Tutorial

Magnetic reconnection in the age of the Heliophysics System Observatory

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Quiet current sheet: Width ~ 1-3 Re (at 20-30 Re from Earth) [Kaymaz et al., 2003; Petrukovich et al., 2007]
CLUSTER PEACE PAD HEEA & LEEA
Time in s since 2001-10-01 09:48:13 UT
Cluster ECS crossing

[Runov et al., 2003]

[Chen et al., 2008, 2009]
Quiet time and growth phase: $Wcs \sim 1\text{-}3\ Re$ (@20-30 Re from Earth) 
During reconnection: $Wcs < 160\ km$
MMS: a fleet of 4 SC to unveil reconnection kinetic physics

- 3D eDFs:
  30 ms (2 orders of magnitude higher cadence than ever)
- 3D iDFs:
  150 ms

Continuous w/o data gaps!
X-line distribution → these accelerated e’s will be ejected from the reconnection layer... and precipitate into the ionosphere?

discrete populations with different # of bounces and amount of acc

[Shuster et al., 2015; Bessho et al., 2014]
In-plane electrostatic potential observed by CLUSTER [Wygant et al, 2008]
and in PIC and MRX

MRX (lab experiment) $\Phi_\text{f} (V)$

[Chen et al, 2008]

[Yamada et al, 2014]
How does the electrostatic potential (and fields) set up by reconnection ‘globalize’?
Impact of earthward fast flows on the ring current

Global Hybrid Model → CIMI equatorial H⁺ flux

Earthward fast flows

- t = 0:40 min
- Injection from the tail
- (82.5-177.8 keV)

- t = 1:30 min
- Penetration to L~3

Yu Lin, Xueyi Wang, Mei-Ching Fok, Natalia Buzulukova, J. D. Perez, Li-Jen Chen, and Lei Cheng
Connecting local processes and global dynamics
Relation between local reconnection and global dynamics

Global polar cap potential derived from data and simulation; reconnection rate along the 3D X-line [Cassak et al., 2017]

whether the global reconnection rate is determined only by solar wind parameters or affected by ionosphere/magnetosphere condition, [e.g., Borovsky et al., 2008, 2014; Zhang et al.2016]

Comparison of X-line location inferred by MMS observation with global model predictions [Trattner et al., 2016]

Nightside reconnection affects field-aligned currents that map to the ionosphere [e.g., Birn and Hesse 1991]
3D behaviors of reconnection

Where does 2D fail?

- An example: A new electron region populated by Msheath-like e’s in the magnetosphere inflow region...
Electron velocity distributions from MMS reveal e dynamics in the diffusion region

[Burch et al., 2016]
2D fails here!

Violating the scaling law,

\[ T_{e\parallel} \propto n^2 / B^2 \]

[from Le et al., 2009, 2017]

[Wang et al., 2017]

[Khotyaintsev et al., 2016; Graham et al., 2017]
Enhanced transport of sheath e’s due to LH turbulence
[Le et al., 2017]
[Le et al., 2017]
[Le et al., 2018]
Reconnection and turbulence in 3D

‘Frustrated’ X-line generates more turbulence

[Liu et al., 2018]
Reconnection and turbulence in 3D

‘Realized’ X-line, more stable

[Liu et al., 2018]
Other 3D behaviors of reconnection

**Kink-mode in magnetotail**  
[Sergeev et al., 2003; Karamabadi et al., 2003]

**Lower-hybrid waves at magnetopause**  
[Le et al., 2017, 2018; Price et al., 2016, 2017; Wang et al., 2017; Graham et al., 2016, 2017]

**Out-of-plane variations**  
[Genestreti et al., 2018; Chen et al., 2016; Zhou et al., 2018]

**X-line expansion speed:**

*Simulation and theory: no guide field, speed of the current carrier,* [e.g., Lapenta et al, 2016];  
*with guide fields, VA based on guide field,* [e.g., Shepherd and Cassak, 2012]  

**THEMIS and SuperDarn dayside observation:** weak guide field, either VA or current carrier speed; strong guide field, current carrier speed [Zou et al., 2017]
Determining the reconnection rate
Magnetopause

[Mozer et al., 2007]
Other measurements of the reconnection rate
e.g. Phan et al., 2001; Mozer and Retino, 2007; Wang et al., 2015; Chen et al., 2017
"Photo" the reconnection region with eDFs

MMS relative positions
2015-12-14/01:17:54

1d~2km

Bg~0.2 Br
Direct measurement of the Reconnection

$E_M \sim 0.1 [B0VA]$

Sheath EDR  $B_g \sim 0.2 \, B_r$

[Chen et al., 2017]
Conjunctions: MMS, THEMIS, RBSP, CLUSTER, ...

MMS orbits