

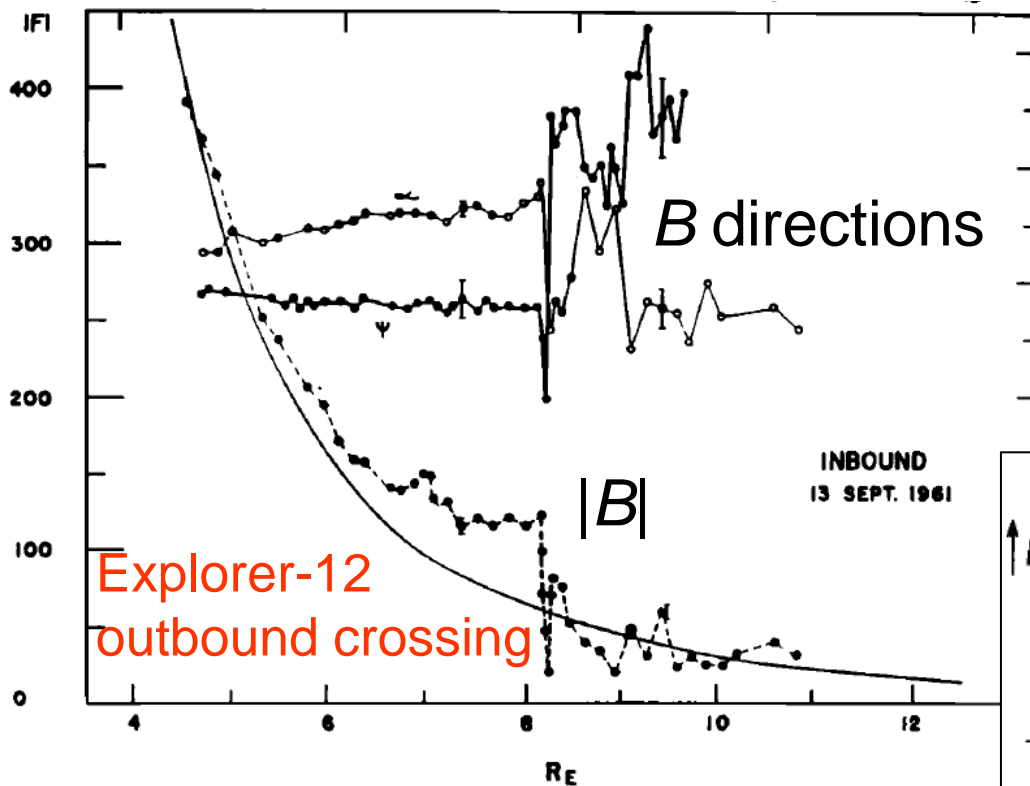
# Magnetopause & its Boundary Layers Reporter Review 2011-2013

Hiroshi Hasegawa

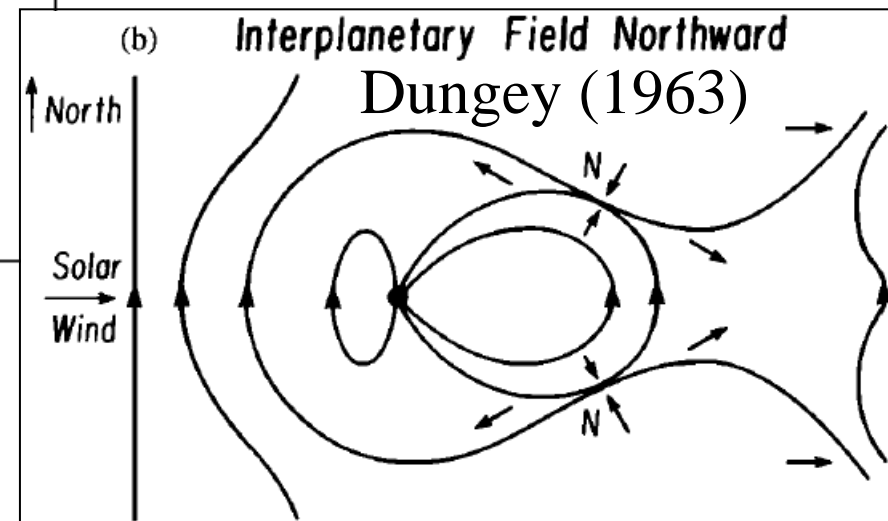
Inst. Space & Astronautical Science (ISAS), JAXA

IAGA 2013 The XII-th Scientific Assembly  
(Merida Yucatan Mexico, 26-31 August 2013)

# 2013: 50th anniversary of the discovery of Earth's magnetopause & proposal of high-latitude reconnection



- $|B_{MP}| \sim 2$  times the dipole value.
- Reconnection may occur also for NBZ.



Cahill & Amazeen (JGR63);  
Heppner+ (JGR63)

# Outline: macro to micro

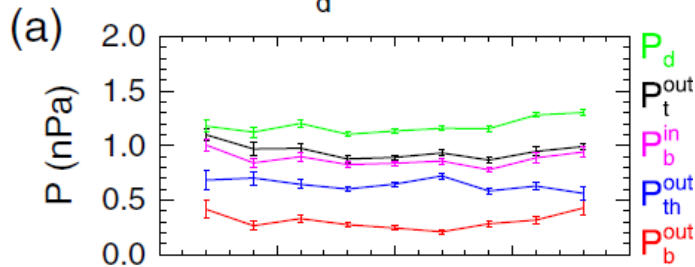
- Global Structure
- Boundary Layers
- Surface Waves/Deformations
- Polar Cusp
- Magnetic Reconnection

Acronyms: MP (magnetopause), SW (solar wind), LLBL (low-latitude boundary layer), ULF (ultra-low frequency), KHI (Kelvin-Helmholtz instability), Q-|| (quasi-parallel), KAW (kinetic Alfvén wave), LHDI (lower-hybrid drift instability) ENA (energetic neutral atom), PIC (particle-in-cell)

# Global Structure

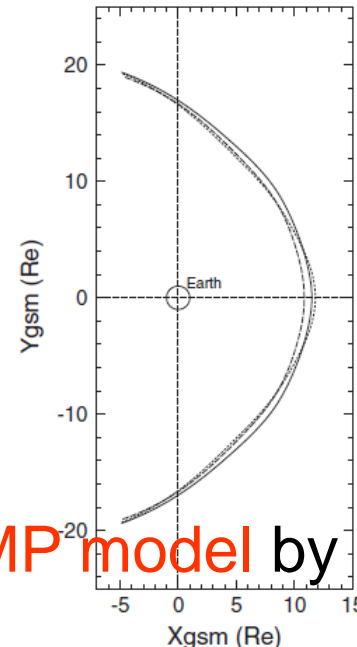
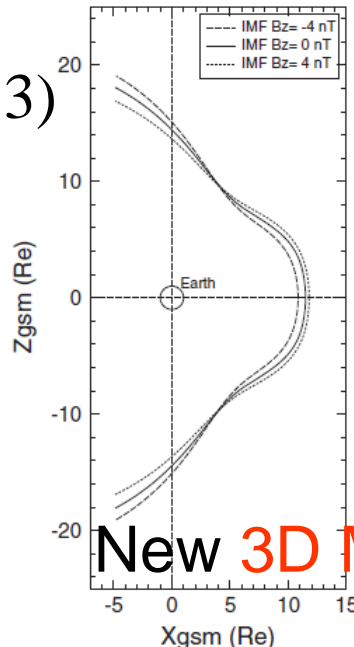
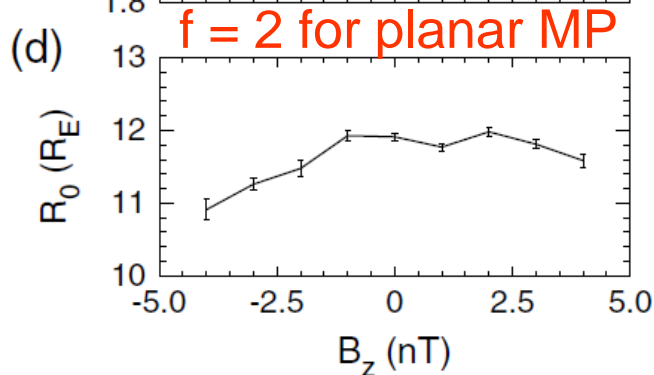
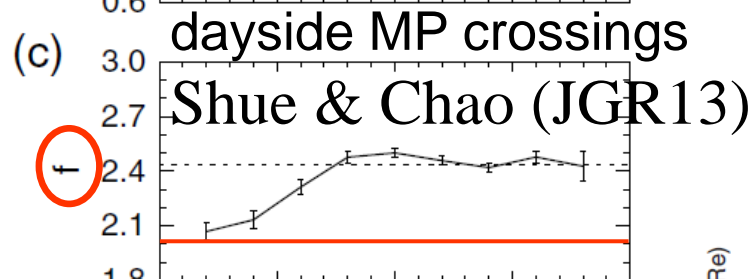
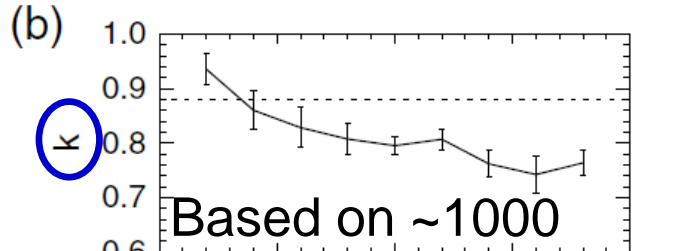
# SW dependence of MP position

$P_d < 1.5$  nPa

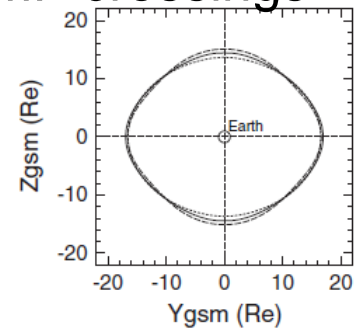


$P$  balance @MP:  $kP_d = \frac{(fB_e)^2}{2\mu_0 R_c^6} + P_{th}^{in}$

- Larger SW pressure exerted on MP for southward than for northward IMF.
- Consistent with blunter MP (larger flaring angle) for southward IMF.

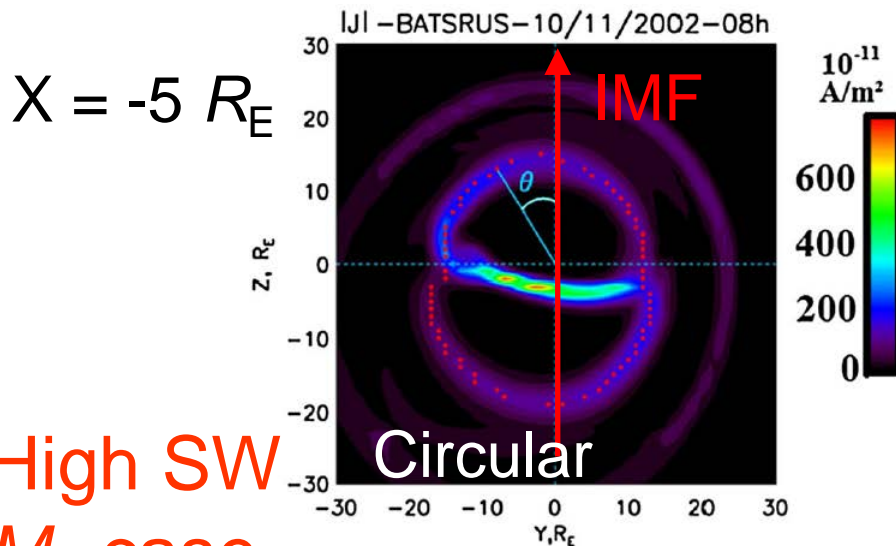


Based on 15,089 MP crossings

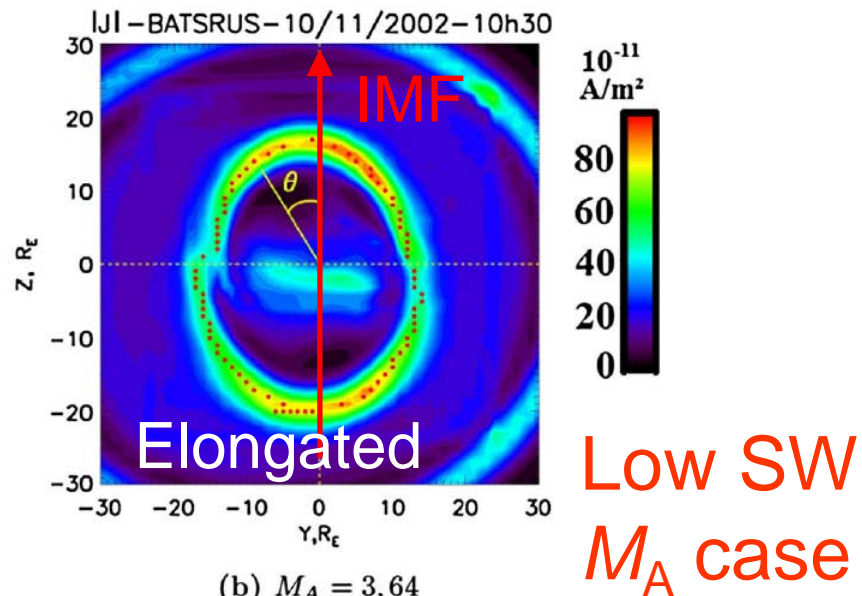


New 3D MP model by Wang+ (JGR13)

