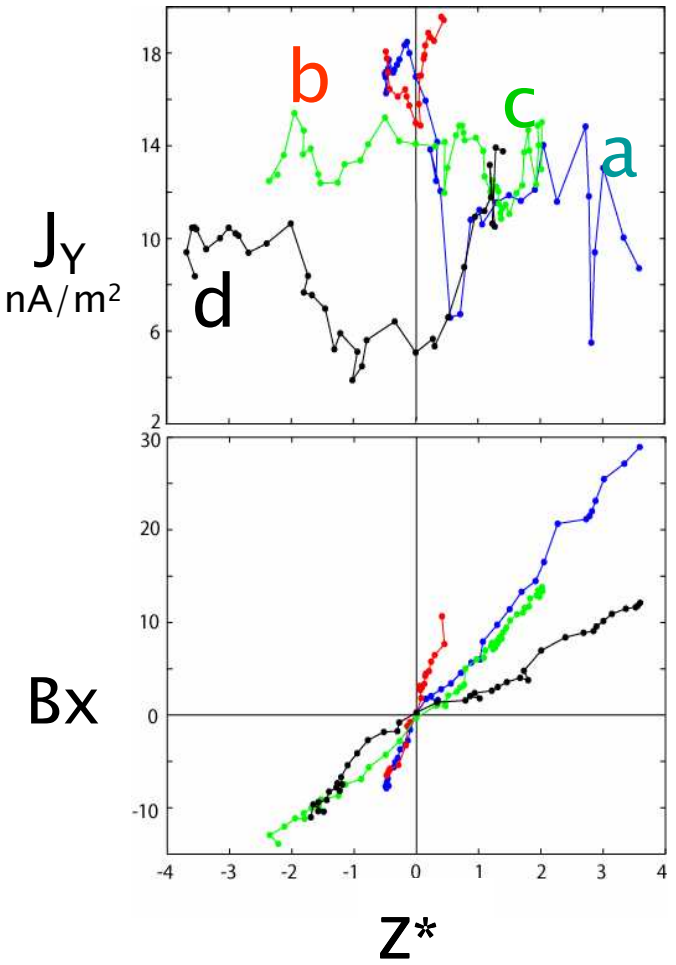
➢ *4-S/C observation of multiple CS crossing around X-line*

- Field line curvature direction consistently changes with X-line geometry
- BY due to Hall current confirmed
- Bifurcated current & thin current sheet



- Thin (~1500 km) bifurcated current sheet occurs more frequent during fast flow intervals [Asano et al., 2005]

[Runov et al., 2003; 2004]



Thin current sheet (2003 event)

➢ *Curlometer resolved current profile near reconnection region*

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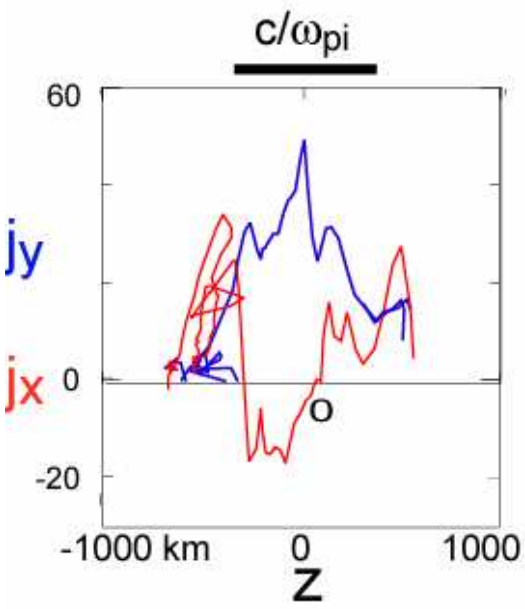
1903:28-1903:39



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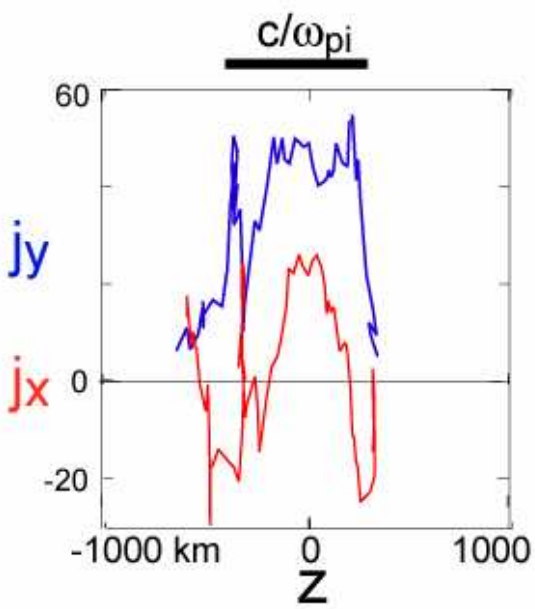
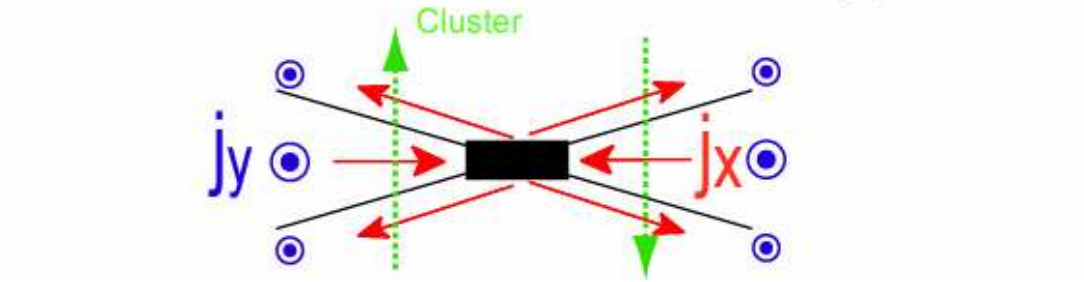




