Magnetic reconnection at Saturn's magnetopause: Response of boundary layers

A. Masters[1], H. Hasegawa[1], S. V. Badman[1], M. Fujimoto[1], T. D. Phan[2],
A. J. Coates[3,4], M. K. Dougherty[5]

[1]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Japan
[2]Space Sciences Laboratory, University of California, Berkeley, USA
[3]Centre for Planetary Sciences at UCL/Birkbeck, UK
[4]Mullard Space Science Laboratory, University College London, UK
[5]Space and Atmospheric Physics Group, Imperial College London, UK

The interaction between the solar wind and a magnetised planet produces a cavity around the planet known as a magnetosphere. Although this cavity effectively shields near-planet space from the solar wind, the occurrence of magnetic reconnection at the manetopause boundary of the magnetosphere allows solar wind energy to enter the system. In the case of Earth's magnetosphere transition regions often form immediately adjacent to the magnetopause (which also can form around other planetary magnetospheres). The internal layer is often referred to as the Low-Latitude Boundary Layer (LLBL), and the external layer is often referred to as the Magnetosheath Transition Layer (MTL). Both Earth's LLBL and MTL respond strongly to magnetopause reconnection. The nature of magnetopause reconnection at Saturn is unclear. We study Saturn's LLBL and MTL using data taken by the Cassini spacecraft. We examine the reponse of these layers to local magnetised plasma conditions, and compare this response to that of Earth's boundary layers. Our results strongly suggest that the response of Saturn's boundary layers is different ot the terrestrial case, implying that the nature of magnetopause reconnection differs between these two planets.

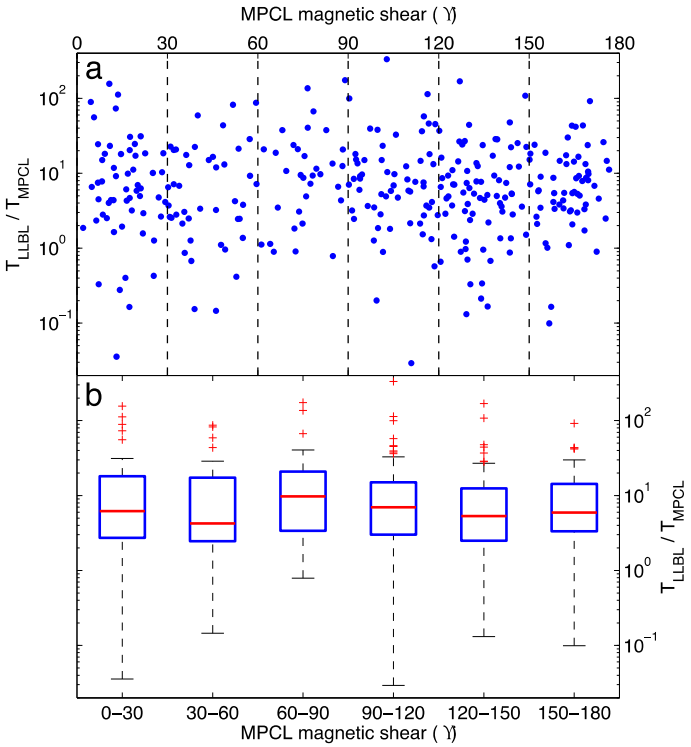

Figure 1. Response of a proxy for the thickness of Saturn's LLBL (y axes) to the magnetic shear across the MagnetoPause Current Layer (MPCL) (x-axis). Although Earth's LLBL shows a strong response to this magnetic shear Saturn's LLBl does not appear to. Taken from Masters et al. (2011, JGR-Space Physics, doi:10.1029/2010JA016421).

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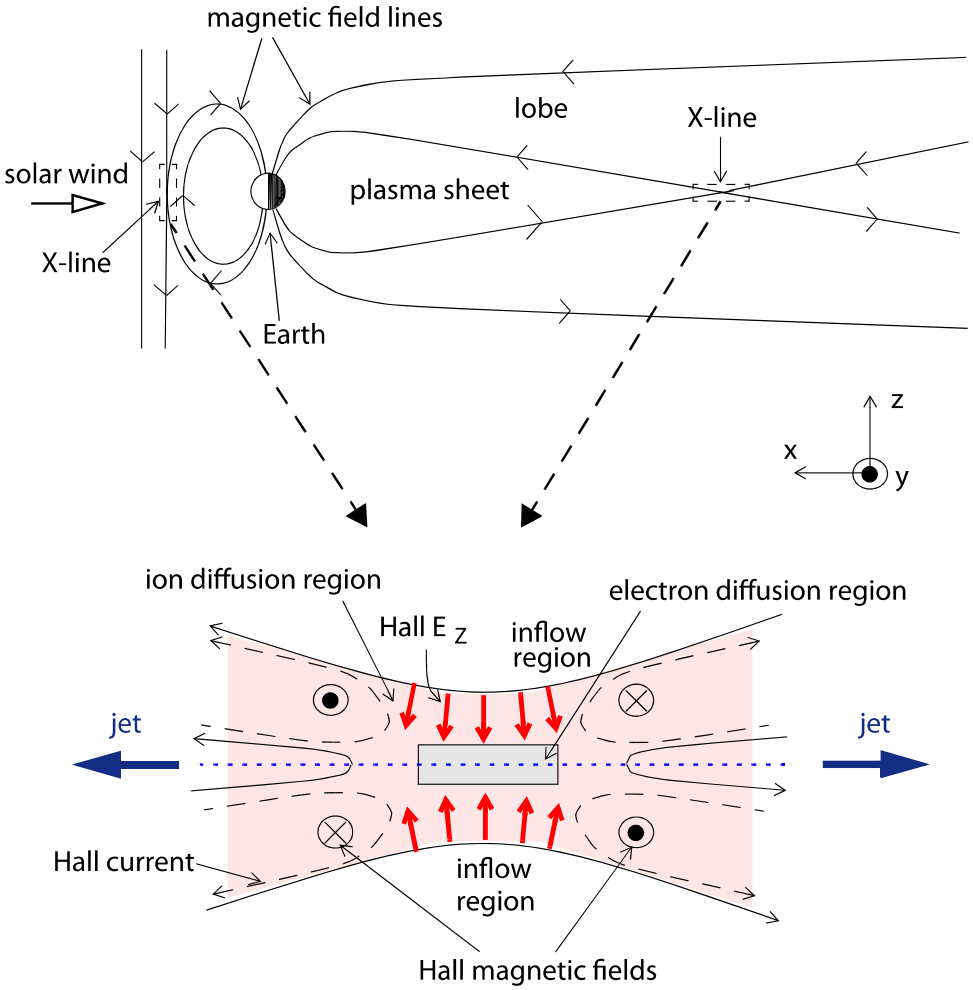
Magnetic reconnection at Earth's magnetopause

