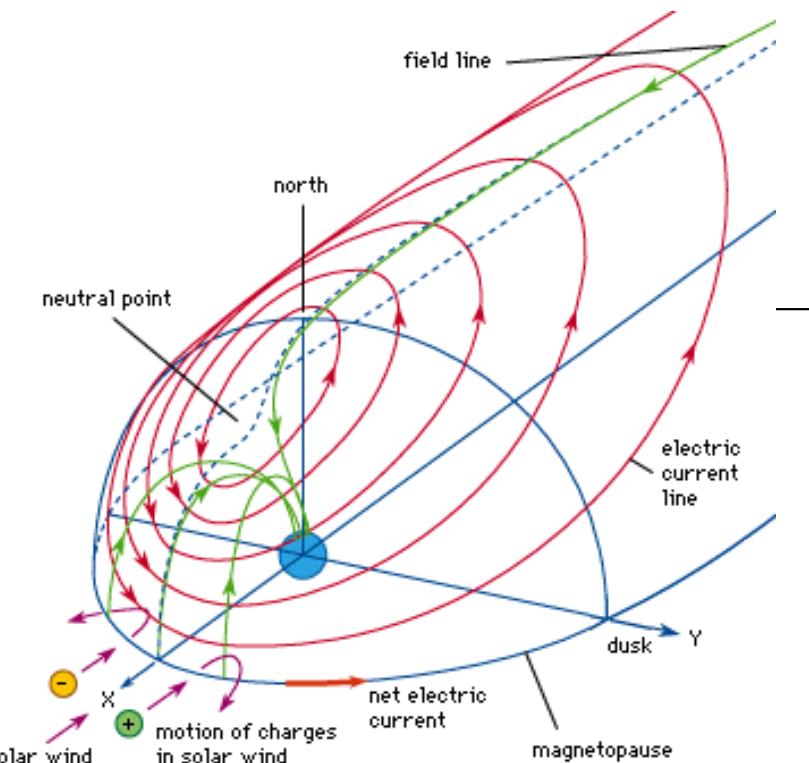


THE MAGNETOPAUSE

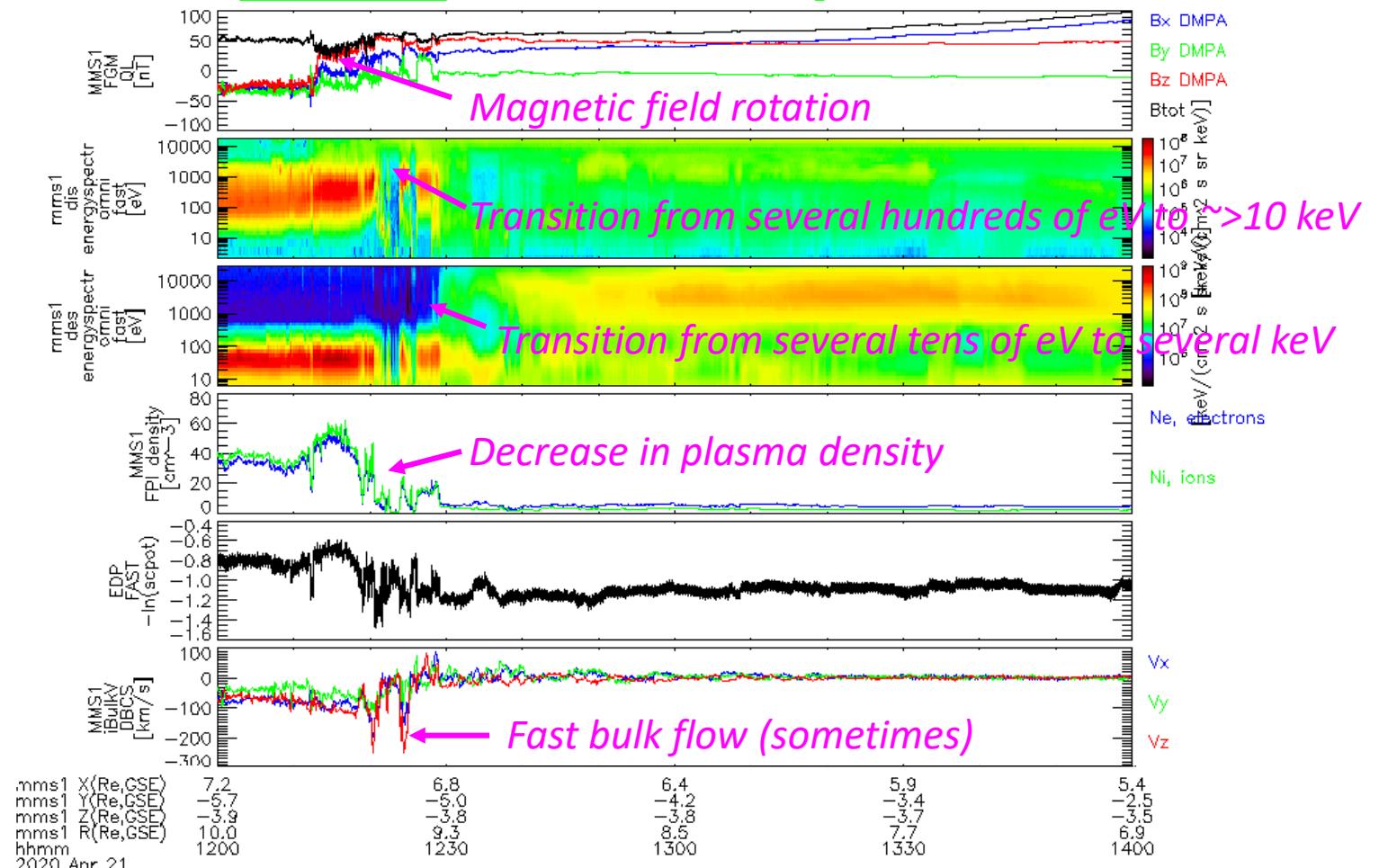
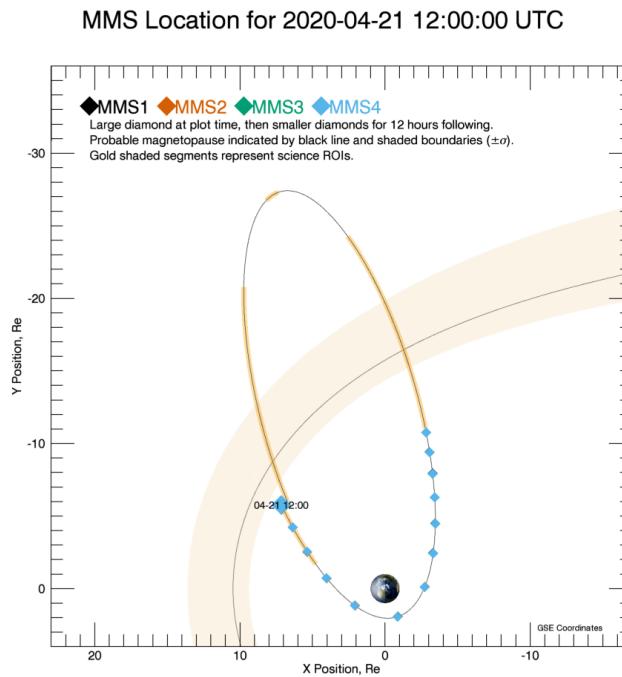
Ying Zou (UAH)



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Recent magnetopause crossings



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Outline

- Structure of the magnetopause
 - Location and shape
 - Motion
 - Thickness
 - Electric current
- Dynamics of the magnetopause
 - Magnetic reconnection
 - Kelvin-Helmholtz Instability

Location and shape of the magnetopause

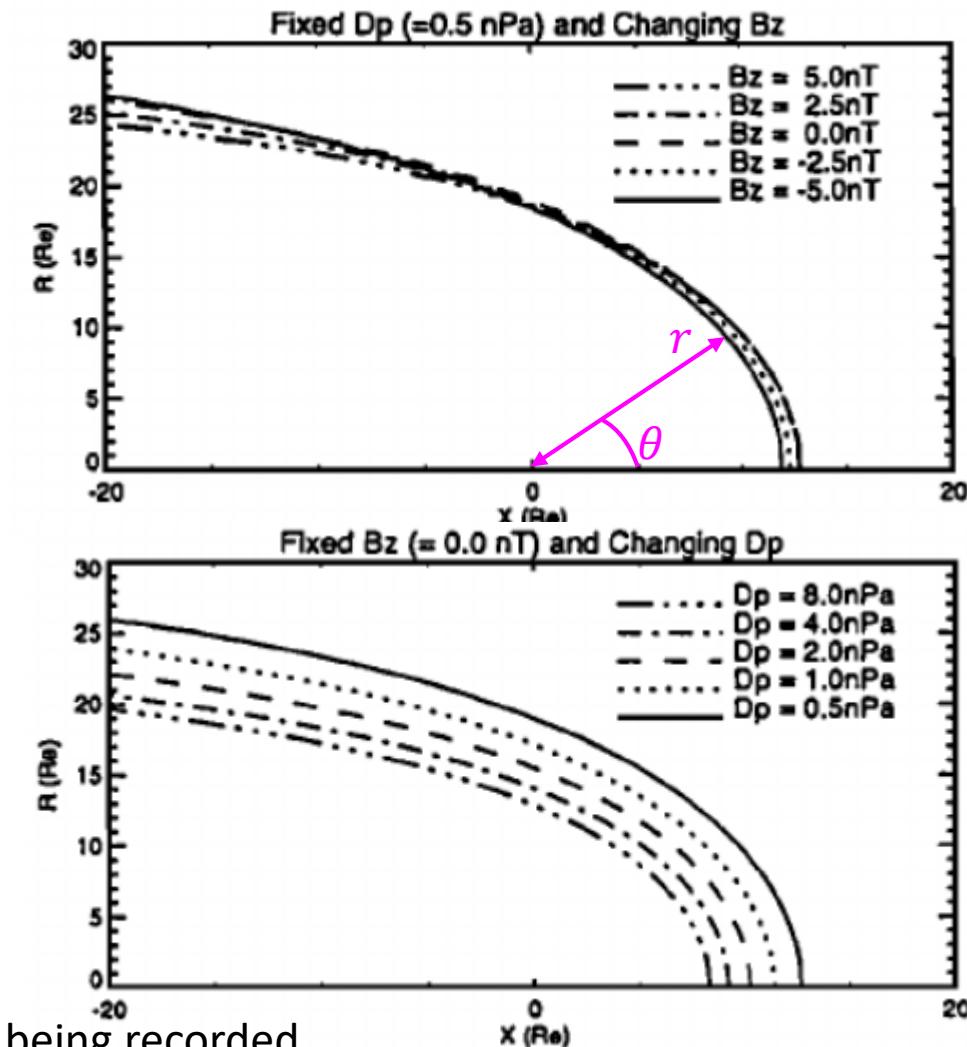
- $P_{sw,dynamic} + P_{sw,thermal} = P_{sph,magnetic}$
- Shue model [Shue et al., 1997, 1998].

$$r = r_0 \left(\frac{2}{1+\cos\theta} \right)^\alpha$$

- Parameters r_0 and α : the standoff distance at the subsolar point and the level of tail flaring.

