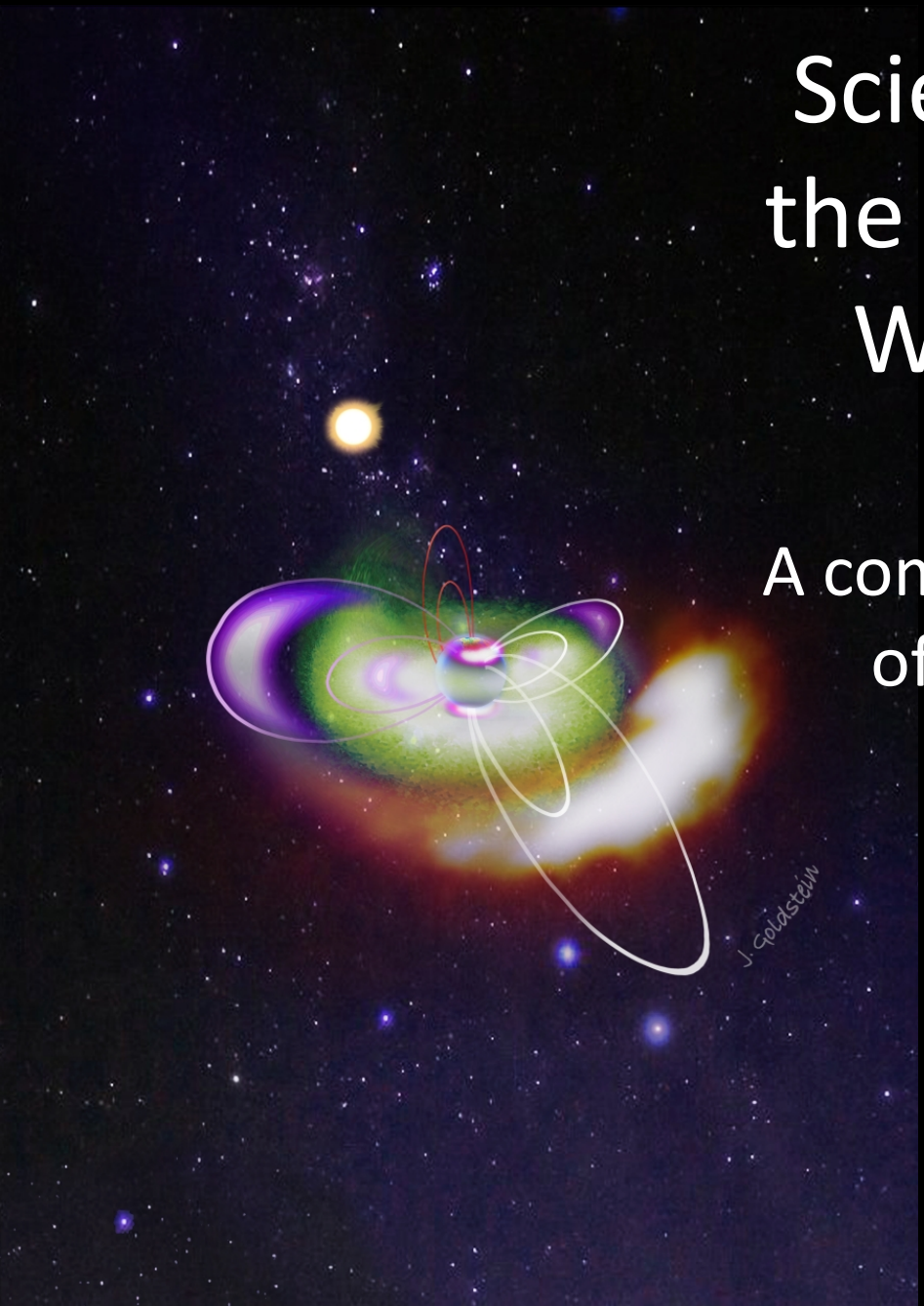