# Non axi-symmetry depends on $M_A$

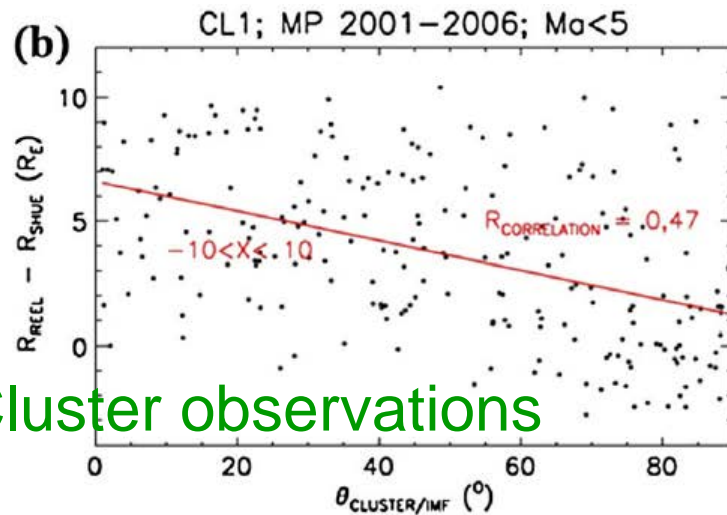
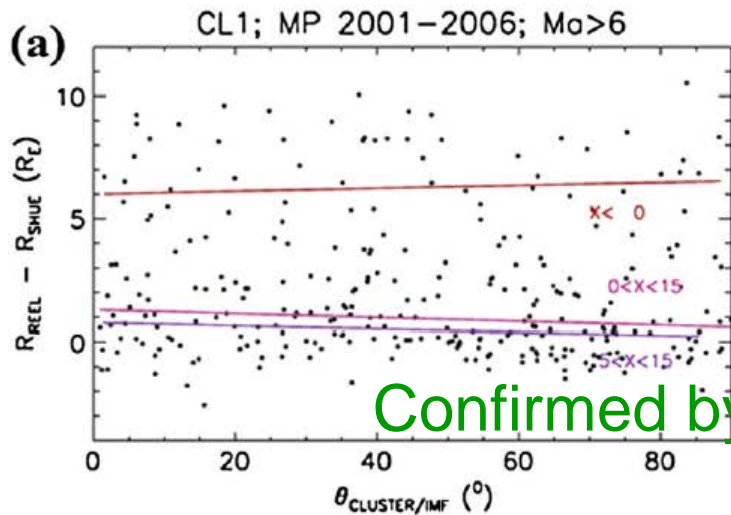


(a)  $M_A = 9, 4$



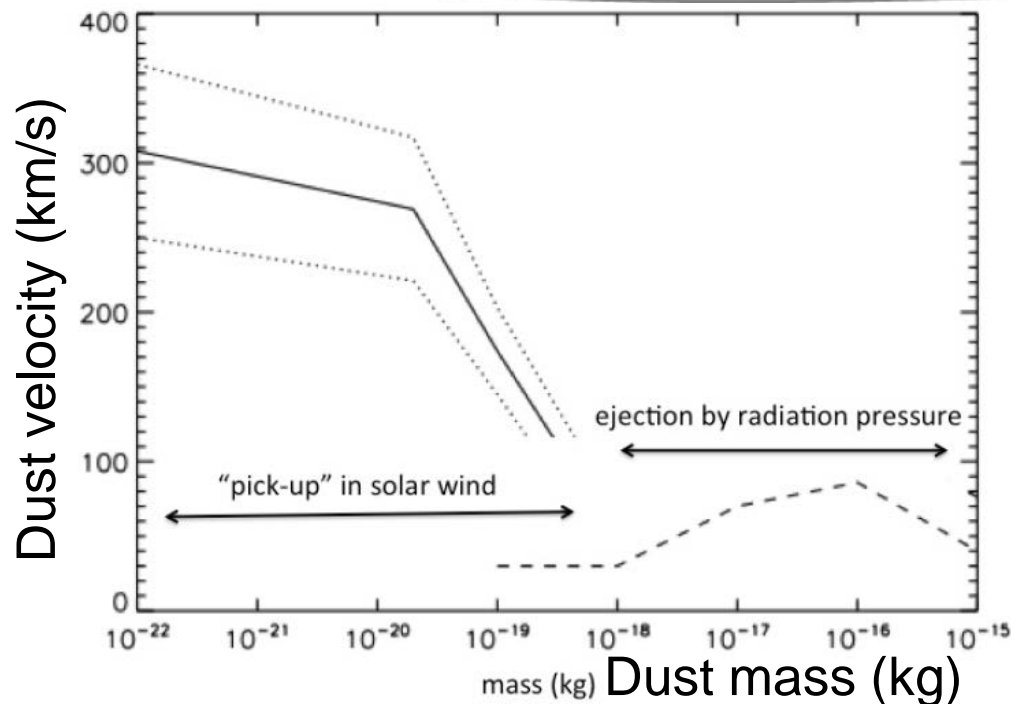
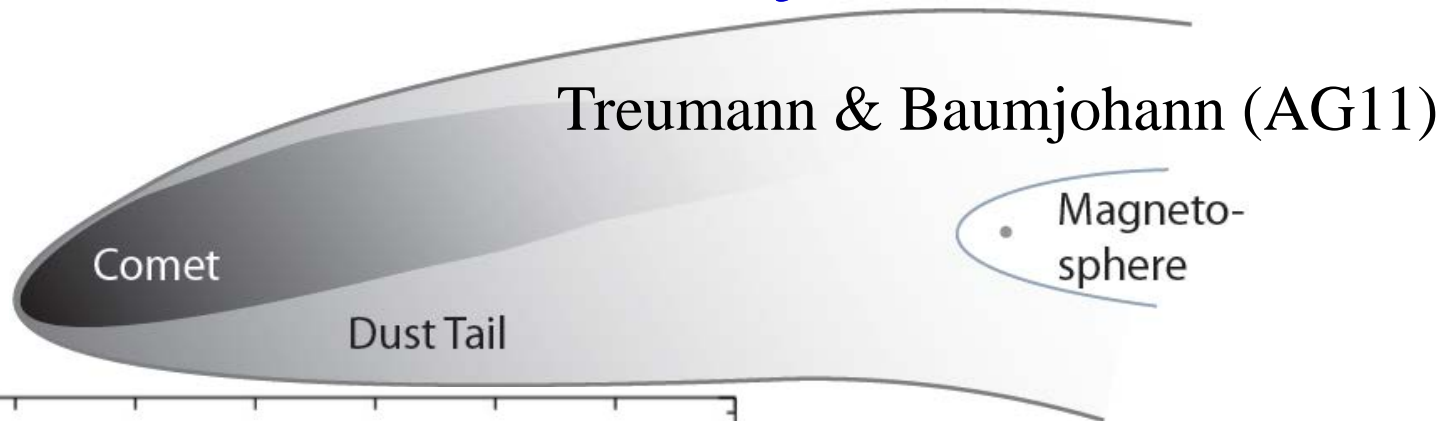
(b)  $M_A = 3, 64$

MP radial position



Difference from Shue97/98's model MP Lavraud+ (JGR13); Lu+ (JGR13)

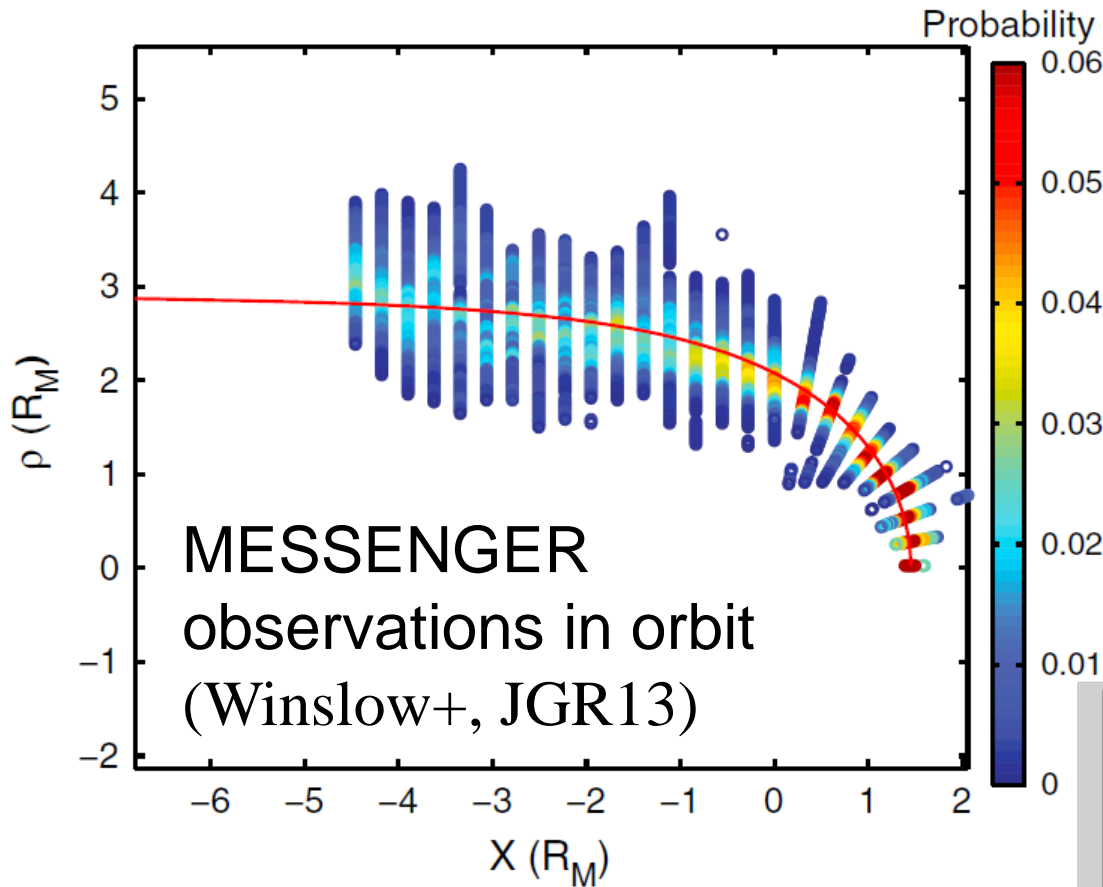
# Dust effect on MP compression? Probably No!



- Only **nanodust** can be picked up to  $\sim$ SW speed, but its **dynamic pressure is too small to displace MP**.
- Larger dust has low speed, i.e., little dynamic pressure.

Mann & Hamrin (AG13)

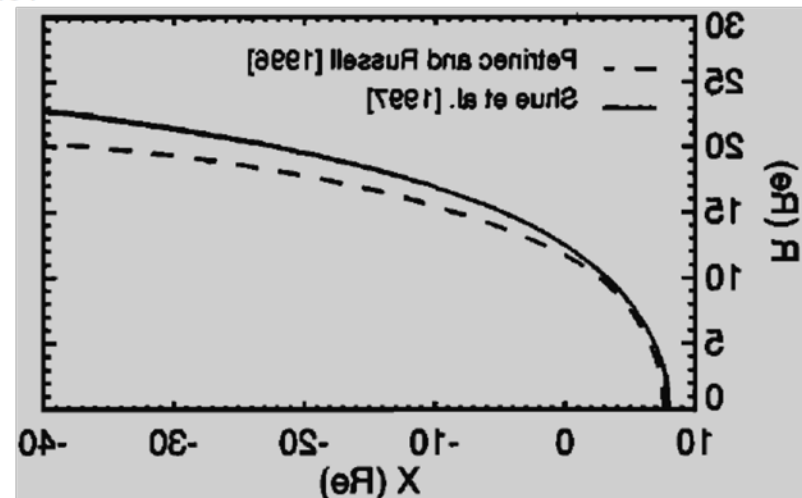
# Mercury's tail MP: More cylindrical



Possible interpretations:

- Tail X-line closer to planet at Mercury.
- **Larger** role of SW “static” pressure in shaping Mercury’s MP (Fujimoto+, SSR08).