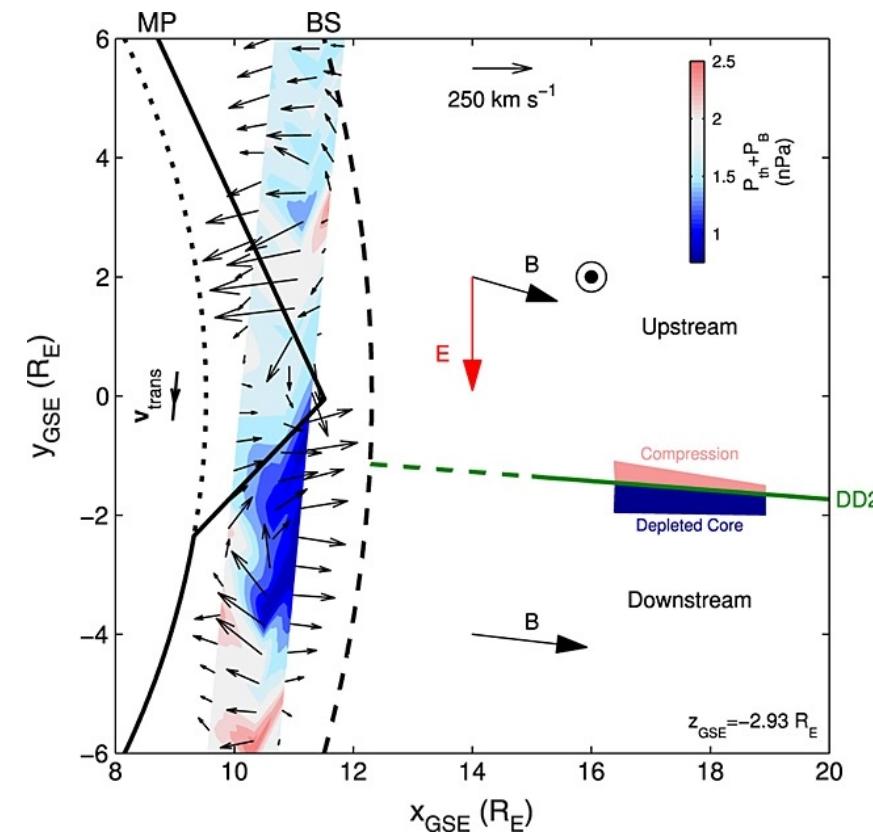
$$r_0 = \{10.22 + 1.29 \tanh[0.184(B_z + 8.14)]\}(D_p)^{-\frac{1}{5}}$$

$$\alpha = (0.58 - 0.007B_z)[1 + 0.024 \ln(D_p)].$$



Location and shape of the magnetopause

- The magnetopause may contain localized structures that are not included in the Shue model.
- These structures can arise from
 - Kelvin-Helmholtz instability
 - Hot flow anomalies
 - Fast magnetosheath jets
 - ...

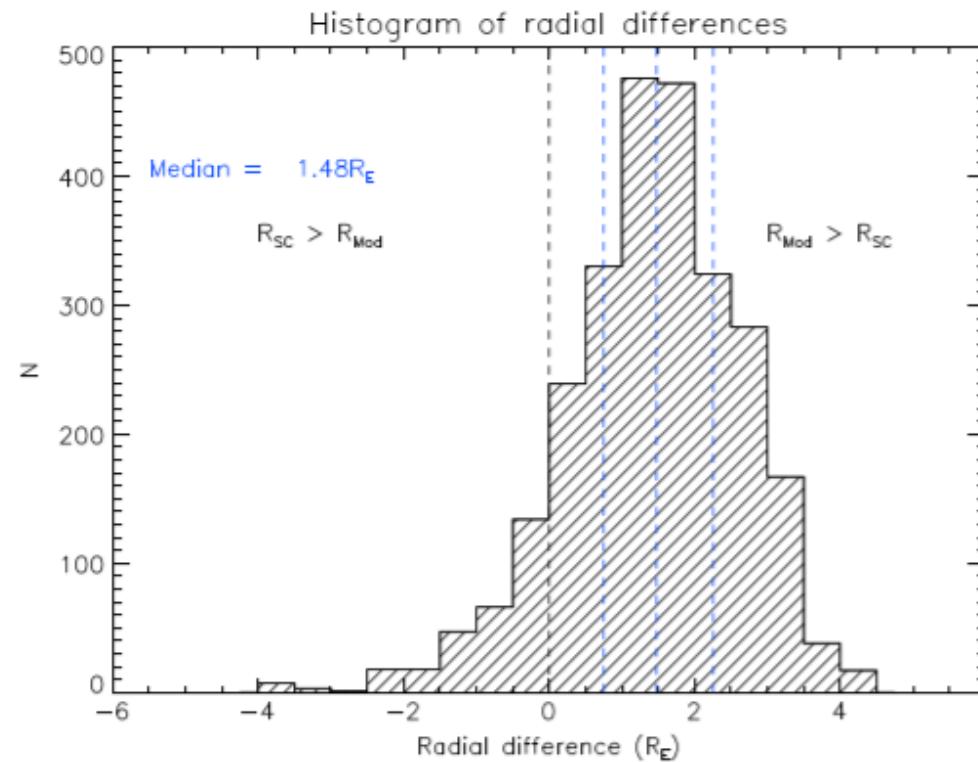


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Archer et al., 2014

Location and shape of the magnetopause

Statistical performance of Shue model

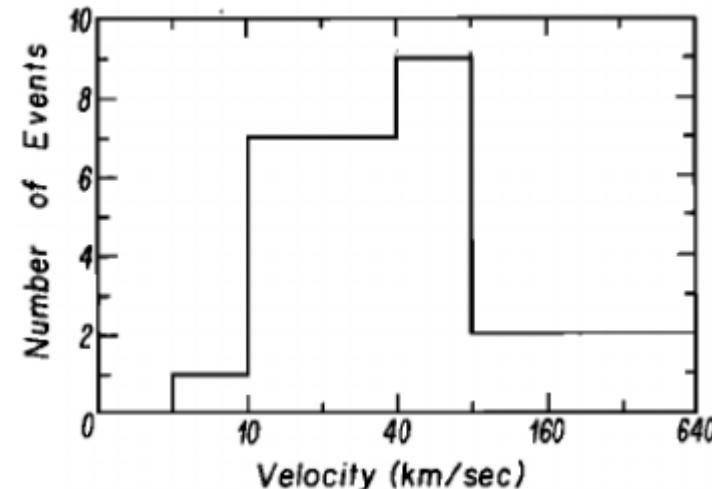


Case and Wild, 2013

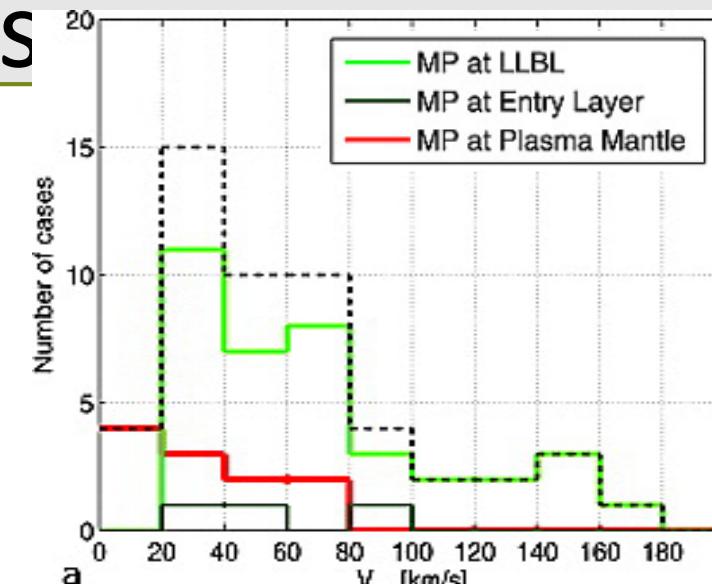
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Motion of the magnetopause

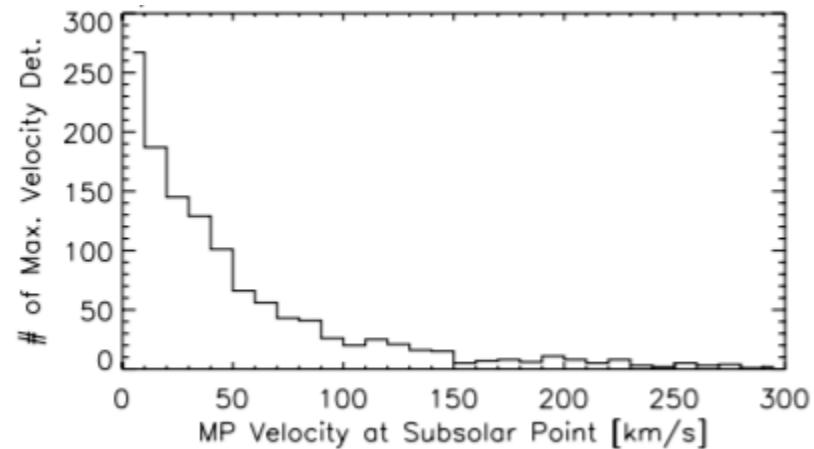
- The magnetopause is constantly moving, due to
 - Time varying solar wind and magnetosheath conditions
 - Waves/instabilities at the magnetopause
 - Reconnection-related phenomena



Berchem and Russell, 1982 This presentation is being recorded



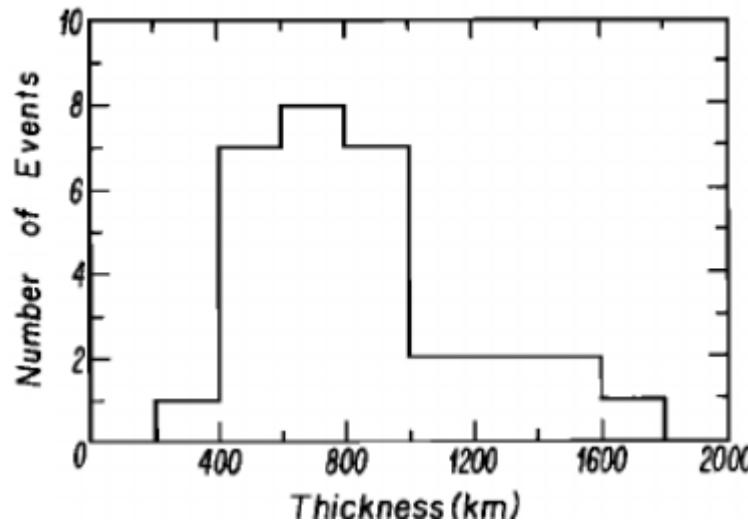
Panov et al., 2008



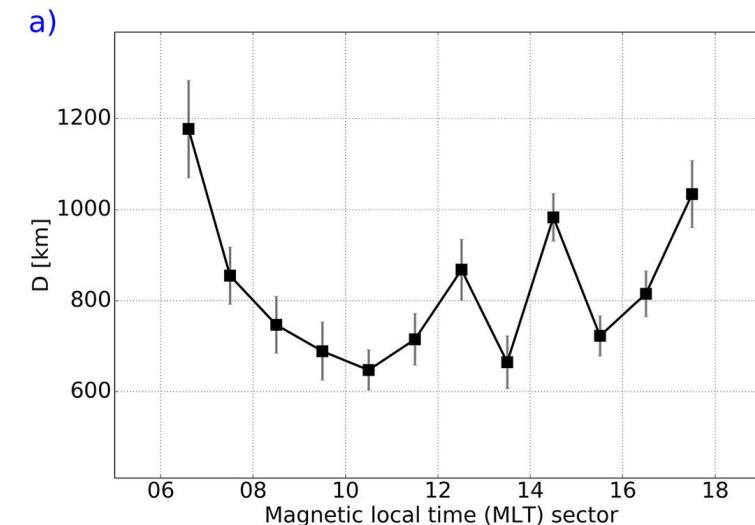
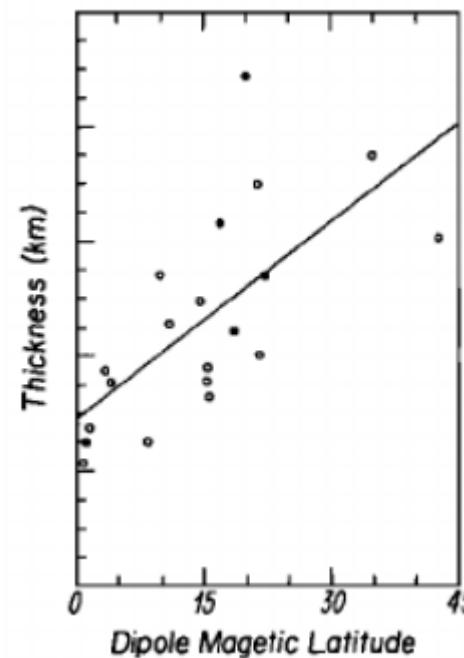
Plaschke et al., 2009