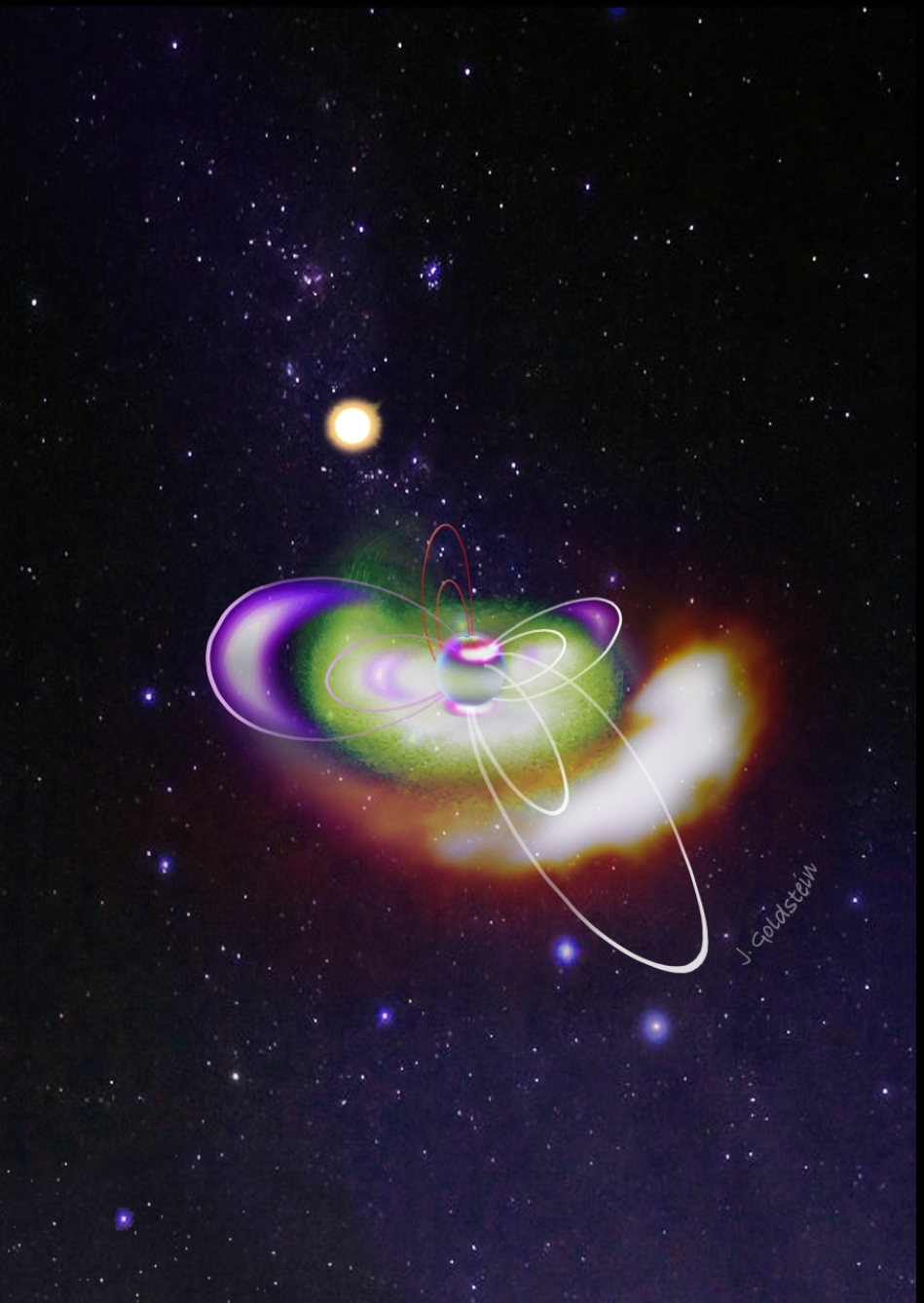