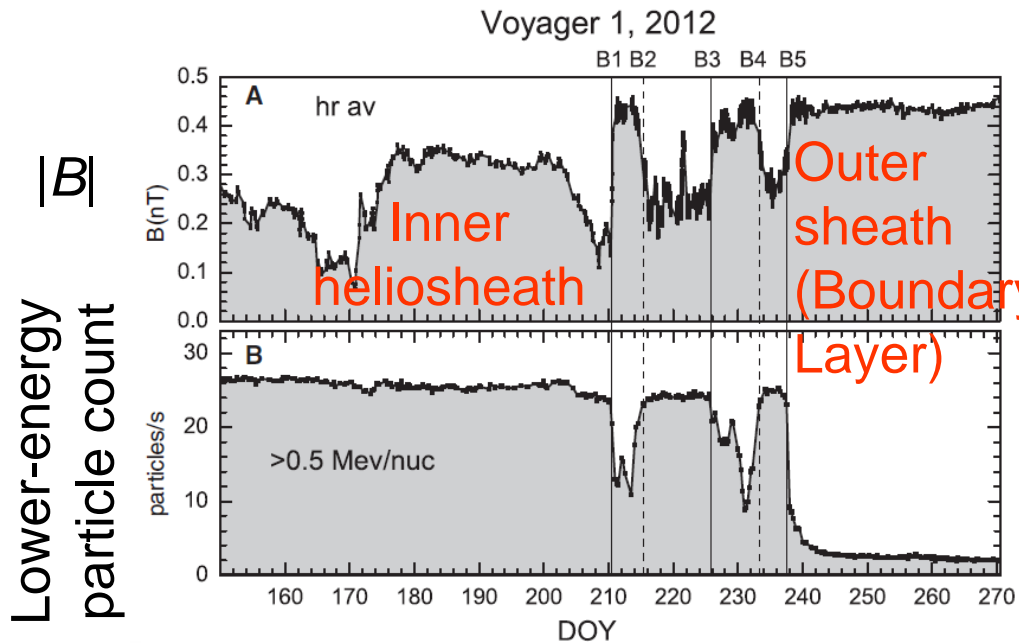
**Earth’s MP** model (Shue+, JGR98) → shows a **larger flaring** of the tail MP.



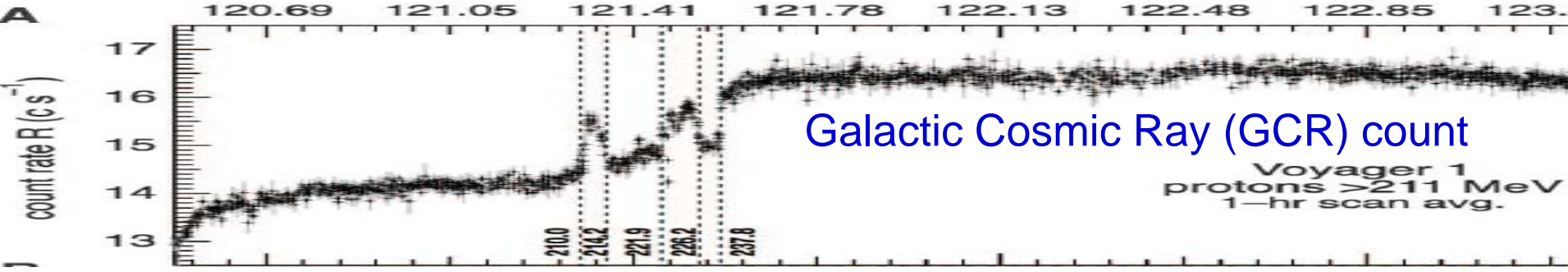


# Boundary Layers

# Voyager not yet at the heliopause, but saw a peculiar BL in the heliosheath

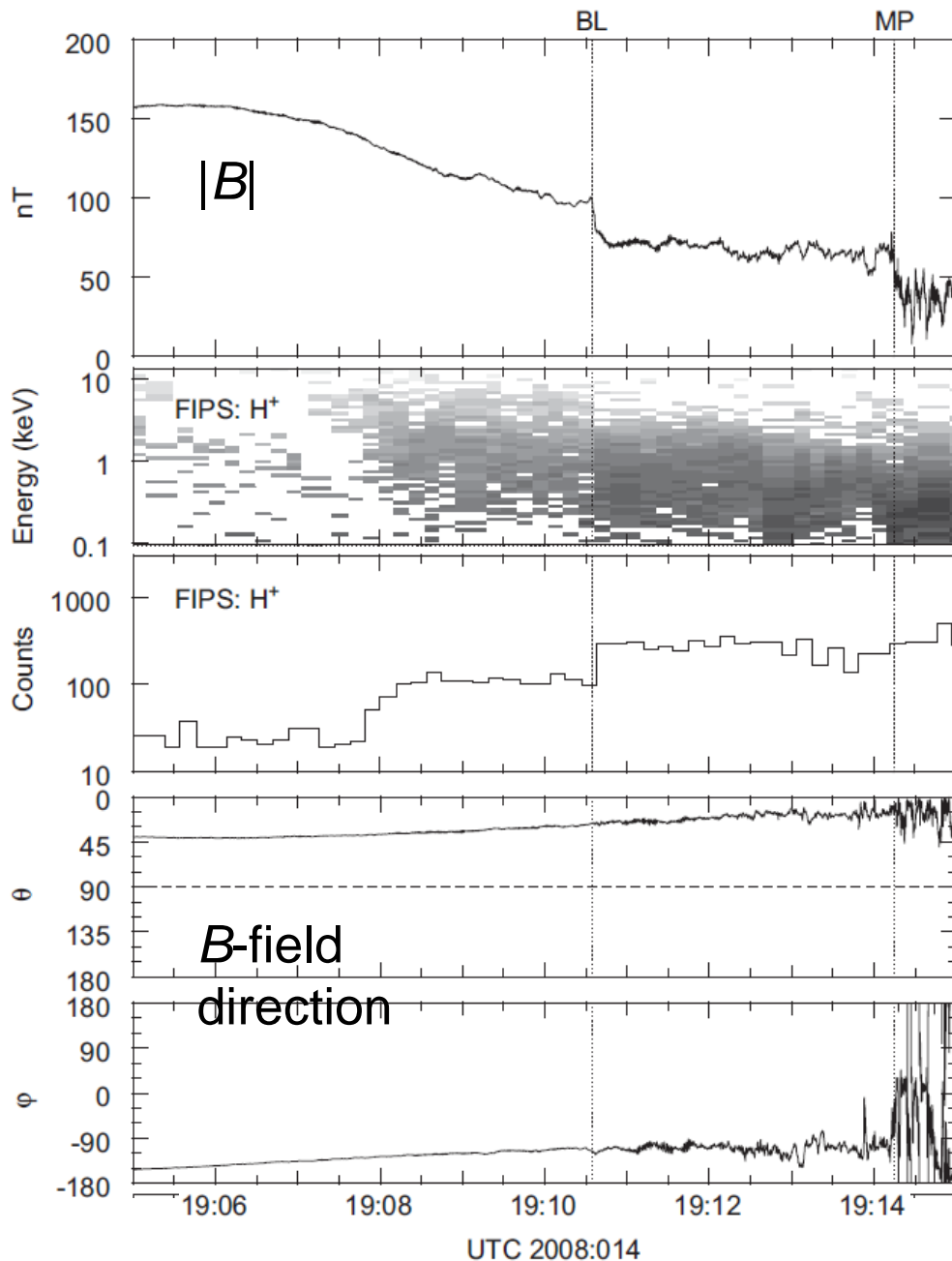


- $|B|$  doubled across the “edge”, but...
- No  $B$ -directional change.
- SW particles decreased, suggestive of a plasma depletion layer, but...
- GCR counts enhanced.



Burlaga+, Krimigis+, Stone+ (Science13)

# Boundary layer at Mercury too



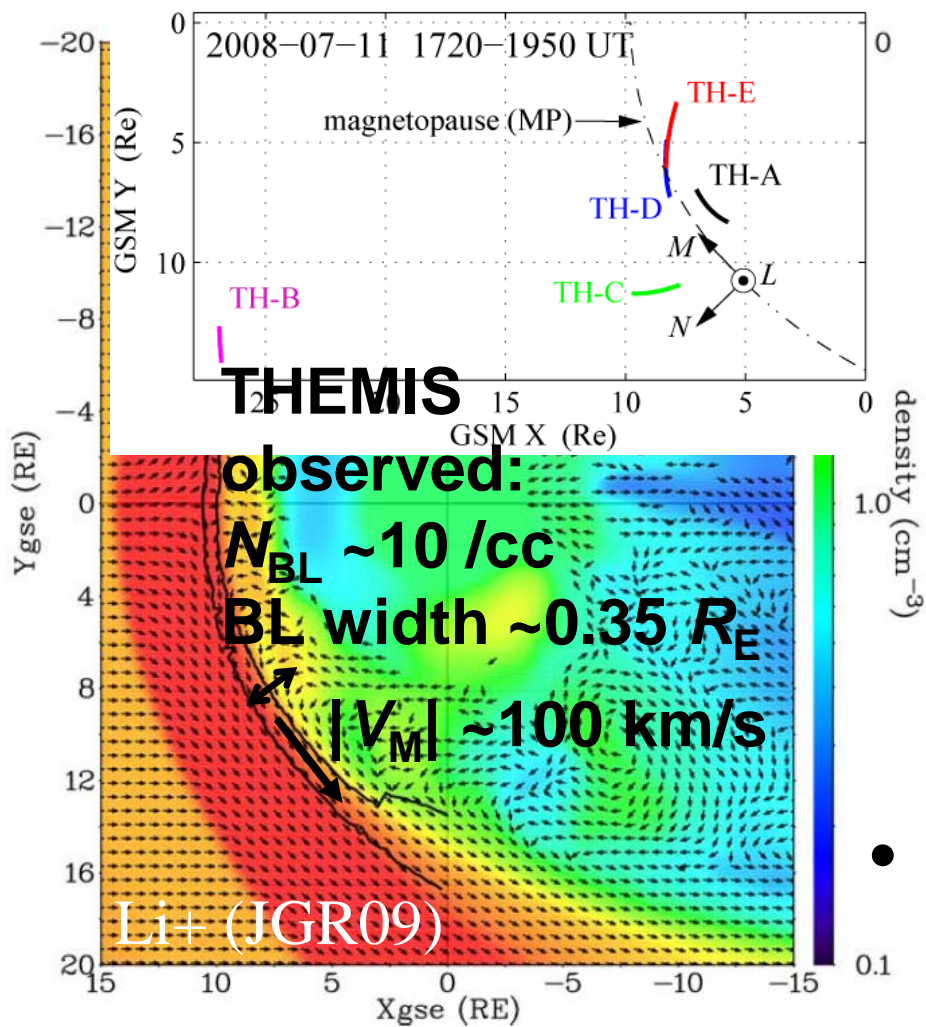
Log rel. PSD  
0  
-2  
-4  
-6

All encountered magnetospheres appear to have a BL.

- MESSENGER first flyby for northward IMF.
- Dawnside boundary layer with thickness  $\sim 1000$  km, comparable to MP standoff altitude.
- Intermediate  $|B|$  value.