Thickness of the magnetopause

- Thickness = (magnetopause motion speed $\cdot \vec{n}$) \times duration



Berchem and Russell, 1982

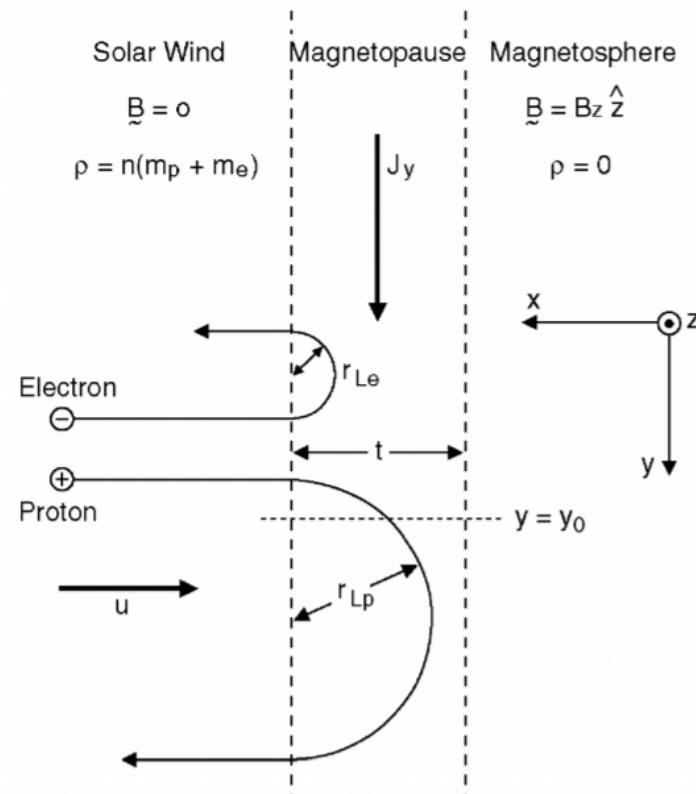


Haaland et al, 2020

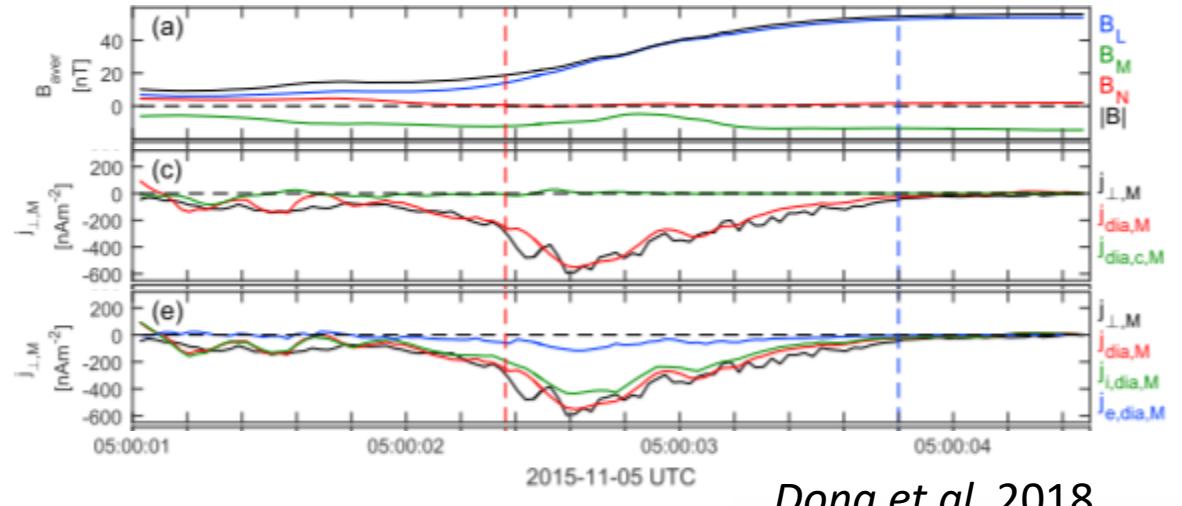
- Magnetopause thickness is often several to 10 ion gyro radius, and is thinnest at the subsolar region.

Electric current of the magnetopause

Chapman and Ferraro model



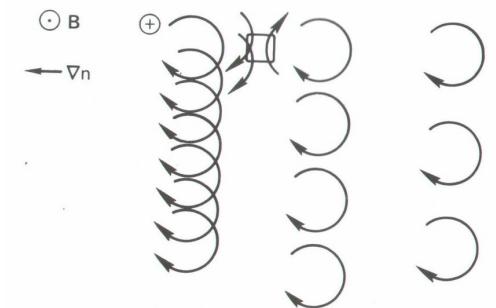
MMS observation



Dong et al, 2018

- Source of magnetopause current is ion diamagnetic current

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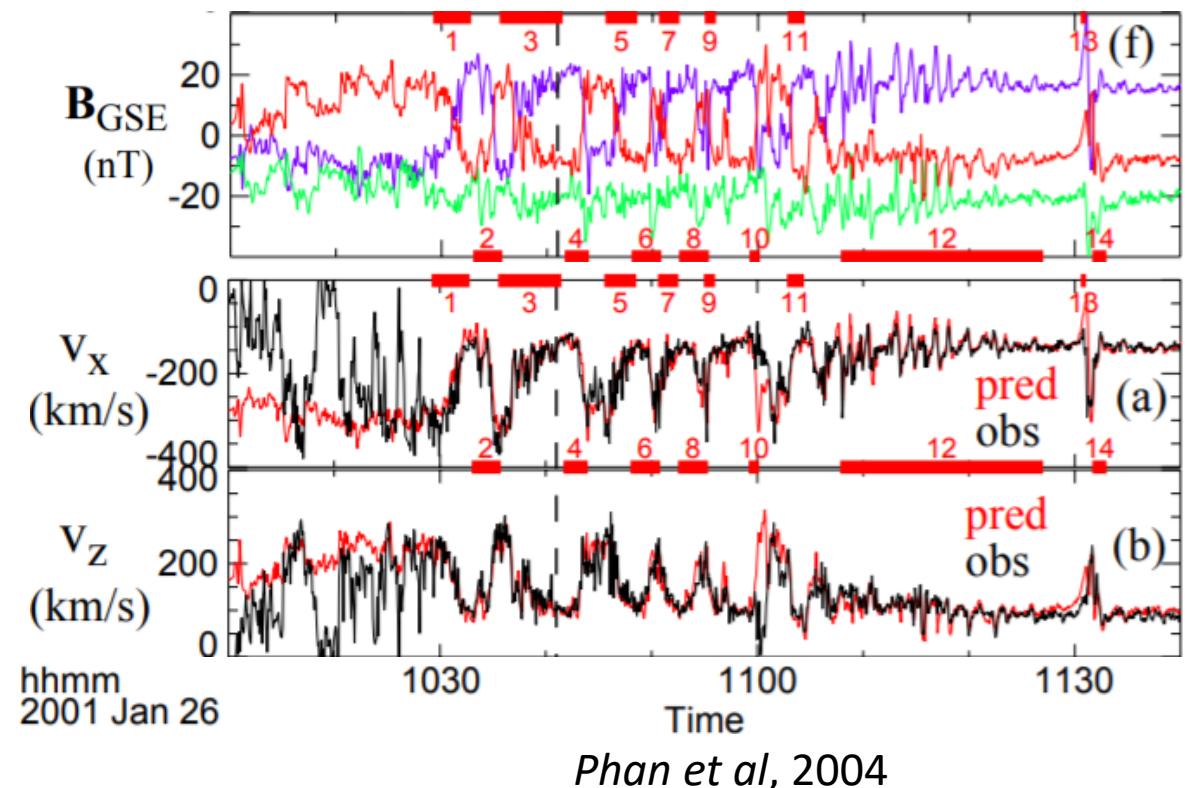
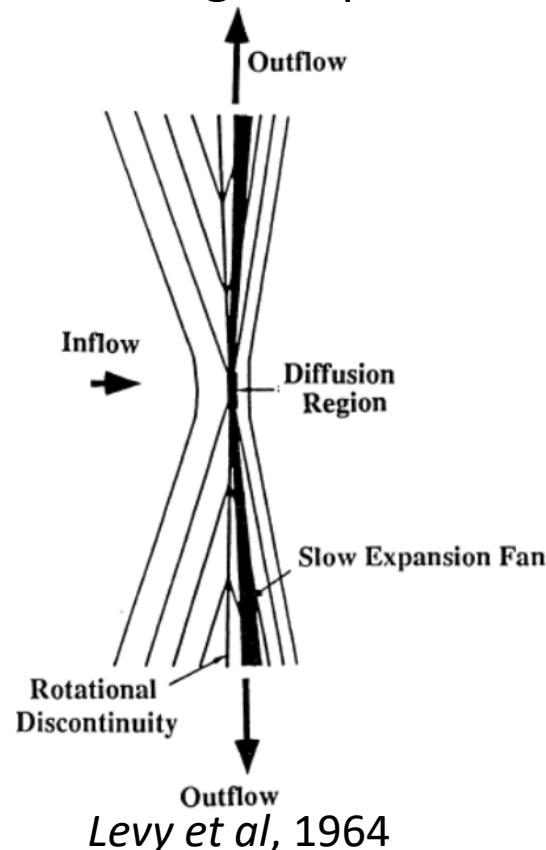


Outline

- Structure of the magnetopause
 - Location and shape
 - Motion
 - Thickness
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- Dynamics of the magnetopause
 - Magnetic reconnection
 - Signatures of reconnection at high-, mid-, and low-altitudes
 - Outstanding questions
 - Kelvin-Helmholtz Instability

