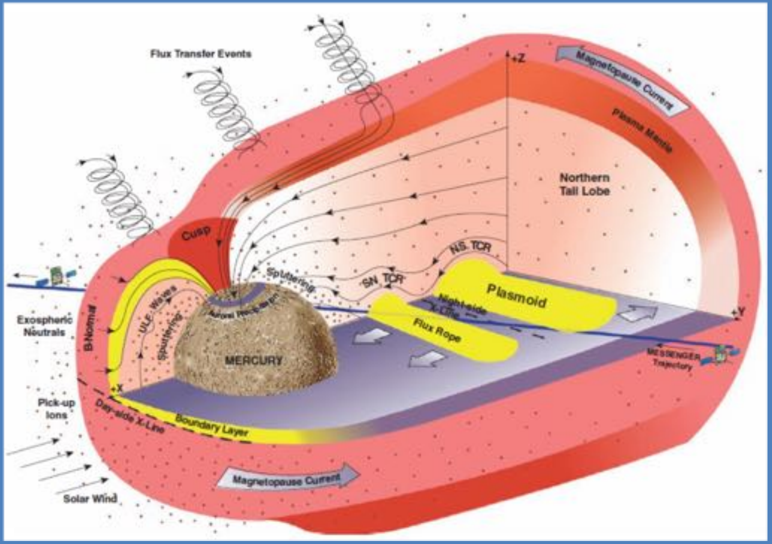
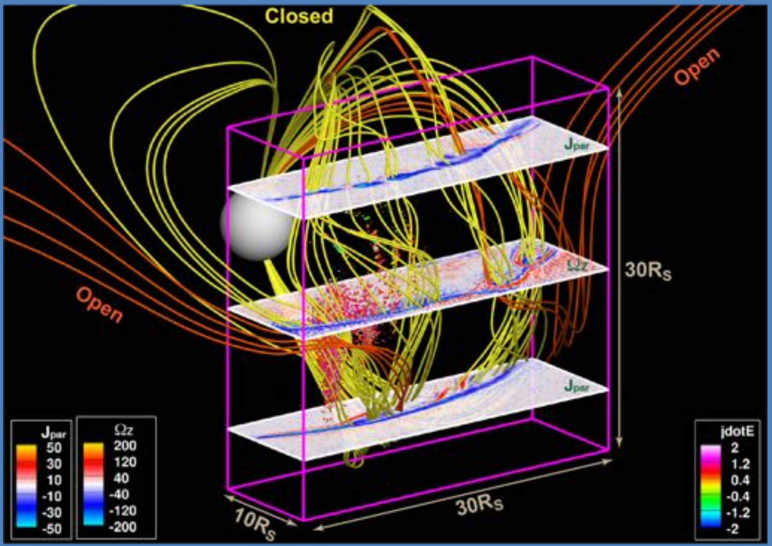


Mercury



Saturn

FLUX TRANSFER EVENTS AT EARTH AND THE OTHER PLANETS

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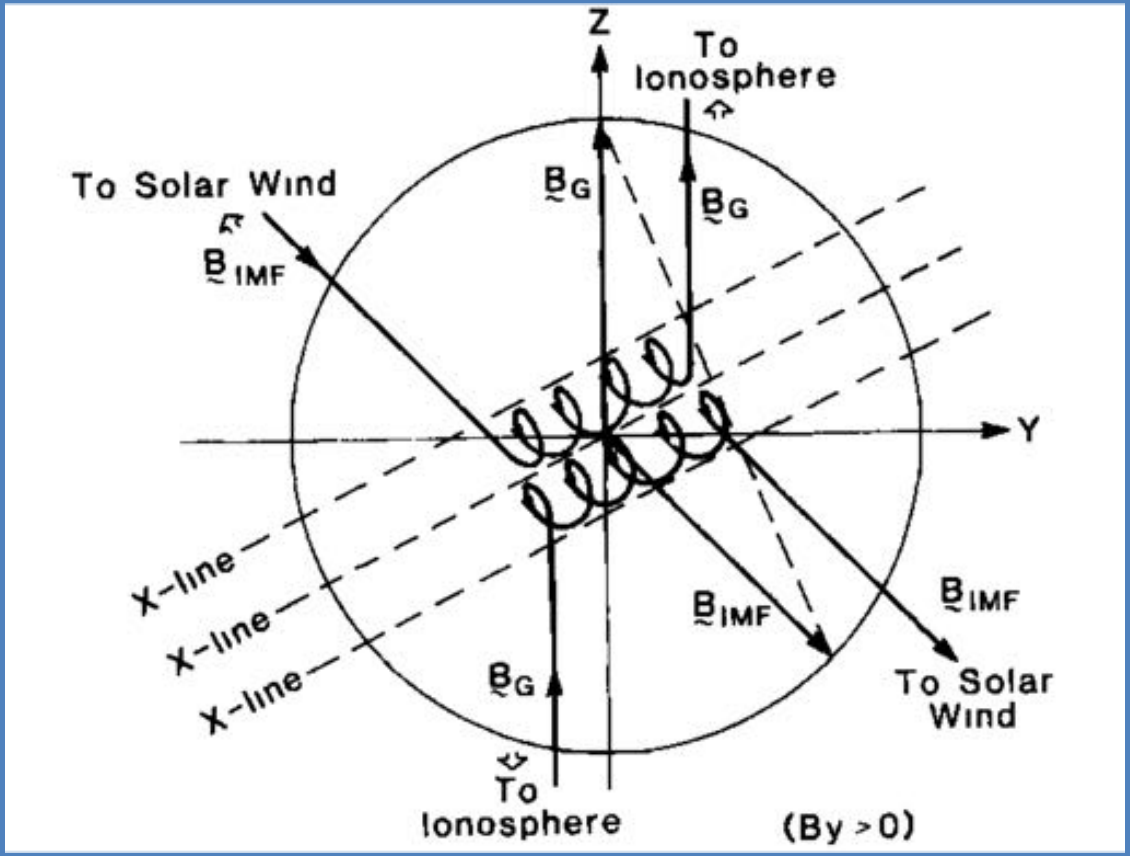
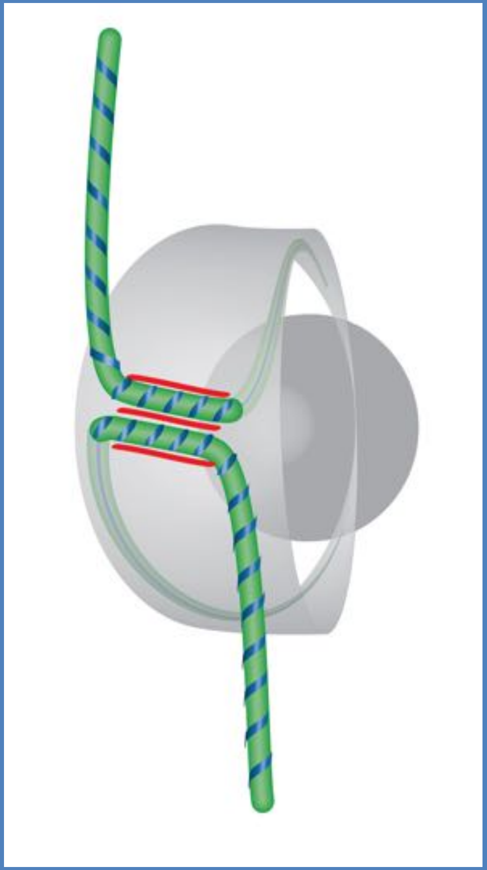
University of Michigan

Planetary Magnetospheres
Lecture #2
Heliophysics Summer School
27 July 2018
Boulder, Colorado

What are Flux Transfer Events (FTEs)?





Lee and Fu (1985)

Imber et al. (2015)

Answer: Open magnetic flux ropes formed by multiple x-line reconnection in the magnetopause current layer

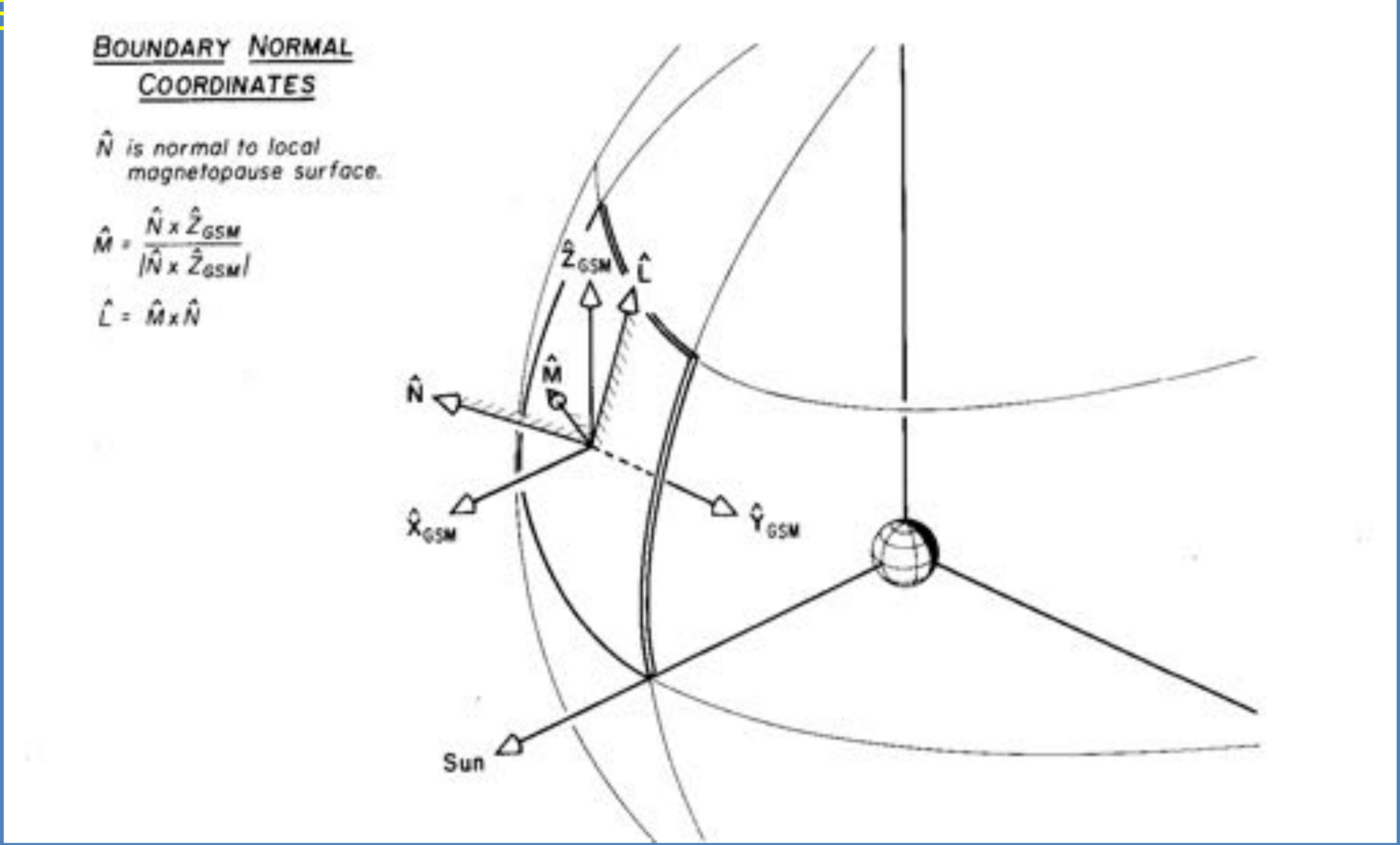
Why study FTEs?

