Cluster Electron Observations of Northward IMF Reconnection

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14:50 - 15:03 UT:
--Cluster traveled from the mantle northward and sunward into the magnetosheath
--Phan, et. al., mapped the location of cluster during its magnetopause crossing to the location of the ionospheric footprint observed by IMAGE.
--81° lat. and 14 MLT, ~ 6-7 $R_E$
FGM (GSE): ~60-70 ° draping

Rotate data to magnetopause-aligned Coordinates (60 deg tilt)

Several crossings; one at 1500 is slowest with minimum fields

Note fields inside (left) and outside (right) are not exactly anti-parallel. Small By gets enhanced near the xline
Topology: Rotation through $B_y$

seen from sun

By enhanced at X-line
both INSIDE and OUTSIDE

Mapped $E$ is along X-line

$E \cdot J > 0$ at X-line

Mapped Electric field causes sunward flow in ionosphere
Rotational Discontinuity Finder

Black trace: (Michel et al)

\((B_1 \times B_2) \cdot B_3\)
X-Line Structure Superposed Epochs

Magnetic Field (nT) Superposed Epochs, 15:00 UT;
c0 crossing: blue, c1 crossing: red, c4 crossing: green

scale: 72 nT
X-Line Structure: Harris Sheet Fit ($B_x (z)$)

Current sheet thickness: ~85 km
Normal component more difficult because of low-frequency boundary waves which are also occurring but is roughly 10 nT
X-Line Structure and Motion

X-line frame
Determined from the Harris fits

The s/c with the smallest measured field is used to place the entire group

Xline appears instantaneously!
X-Line Structure and Motion

Movie of X-line structure and motion available from http://space.rice.edu/cluster
Perpendicular Electron Flows

3D distributions show it is a real flow, not pancake distribution
Ion Diffusion Region?
Strong electron flows (purple) at edges of By enhancement

\[ E' = E + \mathbf{v} \times \mathbf{B} / c = \frac{j}{\sigma} + \frac{m_e}{ne^2} \left[ \frac{\partial \mathbf{j}}{\partial t} + \nabla \cdot (\mathbf{v}j + \mathbf{jv}) \right] - \frac{\mathbf{j} \times \mathbf{B} / c}{ne} - \frac{\nabla \cdot \mathbf{p}_e}{ne} \]

- Collisions
- Electron inertial terms
- Hall term (ion inertial)
- Electron total pressure term
Curlometer Current ==> Hall Current?

Hall Currents with $B_y$ Magnetic Field

- $\zeta_x$
- $\zeta_y$
- $B_y$

Current density (A/m$^2$), magnetic field strength (10$^{-7}$ T)

Electron pressure tensor (symmetric tensor) off-diagonal component $P_{xy} (= P_{yx})$ in magnetopause-aligned coordinate system

- has magnitude $\sim 15\%$ diagonal terms
- has expected asymmetry
  - slowly rotates from $y$ to $x$ via $B_z$
  - then magnetized and symmetric with respect to $B$
  - odd symmetry owing to change in sign of $B_z$
Pressure Divergence Electric Field

\[ E' = E + \mathbf{v} \times \mathbf{B} / c = \mathbf{j} / \sigma + \frac{m_e}{ne^2} \left[ \frac{\partial \mathbf{j}}{\partial t} + \nabla \cdot (\mathbf{v} j + jv) \right] - \frac{j \times \mathbf{B} / c}{ne} - \frac{\nabla \cdot \mathbf{p}_e}{ne} \]

-12 mV/m
-15% of Hall electric field
-0.3v_A B_0

collisions
Electron inertial terms
Electron total pressure term
Hall term (ion inertial)
Superposed Electron Flows

Accelerated Flows along the xline near the xline

Purple has a component along -y

black a component along +y (-E)
Summary

- Magnetic Field structure and electron flows consistent with reconnection structure (overdraped lobe possible to explain exterior flow)
- (Nearly) anti-parallel reconnection with out-of-plane component that enhances during crossing
- Single X-Line oscillates but does not fly tailward
- Current Sheet ~85 km thick
- Cluster spacecraft comes within ~1 km of x-line.
  - Inside Ion diffusion region
  - Electron demagnetization and offdiagonal pressure seen
Backup
$J_y$ Curlometer Current

Current sheet density

Amps/m²

$X$ current density, $x$ axis

$x \times 10^{-6}$