Magnetic reconnection

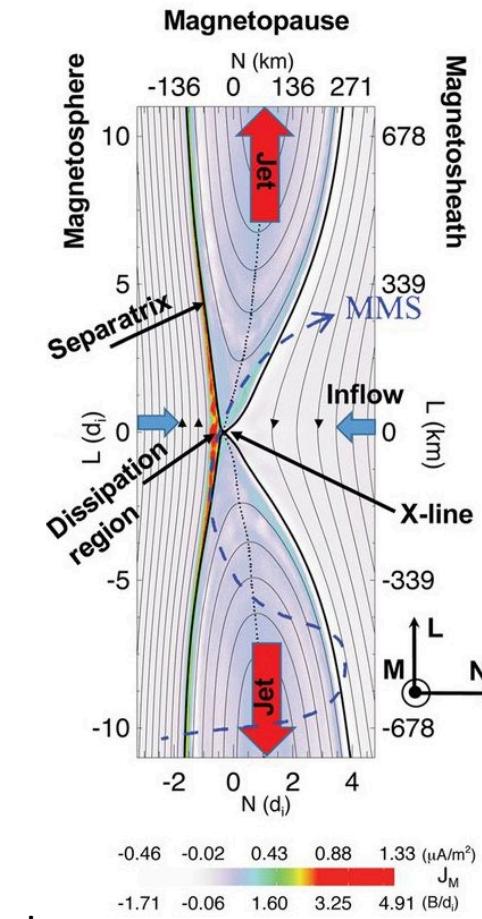
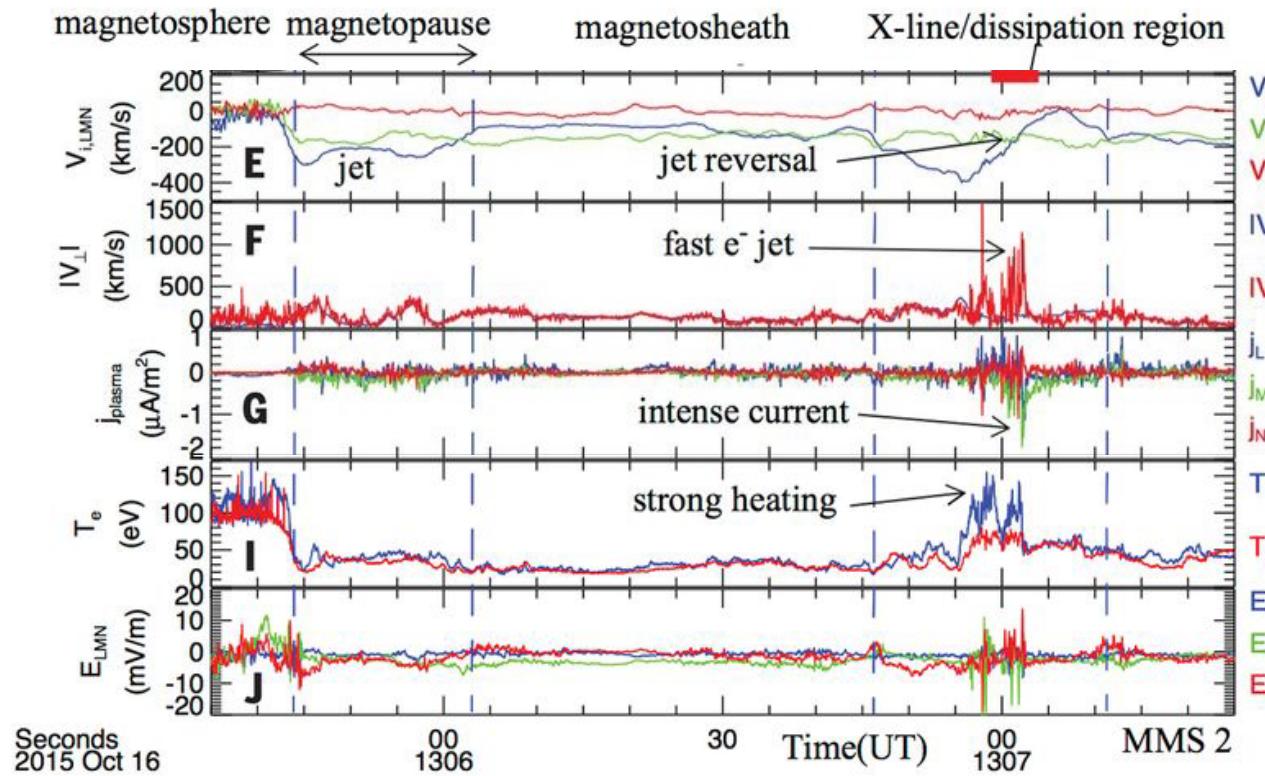
- Signature at the magnetopause: Jetting of plasma (>99% of reconnection encounters)



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Magnetic reconnection

- Signature at the magnetopause: diffusion region (rare encounters)

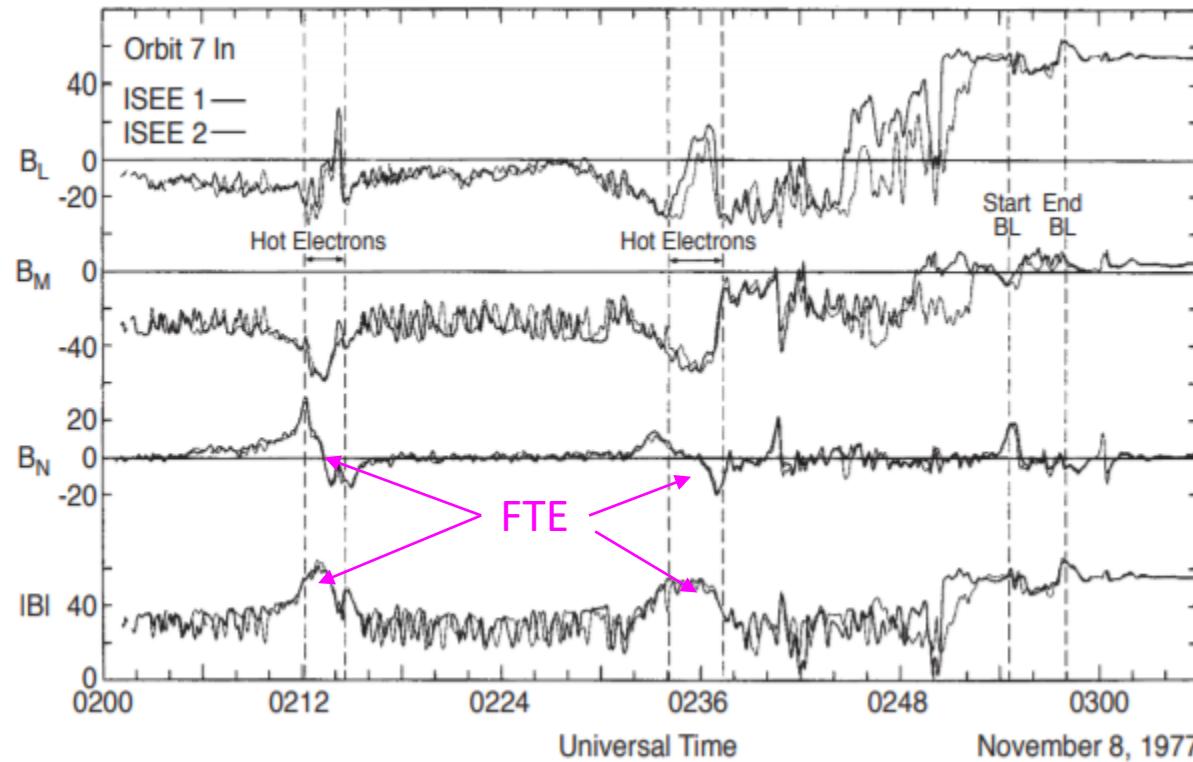


Burch et al, 2016

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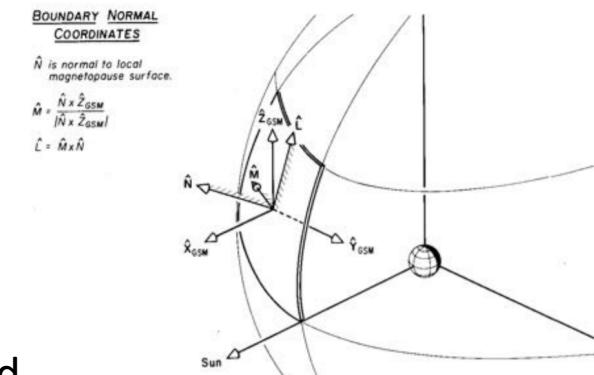
Magnetic reconnection

- Signature at the magnetopause: Flux Transfer Events (FTEs)



Russell and Elphic, 1979

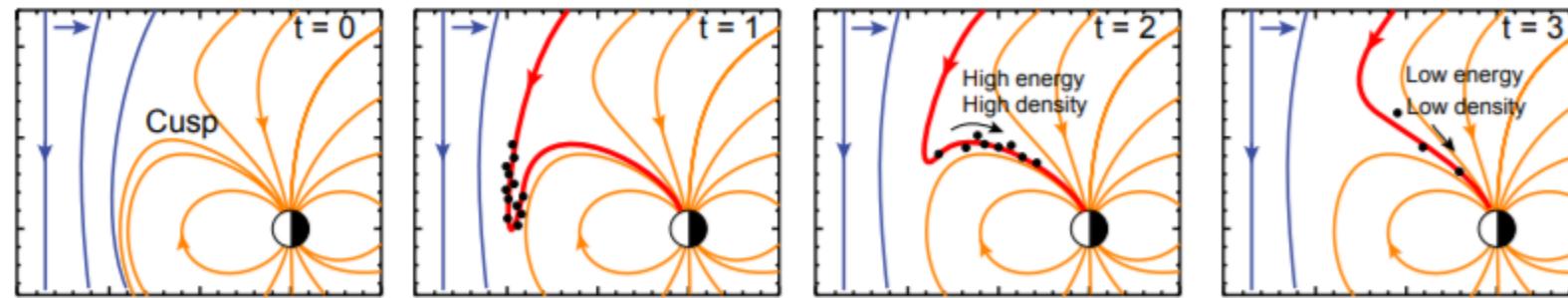
- Bipolar variation in the magnetic field normal to the magnetopause
- Enhancement in the magnetic field strength
- Mixing of plasma from either side of the magnetopause



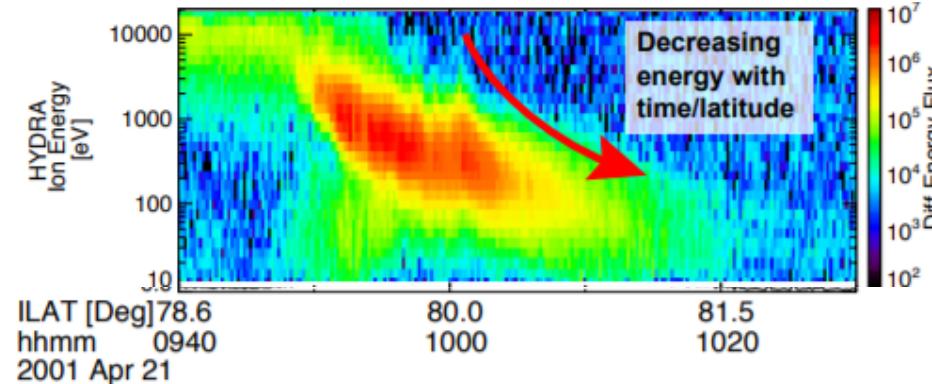
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Magnetic reconnection

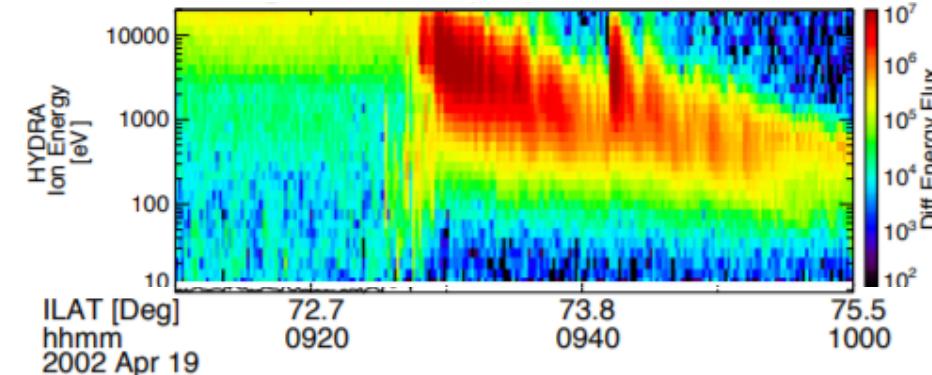
- Signature at mid-altitude: cusp ion steps