- Magnetic reconnection is a fundamental plasma process that occurs in numerous space plasma environments
- It changes the topology of the magnetic field and leads to energy transfer
- Reconnection can occur at the magnetopause boundary of Earth's magnetosphere
- This is the main cause of solar wind energy transport into the system, and is the principal driver of terrestrial magnetospheric dynamics



Taken from Paschmann (2008)

Response of boundary layers adjacent to Earth's magnetopause 3

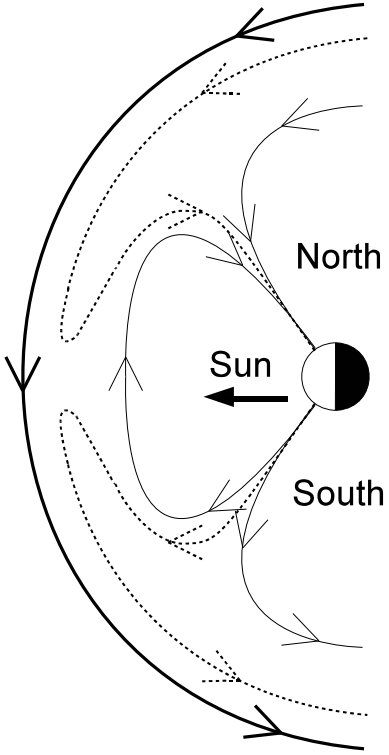
- Internal layer (magnetospheric boundary layer): Adjacent to the magnetopause, inside the magnetosphere, mixture of magnetospheric and magnetosheath plasma
- External layer (magnetosheath transition layer): Adjacent to the magnetopause, outside the magnetosphere, region of the magnetosheath where magnetic flux piles up
- Both respond strongly to magnetopause reconnection, controlled by the orientation of the Interplanetary Magnetic Field (IMF)

Southward IMF

Reconnection at the low-latitude magnetopause

Magnetic flux transported to magnetotail

Low-latitude thickness of both layers decreases

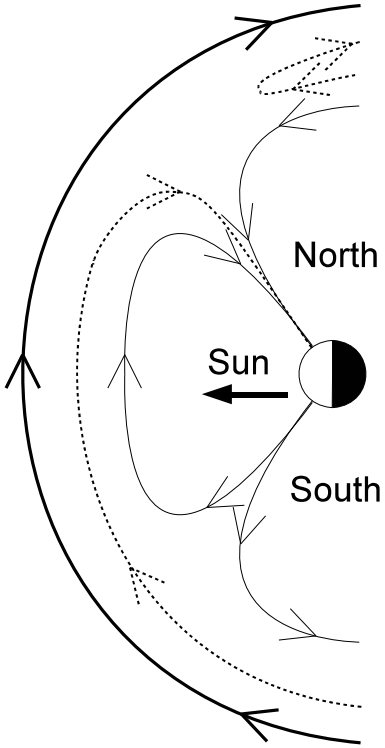


Northward IMF

Reconnection at the high-latitude magnetopause

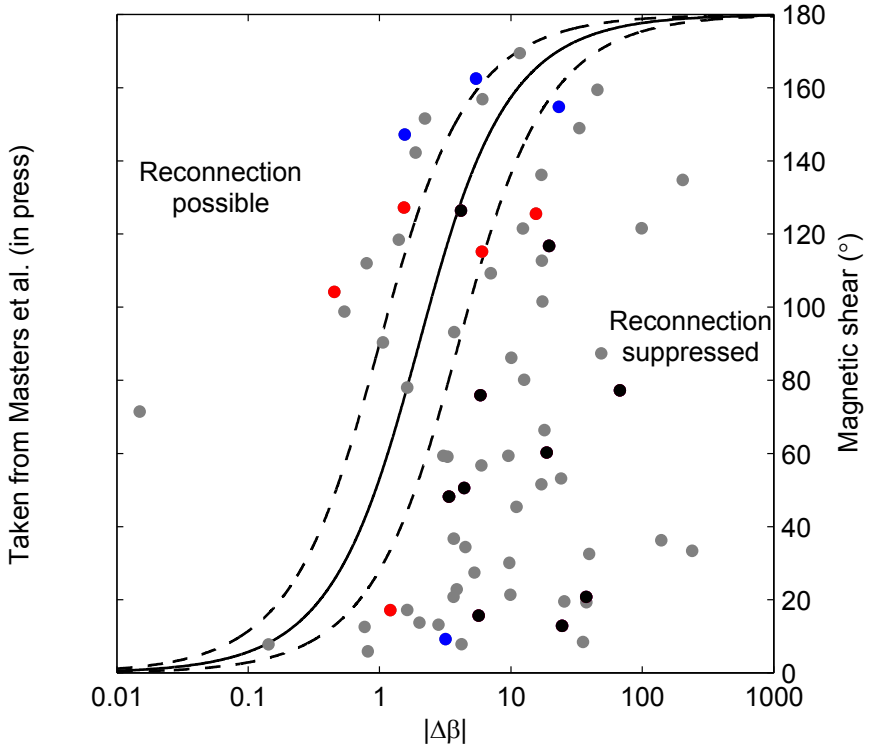
Reconnected flux draped over magnetopause