Anderson+ (PSS11)

# Transport rate based on observations



Density @ equator

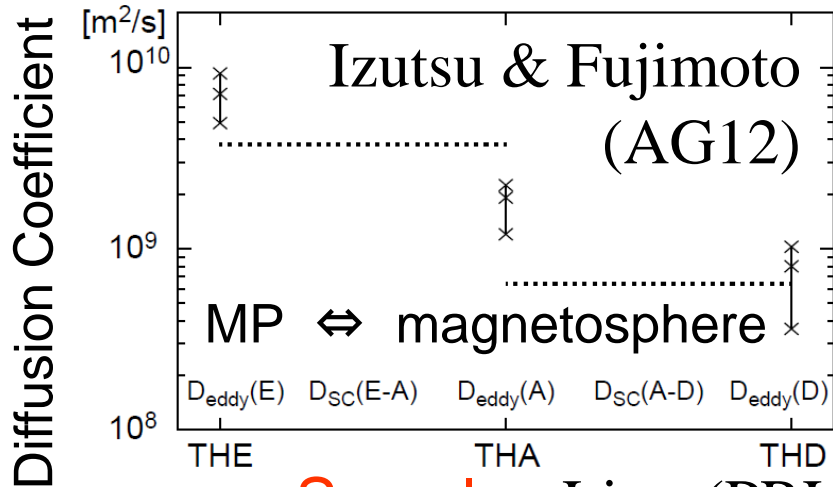
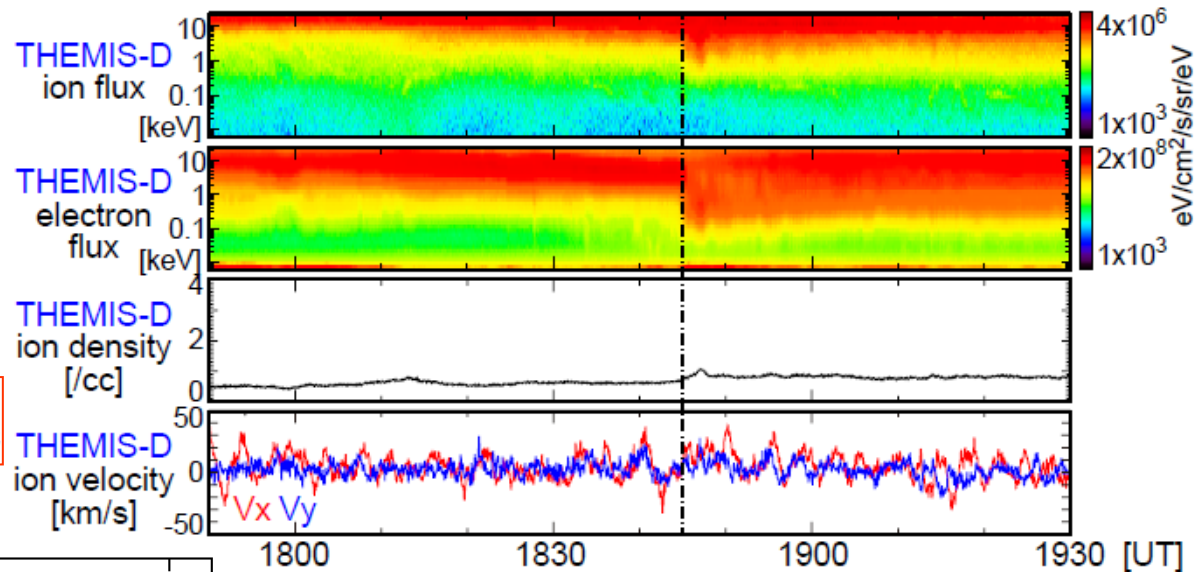
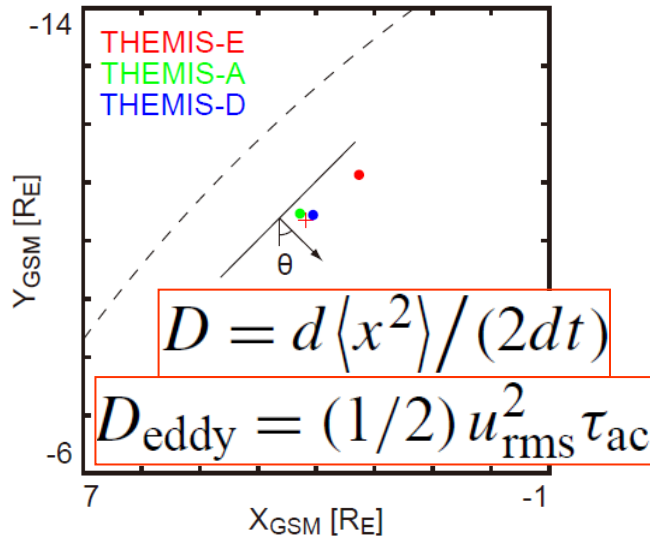
# of ions transferred across the dayside MP:  $\sim 3 \times 10^{26} /s$  assuming flux tube length of  $\sim 10 R_E$ .

This is sufficient to fill the plasma sheet with **volume**  $50R_E \times 50R_E \times 5R_E$  &  $N_i \sim 1$  in only 3 hours.

- Dual high-latitude reconnection can be the dominant “entry” mechanism.

Imber+ (AG07); Hasegawa (MEEP12); Shi+ (Nature Comms13)

# Evidence of eddy diffusion thickening the dayside LLBL for northward IMF



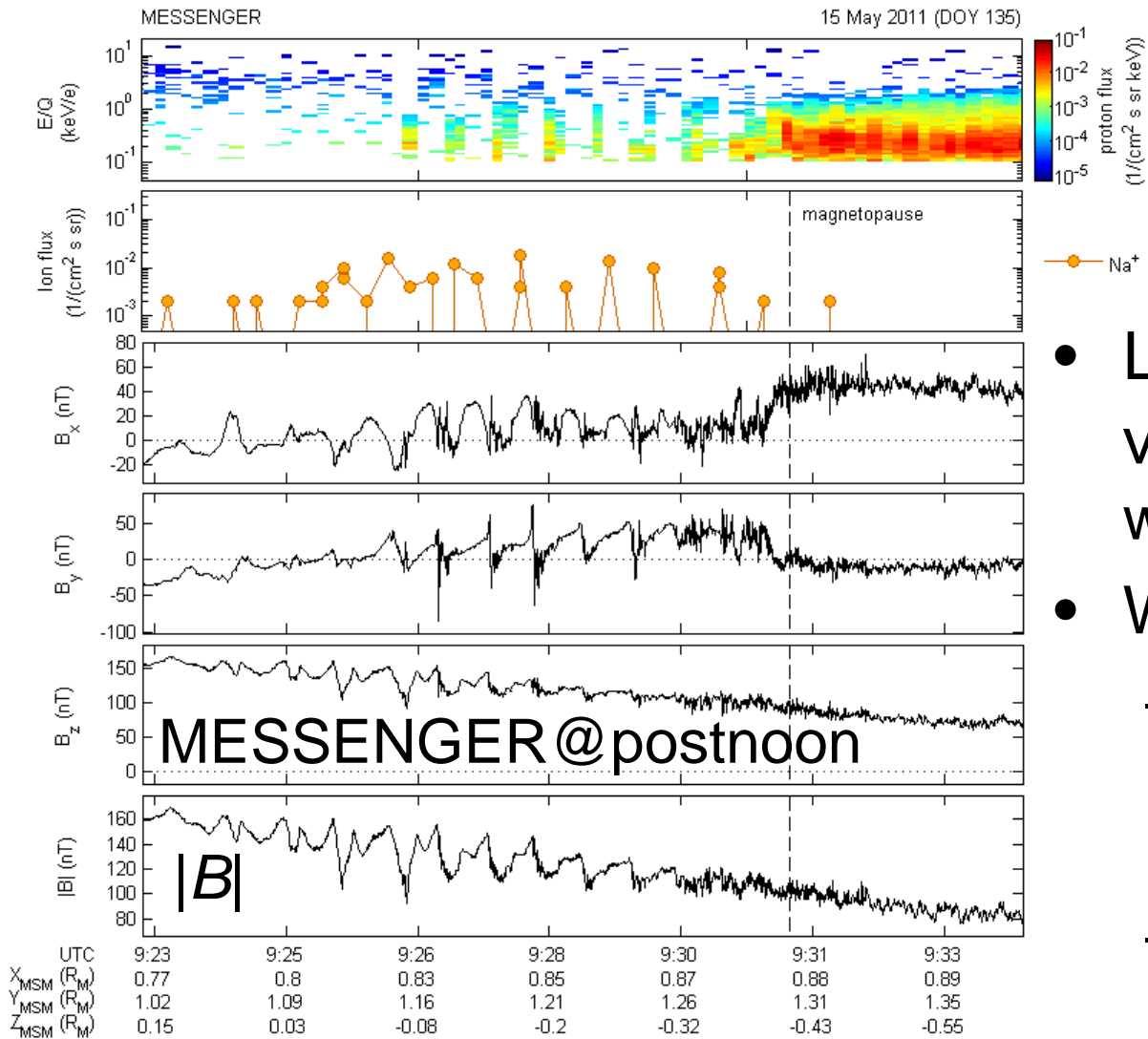
- Eddy diffusion can explain a thickening dayside (prenoon) LLBL for northward IMF.
- Diff. coefficient decreases with distance from MP.

See also Lin+ (PRL12) for generation & role of KAWs.

# Surface Waves/Deformation

# KH waves at Mercury's MP

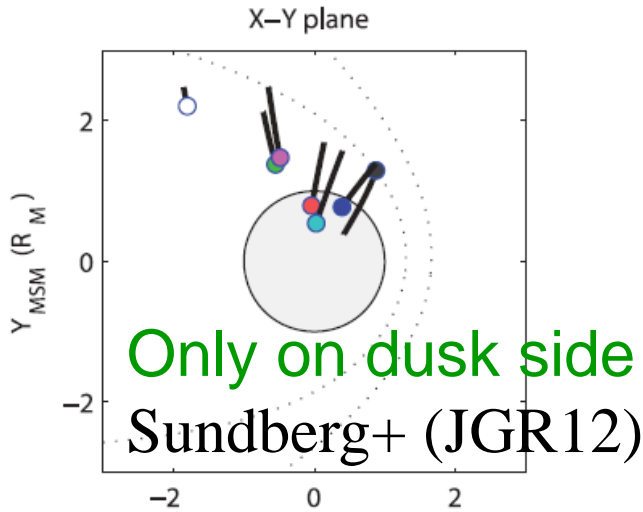
Sundberg+ (JGR12)  
Boardsen+ (GRL10)



- Large periodic  $|B|$  variations, consistent with non-linear waves.
- Wave period: 10-40 s
  - Suggesting MP width  $\sim$ proton gyro-radius  $r_{gp}$  ( $\sim 200$  km)
  - Much thinner than Earth's MP  $\sim 10^* r_{gp}$

# Occurrence position of KH-waves

## Mercury

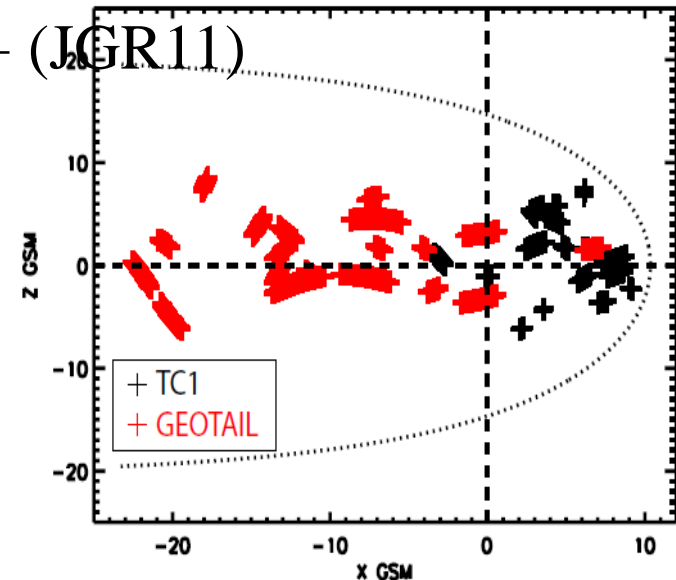
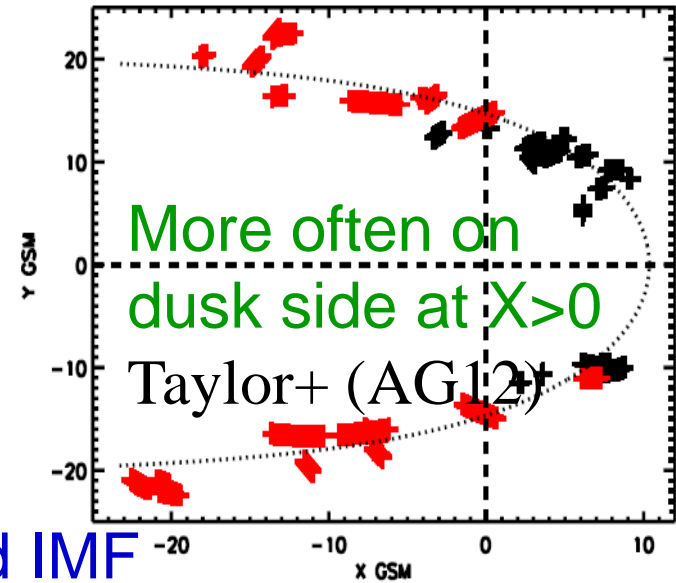


Mostly for northward IMF

But see e.g. Hwang+ (JGR11)