- Rapid CS crossings (<10s)
- S/C separation < c/ω_{pi}
- jy: thin current sheet full width was comparable to c/ω_{pi}
- jx: consistent with electron motion (inflow & outflow)

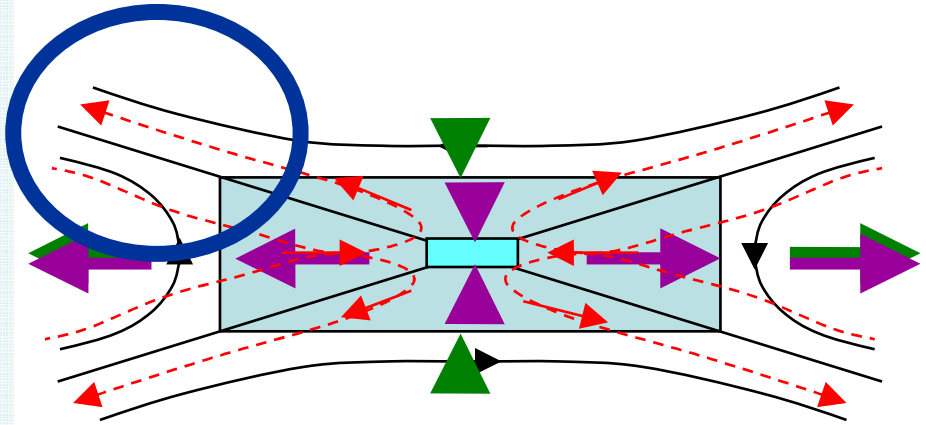
→ observation within ion diffusion region

Electron observations (PEACE)

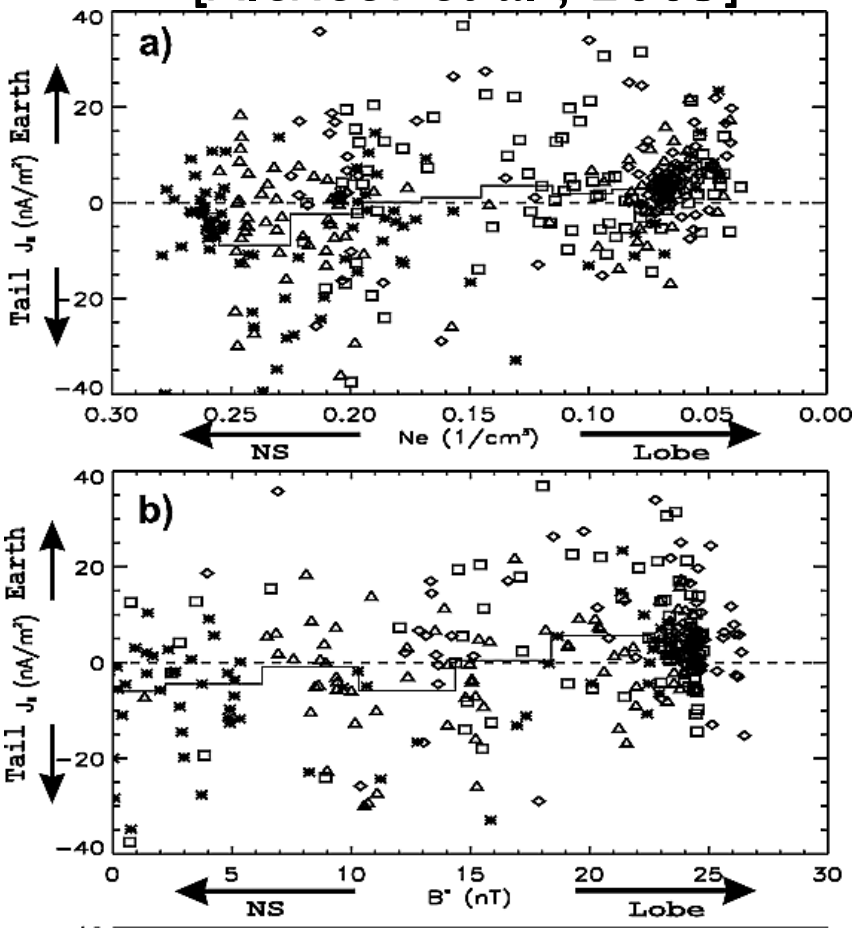
- *Cluster detected current carrying electrons in Hall-current system with fine structures (multi-layers) inside*

  - Parallel electron current closing Hall-current system observed

  - Signatures of multiple reconnection ?