Steady reconnection



Time-varying or patchy reconnection

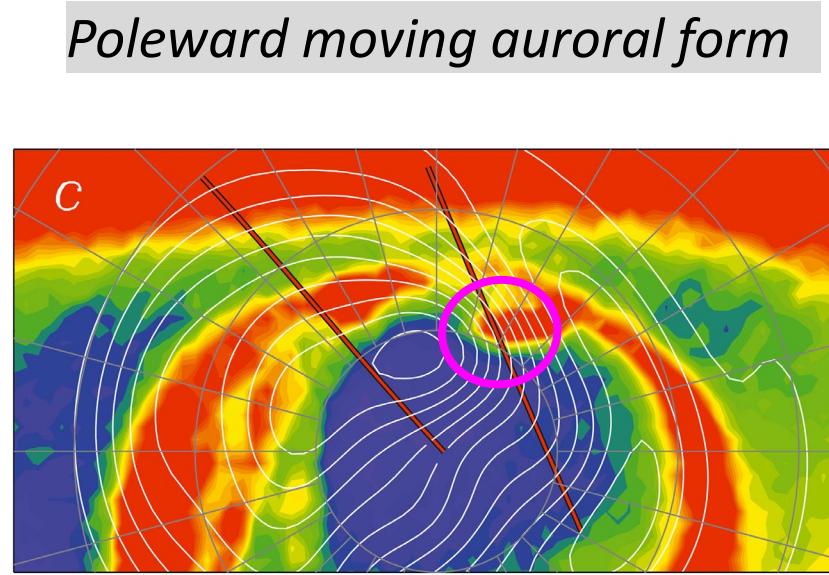
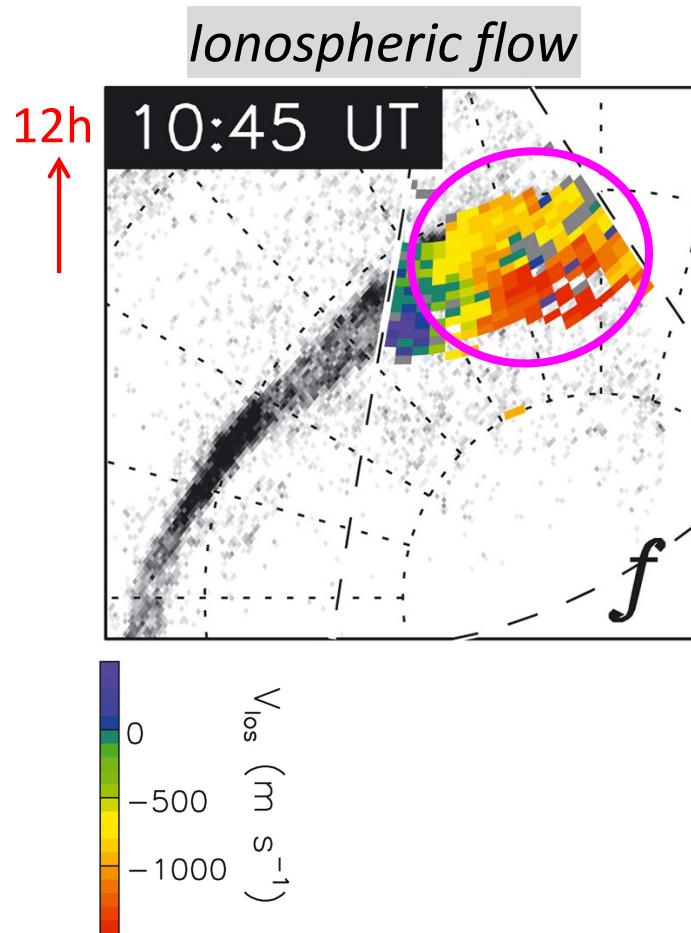


Branduardi-Raymont et al., 2016

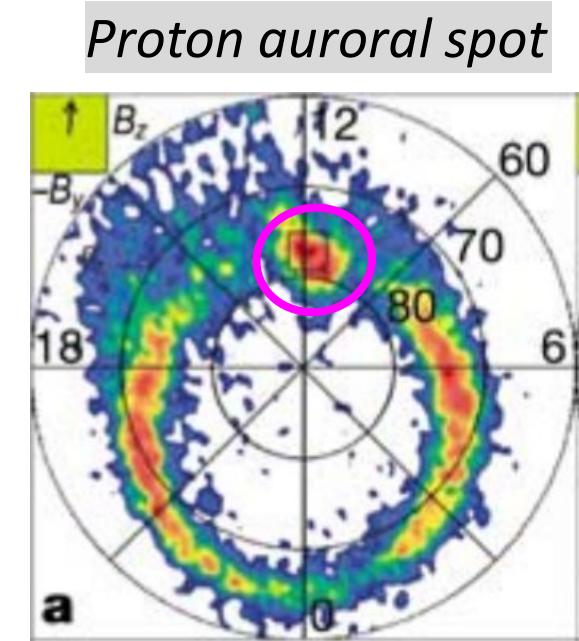
This presentation is being recorded

Magnetic reconnection

- Signature at low-altitude: ionospheric flows and auroras



Milan et al. 2016



Frey et al. 2003

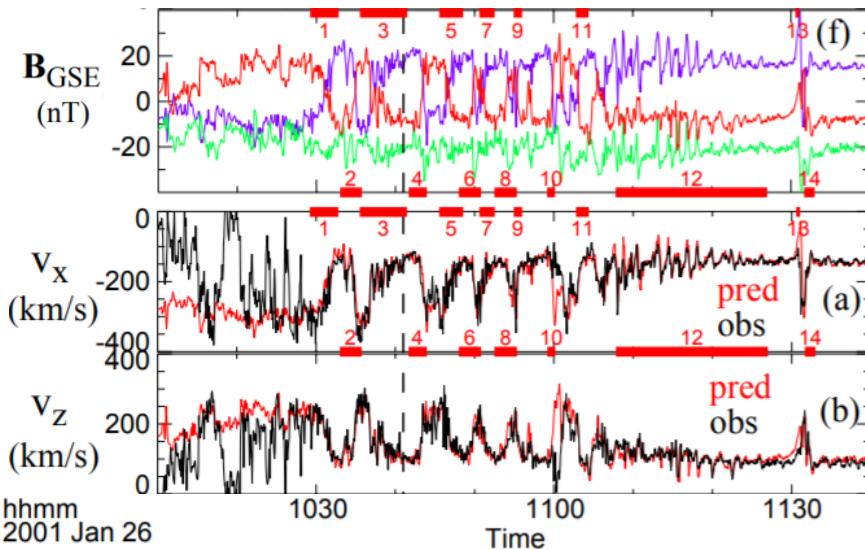
Magnetic reconnection

- Outstanding question
- Is reconnection intrinsically intermittent, continuous, or even quasi-steady?
 - *Intermittent: reconnection turns on and off.*
 - *Continuous: reconnection may operate at a variable rate but never cease.*
 - *Quasi-steady: fluctuation of reconnection rate, if present, is a small fraction of the average rate.*

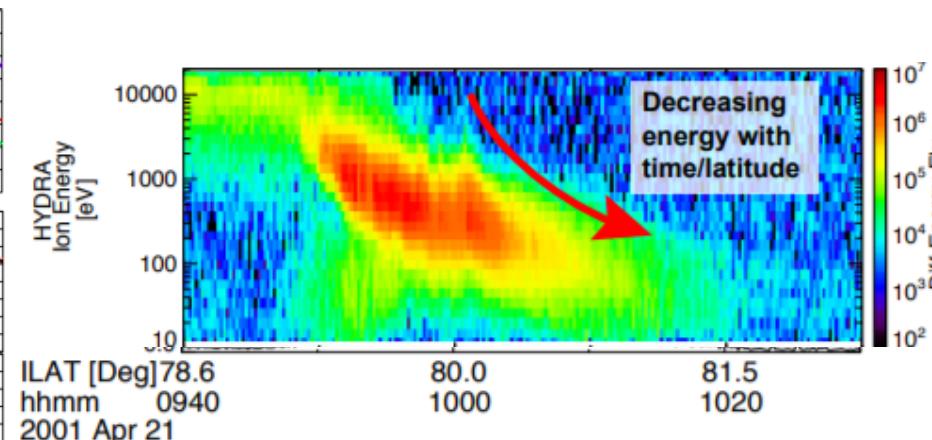
Magnetic reconnection

- Outstanding question

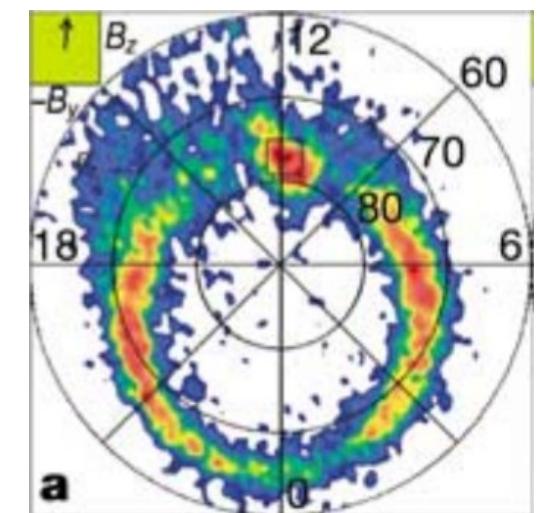
Continuous (or even steady) reconnection