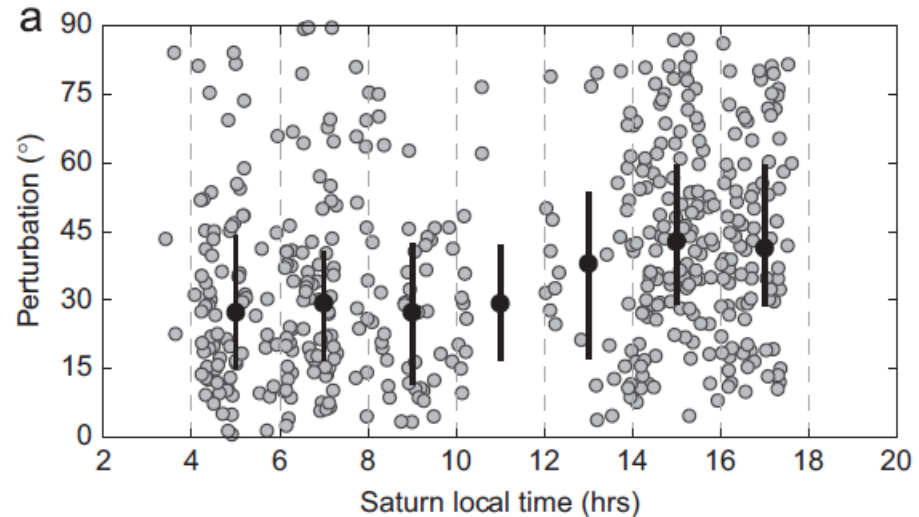
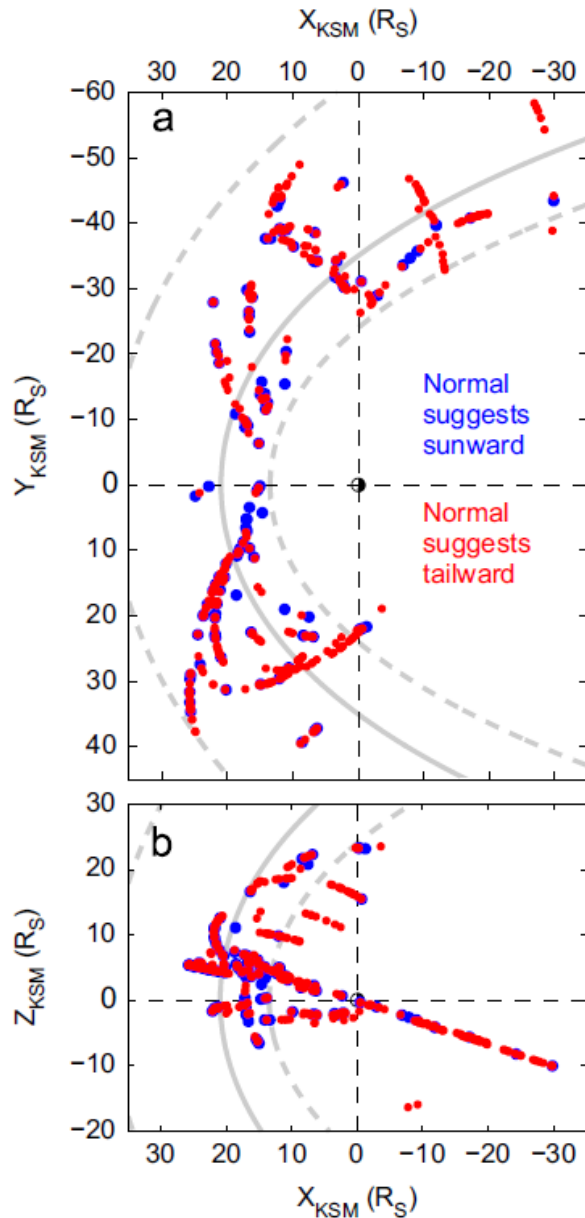
Possibly higher growth rate on the dusk side is consistent with 2D PIC simulations by Nakamura+ (PoP10)

## Earth





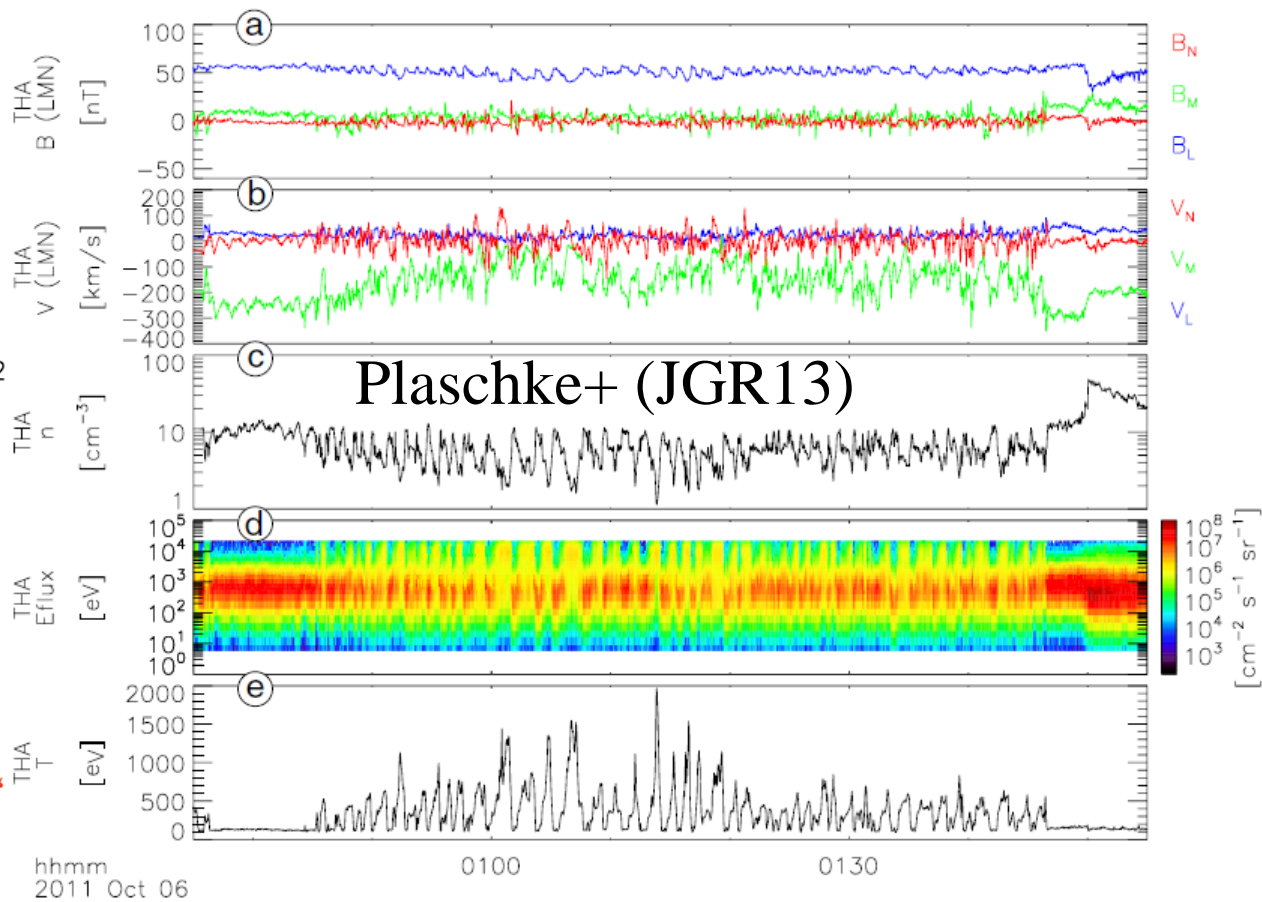
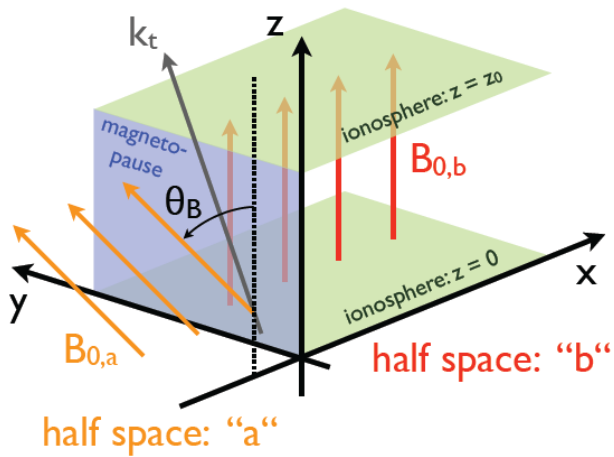
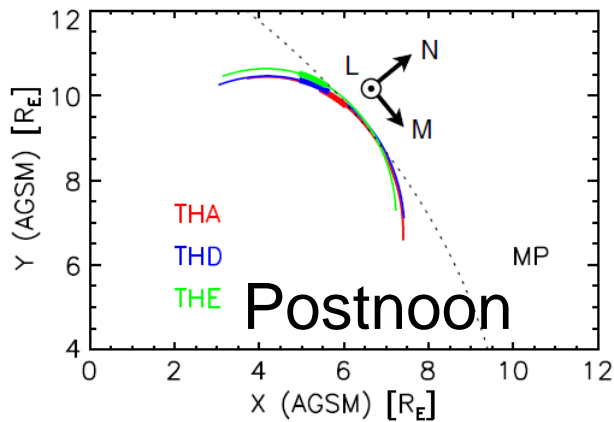
# Surface waves on Saturn's MP



Masters+ (PSS12)

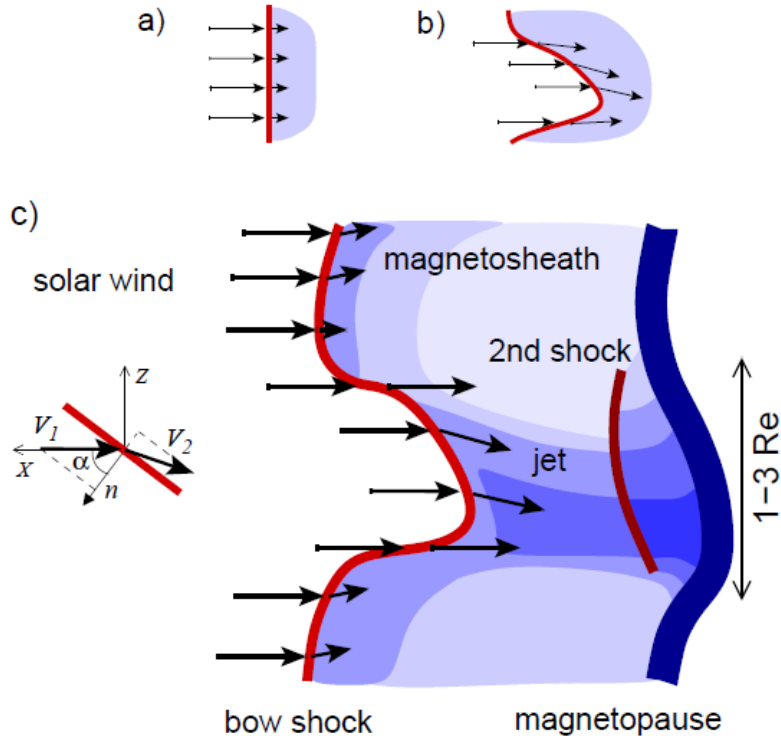
- No clear dawn-dusk asymmetry in occurrence, contrary to expectation based on the flow shear magnitude.
- The surface waves mostly propagate tailward.
- Perturbation is somewhat larger on the dusk side.