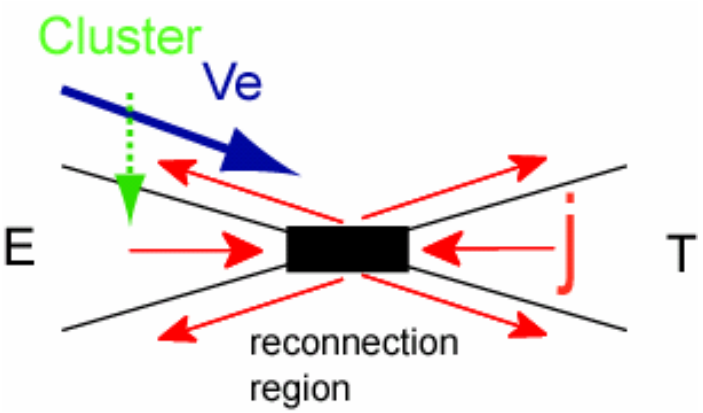
[Alexeev et al., 2005]



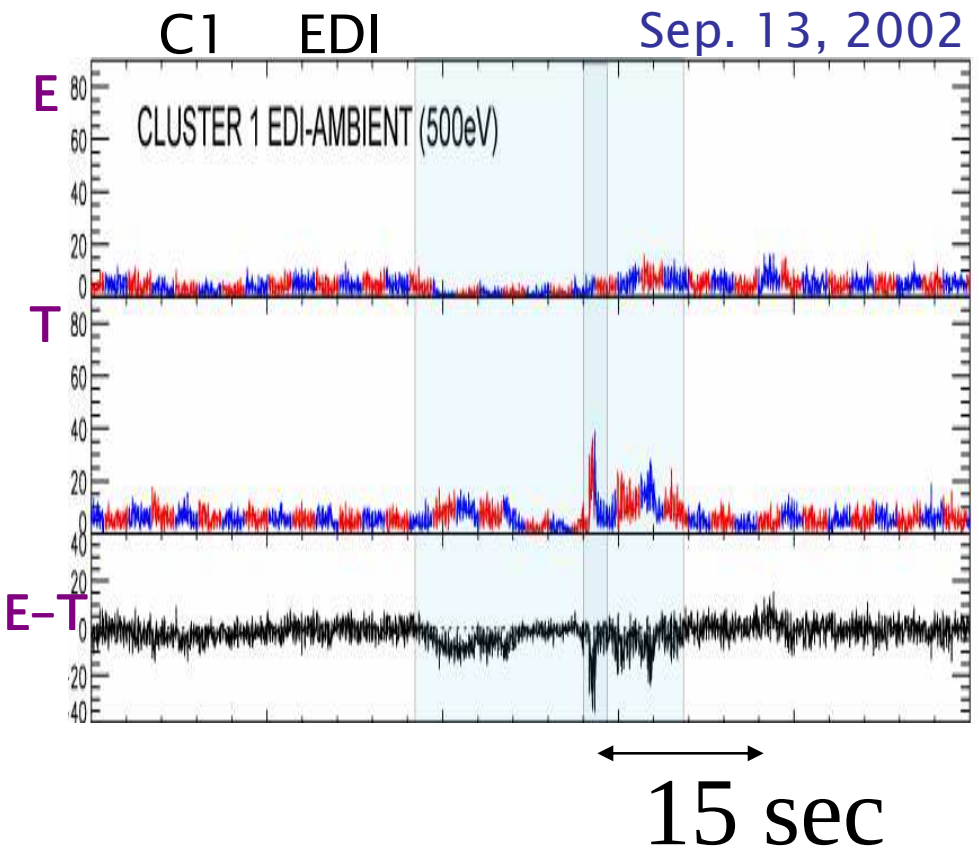
Low energy electron beam (EDI)

➢ *Fine structures of inflow electron beam detected*

- EDI : 0, 180 deg. 500 eV electrons with high-time resolution (4 ms BM, 64 ms NM)
- tailward beam on Earthward side of X line with fine structures



[Asano et al., 2004]