1. Fundamental plasma physics – for example, is reconnection onset due to a "plasmoid-instability?"

2. Plasma injection into magnetospheric cusps and the plasma mantle.

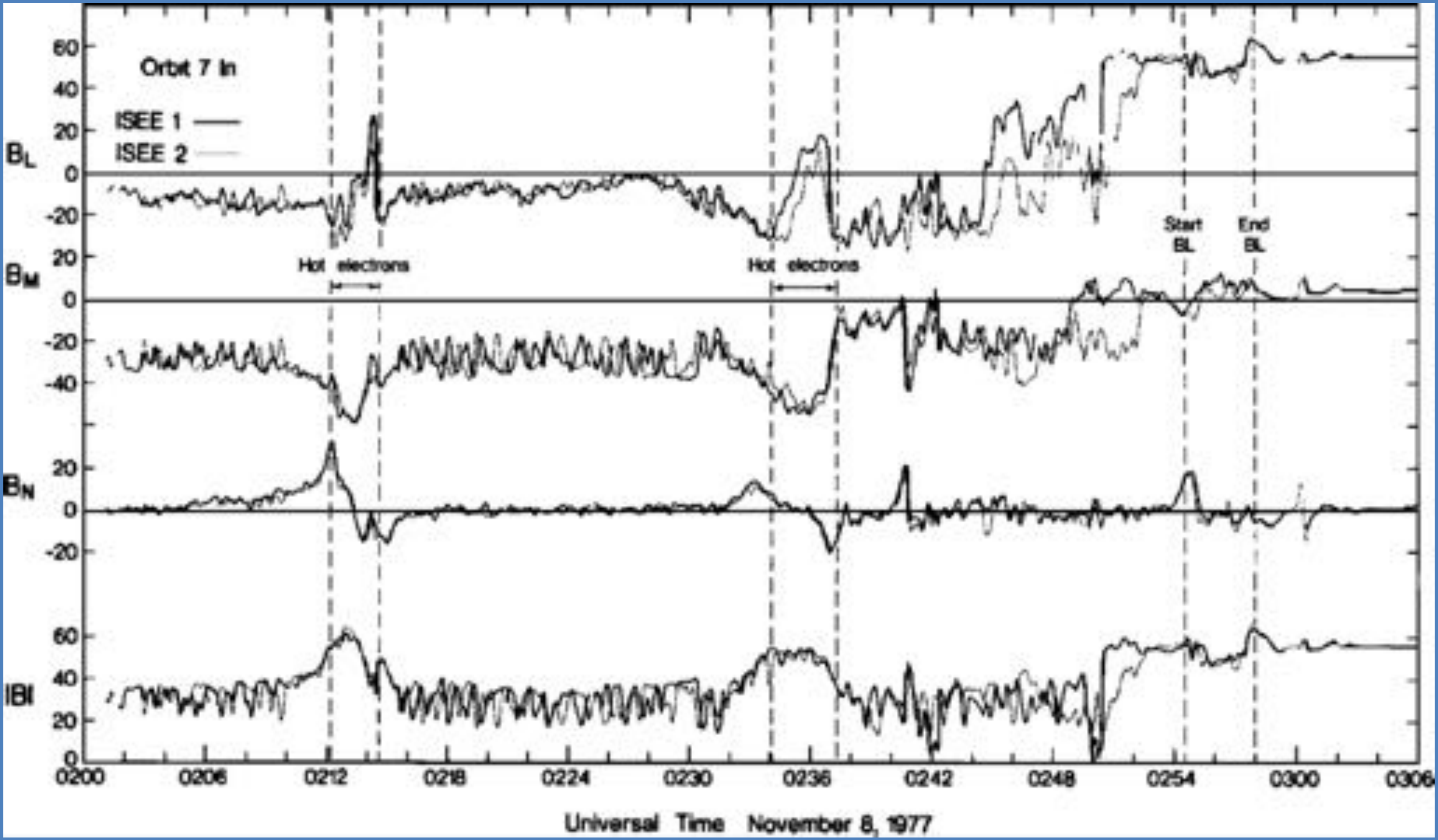
3. Magnetic flux circulation in planetary magnetospheres

How were FTEs discovered?