Phan et al., 2004



Branduardi-Raymont et al., 2016

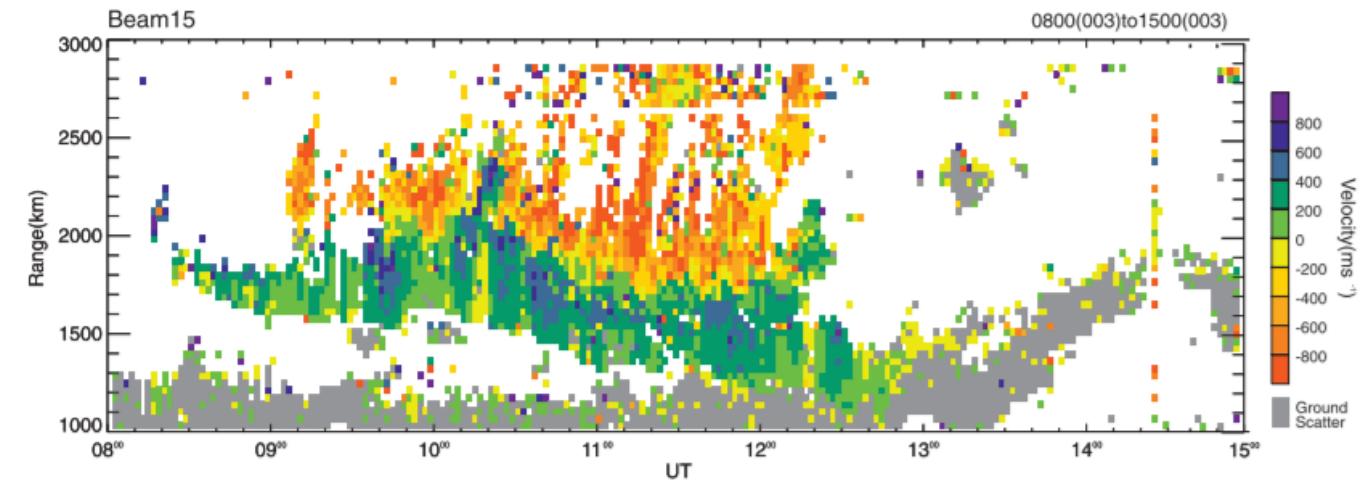
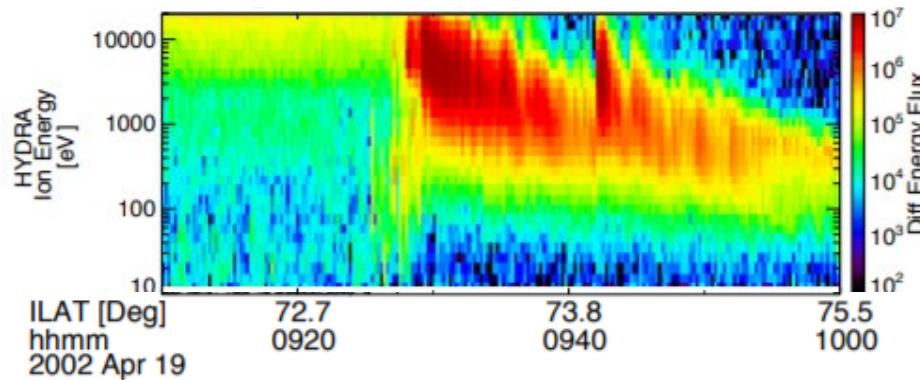


Frey et al., 2003

Magnetic reconnection

- Outstanding question

Intermittent reconnection

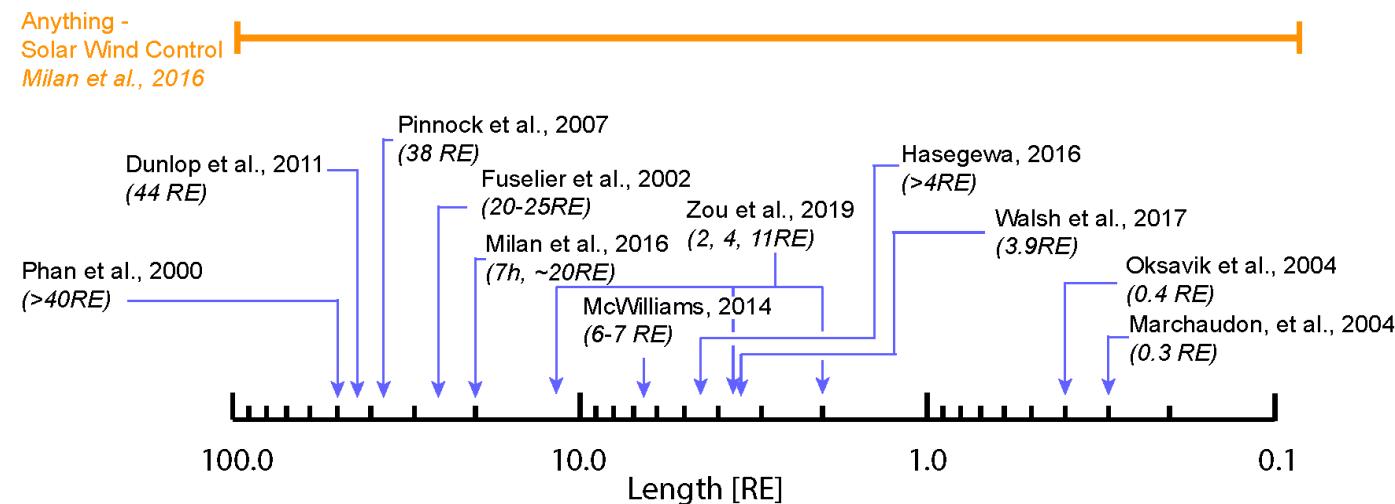


Branduardi-Raymont et al., 2016

McWilliams et al., 1999

Magnetic reconnection

- Outstanding question
- Is reconnection spatially extended, or patchy? What controls the extent of reconnection?