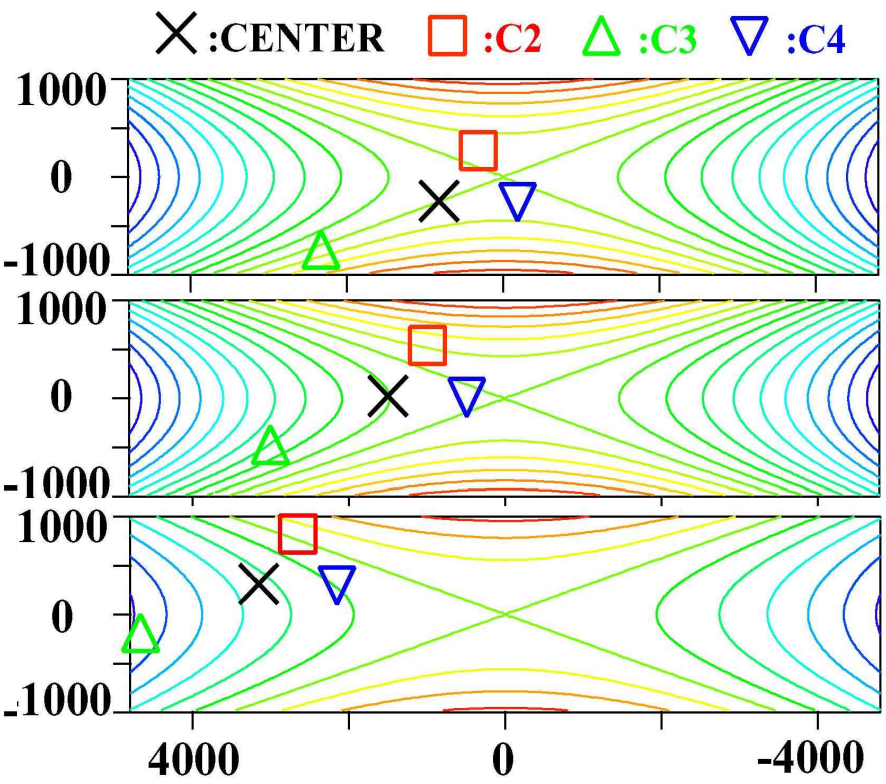


… and more X-line studies

- Electron-scale physics
  - Solitary waves indicating electron holes, observed at consistent location predicted from simulations **(Cattell et al., 2005)**
- Presence of oxygen
  - Speiser-type motion of oxygen identified during storm-time substorm reconnection event dominating pressure and density **(Kistler et al., 2005)**
  - Multi-scale current sheet with electric potential wells normal to the currrent sheet accelerating H+ and O+ **(Wygant et al., 2005)**
- Slow mode shocks
  - Successful joint Walen and slow shock analyses on the tailward side. Earthward side: less successful due to effect from dipolar field. **(Eriksson et al., 2004)**

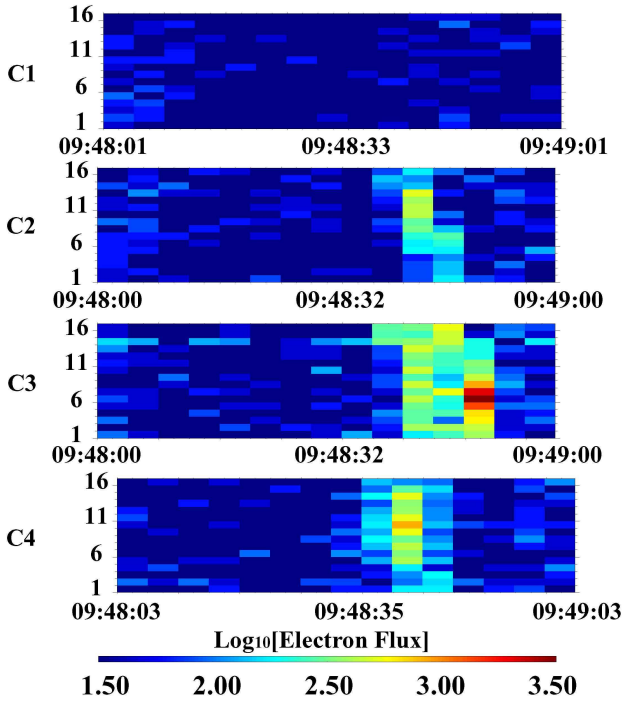
How does X-line evolve ?

Electron acceleration associated with X line evolution



X-line configuration change: fit to FGM data

[Imada et al.]