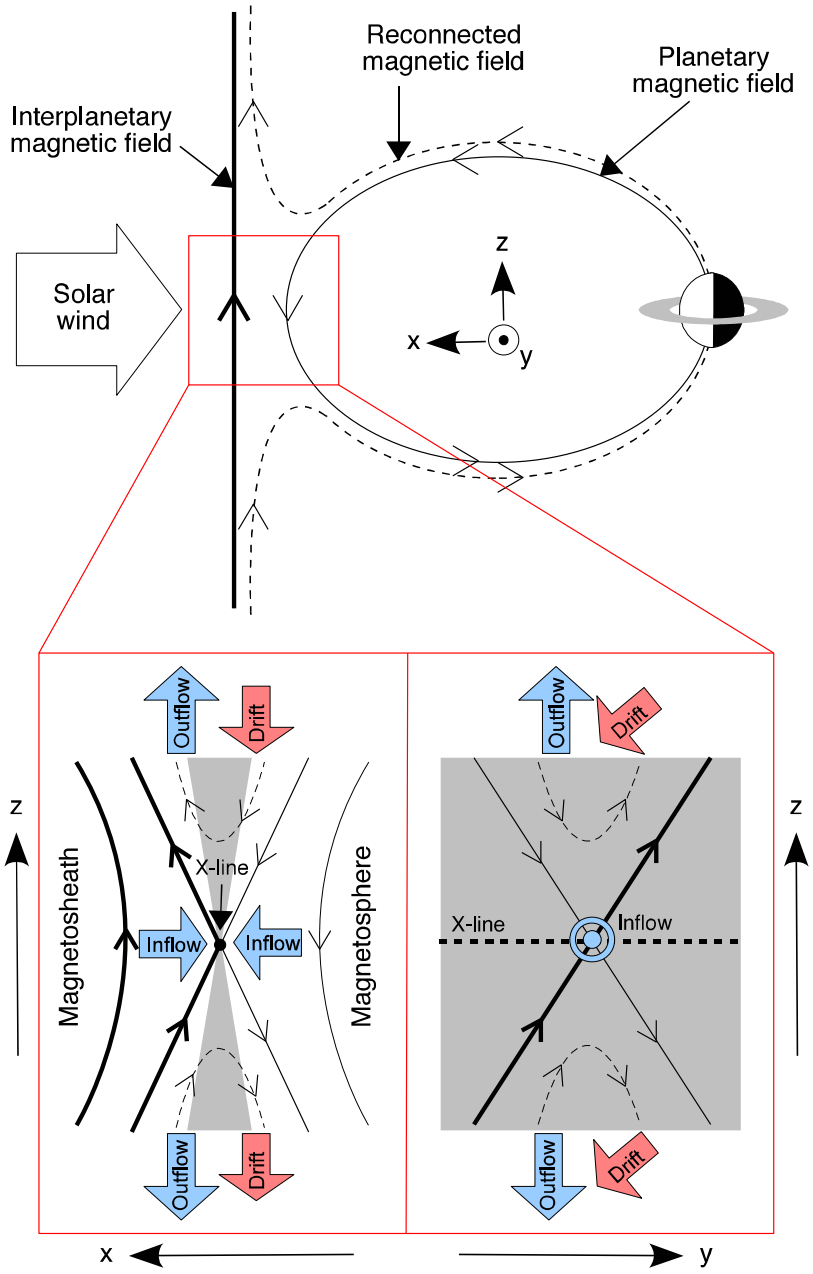
Low-latitude thickness of both layers increases



Magnetic reconnection at Saturn's magnetopause

- Limited evidence for reconnection has been reported to date
- Theory and measured local conditions suggest that the prevailing plasma β conditions should severely restrict the occurrence of reconnection