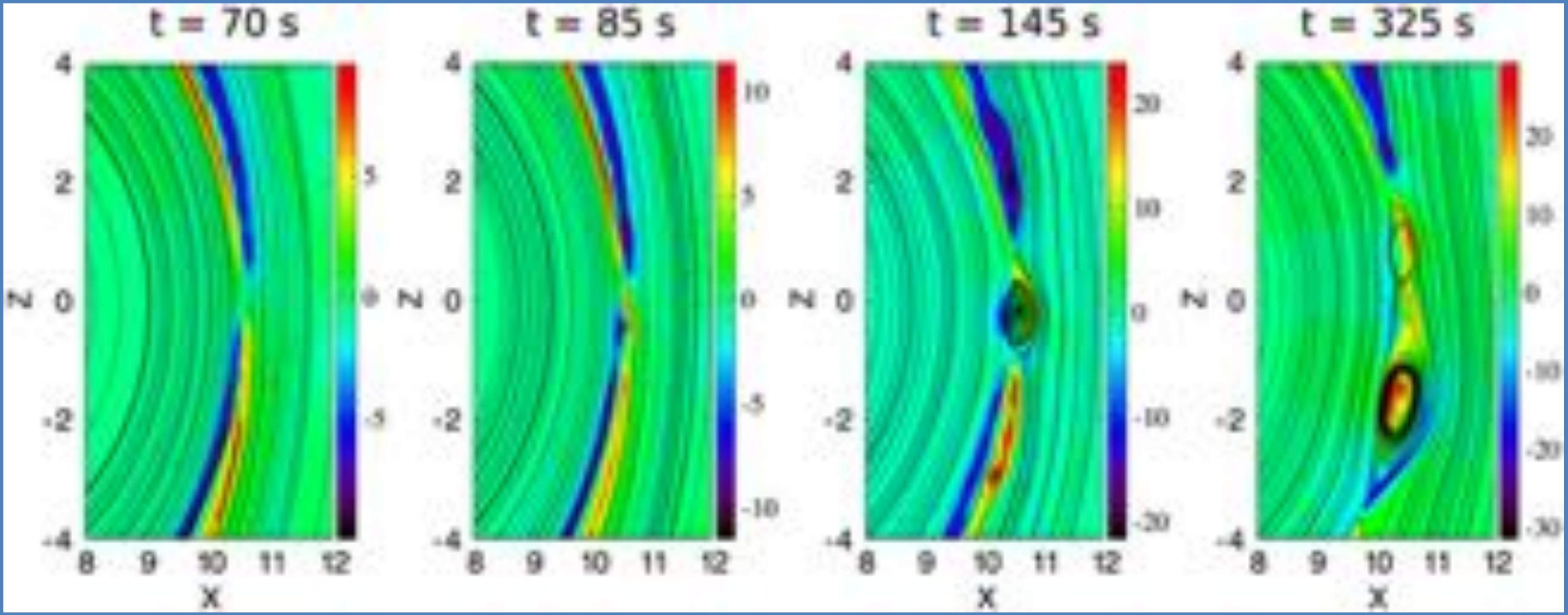
Berchem and Russell 1982

Initial FTE Observations by ISEE 1/2



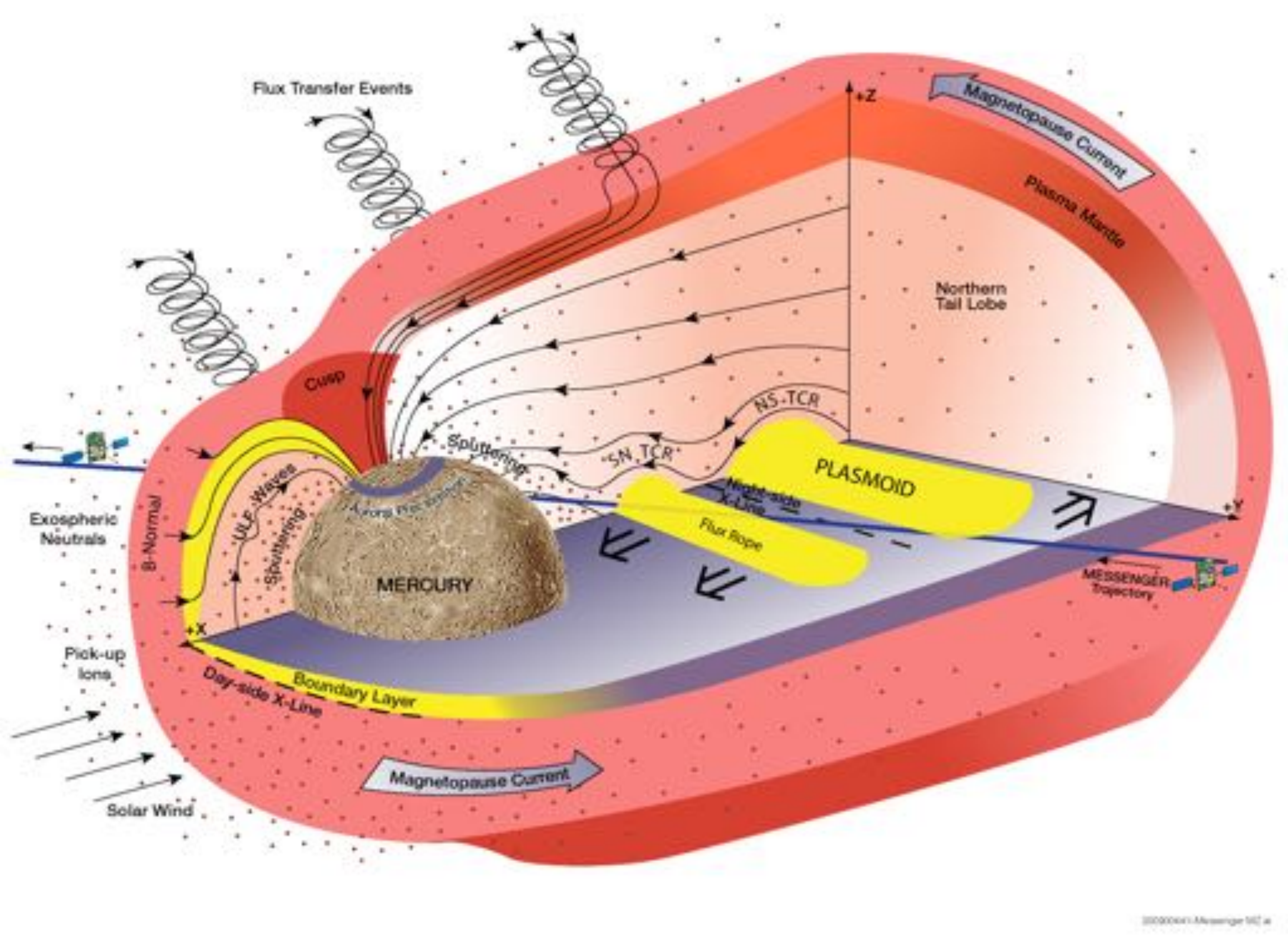
Russell and Elphic (1979)

EPIC Global MHD Embedded PIC Simulation

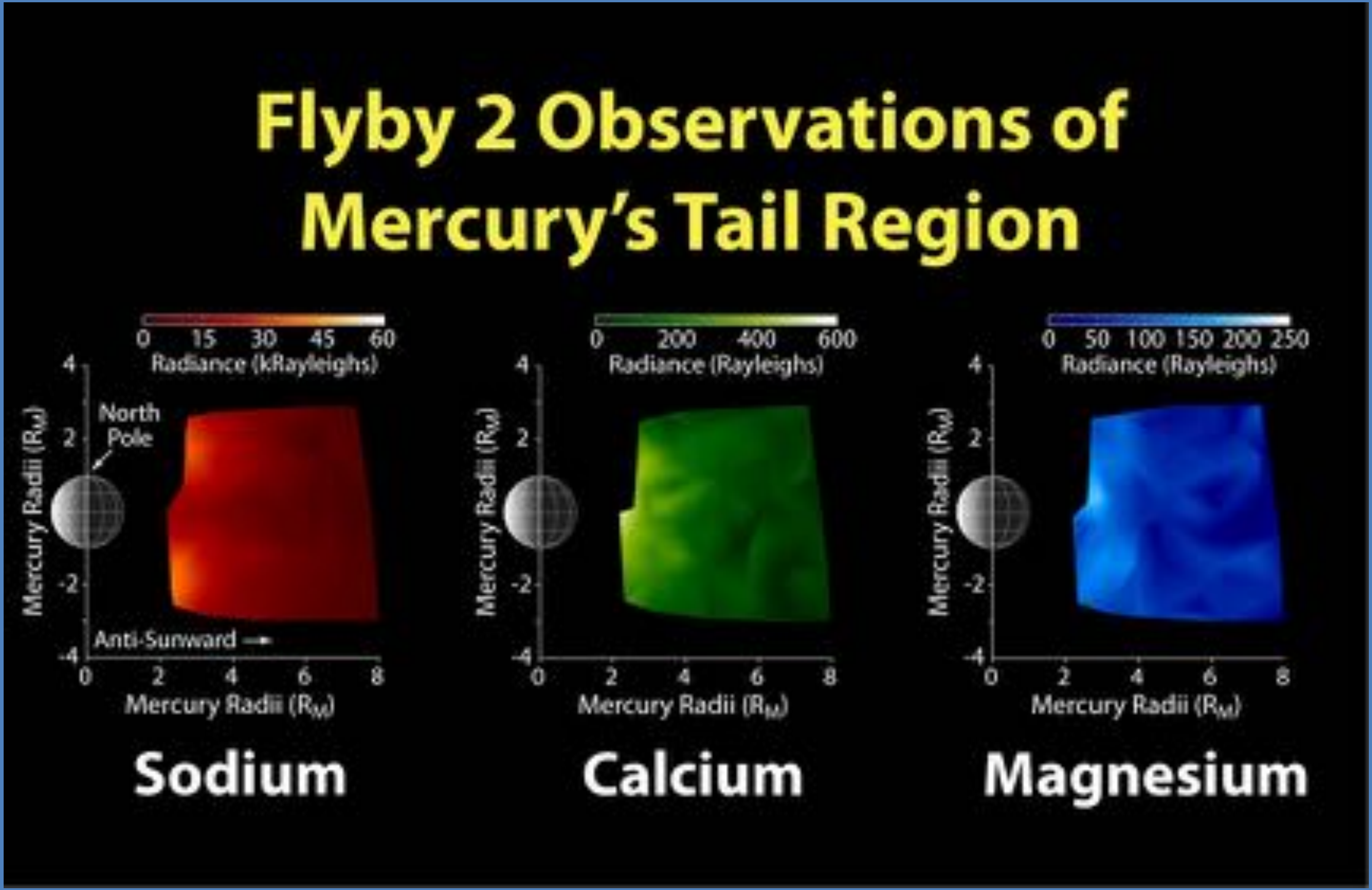


Chen et al. (2017)

Mercury

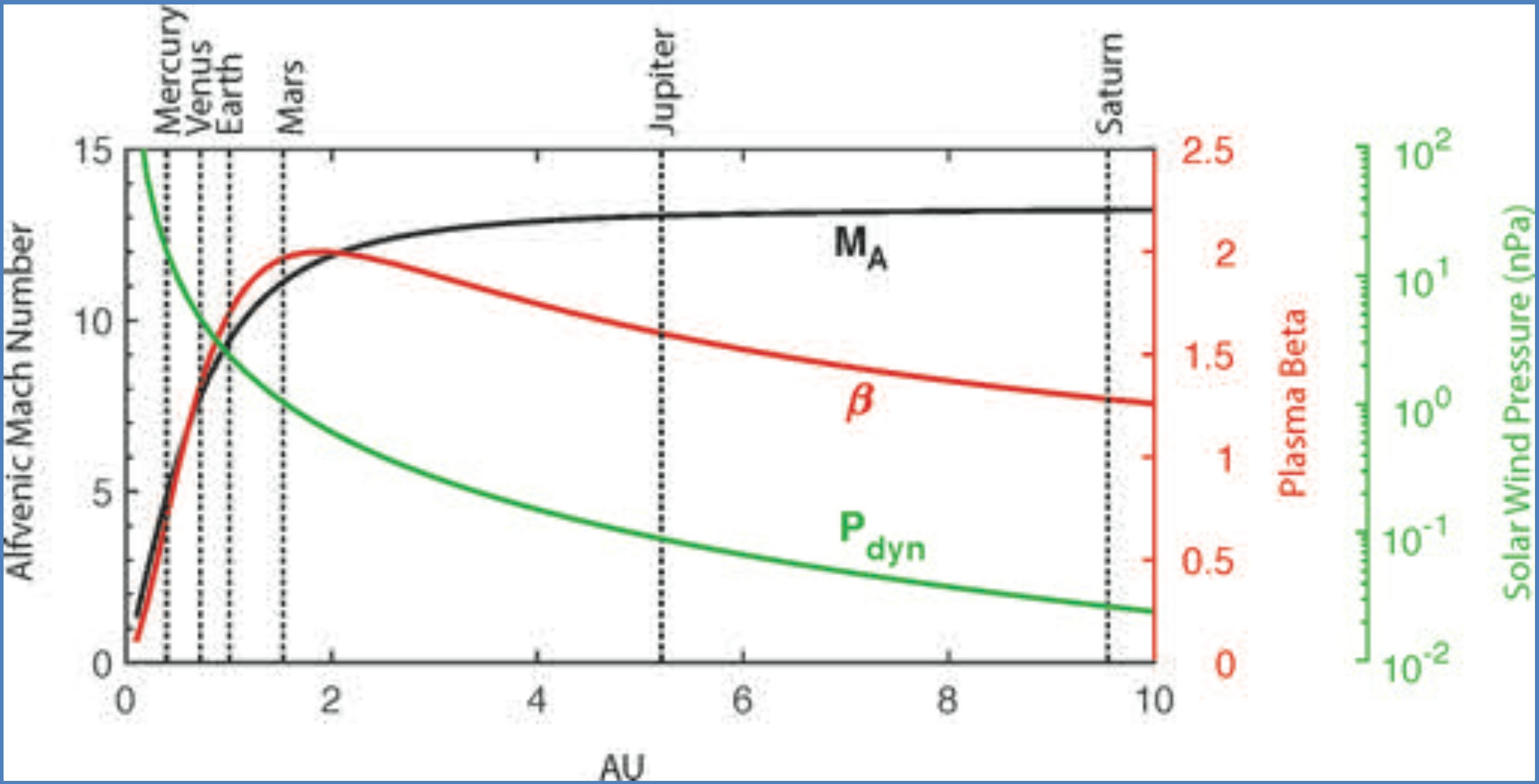


Slavin et al. (2009)



