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Magnetotail reconnection and plasma sheet fast flows

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Plasma sheet fast flows

Spatial scale and 3-D shape

Interaction with ambient plasma/field





Multi-scale process involved

- Fast ion flows outside ion diffusion region
- Ion and electron decoupling \rightarrow 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]



Thin current sheet (2003 event)

Curlometer resolved current profile near reconnection region



WAVE

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 ?





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









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 current 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



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





Global consequence of reconnection identified from multi-spacecraft observation



- 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.





- ➤ 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 gradient of flow obtained from S/C-pairs along Y' (and Z) [Nakamura et al., 2004] ion measurements only at 3 SC 0.3 $n = 358 |\Delta V / (\Delta Y \cdot V)| = 0.17 \pm 0.008$ North $\Delta Y < 0$ dawnside edge Cluster 0.2 occurrence 0.1<mark>-</mark> ∆Y>0 Х duskside Earth Vmax Dusk edge Ymod 0.0 0.2 0.0 0.4 0.6 0.8 Dawn-dusk scale: 2-3 R_F $|\Delta V / \Delta Y mod| / V max [/1000 km] rate of change in velocity along <math display="inline">~Y$

- Vertical scale: $1.5-2 R_{F}$
- Spatial scale suggests localized source region (reconnection site)



Dipolarization front





- 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







Summary



- Cluster four spacecraft enabled to identify signatures in reconnection region due to Hall-physics, effect of multicomposition 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