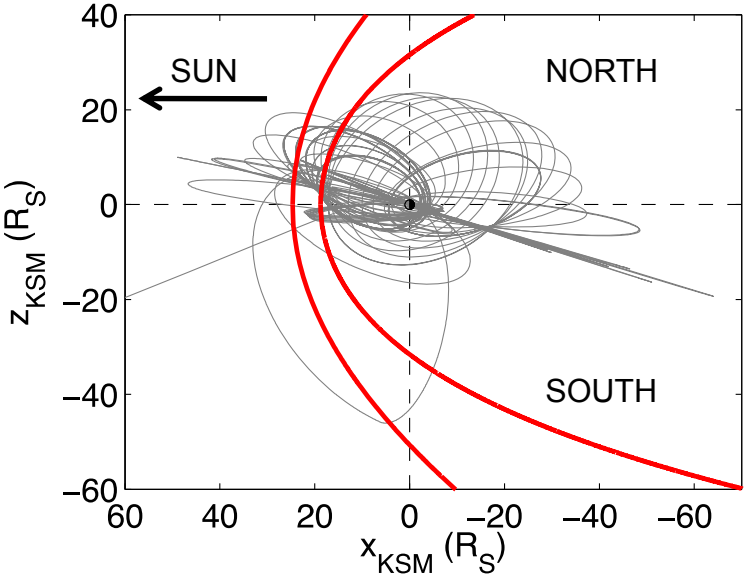


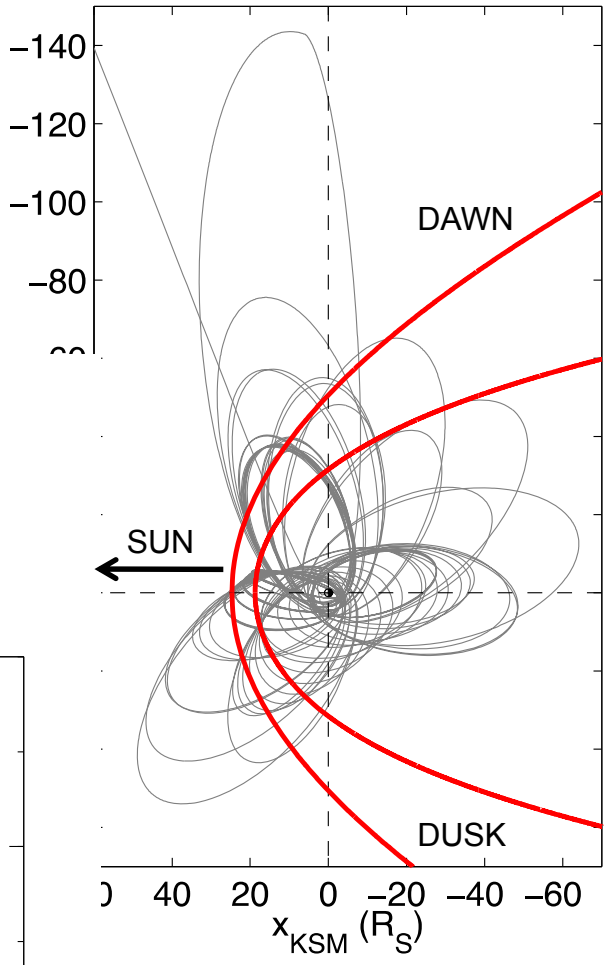


Response of boundary layers adjacent to Saturn's magnetopause? 5

- The spacecraft that have observed Saturn's magnetopause have been unable to comprehensively study the occurrence of reconnection at the boundary (due to a combination of pointing, instrumentation, and sampling constraints)
- However, the boundary layers adjacent to Saturn's magnetopause can generally be detected by spacecraft much more easily
- At Earth, we know that variations in the low-latitude thickness of these layers are related to magnetopause reconnection, which was first established by single spacecraft studies
- Comparing the response of Saturn's low-latitude magnetopause boundary layers to Earth's will show if the nature of magnetopause reconnection is the same at both planets
- Data taken by instruments mounted on the Cassini spacecraft allow this study to be carried out

- This mission is a collaboratic
  and the Italian Space Agenc
- The Cassini spacecraft arriv
  and has been orbiting the pl
- Cassini's orbital tour o
  continue until Septemb





Prime mission: 1 July 04 – 1 July 08

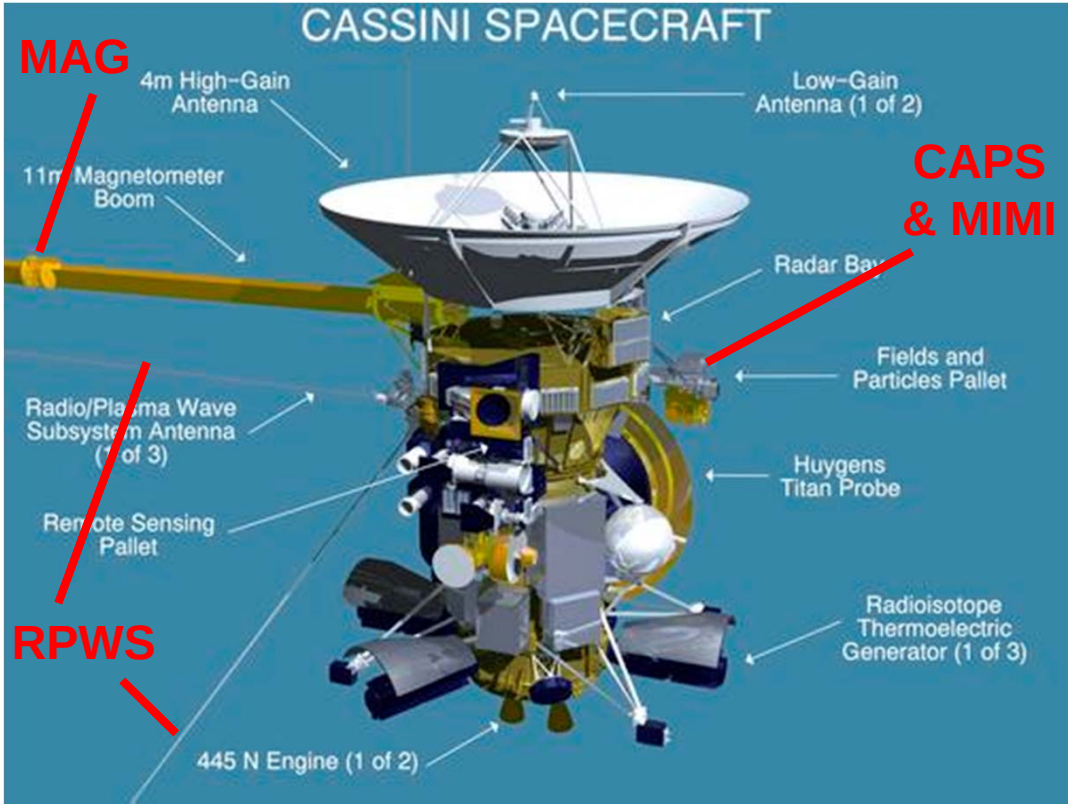
Typical positions of
Saturn's bow shock (outer)
and magnetopause (inner)
Spacecraft trajectory

- Spacecraft is three-axis stabilised, leading to pointing constraints
- Fluxgate magnetometer (MAG) provides 32 vector s^{-1} magnetic field measurements
- Radio and plasma wave system (RPWS)

  Detection of plasma waves, electron densities from wave frequencies
- Plasma spectrometer (CAPS)