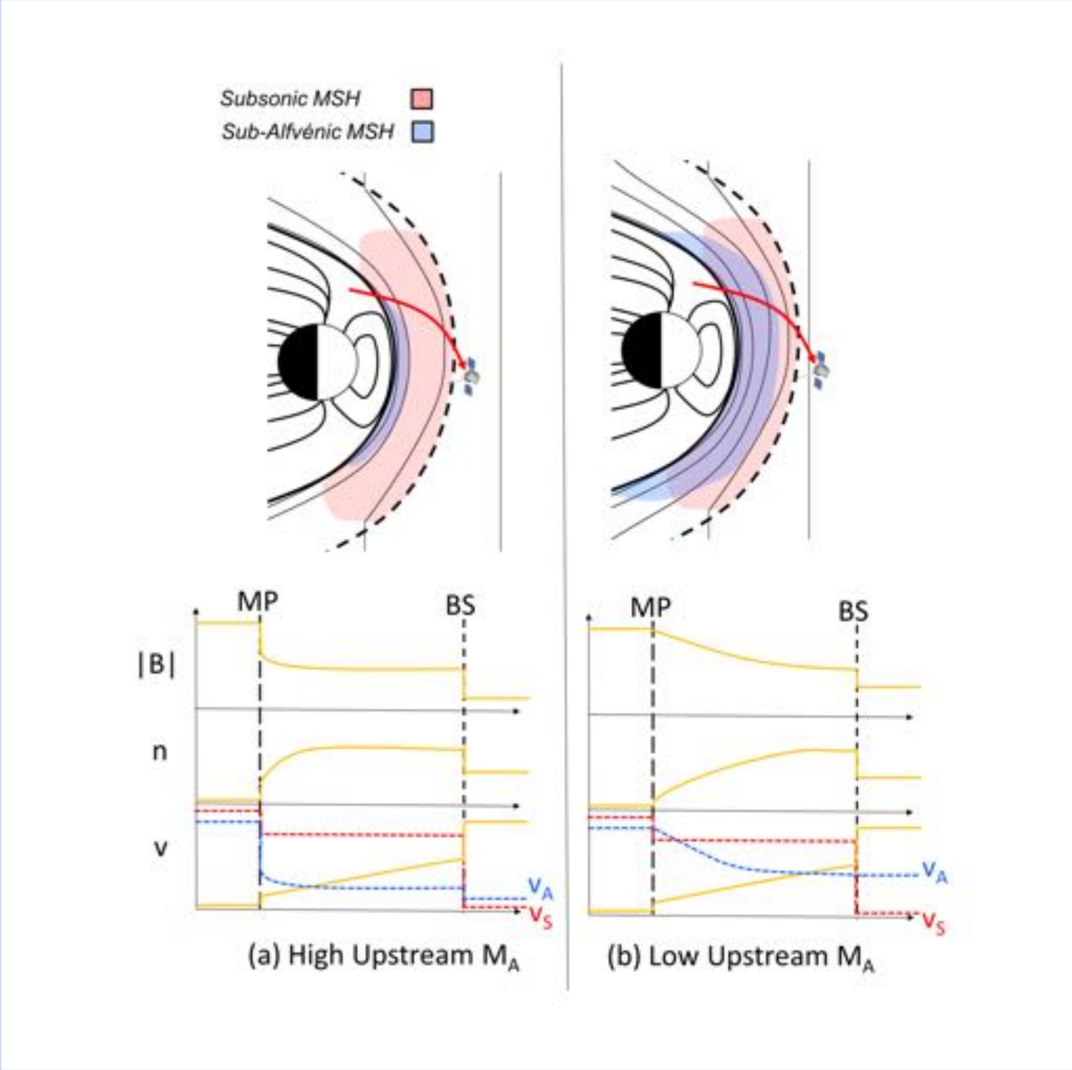
McClintock et al. (2009)

Radial Variation in the Solar Wind



Slavin and Holzer (1981)

Low M_A at 0.3 AU: Thick Plasma Depletion Layers

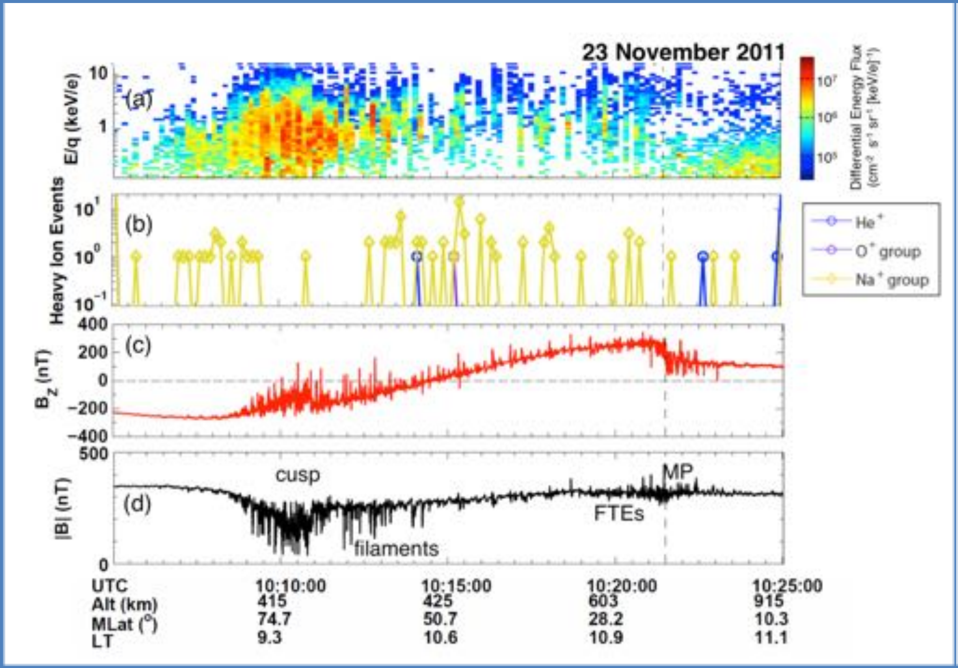


(a) High Upstream M_A (b) Low Upstream M_A

Gershman et al. [2013]

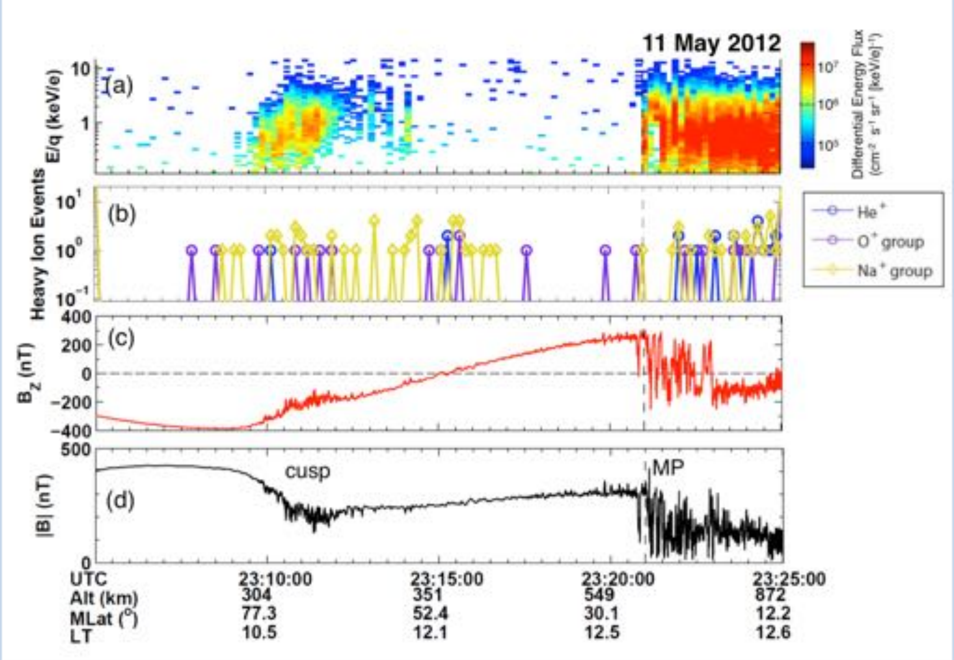
Reconnection at Mercury is typically "Symmetric"