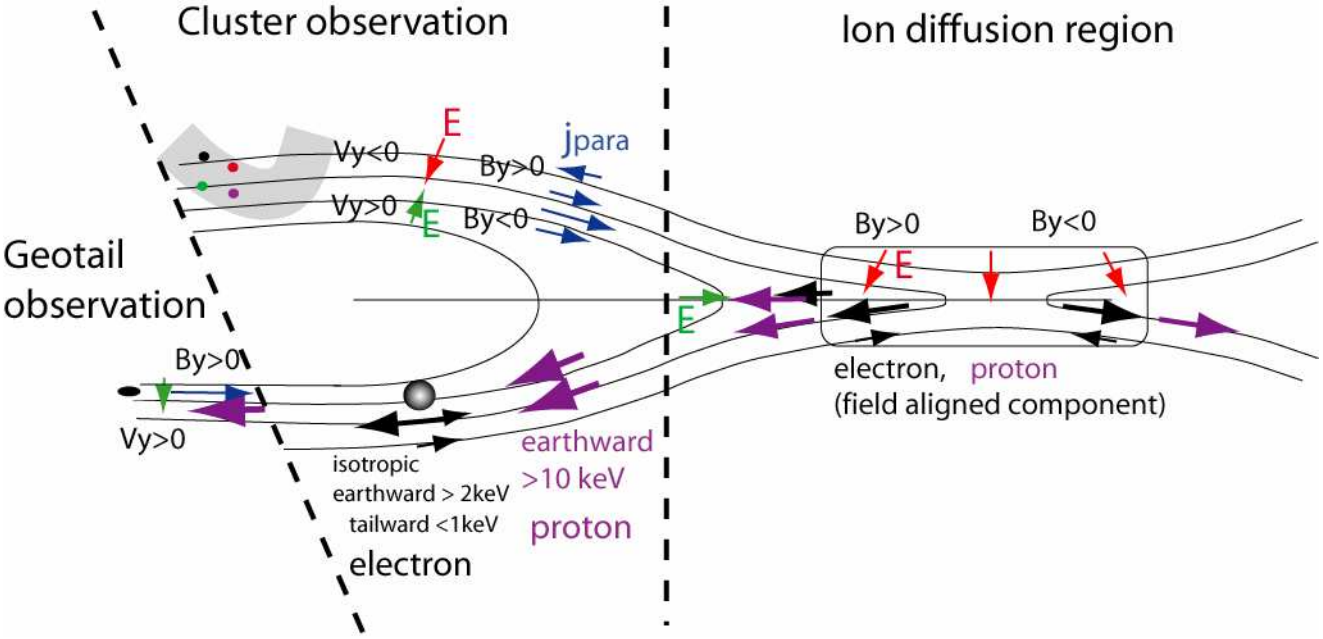
RAPID (>50 keV) flux
(Courtesy of P. Daly)

- Model X-line configuration and relevant spacecraft position
- Enhancement of RAPID >50 keV electron outward from X line

Large-scale effects of X-line

- Global consequence of reconnection identified from multi-spacecraft observation

[Nakamura et al., 2004]

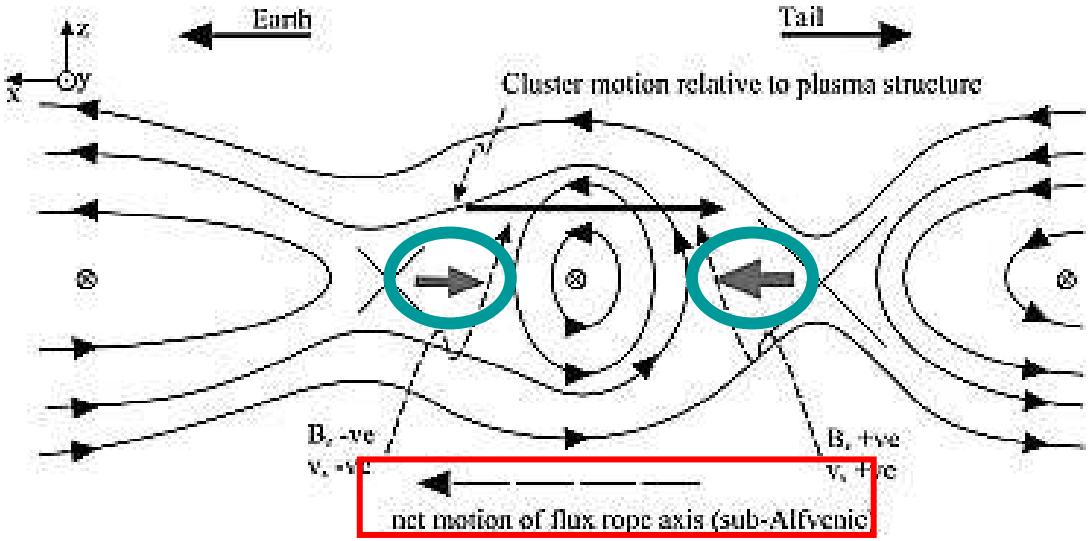


- Strong flow shear (N-S electric field) and field aligned current at boundary of plasma sheet.
- Consequence of Hall-effects in reconnection region and reconnection jets interacting with ambient field.