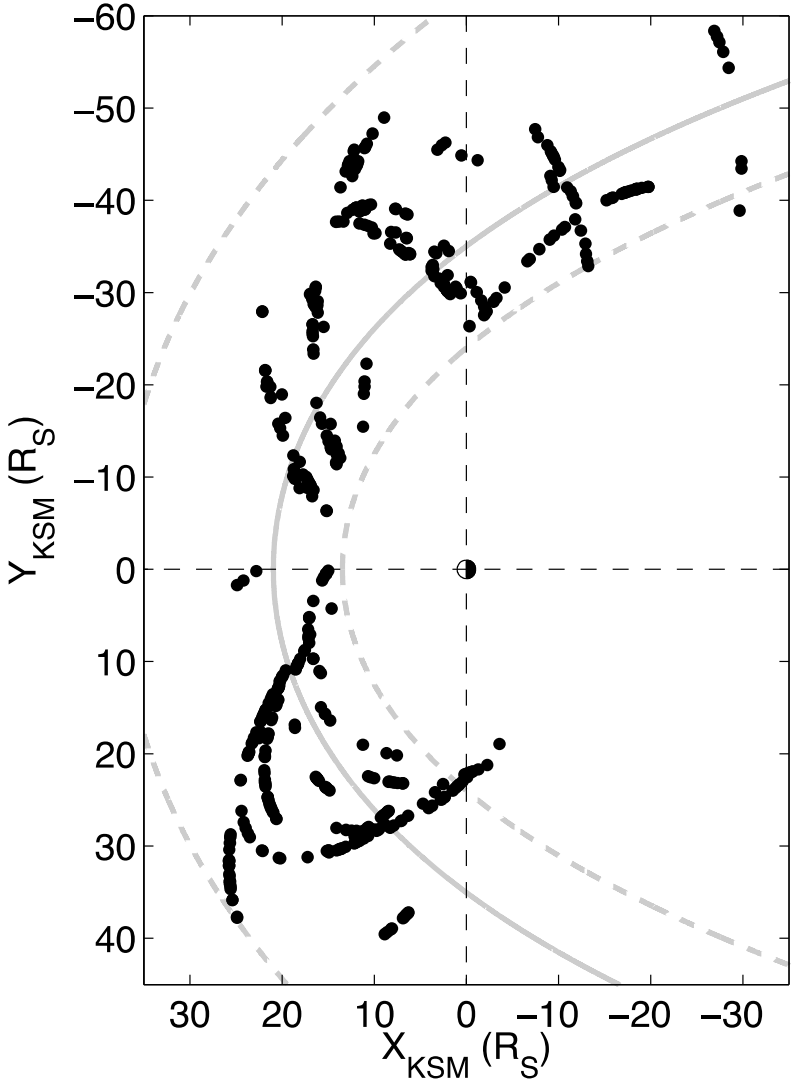
  Electrons: 0.6 eV to 27 keV
  Ions: 1 eV to 50 keV,
  with mass resolution
- Magnetospheric imaging instrument (MIMI)

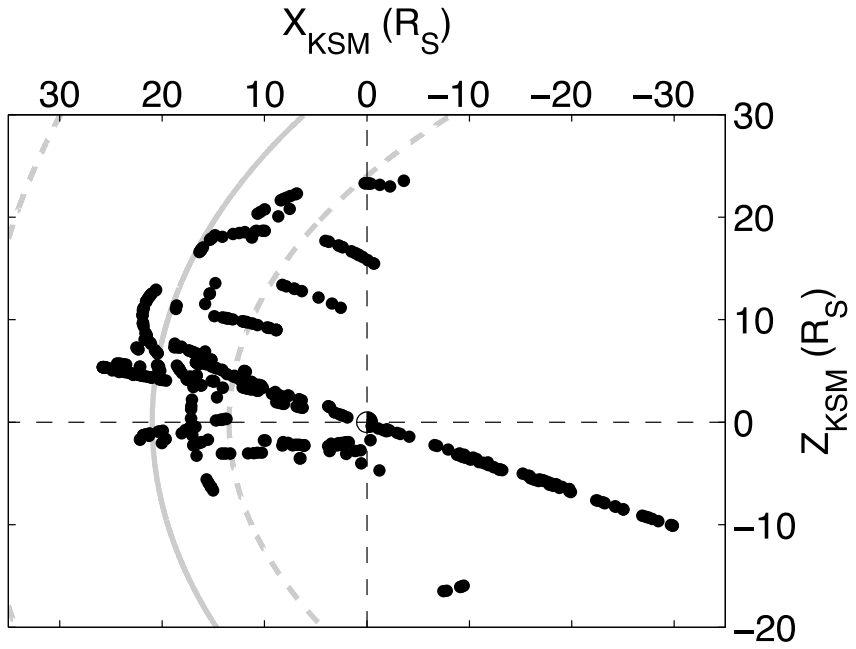
  Electrons: 18 keV to 5 MeV
  Ions: 3 keV to 160 MeV,
  with mass resolution