Symmetric Reconnection



Coronal Mass Ejection

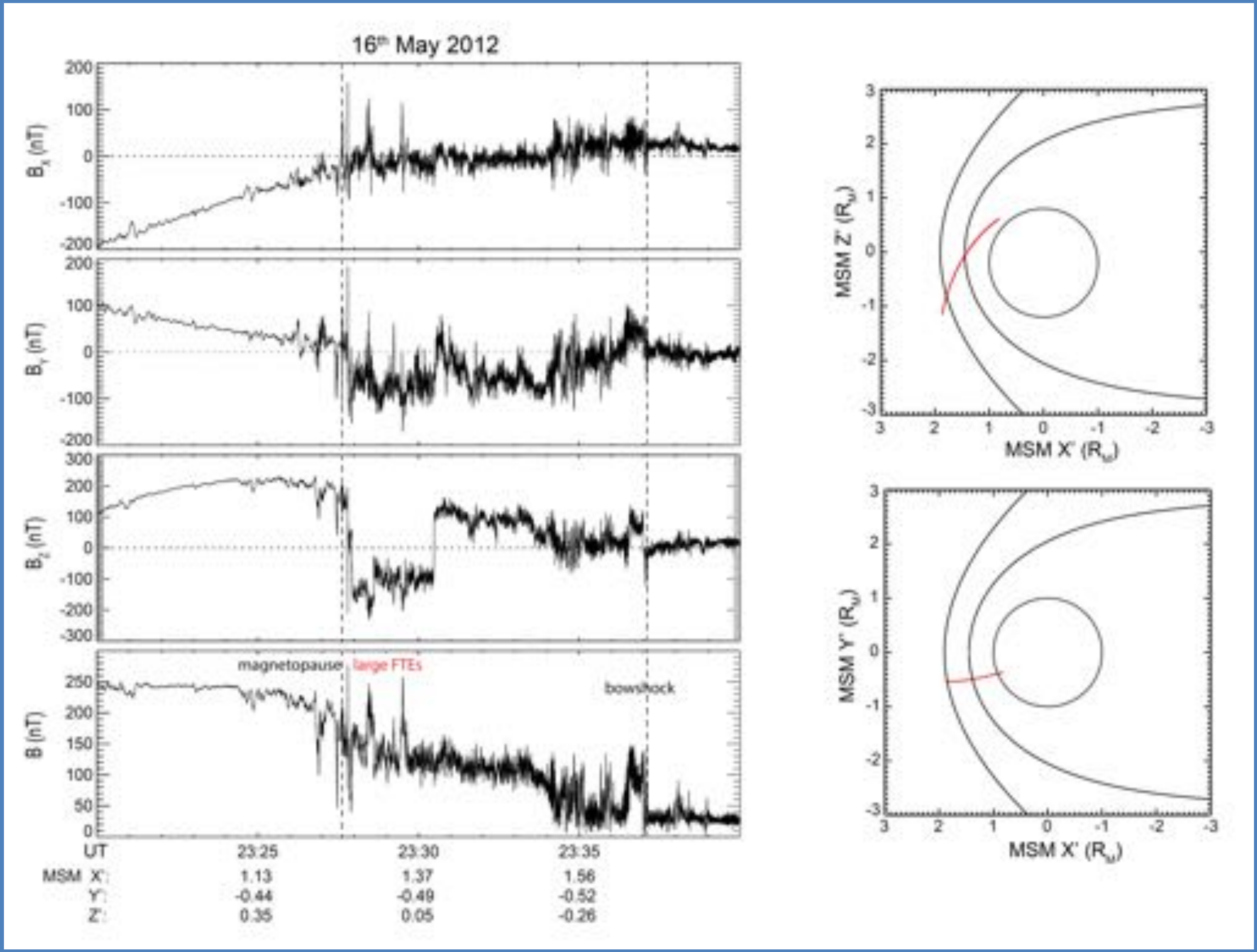
Asymmetric Reconnection



High Speed Stream

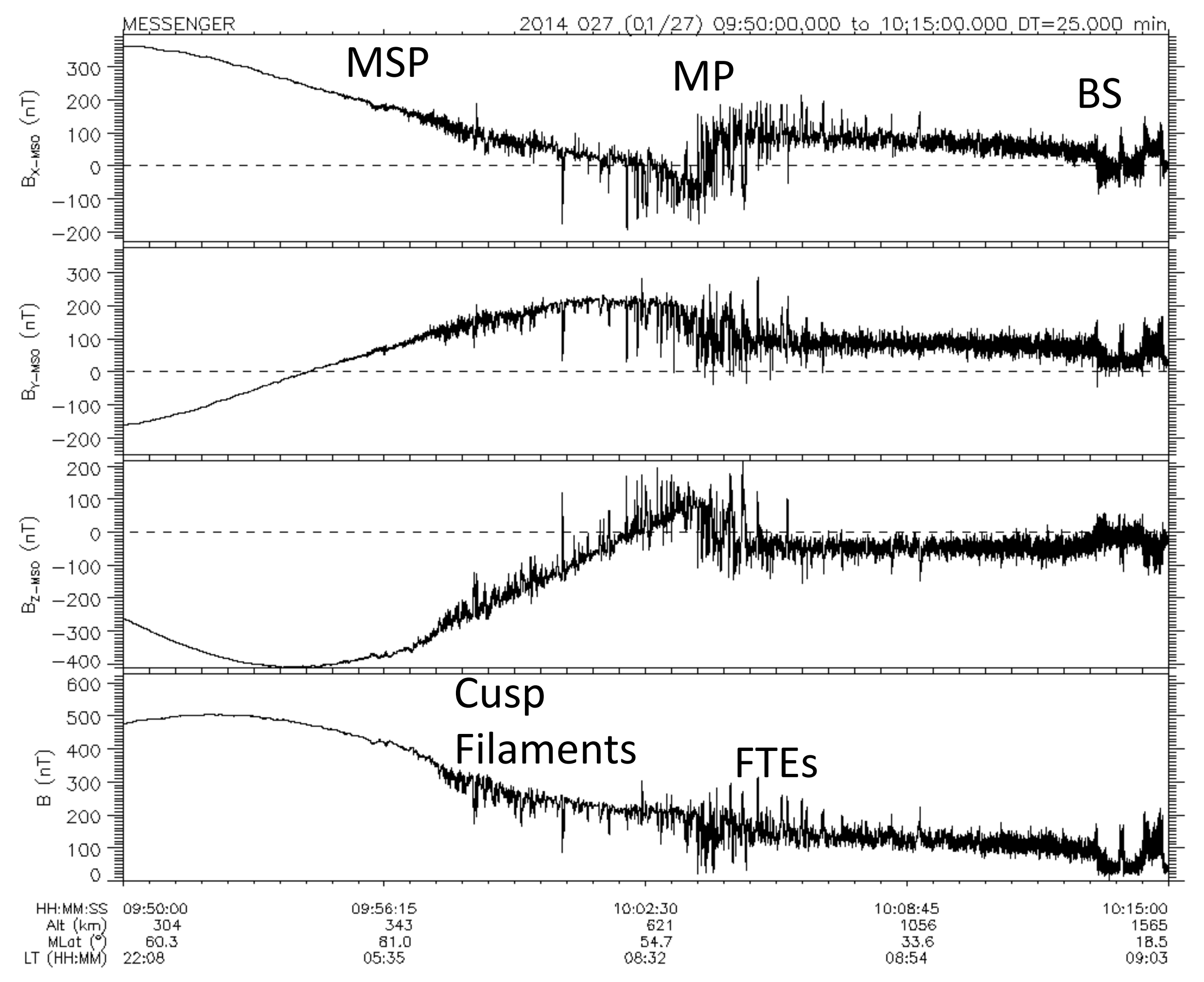
Slavin et al. (2009; 2014) and DiBraccio et al. (2013)

“Giant” FTEs at Mercury

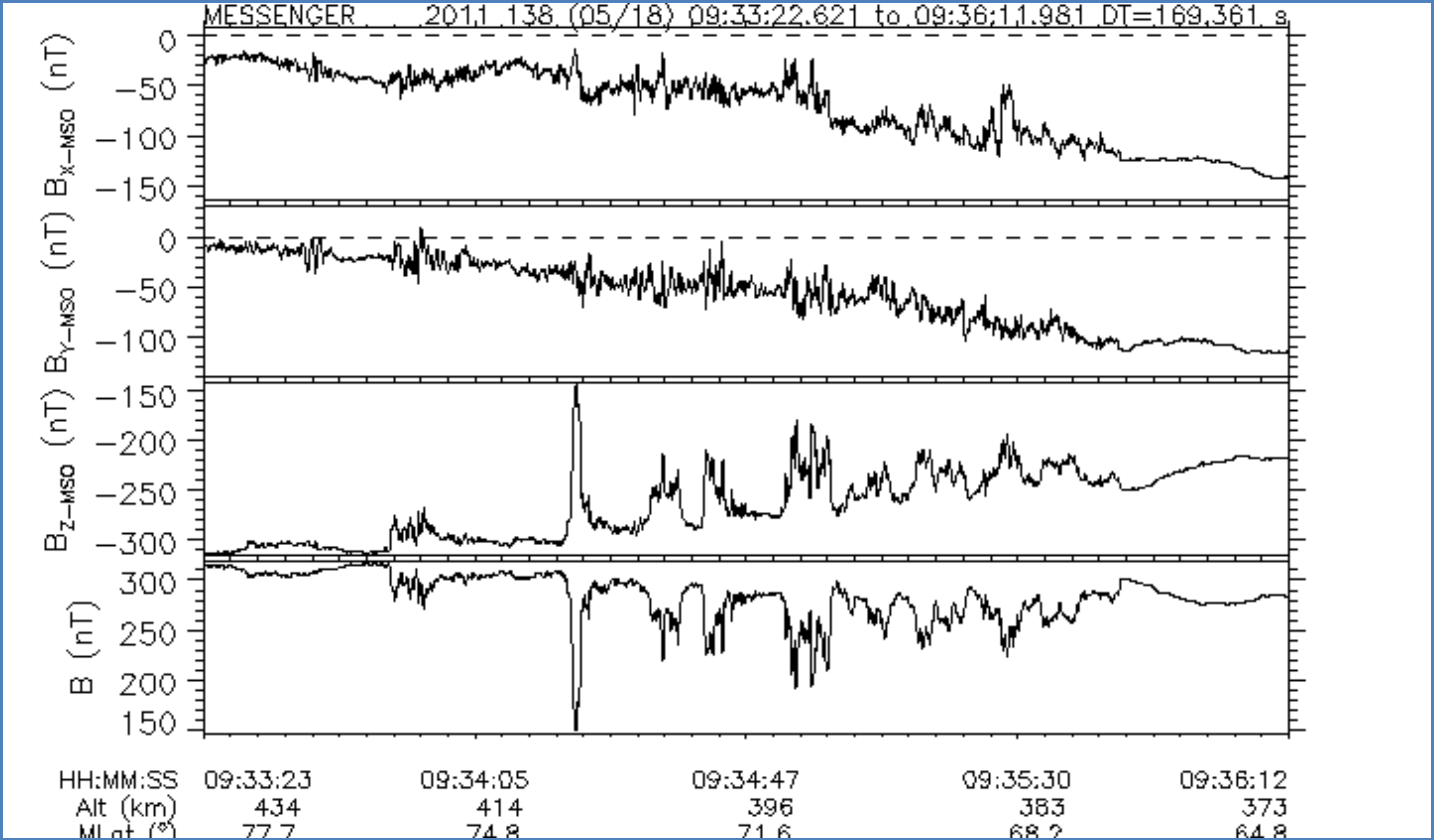


Imber et al. (2014)

FTEs and Cusp Filaments are Common at Mercury!