Development of O/X-line(s)

- Earthward moving bipolar Bz signature → flux rope/TCR (traveling compression region) due to multiple reconnection and/or NFTE (night side flux transfer event) due to transient reconnection

  - Cluster can detect motion of magnetic structure independently from plasma flows



[Eastwood et al., 2004]

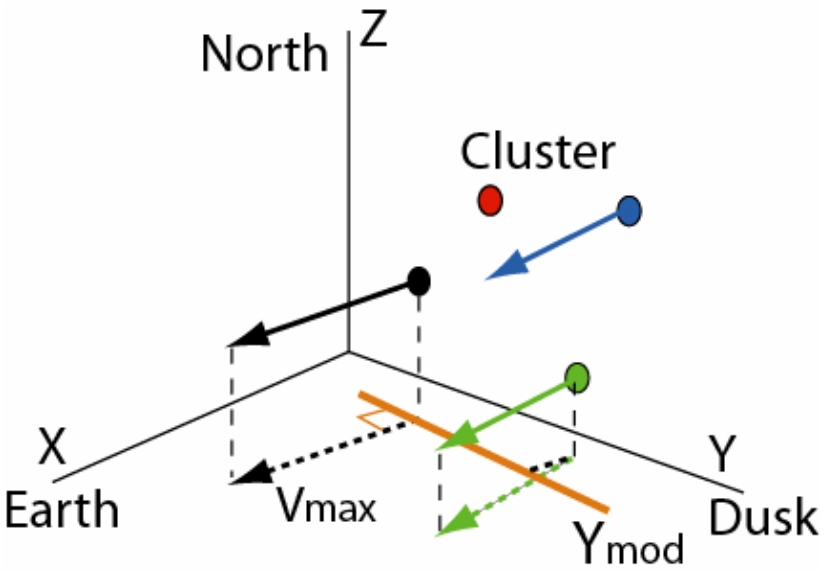
- Structures & motion & compositions of flux ropes/TCR determined (Slavin et al., 2003; Zong et al.,2004; Owen et al., 2005; Eastwood et al.,2005)
- Temporal change of reconnection rate obtained (Penz et al., 2005; Sergeev et al., 2005; Semenov et al., 2005)

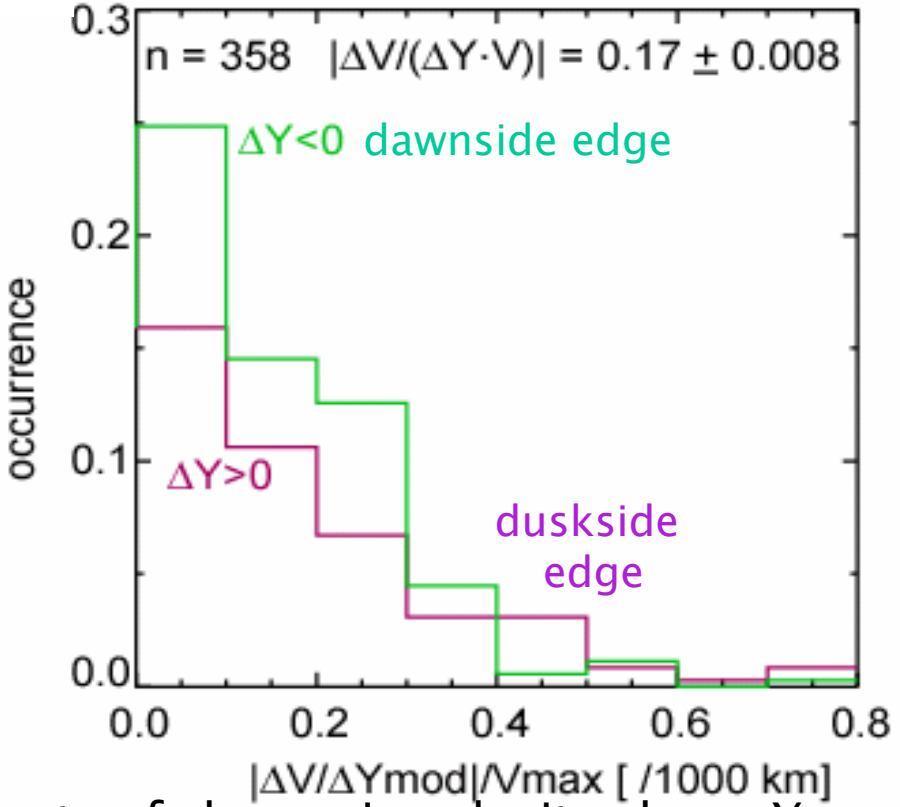
Spatial scale of fast flows

Spatial gradient of flow obtained from S/C-pairs along Y' (and Z)

- ion measurements only at 3 SC

[Nakamura et al., 2004]