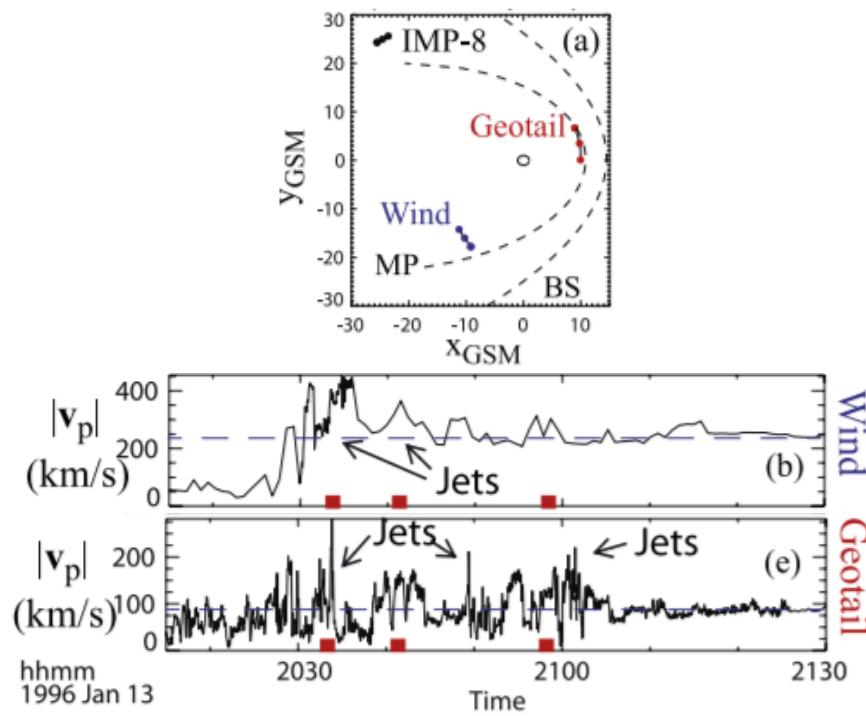


Courtesy : B. Walsh

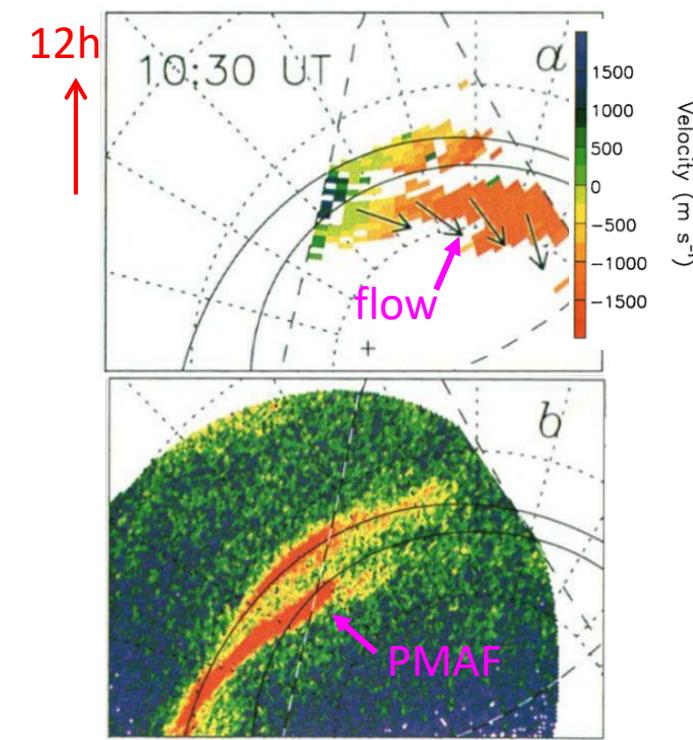
Magnetic reconnection

- Outstanding question

Extended reconnection



Phan et al. 2006

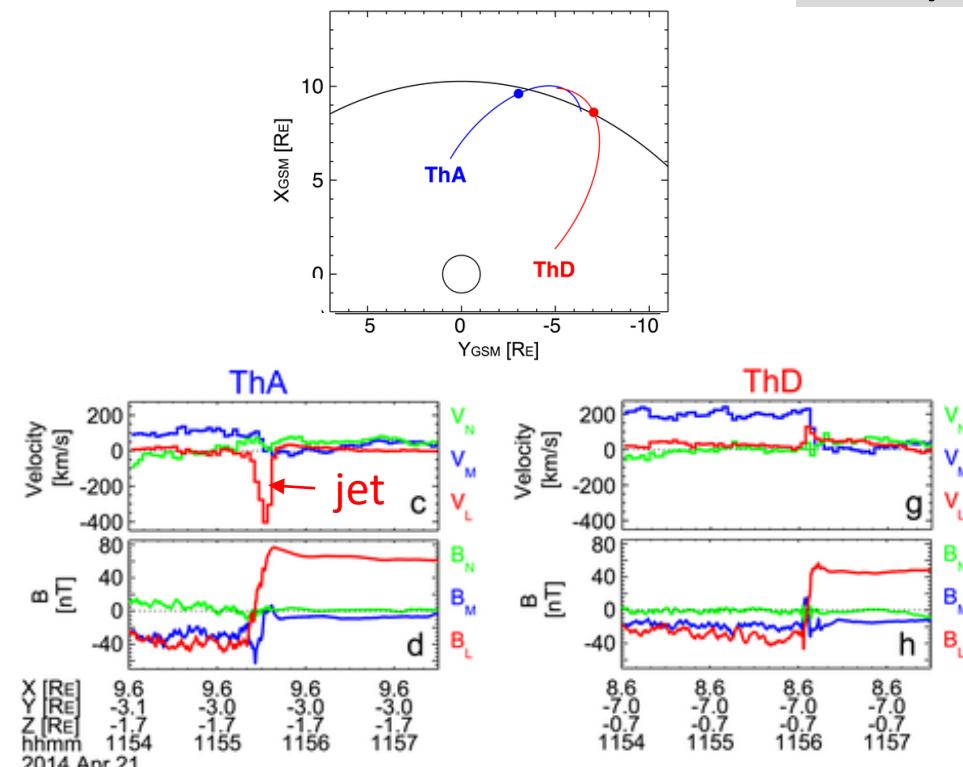


Milan et al. 2000

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Magnetic reconnection

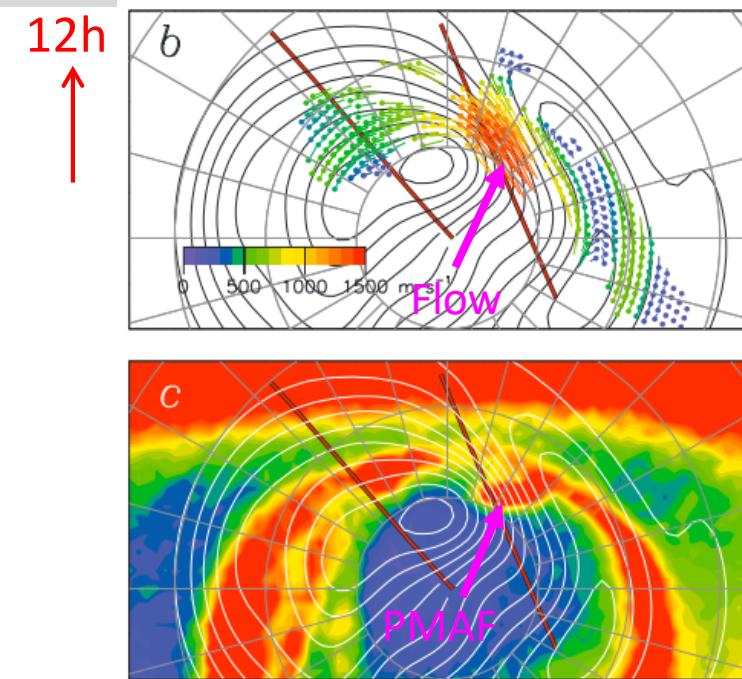
- Outstanding question



Walsh et al., 2017

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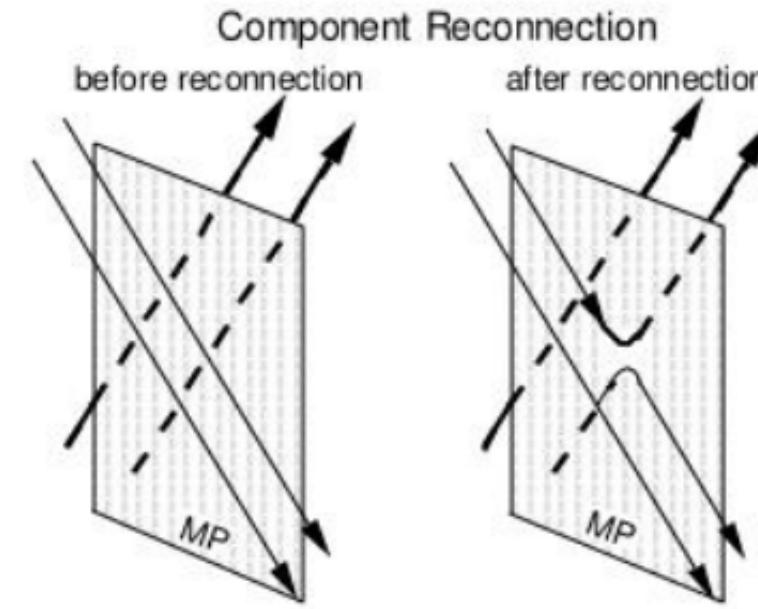
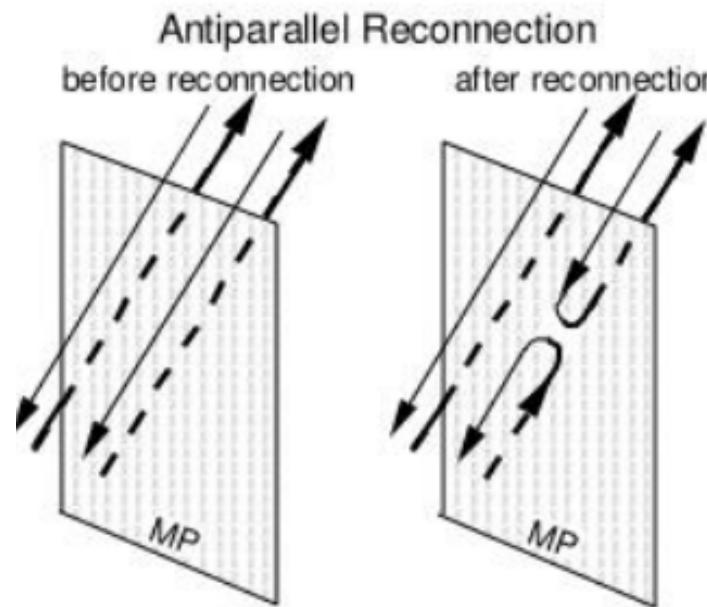
Patchy reconnection



Milan et al., 2016

Magnetic reconnection

- Outstanding question
- Does the global configuration of reconnection follow ‘component merging’ or ‘anti-parallel merging’?

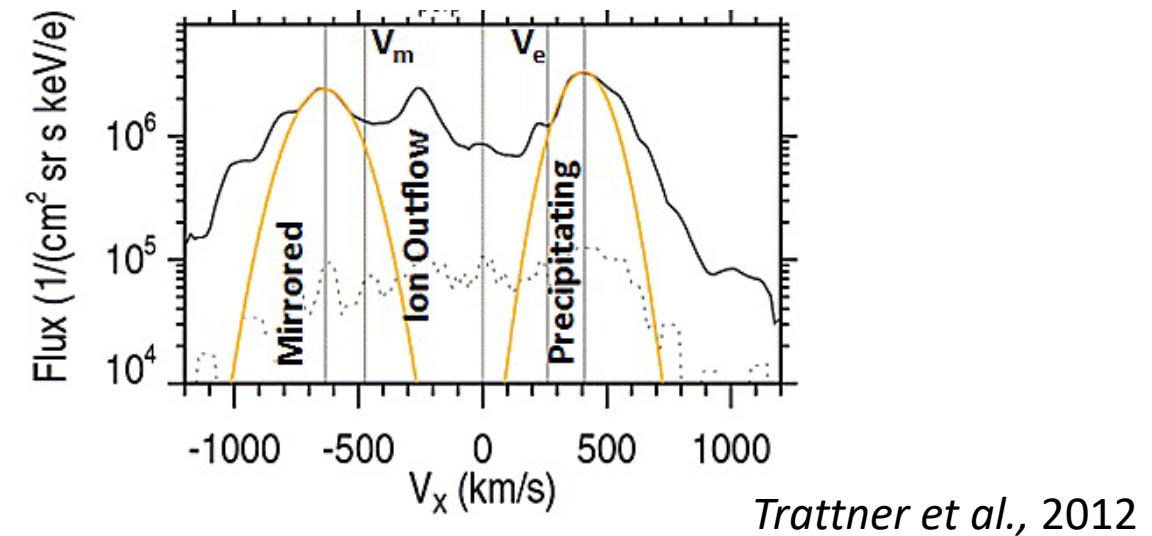
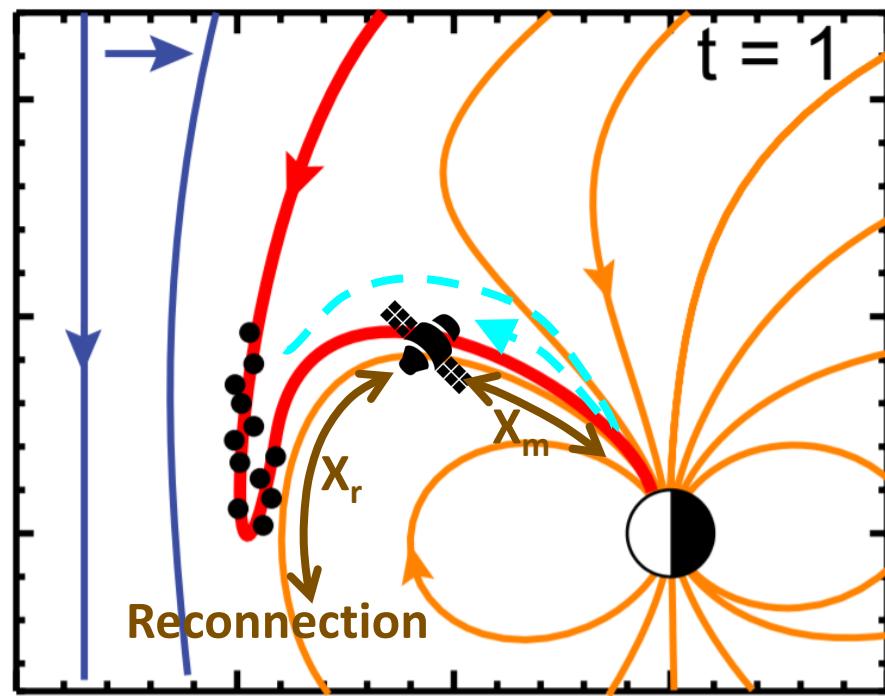


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Courtesy: K. J. Trattner

Magnetic reconnection

- Outstanding question



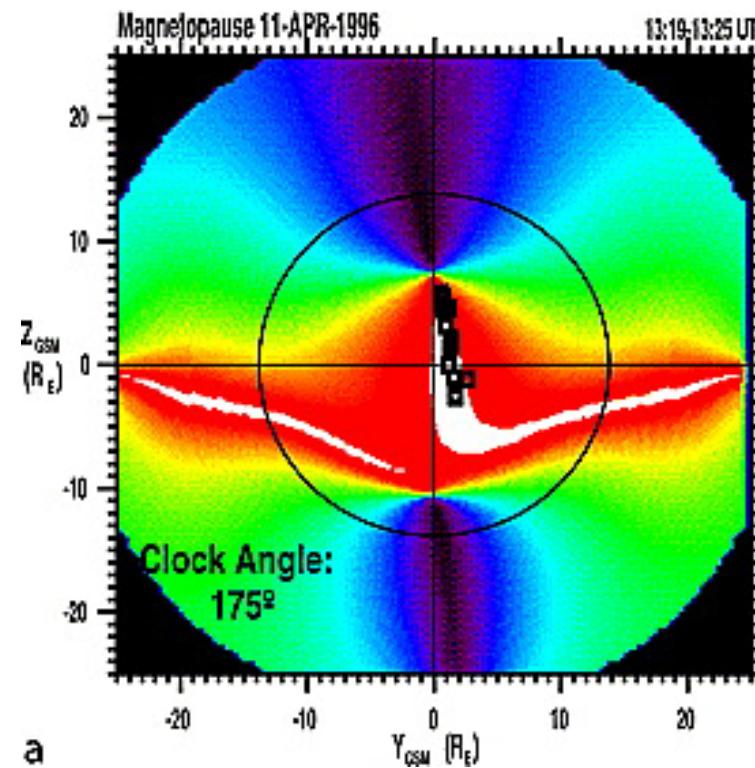
$$\frac{X_r}{V_e} = \frac{X_r + 2X_m}{V_m} \rightarrow \frac{X_r}{X_m} = \frac{2V_e}{V_m - V_e}$$