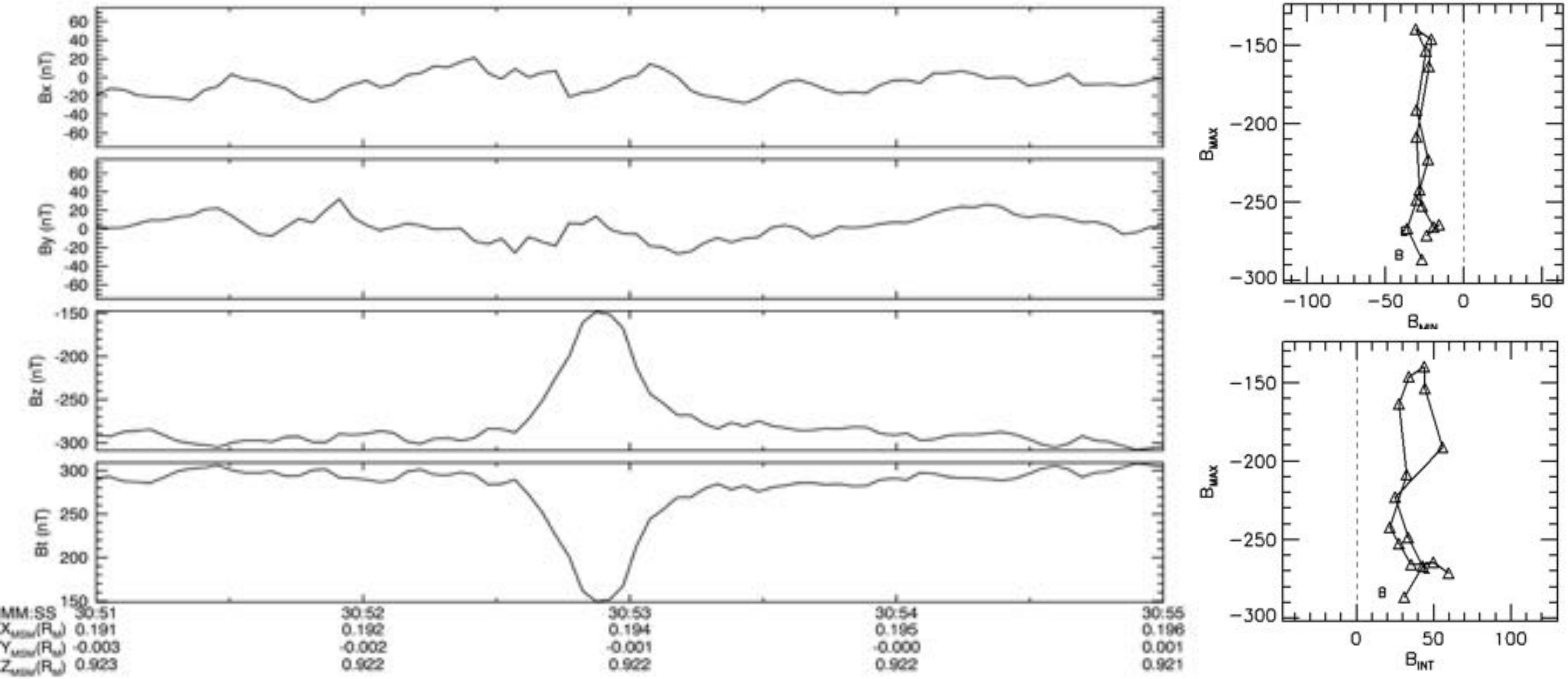


Cusp Filaments are common at Mercury!



Poh et al. (2017)

Most Filaments are 1-D Diamagnetic Depressions

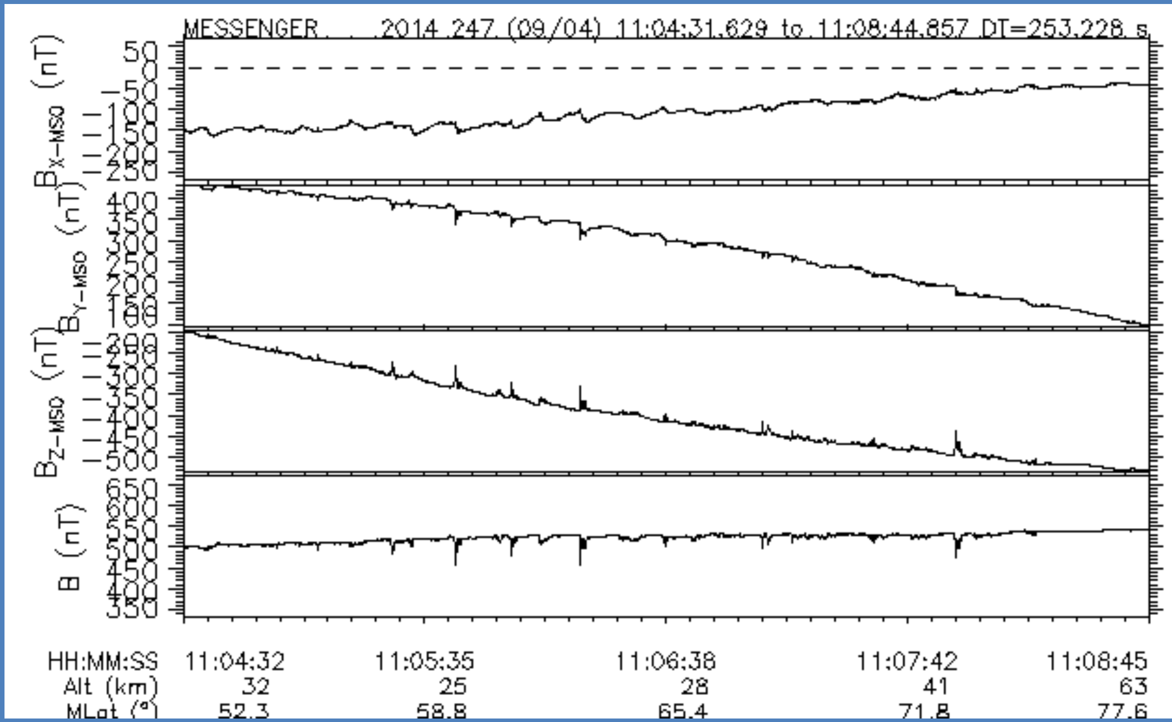


	λ_{MIN}	λ_{INT}	λ_{MAX}
EIGENVAL	26.12	119.14	2401.44
EIGENVEC	−0.388	−0.917	−0.095
	−0.907	0.362	0.214
	0.161	−0.169	0.972

Poh et al. (2017)

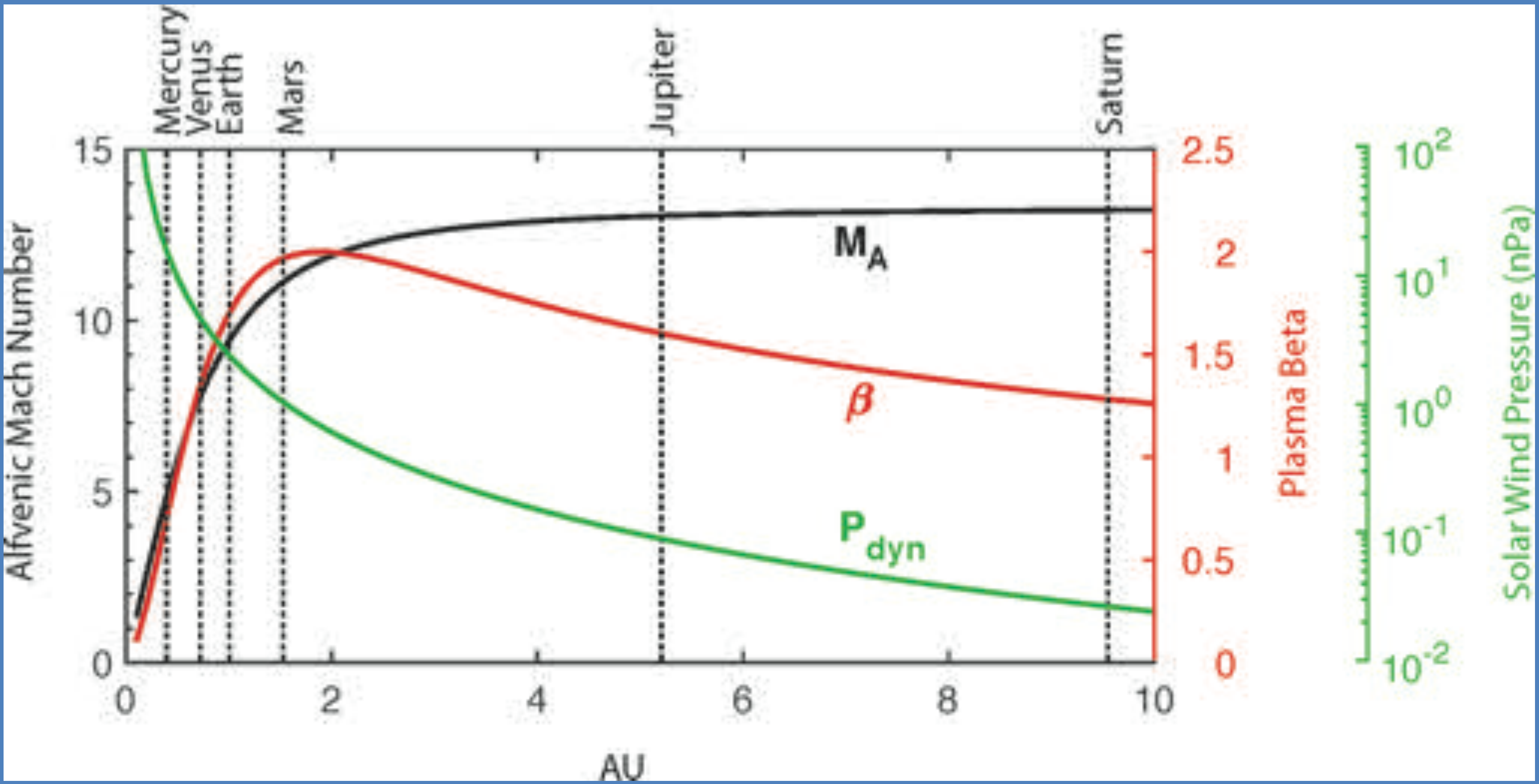
MESSENGER Filaments Extend down to altitudes < 20 km!