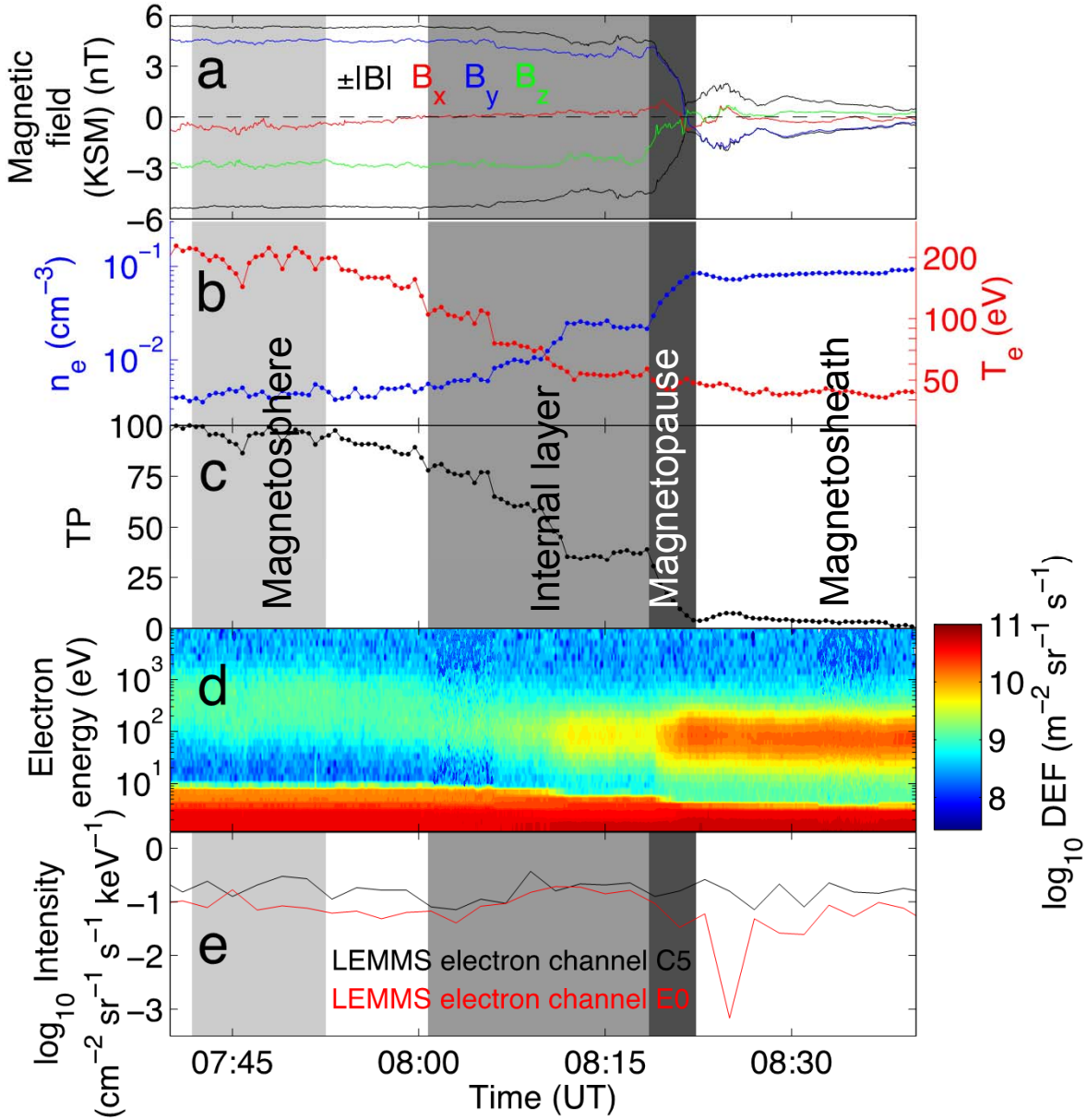
Cassini crossings of Saturn's magnetopause

Taken from Masters et al. (2011a)





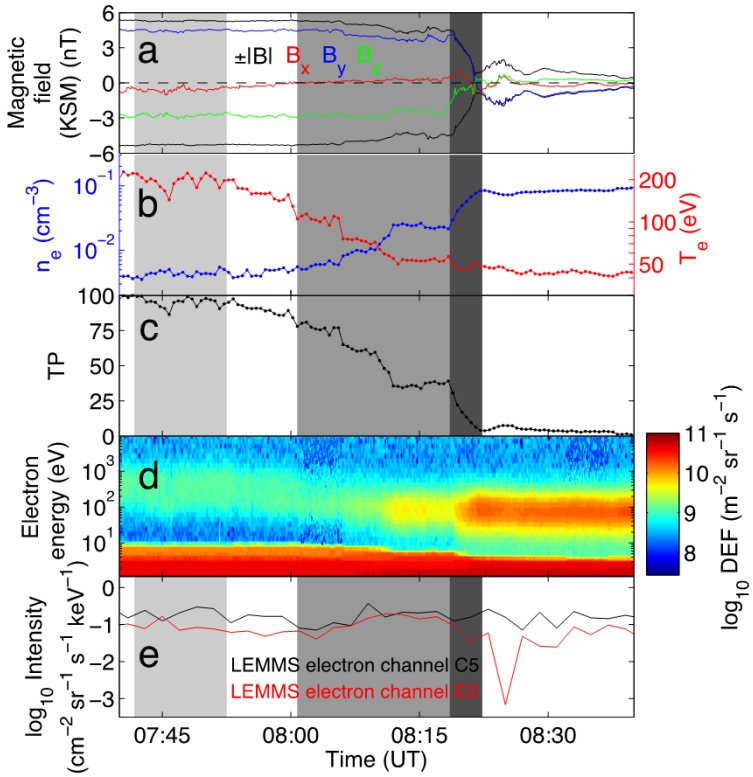
Cassini magnetopause crossings
Saturn orbit insertion (Jun '04) – Aug '07



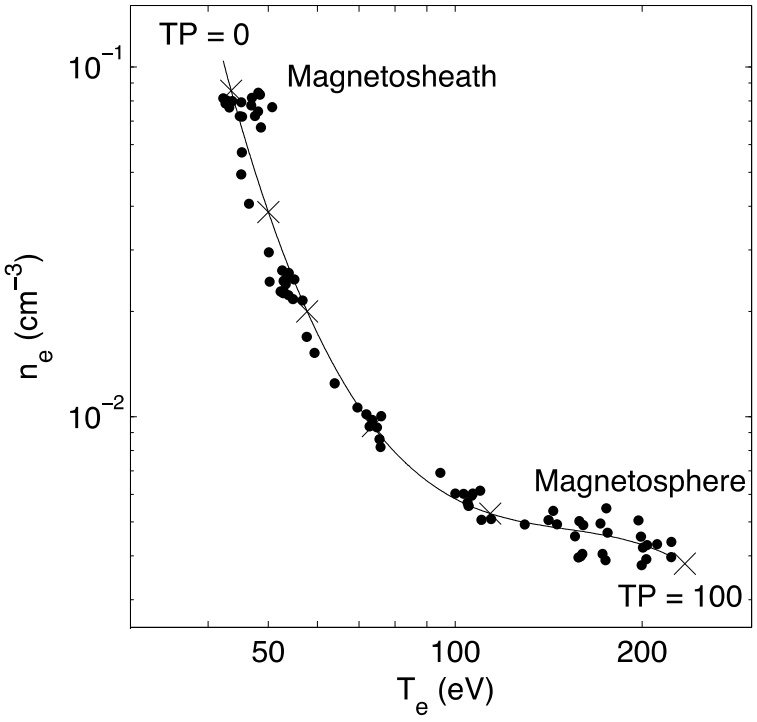
Taken from Masters et al. (2011a)

