Observational Evidence of Component and Antiparallel Reconnection at the Earth’s Magnetopause

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Agenda

- Definitions: Antiparallel and Component Reconnection
  - Theory
  - Observations
- Identifying Component and Antiparallel Reconnection
  - Flow velocities (1)
    - Antiparallel reconnection example
  - Ionospheric footprints
  - Flow velocities (2)
    - Component reconnection example
  - Distance to the reconnection site from Cusp Observations
    - A unified, empirical model for magnetopause reconnection type
- Implications for Magnetospheric Multiscale
- Conclusions
Definitions: Theory

• Theory – Antiparallel and “Guide Field” Reconnection
  – Antiparallel – Electrons are demagnetized in the electron diffusion region
  – “Guide Field” – Guide field is large enough that the electrons are not demagnetized in the electron diffusion region
Definitions: Observations

• **Antiparallel Reconnection**
  – Occurs where the shear across the magnetopause is \(=180^\circ\)

• **Component Reconnection**
  – Occurs where the shear across the MP \(\neq 180^\circ\)
Reconciling Theory and Observations: Identifying Antiparallel Reconnection

- When does $\beta_e$ become $>>1$ (i.e., $\sim 5-10$) (electrons are magnetized)?
  - Sample MP
  - Answer: “Antiparallel” when angle between guide field and total field = 174-176°

<table>
<thead>
<tr>
<th>$B(\text{guide field})/B_o$</th>
<th>$\beta_e$ (diffusion region)</th>
<th>Shear angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>1.2</td>
<td>169°</td>
</tr>
<tr>
<td>0.1</td>
<td>4.8</td>
<td>174°</td>
</tr>
<tr>
<td>0.075</td>
<td>8.6</td>
<td>176°</td>
</tr>
</tbody>
</table>

- How well are shear angles measured?
  - Answer: To within $\sim 4-8°$

Cannot identify “theoretical antiparallel reconnection” at the MP

Paschmann et al., JGR, 1989

$T_e = 60$ eV, $n_e = 20$ cm$^{-3}$, $B_o = 100$ nT

Haaland et al., GRL, 2004
Flow Velocities (1): An Antiparallel Reconnection Example

- Cluster spacecraft sees oppositely directed jets as it crosses the MP
  - Crosses very near the (antiparallel) reconnection site
  - Shear angle at crossing is $\sim 180^\circ$ ($\pm 10^\circ$)
- Unique signature in the ionosphere
  - "Spot" at the foot of the antiparallel reconnected field lines
  - Energized protons precipitating from the reconnection site
Ionospheric Footprint: Antiparallel Reconnection

- Ionospheric signature can be explained entirely by antiparallel reconnection
- How often is this “spot” signature observed? ~1/3 of the time for Northward IMF
"Flow Reversal Events" are purely a component reconnection phenomenon

Observed for southward IMF when the IMF $B_y$ is "Large"
Distance to the Reconnection Site (1)

Cusp Velocity Filter Effect

Magnetospheric Cusp

Magnetopause

Solar Wind

Fast Particle

Slow Particle

Particle Energy

Spacecraft (Magnetic) Latitude

Time-of-Flight (or Velocity Filter) Effect
Due to Magnetic Reconnection

+By

reconnection line

DAWN

DUSK

Yosemite– February 2010
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A Unified Model (1) Large $B_y$ cases

MP magnetic shear as viewed from the Sun, red = large shear
Squares – “observed”
reconnection sites

Antiparallel reconnection at the flanks of the magnetopause

Component reconnection occurs along a line that is not hinged at the subsolar point – follows maximum shear across the dayside
Location depends on dipole tilt (i.e., season)

Yosemite– February 2010
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A Unified Model (2) Large $B_x$ or Large $B_z$ cases

- When IMF $B_x$ or $B_z$ dominate, the magnetopause reverts to antiparallel reconnection all across the dayside MP
How Well are We Doing? Test the Model Using THEMIS Data

• THEMIS magnetopause crossing
  – Observed bi-directional reconnection jets
  • Spacecraft at the reconnection site

• Independent prediction of the reconnection line using only the solar wind information and the empirical model
Implications for MMS: Mission Planning

- Create a probability map of the dayside magnetopause
  - Use solar wind conditions over several months and spacecraft crossings of the magnetopause
- “Target” regions of high probability for encountering the reconnection diffusion region

- 3 months of solar wind data
- MMS predicted magnetopause crossings

Yosemite—February 2010
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Conclusions: Antiparallel and Component Reconnection - From an Observational Perspective

• Not able to demonstrate “theoretical” antiparallel reconnection conclusively
  – Can’t be done with present day measurements because of (small) uncertainties in the shear angle

• Clear evidence of a reconnection line that follows the antiparallel line(s) at the MP
  – Ionospheric footprint of the antiparallel line
  – Cusp observations: Locations that follow the antiparallel line

• Also clear evidence of component reconnection

• An empirical model reconciles these observations
  – $B_x$, $B_z$ dominant, or on the MP flanks – Antiparallel Reconnection
  – $B_y$ dominant – Component Reconnection

• These results have important implications for MMS
Backup
Distance to the Reconnection Site (2) Computing the Distance to the Reconnection Site

Reflecting Wall (ionosphere) → Convection → Reconnection Site → Extended Source (Magnetopause) → Observer

\[
\frac{X_r}{X_m} = \frac{2V_e}{(V_m - V_e)}
\]

Source Distribution (Magnetosheath) flux

Observed Distribution

Ion distributions from the Earth’s magnetospheric cusps

"Earthward" and "mirrored" ionospheric ion outflow
Occurrence of reconnection jets at the dayside magnetopause: Double Star observations

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Bz = +38nT, Vz = +200 km/s

Bz = +34nT, Vz = -210 km/s

120 full 3D particle distributions in reconnection layer!