- A total of 43 Filaments were identified and analyzed during low altitude campaign



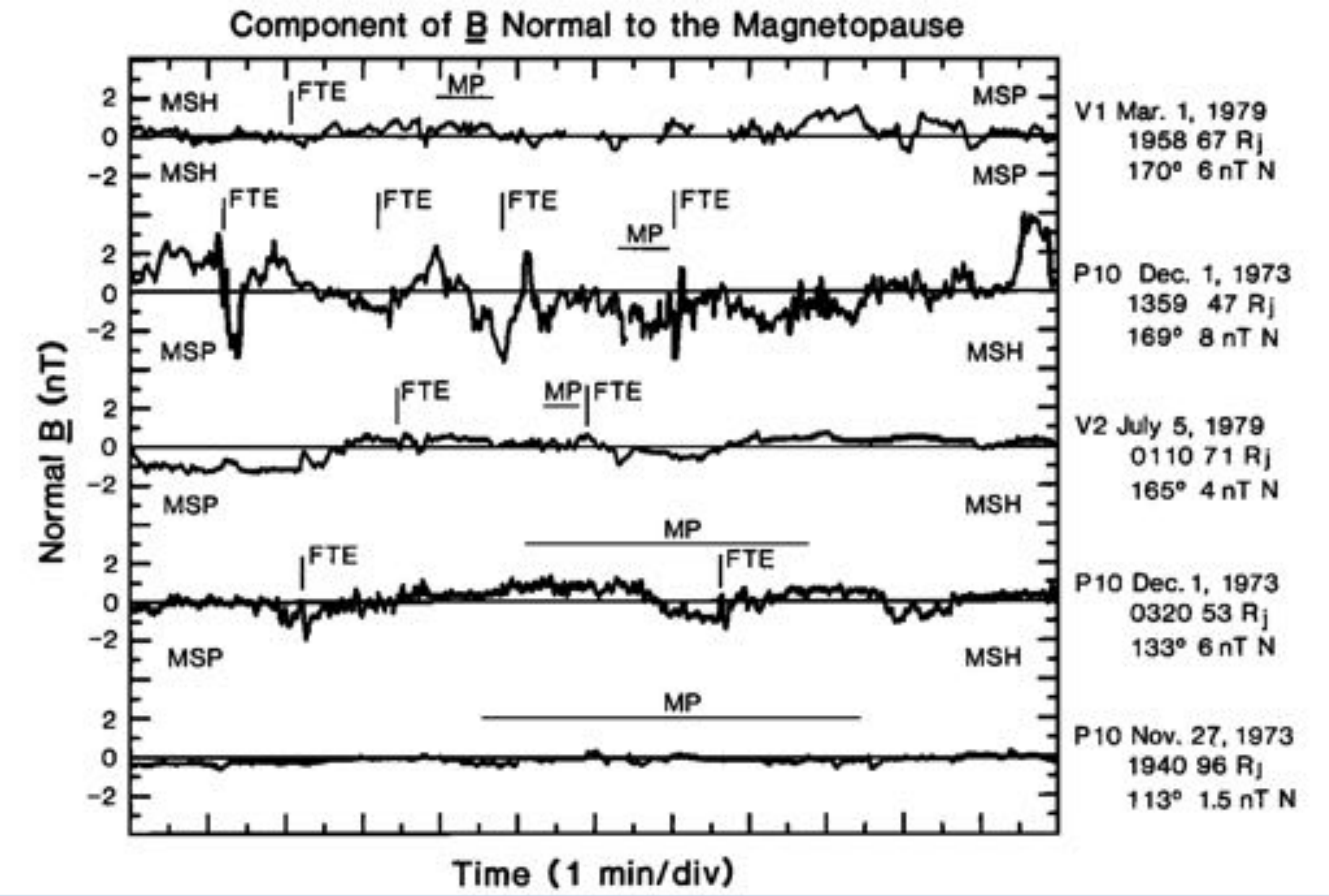
Poh et al. (2017)

Radial Variation in the Solar Wind



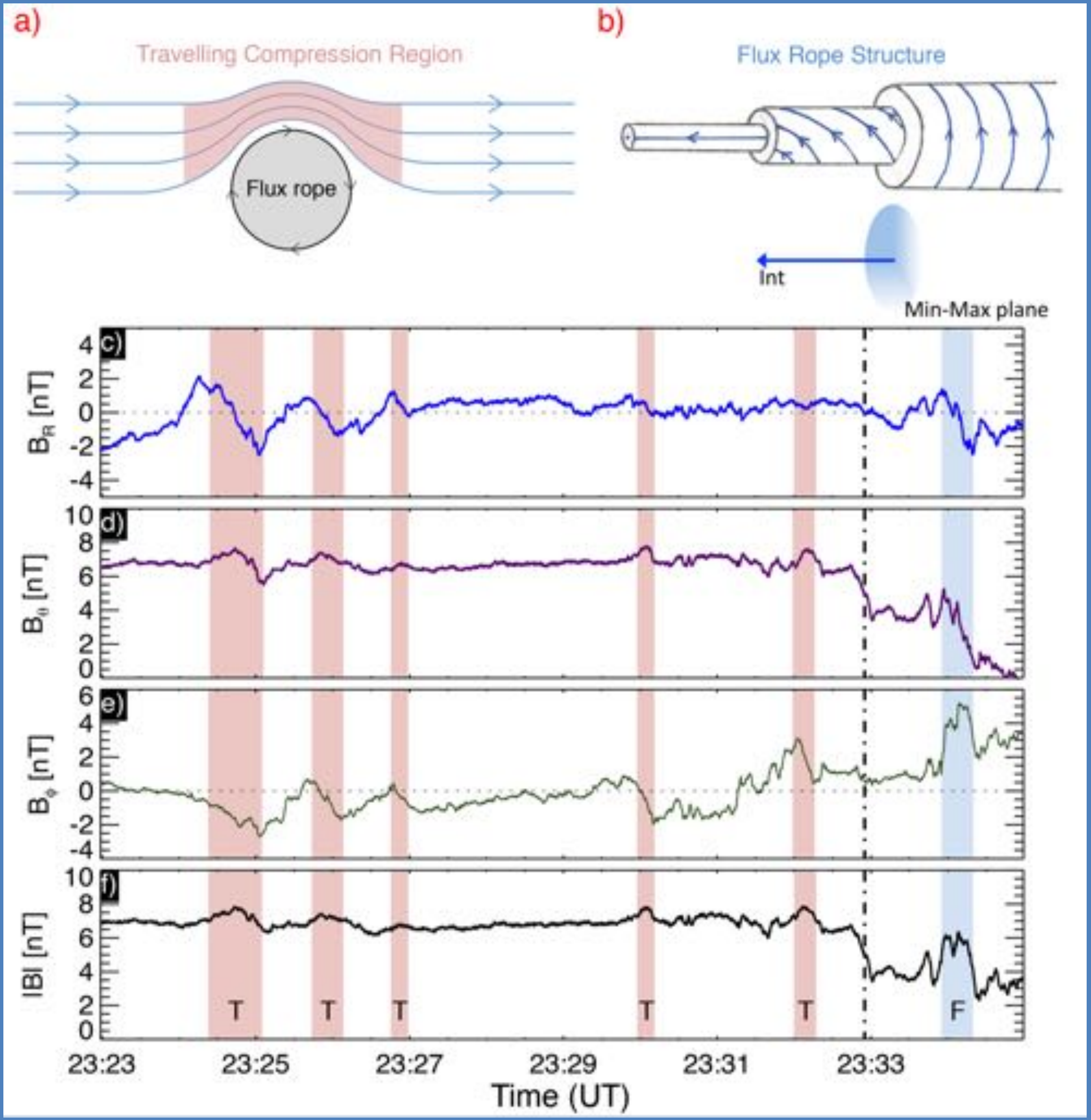
Slavin and Holzer (1981)