# MP surface waves driven by foreshock or Q-|| shock waves?



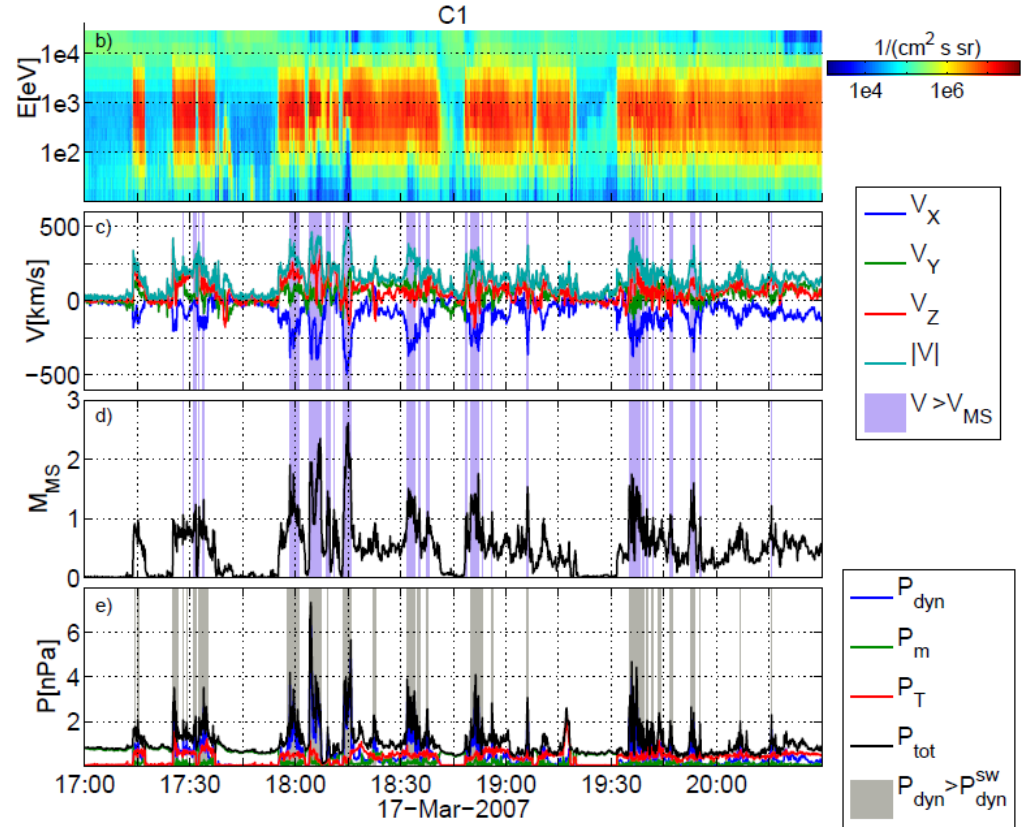
- Data do not satisfy the KHI condition, but are consistent with the MHD surface wave theory (Plaschke & Glassmeier, AG11).

# Transient phenomena under radial IMF can deform dayside MP



See also Dmitriev+ (JGR12)

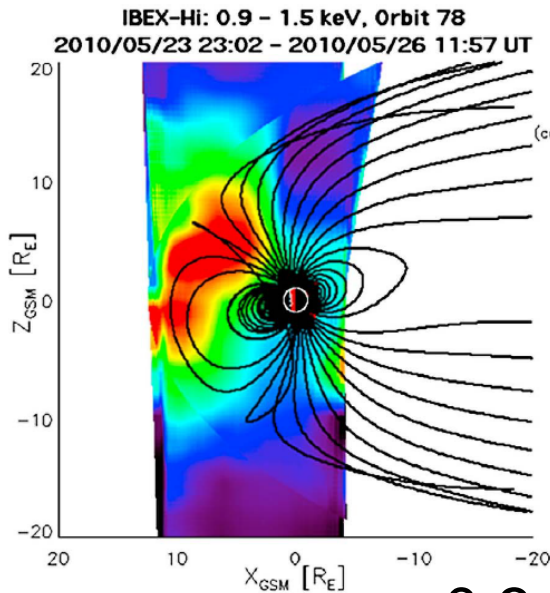
- Sheath super-magnetosonic flows (Hietala+, AG12) or transient ion foreshock phenomena (Safrankova+, GRL12; Hartinger+, JGR13) can deform MP & excite Pc5 ULF waves.



# Polar Cusp

For some details, see [JASTP 2012 special issue](#)  
“Physical Process in the Cusp: Plasma Transport & Energization”

# ENA imaging of the cusps



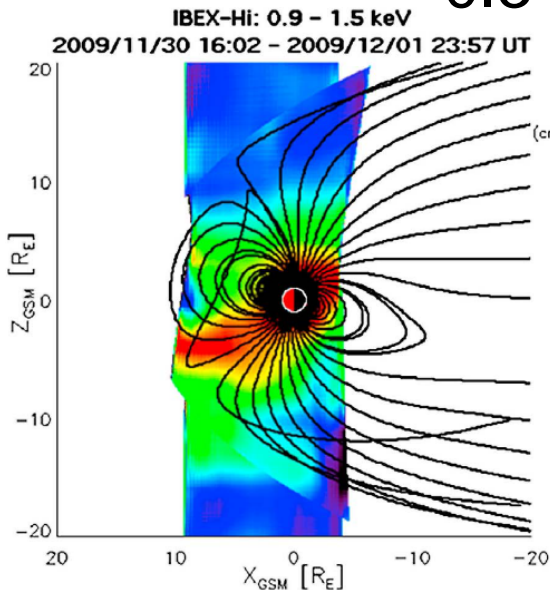
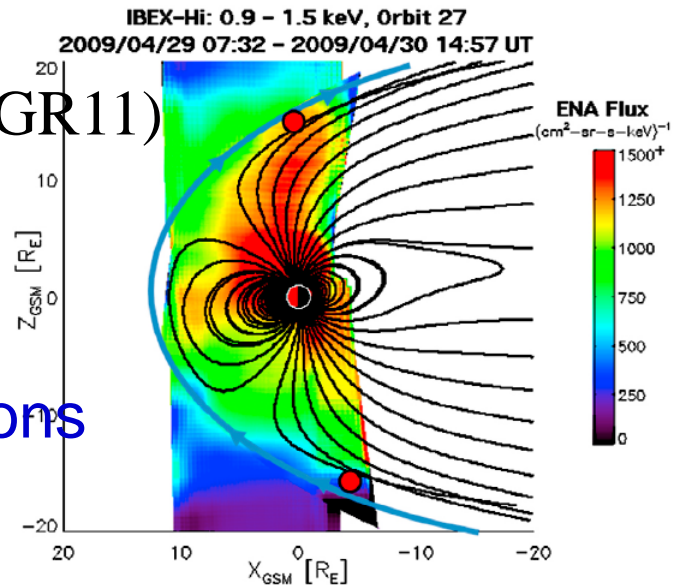
← Southward IMF

↓ Northward IMF

Petrinec+ (JGR11)

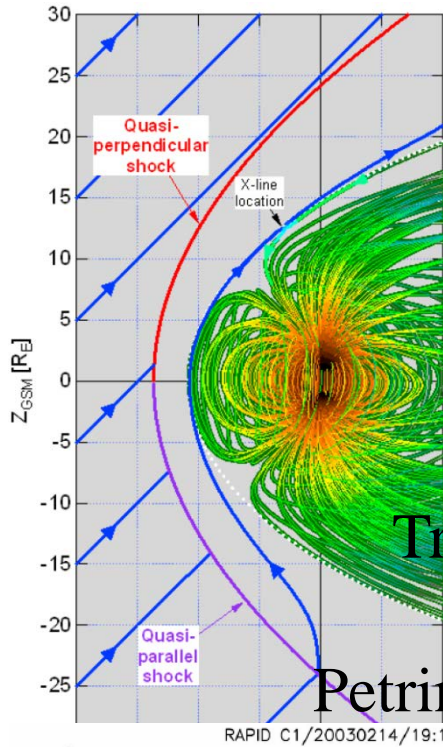
IBEX observations

0.3 - 6 keV



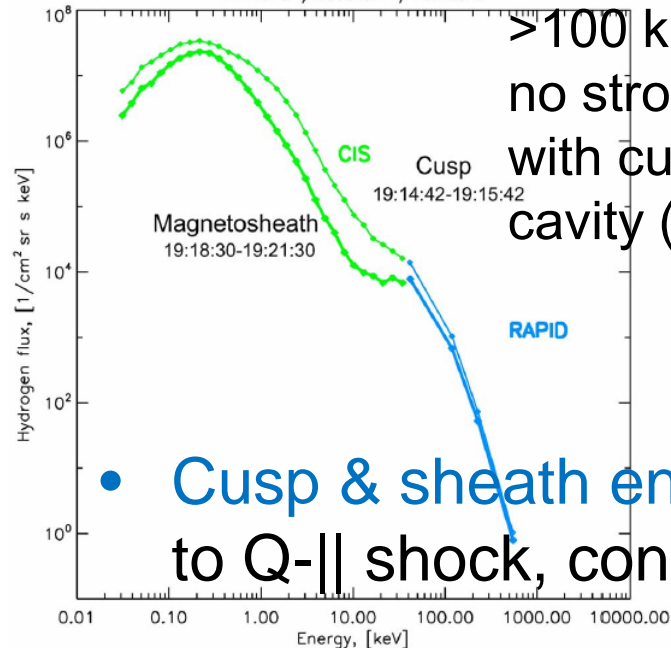
- Clear dipole tilt dependence, leading to north-south asymmetry.
- Emission also for northward IMF.
- Stronger emissions in regions more favorable for reconnection.

# Cusp energetic particles: Q-|| shock (remote) origin?



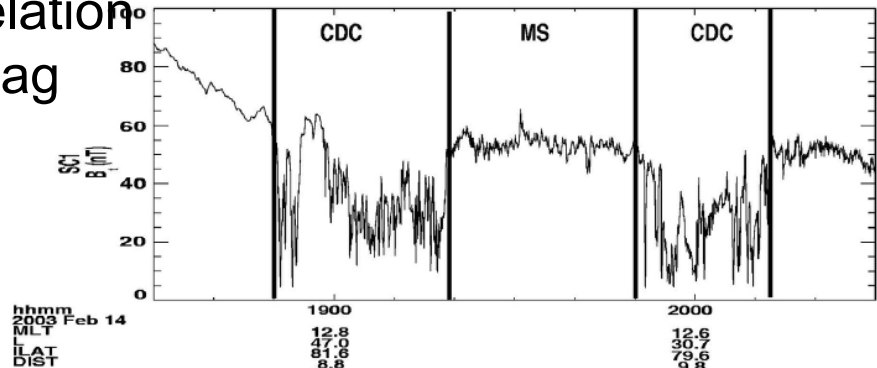
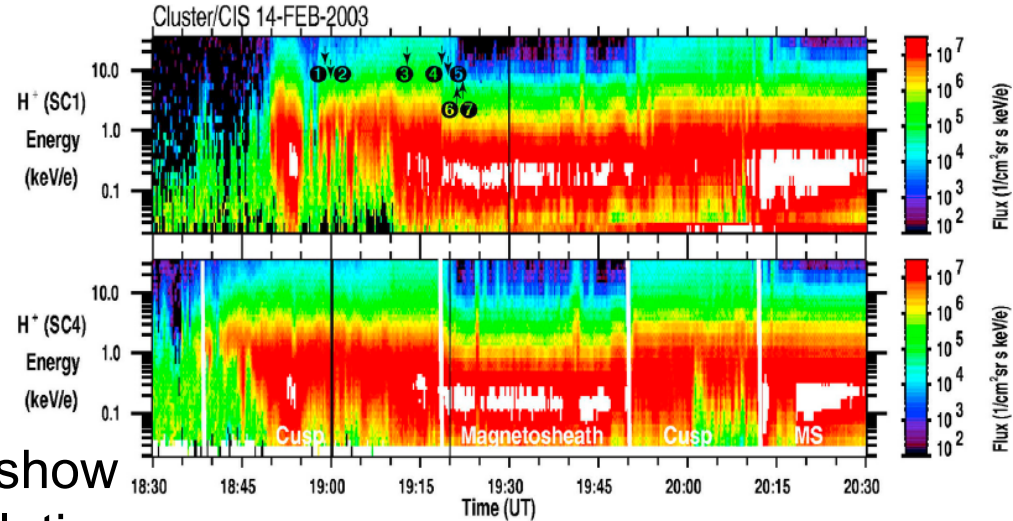
Trattner+ (JGR11;  
JASTP12);  
Petrinec+ (JASTP12)

RAPID C1/20030214/19:15:12



>100 keV ions show  
no strong correlation  
with cusp diamag  
cavity (CDC).