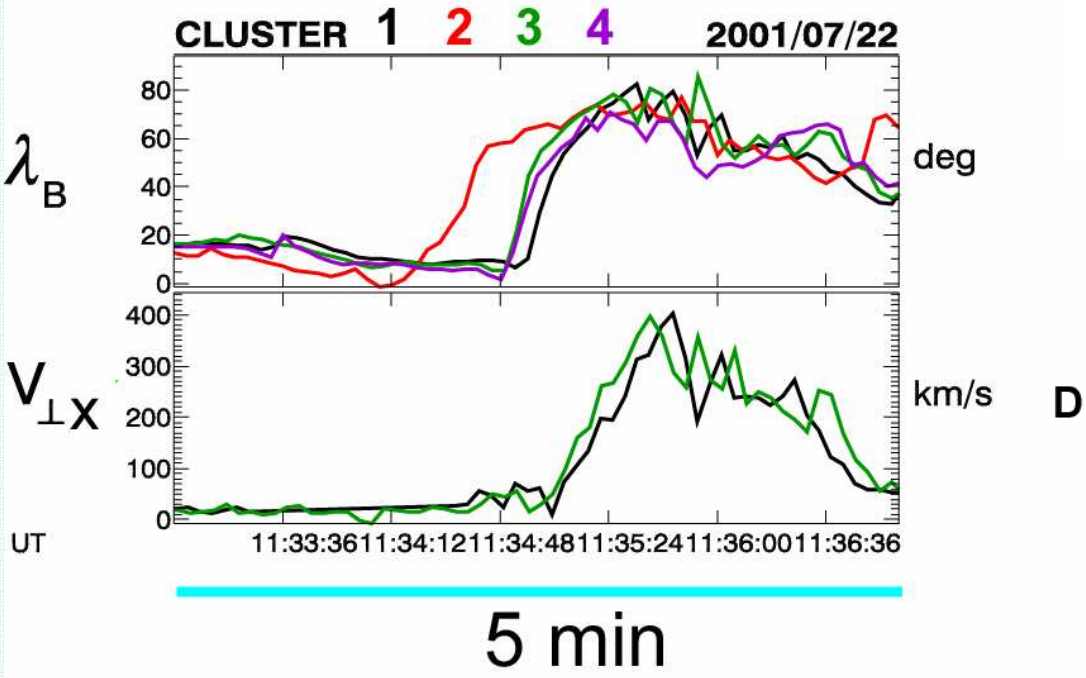


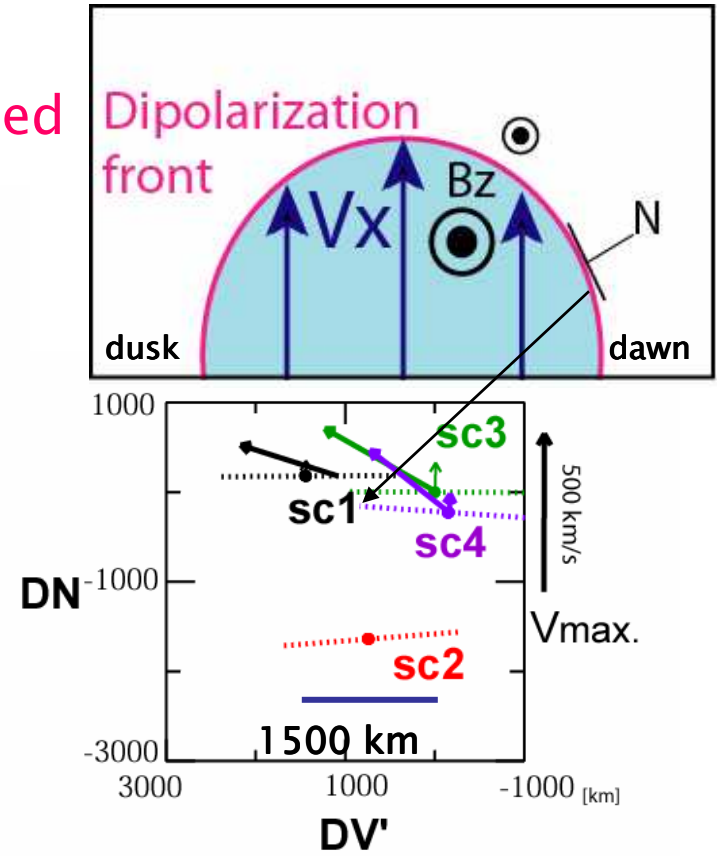
rate of change in velocity along Y

- Dawn-dusk scale: 2-3 R_E
- Vertical scale: 1.5-2 R_E
- Spatial scale suggests localized source region (reconnection site)

Dipolarization front

- Structure of Bz (λ_B) enhancement at the front of jetting plasma identified





- Minimum variance analysis + timing analysis
- Front velocity is almost perpendicular to plasma jet (at dawnside edge)
- Tangential discontinuity (Timing velocity = normal flow speed.)