Internal layer (magnetospheric boundary layer)

- Thermal electron measurements made by Cassini allow us to identify Saturn's low-latitude internal layer [Masters et al., 2011a, b]
- The spacecraft generally spends between ~3 and ~23 minutes within the layer
- The layer has a typical thickness of ~1 R_S, but this is highly variable

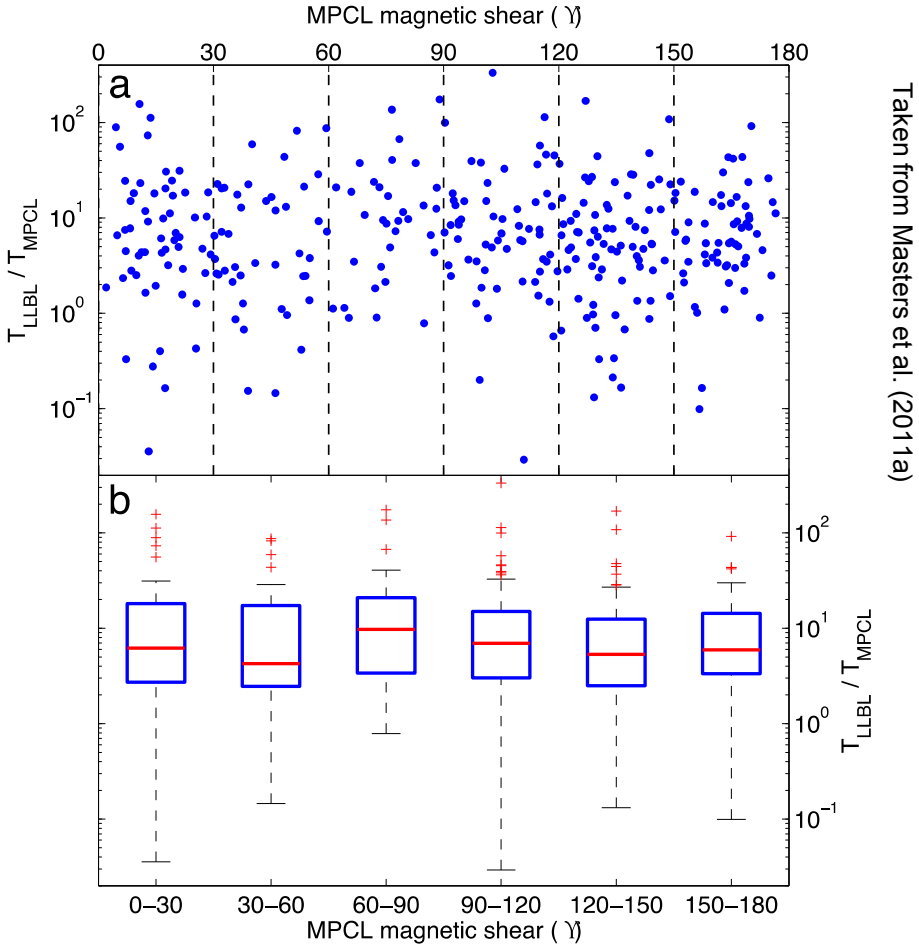


Taken from Masters et al. (2011a)



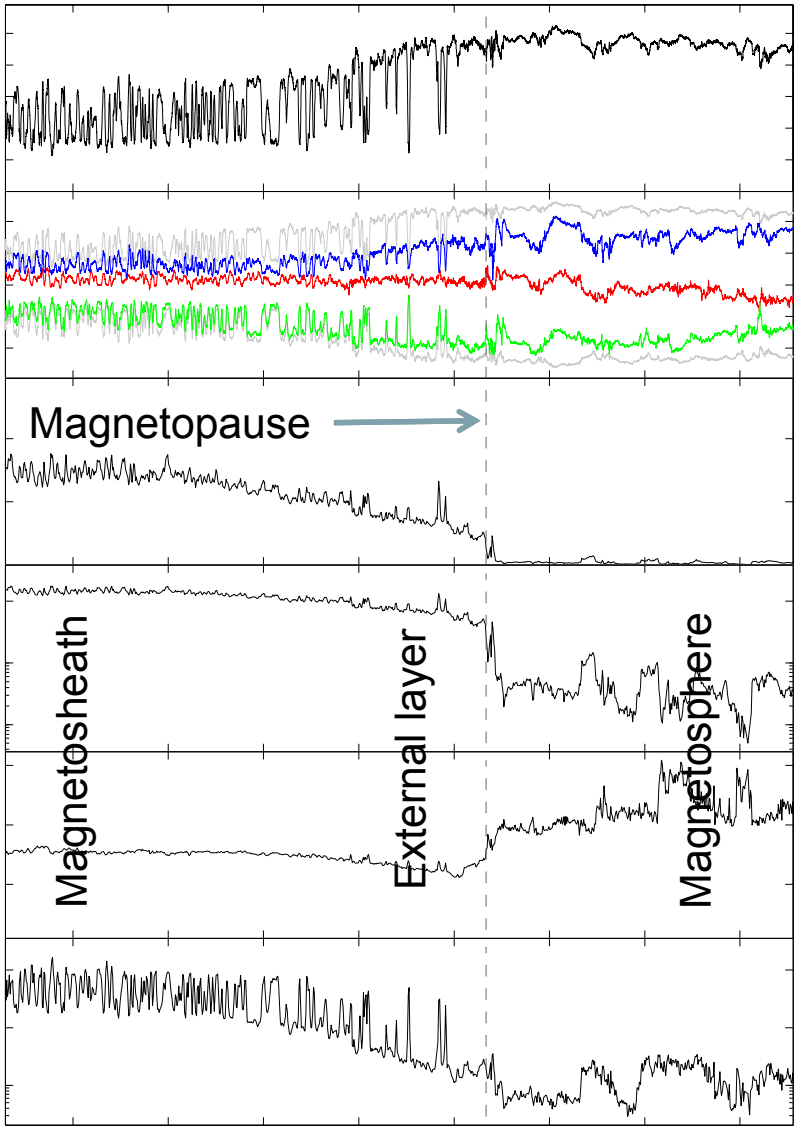
Internal layer (magnetospheric boundary layer)