- Cusp & sheath energy spectra are similar, when connected to Q-|| shock, consistent with the shock origin.



hhmm  
2003 Feb 14  
MLT  
LAT  
DIST

1900  
12.8  
47.0  
61.6  
8.8

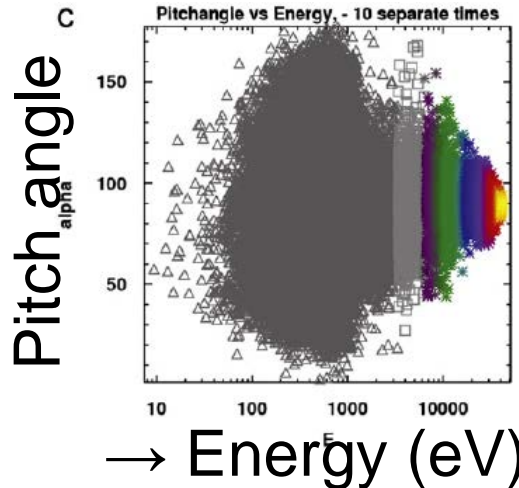
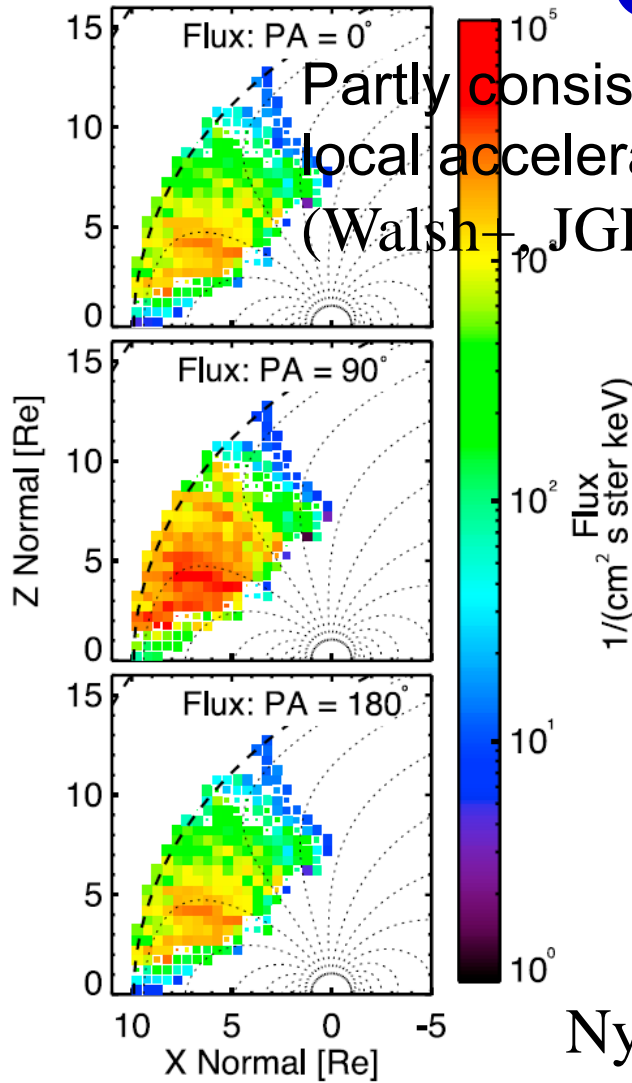
2000  
12.6  
30.7  
79.6  
9.8

>37 keV Electrons

# Cusp energetic particles: Local origin?

Partly consistent with  
local acceleration.  
(Walsh+JGR11)

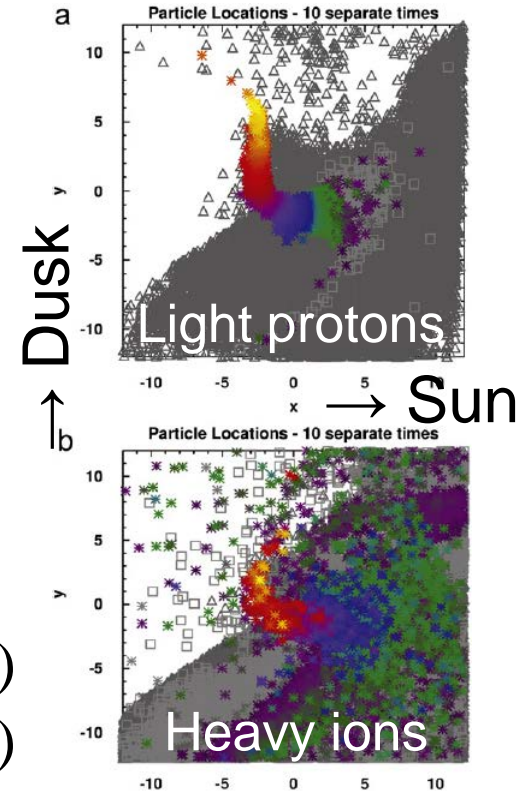
Positively charged particles for SBZ



Acceleration by reconnection  
-driven potential difference.

Adamson+(AG12)

Nykyri+ (JGR11a,b; JASTP12)

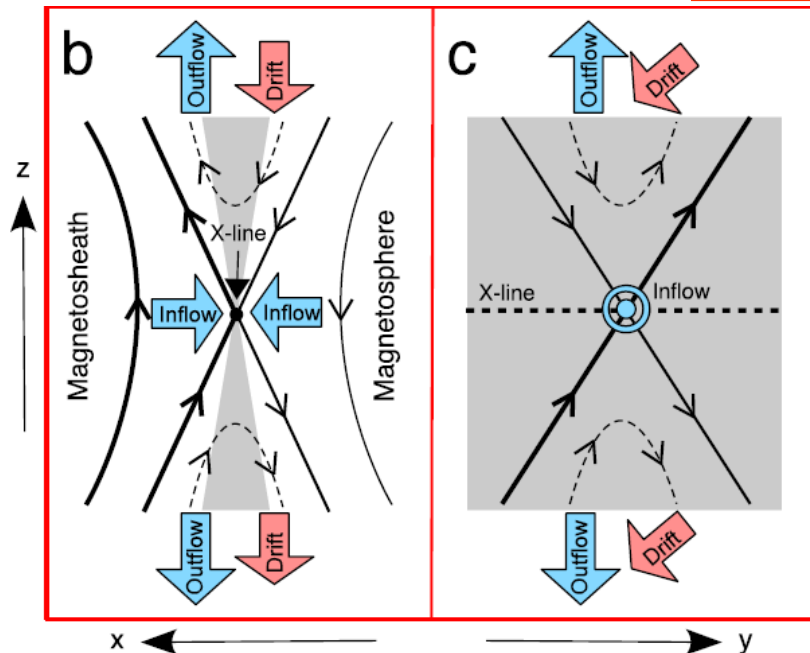
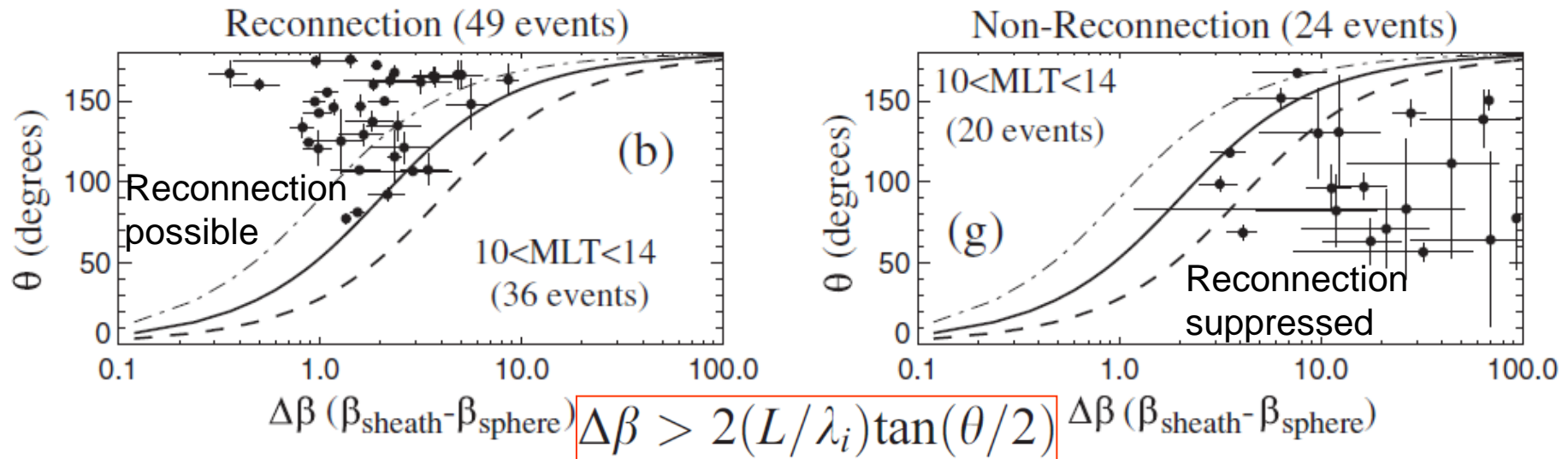


- Test particle simulations → local acceleration up to ~50keV.
- Weak wave power at  $\sim f_{ic}$ . Role of kinetic effects remain unclear.

# Magnetic Reconnection

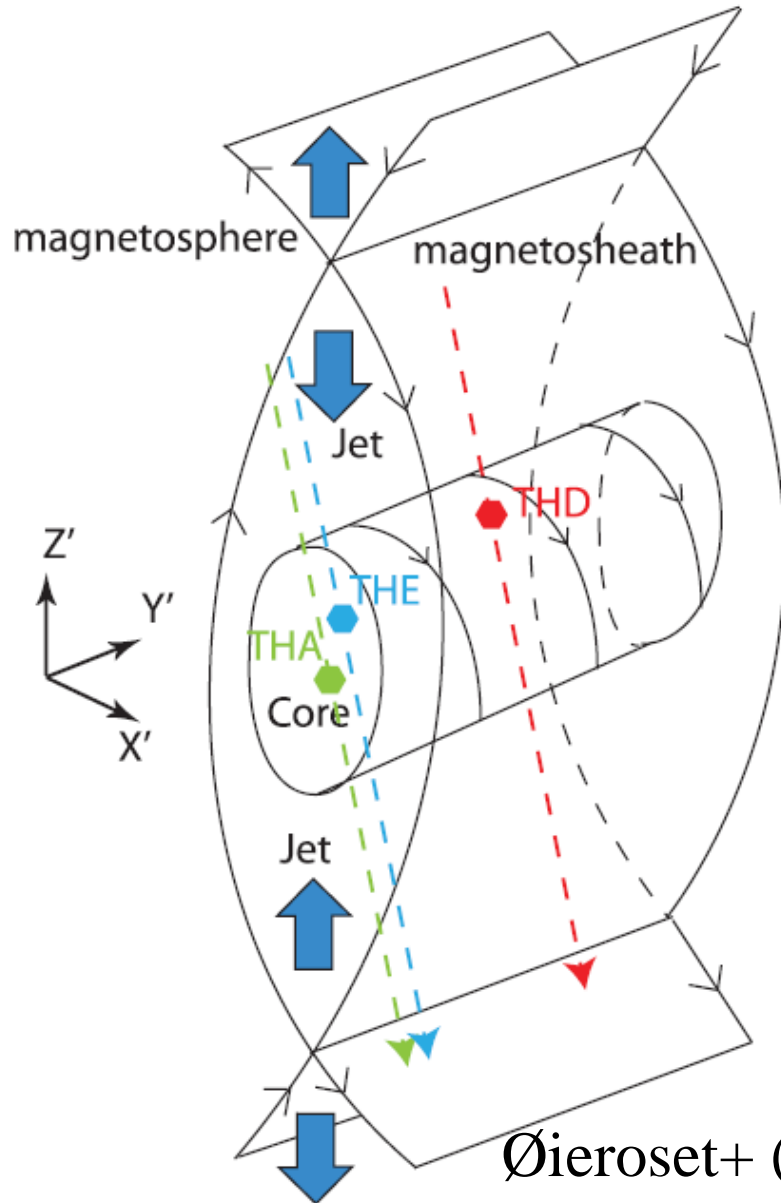


# Diamag suppression of reconnection

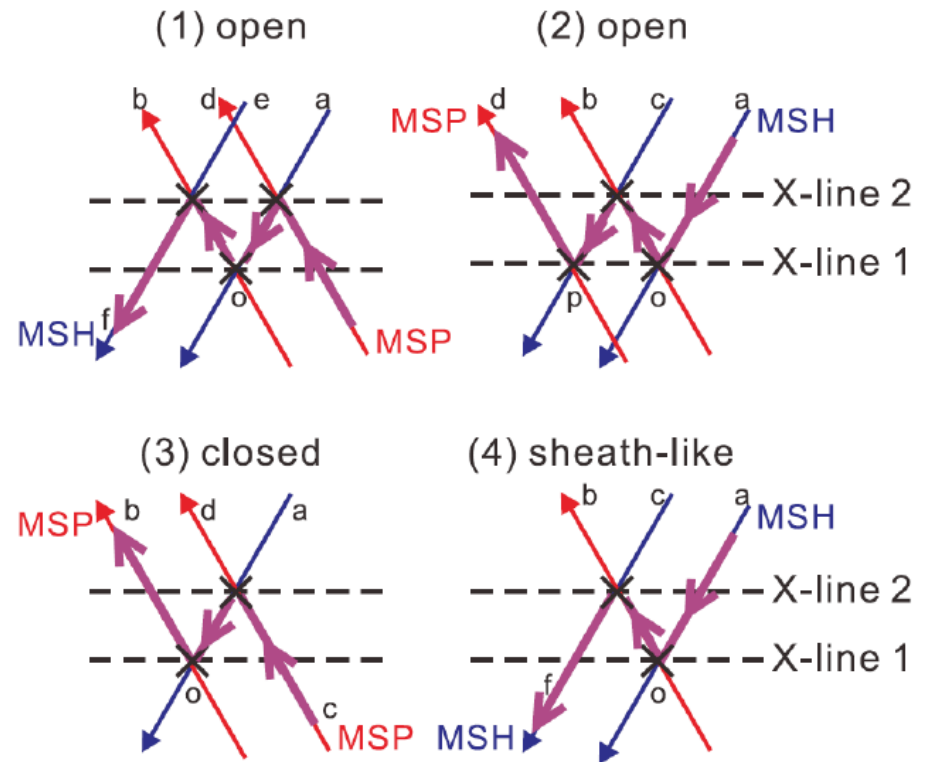


- **Diamagnetic suppression** of reconnection (Swisdak+, JGR03), first tested in solar wind (Phan+, ApJ10), has been **confirmed for MP** too (Phan+, GRL13).
- **At Saturn, high  $\beta$  sheath** likely suppresses reconnection (Masters+, GRL12).