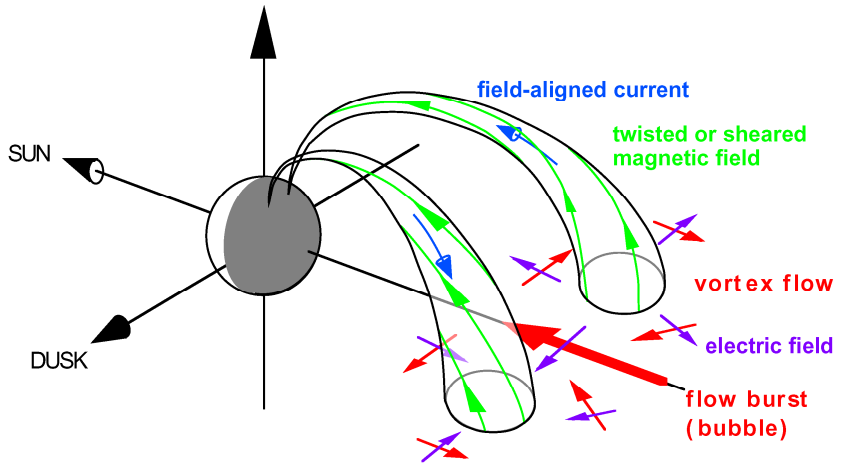
[Nakamura et al, 2002]

3D structure of BBF

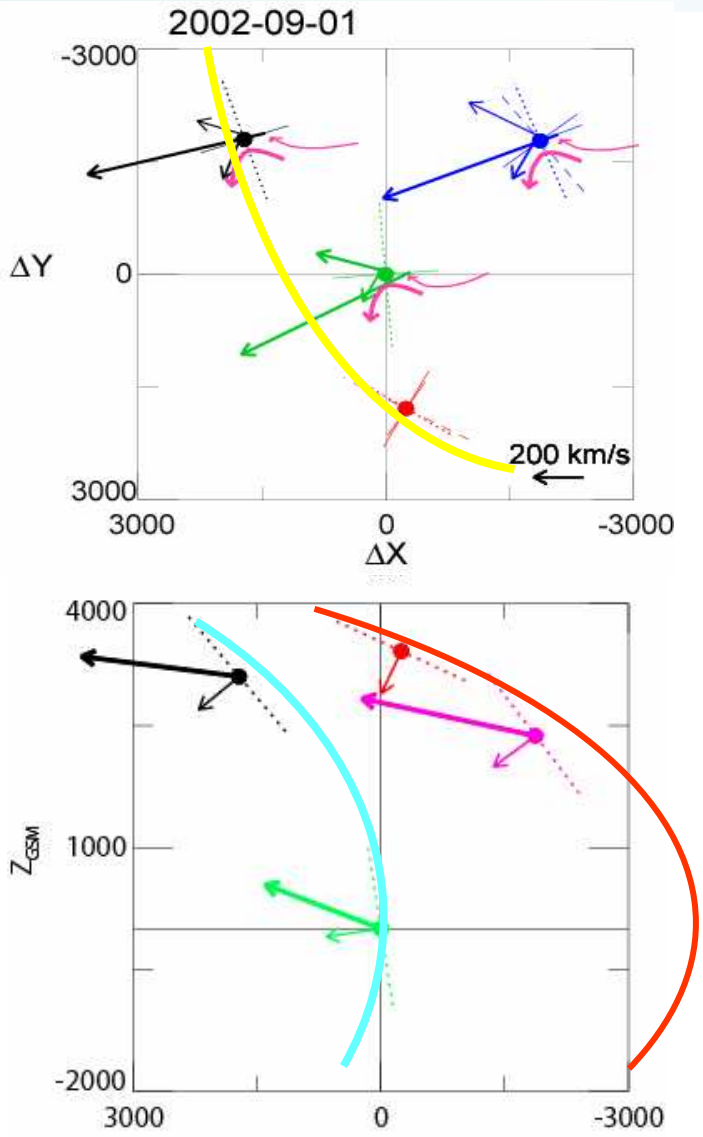
- 3D shape of BBF determined from 4-sc dipolarization front → Localized flux tube (Concave shape in X-Z plane)
- Flow shear at the front →

  Field aligned current

  Confirmed from ionospheric observation



[Birn et al., 2004]
Plasma bubble and associated field aligned current



[Nakamura et al., 2005]

Summary

- Cluster four spacecraft enabled to identify signatures in reconnection region due to Hall-physics, effect of multi-composition plasma, electron physics by simultaneously monitoring the scale of the current sheet (structure in Z direction).
- Further detailed comparison with theory is ongoing.
- Challenging task is to understand the signatures of reconnection also in time domain with knowledge of the spacecraft location relative to X-line (in X direction).
- Remote observations of flow/field disturbances are shown to reflect temporal and/or spatial characteristics of reconnection.
- Larger scale tetrahedron (>10000 km) will enable to characterize the entire structure and evolution of flux rope/plasmoid/NFTE.
- Cluster/Double Star observation is expected to understand BBF in a more global context