FTEs at Jupiter's Magnetopause



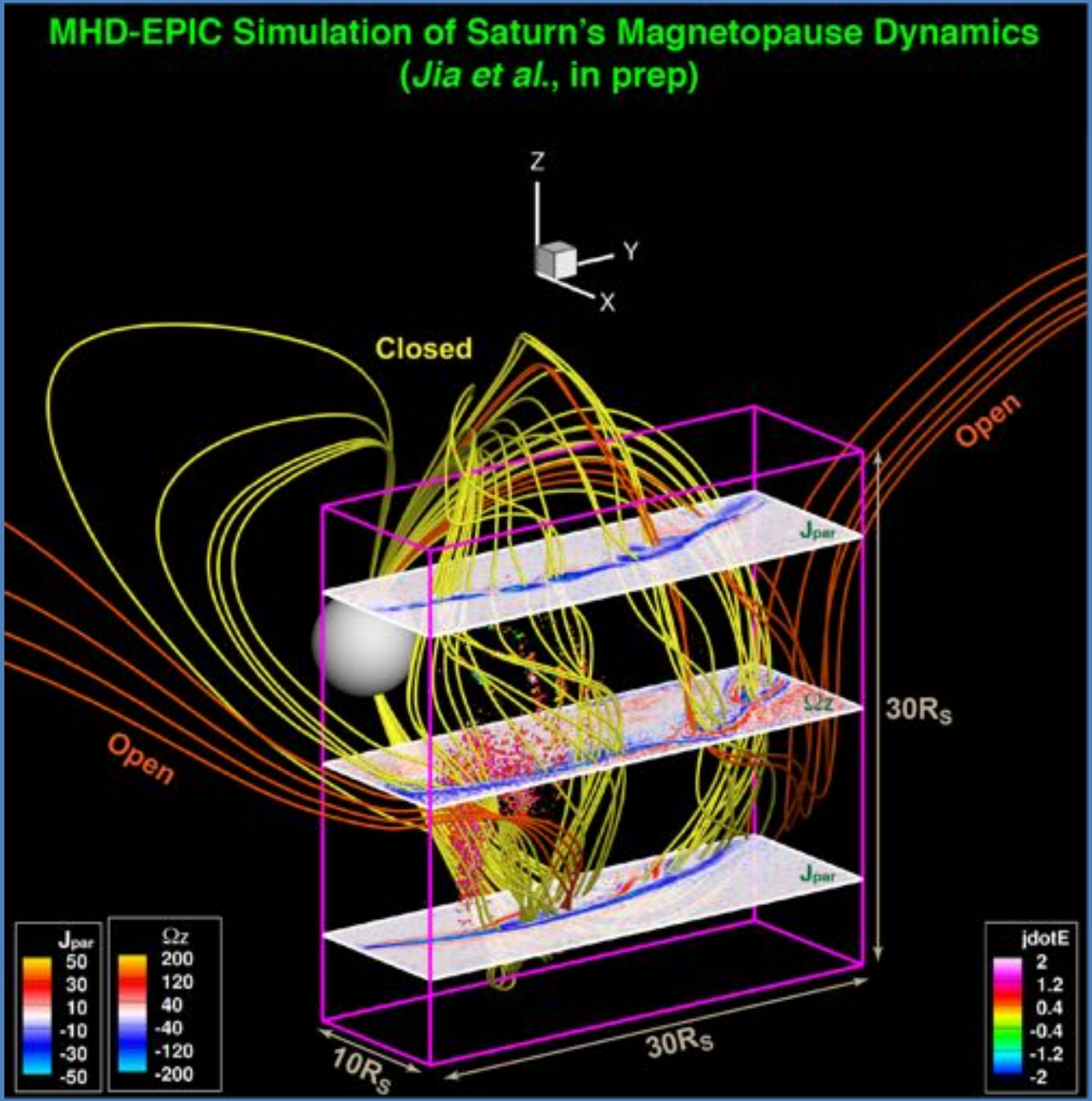
Walker and Russell (1985)

FTEs at the Saturn Magnetopause



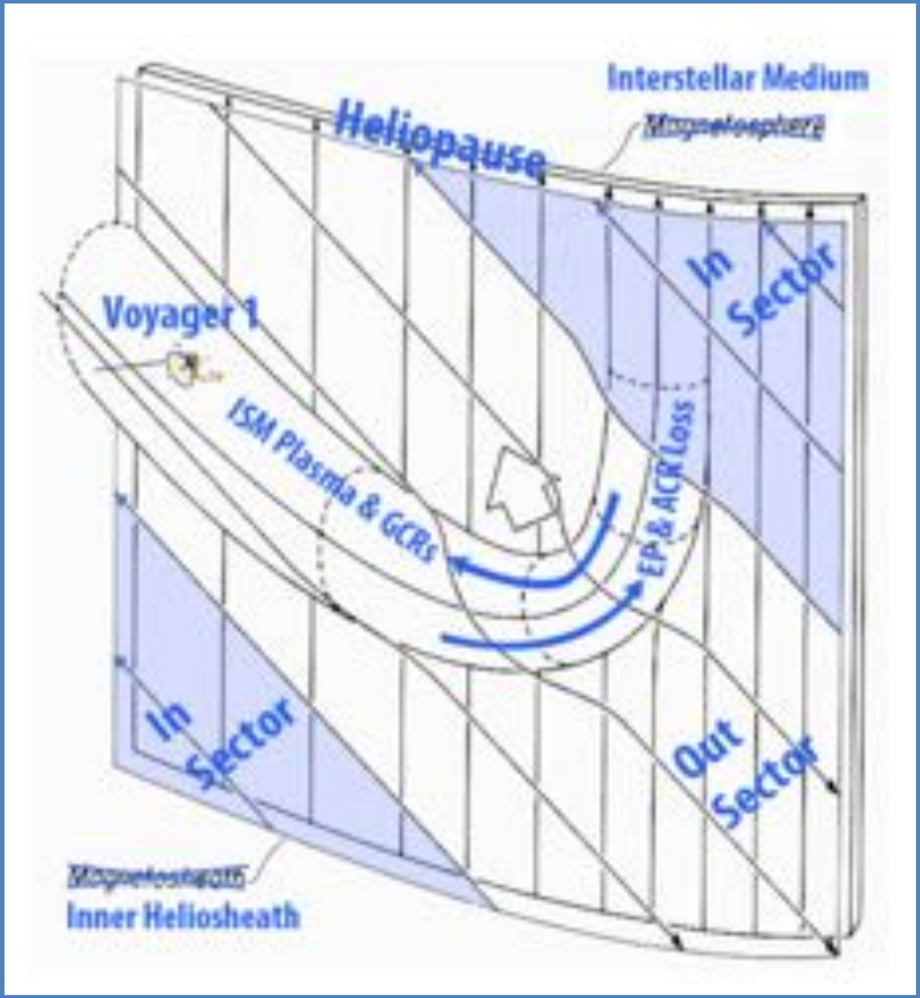
Jasinski et al. (2017)

Saturn’s Magnetopause



Jia et al. (MOP, 2018)

Heliopause FTE?



Schwadron and McComas (2013)

Summary

- FTE-type flux ropes in the magnetopause and Plasmoid-type flux ropes in the cross-tail current sheets are closely related to the onset and development of magnetic reconnection.

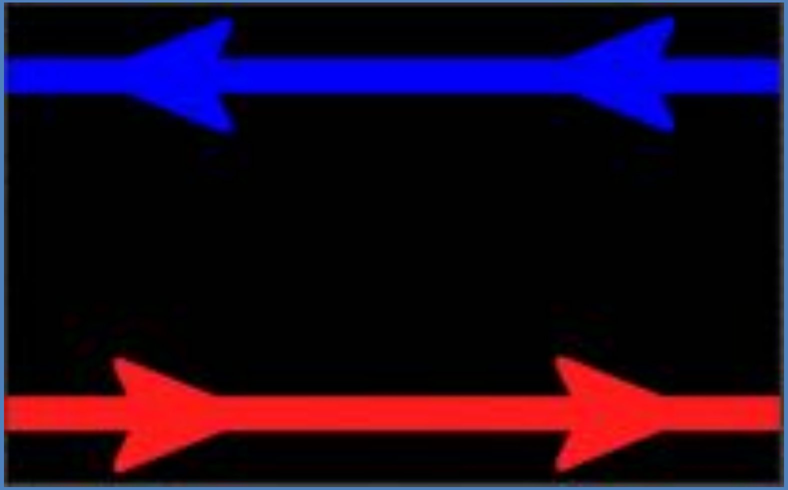
- FTEs are produced in greatest abundance and have their maximum impact on magnetospheric dynamics at Mercury and Earth; they are rarely observed and do not appear to have significant impact on the outer planets, presumably due to radial variation in M_A.

- The comprehensive two-spacecraft particles and fields measurements to be returned from Mercury by the BepiColombo mission in the mid-2020's combined with the on-going MMS mission at Earth promise to greatly enhance our knowledge of FTE formation and dynamics at both of these terrestrial-type planets.

Supplemental Material

What Is Magnetic Reconnection?

- Topological rearrangement of magnetic field in a plasma
- Leads to a new equilibrium configuration of lower magnetic energy
- During this process magnetic energy is converted to kinetic energy through acceleration or heating of charged particles.
- Evidence for particle energization:
  - Solar flares
  - Magnetospheric substorms
  - Laboratory sawtooth crashes



Animation courtesy of ESA

Ohm’s Law

- Ohm’s Law $\vec{\mathbf{J}} = \sigma\left(\vec{\mathbf{E}} + \vec{\mathbf{u}} \times \vec{\mathbf{B}}\right)$
- Ideal MHD ($\sigma = \infty$) $0 = \vec{\mathbf{E}} + \vec{\mathbf{u}} \times \vec{\mathbf{B}}$

In the limit of a highly conducting fluid, $J/\sigma \ll 1$ and eq. (7.1) shows that in the limit $J/\sigma \to 0$, $\mathbf{E} = \mathbf{u} \times \mathbf{B}$. The “frozen-in-condition” follows from Faraday’s law

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times \left(\mathbf{u} \times \mathbf{B}\right)$$

It follows from this equation that a) the flux of a magnetic field through any closed contour moving with the fluid is a constant, and b) fluid elements that lie on a magnetic field line remain on the same field line. Infinite conductivity requires that the magnetic field lines are equipotentials. In MHD the electrons can be considered as massless so there is no inertia associated with motion along the magnetic field. Any charge imbalance due to plasma motion is instantly “corrected” by neutralizing electrons moving along the magnetic field.

Generalized Ohm's Law

$$\mathbf{E} + \mathbf{u} \times \mathbf{B} = \eta \mathbf{J} + \frac{1}{nq} \mathbf{J} \times \mathbf{B} - \frac{1}{nq} \nabla \cdot \mathbf{P}_e + \frac{m_e}{nq^2} \frac{\partial \mathbf{J}}{\partial t}$$

The η**J** term may be due to classical collisional resistivity or "turbulent resistivity" due to fluctations. The Hall Term, (1/*nq*)**J** × **B**, is associated with differential flow of ions and electrons and must be considered at the ion inertial scale, c/ω_{pi}, and where collisions (i.e. ion/neutral elastic collisions and charge exchange) are important. The third term is due to electron pressure. The fourth term is the electron inertial term and is appreciable at the electron inertial scale, c/ω_{pe}.