Magnetotail reconnection
and plasma sheet fast flows

Rumi Nakamura
Space Research Institute, Austrian Academy of Sciences

Special thanks to:
Cluster traversed key region

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- Reconnection
- Plasma jets
- Plasma sheet fast flows
- Thin current sheet
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- Cluster
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- 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 $\rightarrow$ Hall electric current
- Electron diffusion (Cluster cannot resolve)
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]

\[ B_{\parallel} \]
Thin current sheet (2003 event)

- Curlometer resolved current profile near reconnection region

- Rapid CS crossings (<10s)
- S/C separation < \(c/\omega_{pi}\)
- \(j_y\): thin current sheet full width was comparable to \(c/\omega_{pi}\)
- \(j_x\): 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]
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

X-line configuration change: fit to FGM data

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

[Imada et al.]
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

- 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)

[Eastwood et al., 2004]
Spatial scale of fast flows

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

- ion measurements only at 3 SC
- Dawn–dusk scale: 2–3 $R_E$
- Vertical scale: 1.5–2 $R_E$
- Spatial scale suggests localized source region (reconnection site)

[Nakamura et al., 2004]
Structure of Bz ($\lambda_B$) enhancement at the front of jetting plasma identified [Nakamura et al, 2002]

- 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]
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.