Scientific Progress Over the Past Decade in Solar Wind-Magnetosphere Interactions

A compilation by the SWMI Panel of the 2011 Decadal Survey in Solar and Space Physics

Michelle F. Thomsen

SWMI Panel Chair



SWMI Panel Members

Joe Borovsky

Joe Fennell

Jerry Goldstein

Janet Green

Don Gurnett

Lynn Kistler

Mike Liemohn

Robyn Millan

Don Mitchell

Tai Phan

Mike Shay

Harlan Spence

Michelle Thomsen

Richard Thorne

Mike Wiltberger

Caveats

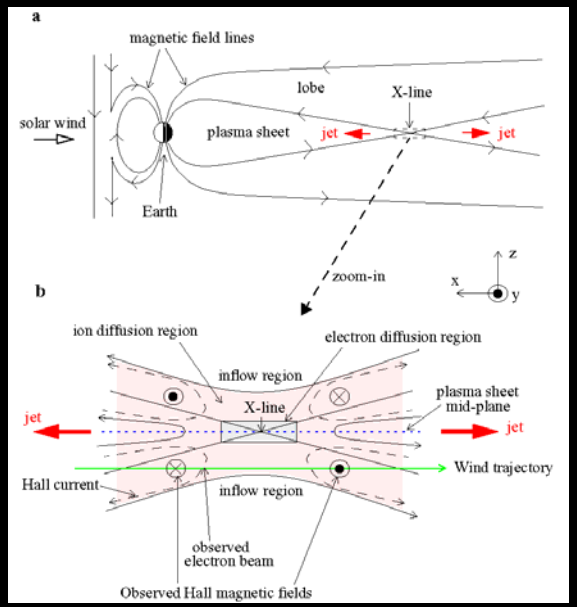
- This task is impossible.
- This is just a sample. (Your favorite may be missing.)
- A different panel would probably pick a different set.
- I’m not an expert on much of this.

Top Science Objectives
2003 Solar and Space Physics Decadal Survey
Solar Wind-Magnetosphere Panel Report

1. A deeper physical understanding of fundamental plasma processes, such as particle acceleration, magnetic reconnection, and the role of turbulence
2. Understanding the scale sizes of the solar wind structures that power Earth's magnetosphere
3. Understanding the dynamics of the coupled magnetospheric system and of space weather
4. Understanding the complex interaction between the solar wind and the polar ionosphere
5. Measurement of the density of the invisible populations within the magnetosphere
6. Understanding the energization of the radiation belts
7. Understanding planetary magnetospheres; Understanding the complex interactions of the solar wind and planetary magnetospheres and atmospheres

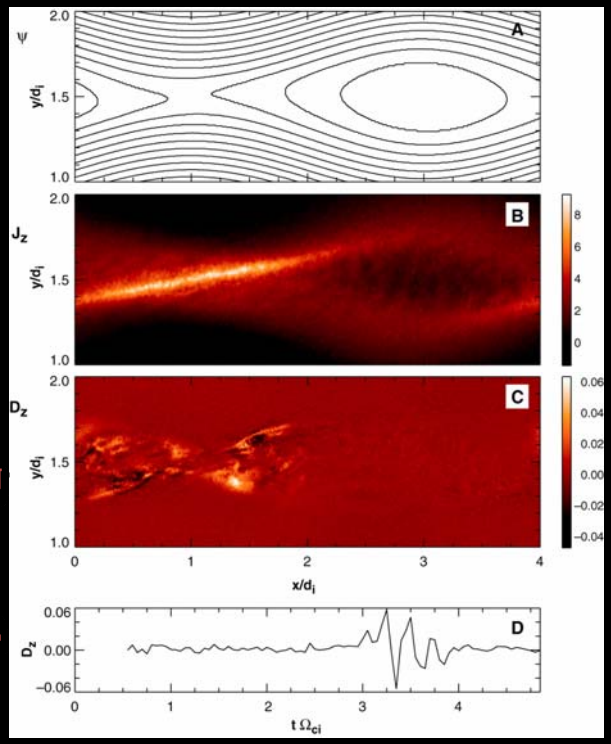
1. A deeper physical understanding of fundamental plasma processes, such as particle acceleration, magnetic reconnection, and the role of turbulence