- The orientation of the IMF plays the dominant role in controlling the magnetic shear across the magnetopause
- Conditions are more favorable for reconnection when the shear is higher
- At each crossing the magnetic shear across Saturn's magnetopause was measured
- The duration of time Cassini spent in the internal layer shows no strong dependence on the magnetic shear
- This is unlike Earth, suggesting that IMF orientation is not the most important factor controlling magnetopause reconnection at Saturn



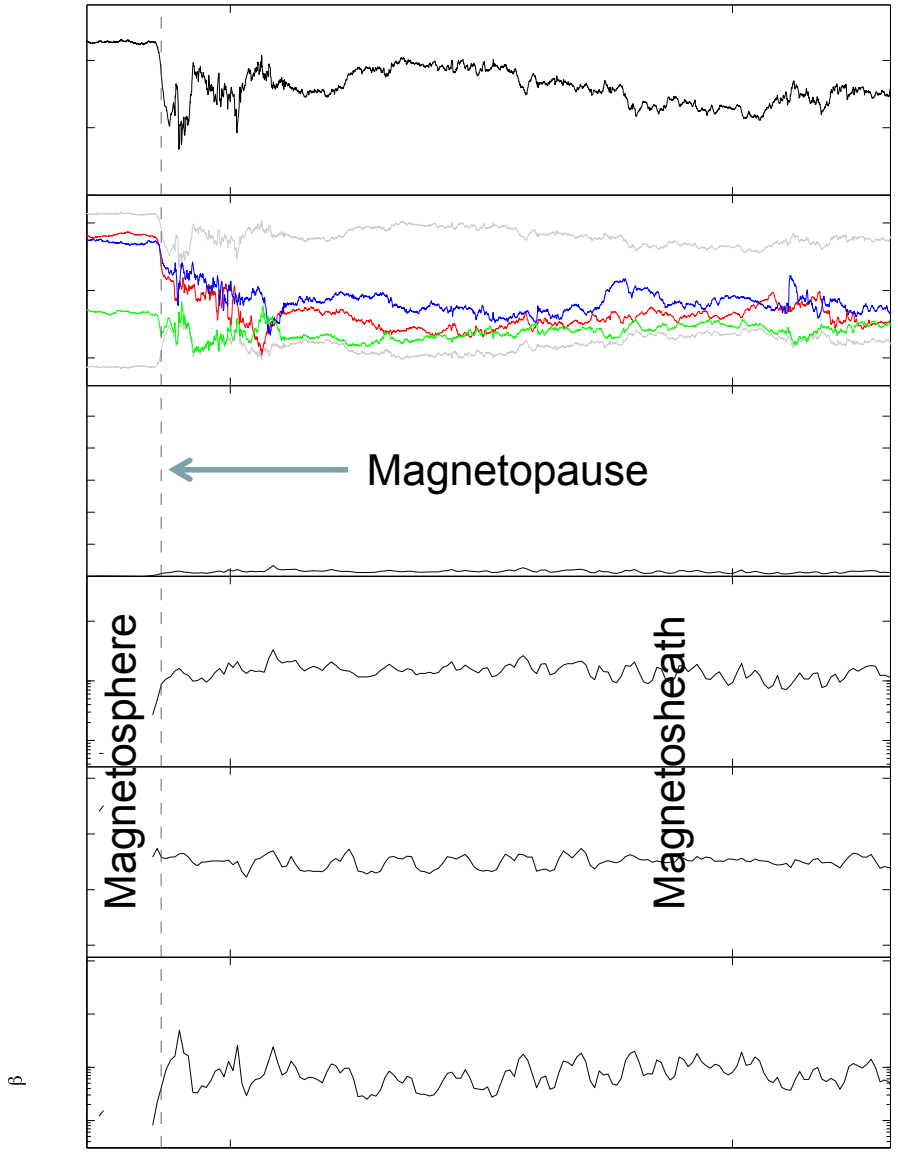
External layer (magnetosheath transition layer)

- Work on the low-latitude external layer is at an early stage
- However, examples of a clear external layer, and the absence of a clear external layer, have been identified
- In this case there is a clear external layer, where the the IMF is heavily draped around the magnetopause
- As the magnetopause is approached the strength of the IMF increases, and the plasma density decreases (preserving total pressure balance)
- This example corresponds to a low-magnetic shear across the magnetopause (Earth-like case)



External layer (magnetosheath transition layer)

- In this second example there is no clear external layer
- The strength of the IMF is not significantly higher closer to the magnetopause
- The density of the solar wind is not significantly lower closer to the magnetopause
- This is higher shear case, potentially also an Earth-like case
- 32 such crossings have been identified in Cassini observations
- The presence/absence of the external layer needs to be assessed in each case



Summary

- Magnetic reconnection is a fundamental space plasma process that releases magnetic energy and changes the topology of the magnetic field
- When reconnection occurs at the magnetopause boundary of a planetary magnetosphere it leads to the transport of solar wind energy into the system
- At Earth, this process strongly affects both the internal and external boundary layers that lie adjacent to the magnetopause
- At Saturn, the internal layer does not respond in the same way as the equivalent region of Earth's magnetosphere
- New results concerning the external layer at Saturn need to be analyzed in detail
- This combined study may provide further evidence that the nature of the solar wind-magnetosphere interaction at Saturn is not Earth-like