# Evidence of 3D topology of flux rope

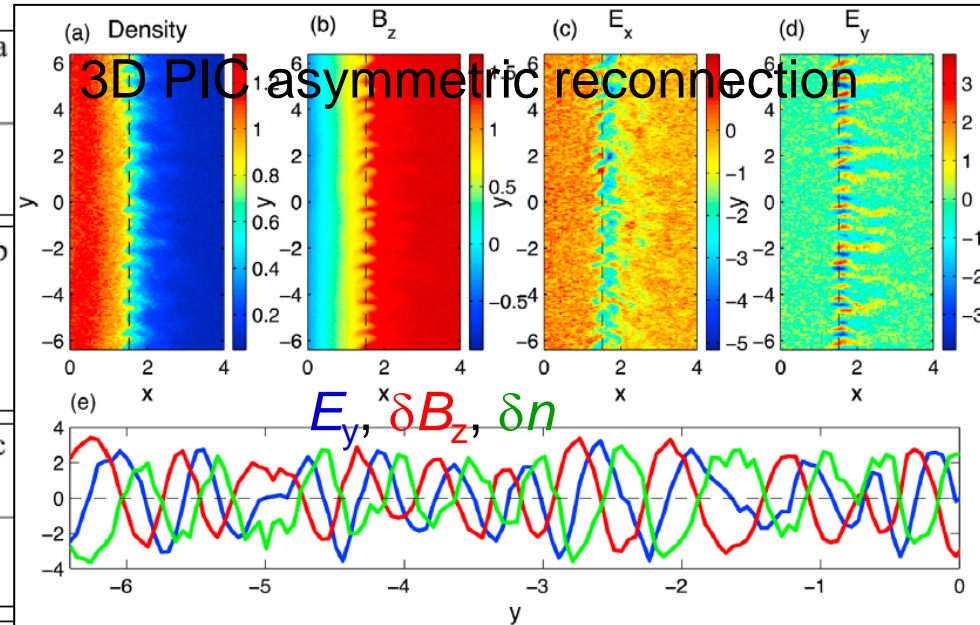
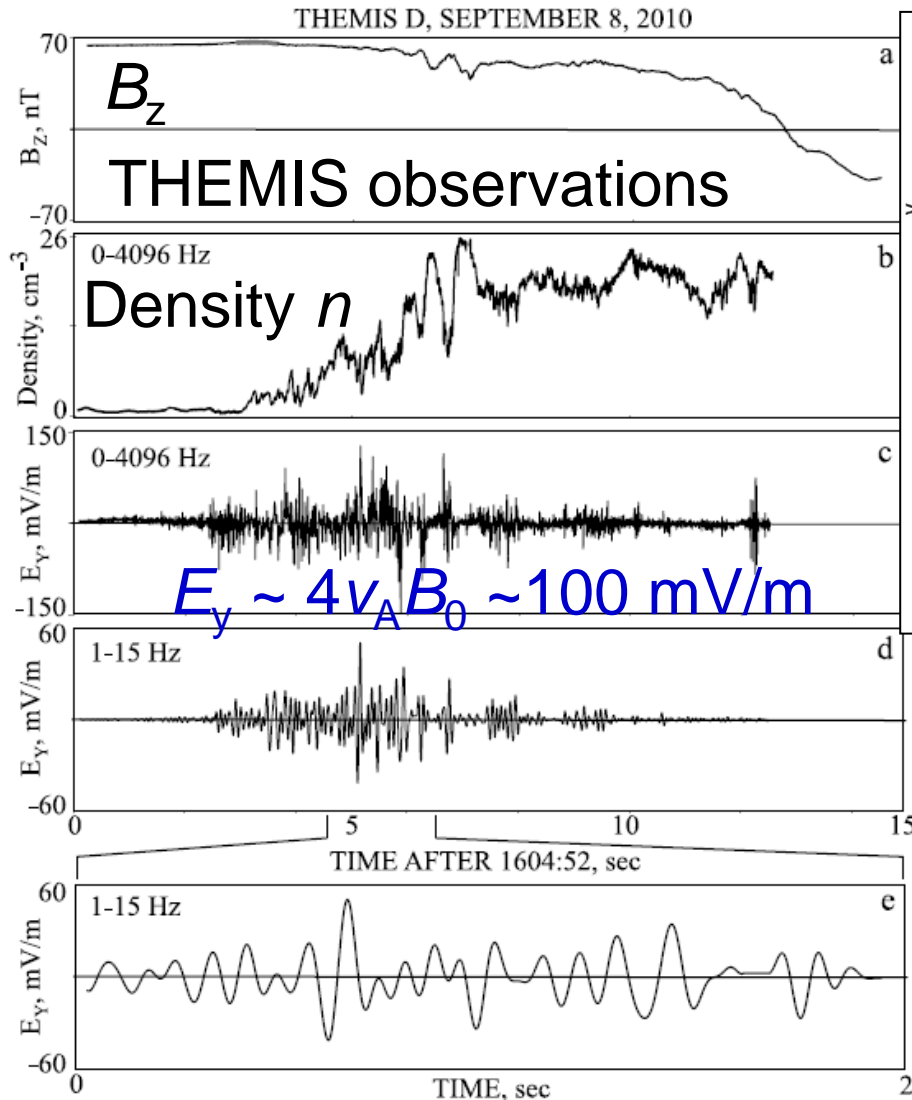


- Field lines in MP flux ropes can have various magnetic topologies.
- Suggest complex nature of MP reconnection & energy transfer.



Øieroset+ (PRL11); Zhang+ (JGR12); Pu+ (GRL13)

# Intense waves in reconnection layer, but not exactly at the X line



- Frequency between  $f_{pc}$  &  $f_{LH}$ , not exactly LHDI mode.
- No role in the reconnection process (resistivity) itself.

Pritchett+ (JGR12); Tang+ (GRL13)

# MAGNETOSPHERIC MULTISCALE

To be launched in late 2014

A SOLAR-TERRESTRIAL PROBE

## What's coming next???

### Multi-scale obs. by MMS, THEMIS, Cluster, Geotail

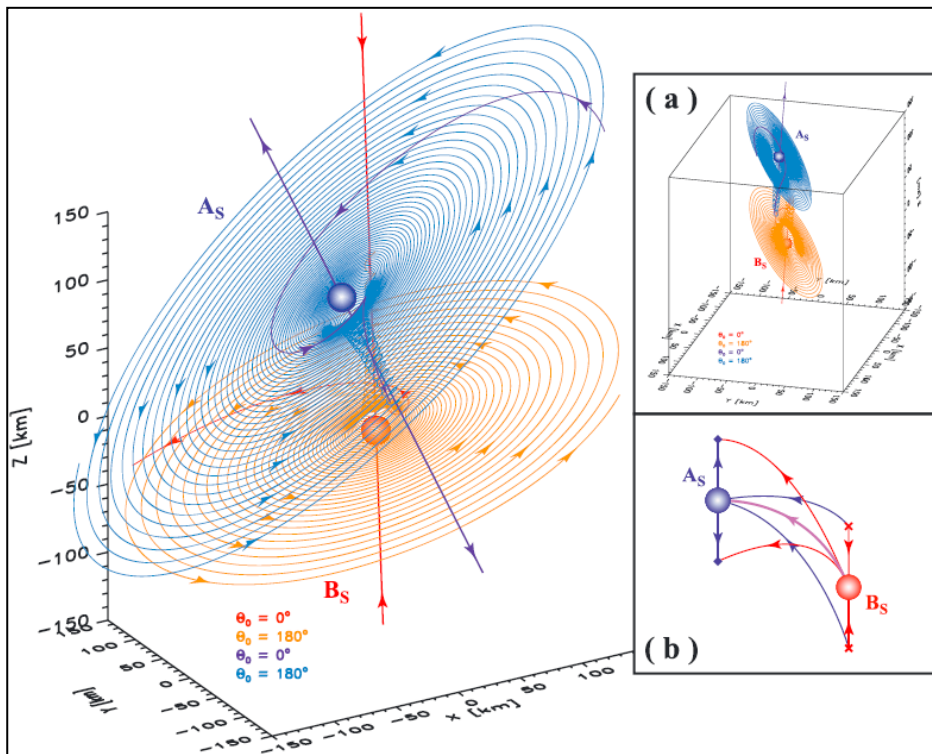
- Electron diffusion/dissipation region in reconnection finally detected?
- Fully 3D nature of flux ropes, magnetic null, separator, KH vortices revealed?
- Cross-scale coupling/feedback processes unveiled?

## Stay tuned for updates!

UNLOCKING THE MYSTERIES OF  
MAGNETIC RECONNECTION

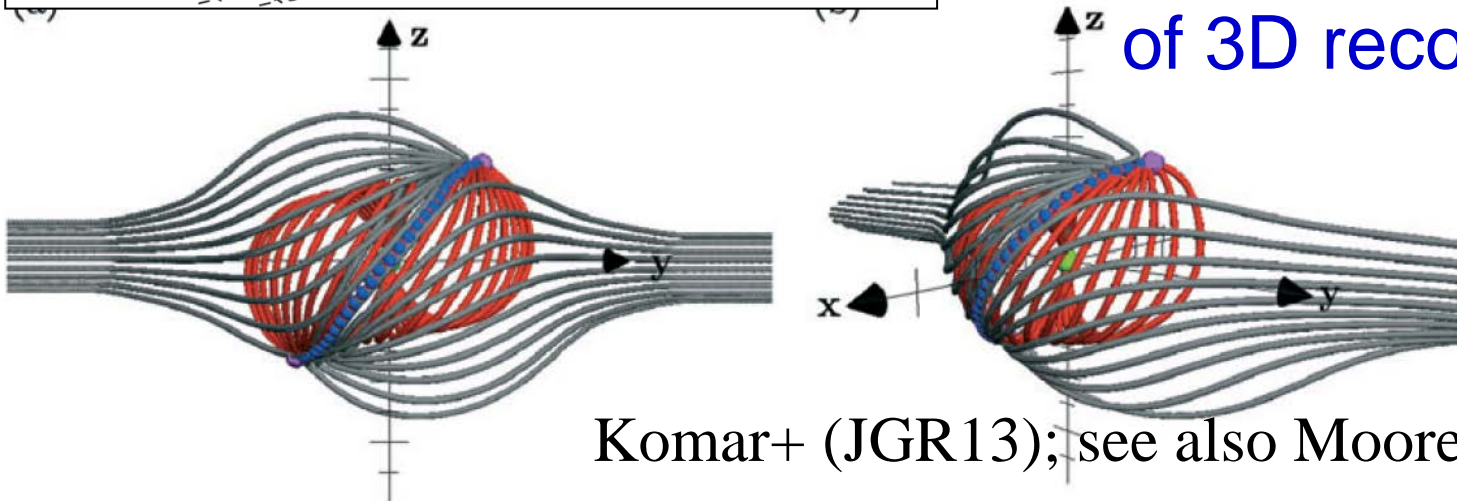
<http://mms.space.swri.edu/>

# Identifying magnetic nulls/separators



- In-depth analysis of null structures in the tail, based on Cluster observations (Wendel & Adrian, JGR13).
- A new method developed for tracing the separators (Komar+, JGR13).

Time is ripe for study of 3D reconnection!



Komar+ (JGR13); see also Moore+ (JASTP13)