The diffusion region of magnetic reconnection



Kinetic simulations reveal structure of diffusion region

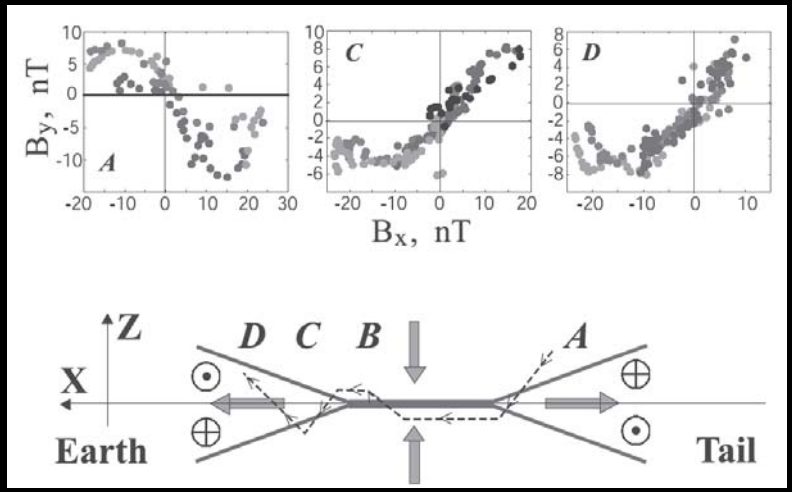
[Drake et al., *Science*, 2003]



Anomalous Drag
(not proportional to Jz)

In-situ detections of the diffusion region

Out of plane Hall component of **B**

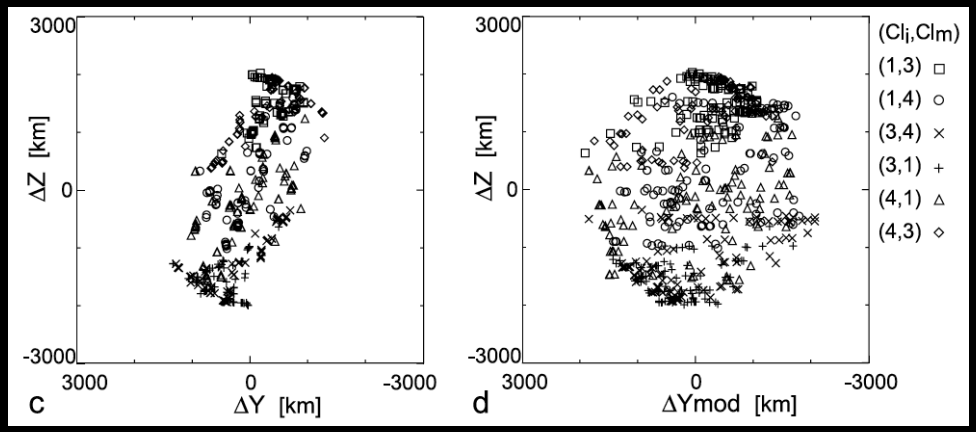


Reconstructed Cluster trajectory through diffusion region

[Runov et al., *Geophys. Res. Lett.*, 2003]

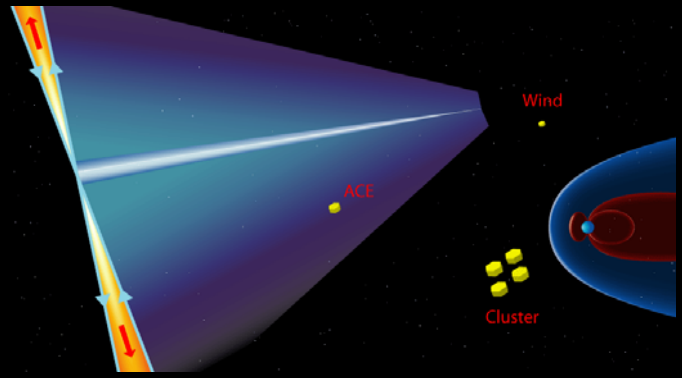
Spatial and temporal structure of reconnection region