Onsager et al., 1990

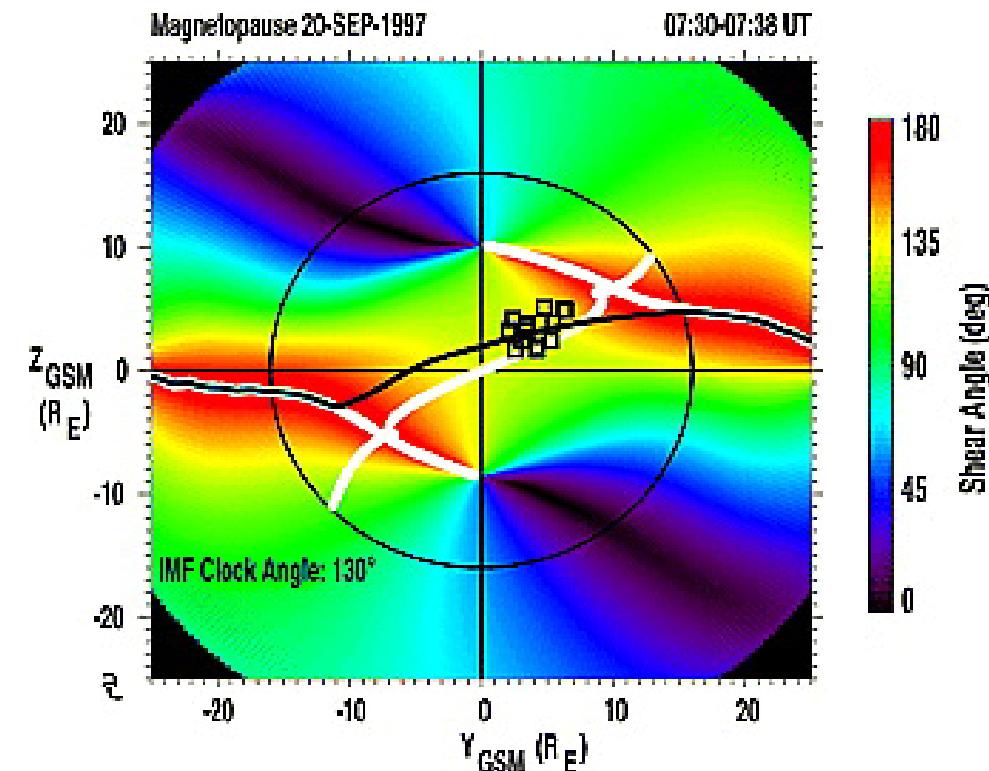
Magnetic reconnection

- Outstanding question

Antiparallel reconnection



Component reconnection



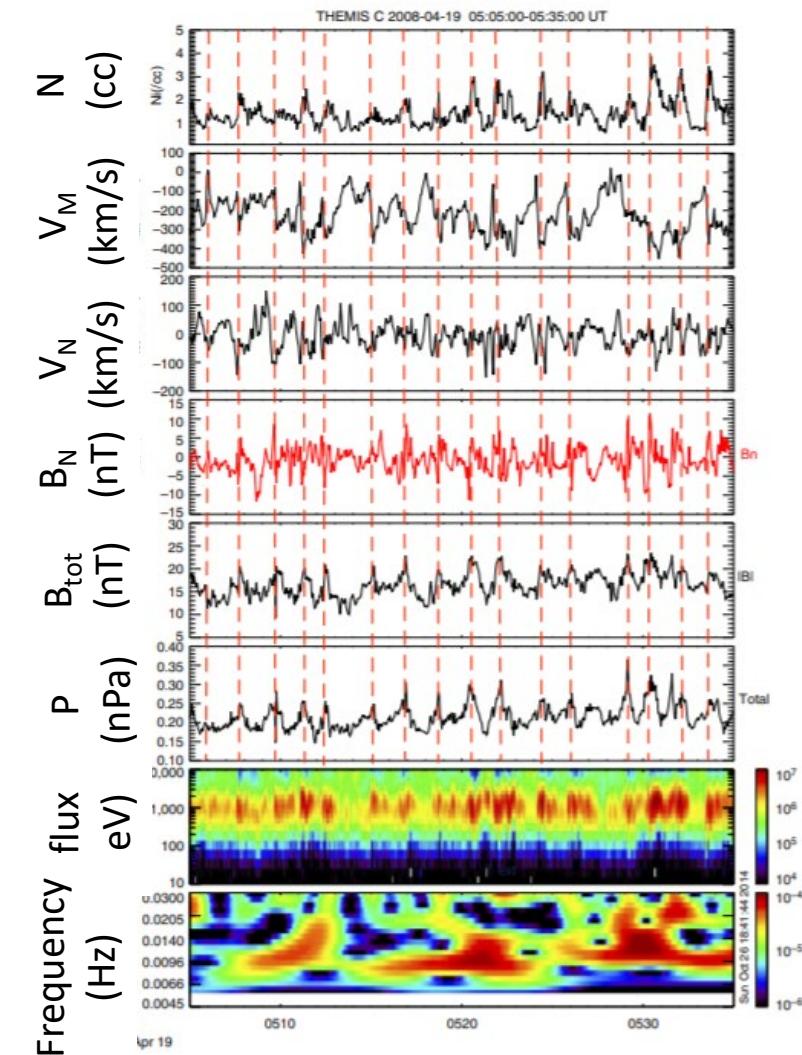
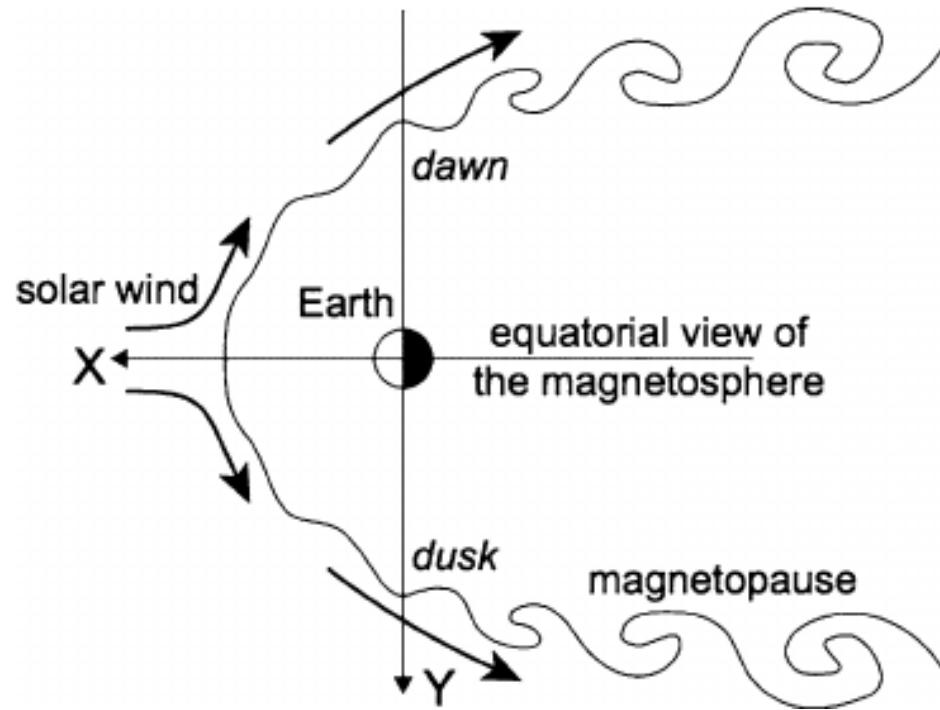
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Trattner et al., 2007 24

Outline

- Structure of the magnetopause
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 - Open questions
 - Kelvin-Helmholtz Instability

Kelvin-Helmholtz Instability

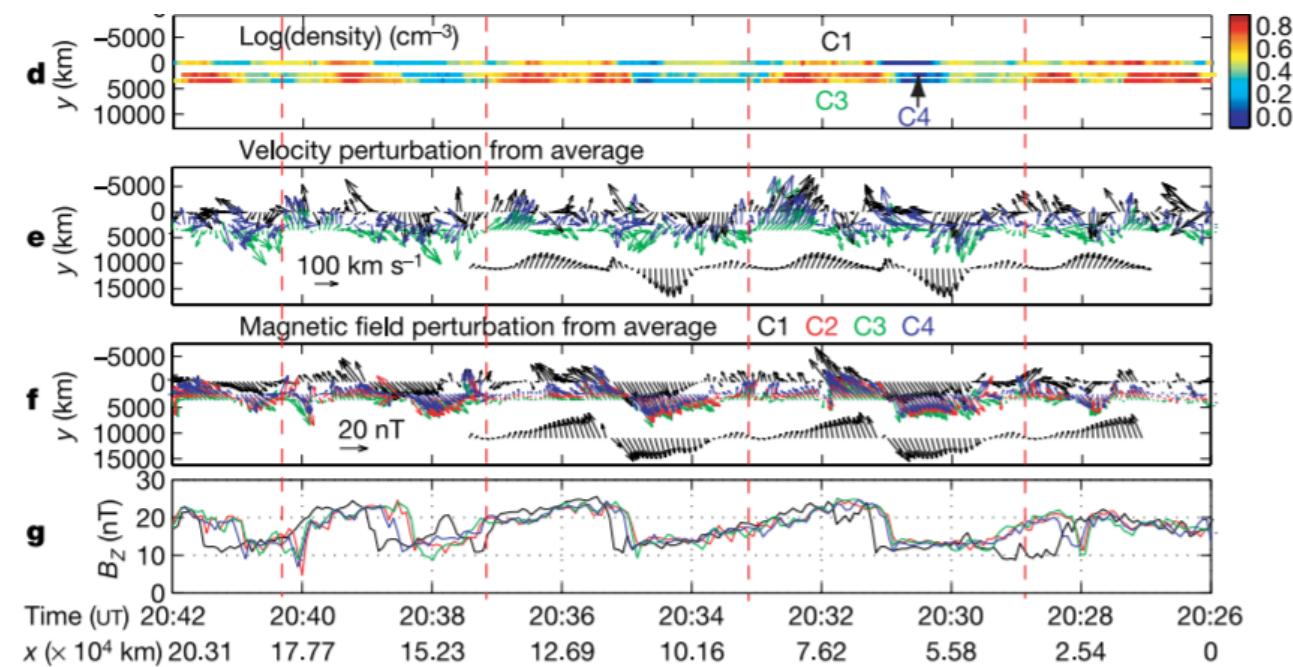
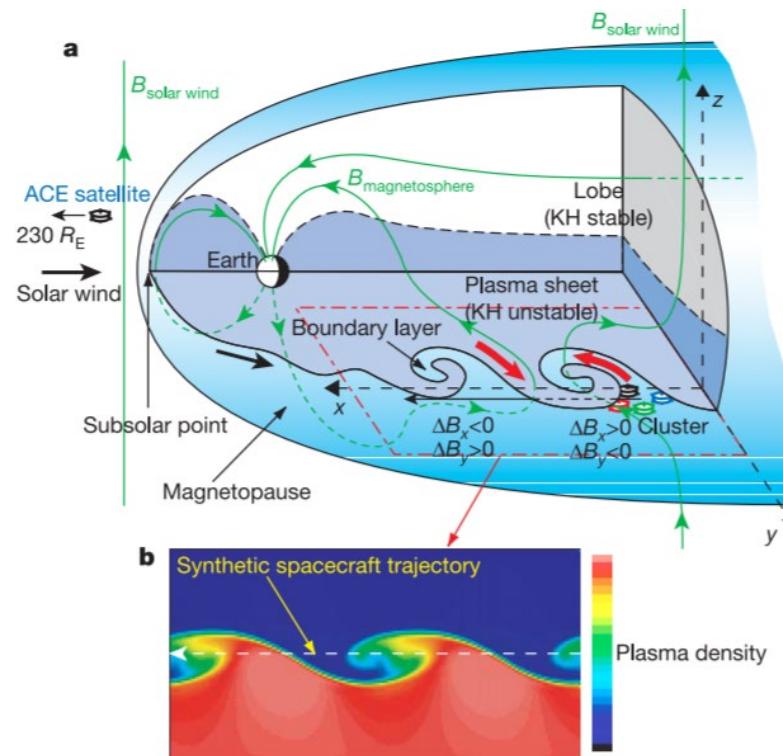


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Kavosi and Raeder, 2015 26

Kelvin-Helmholtz Instability

Rolled-up Kelvin-Helmholtz Vortices



Hasegawa et al., 2004

Kelvin-Helmholtz Instability

- Outstanding questions
- How does a Kelvin–Helmholtz vortex evolve from birth to collapse?
- Is and how is magnetic reconnection initiated within a Kelvin–Helmholtz vortex?
- Is Kelvin–Helmholtz instability dawn-dusk symmetric or asymmetric?
- What is the relative contribution of the KHI vs. magnetic reconnection to plasma entry for various solar wind conditions?
- ...

Summary

- Structure of the magnetopause
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