BBF (reconnection outflow) scale size <0.5 Re
=> Reconnection region is small



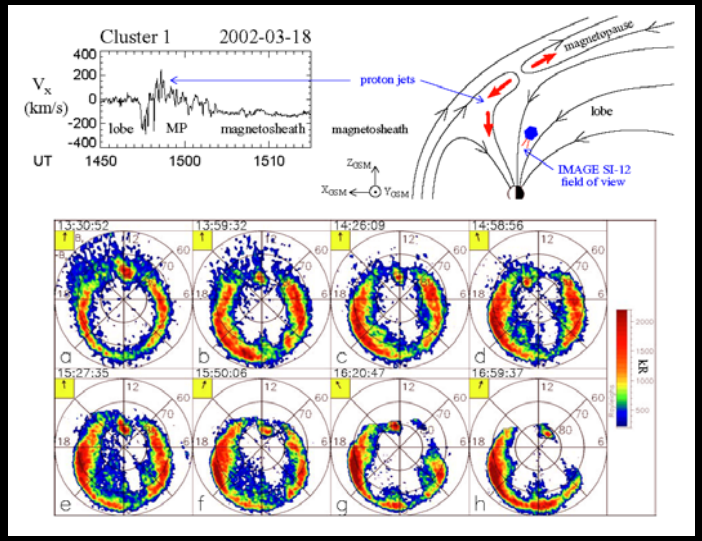
[Nakamura et al., *Geophys. Res. Lett.*, 2004]

Reconnection X-line in solar wind extends ~600 Re
=> Reconnection region is vast



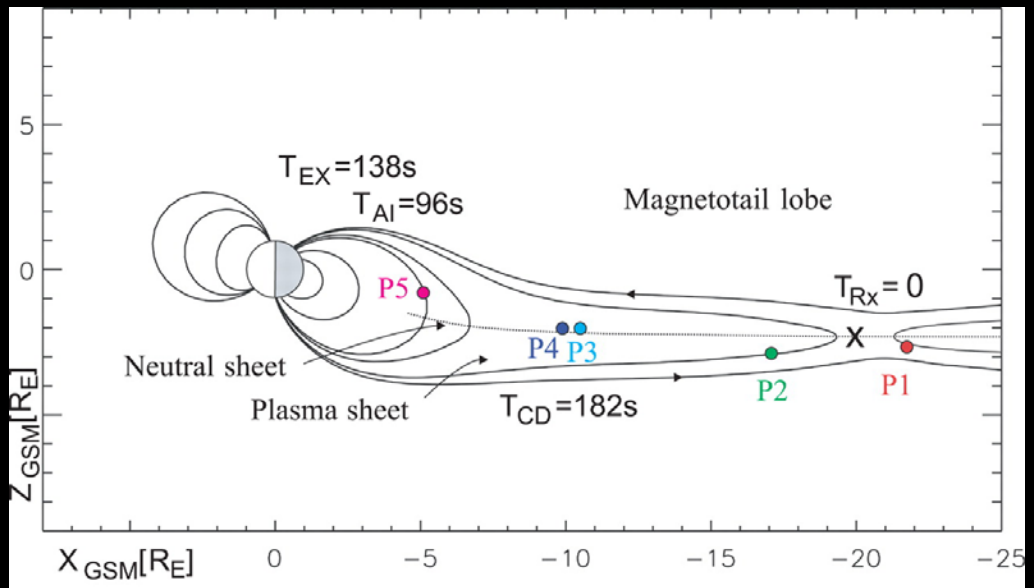
[Gosling et al., *J. Geophys. Res.*, 2007a]

Well-known (substorms, solar flares): Reconnection occurs suddenly and explosively



Prolonged (at least several hours) magnetic reconnection at the magnetopause

[Frey et al., *Nature*, 2003]



Satellite	Color	X	Y	Z	Neutral Sheet
THEMIS-A (P5)		-5.483	5.326	-0.623	0.6
THEMIS-B (P1)		-21.475	3.927	-2.806	-0.5
THEMIS-C (P2)		-17.165	4.573	-3.046	-0.8
THEMIS-D (P3)		-10.881	3.759	-2.086	0.2
THEMIS-E (P4)		-10.194	4.506	-1.913	0.2

Event	Observed time (UT)	Inferred delay (seconds since 04:50:03 UT)
Reconnection onset	04:50:03 (inferred)	T_{Rx} = 0
Reconnection effects at P1	04:50:28	25
Reconnection effects at P2	04:50:38	35
Auroral intensification	04:51:39	T_{AI} = 96
High-latitude Pi2 onset	04:52:00	117
Substorm expansion onset	04:52:21	T_{EX} = 138
Earthward flow onset at P3	04:52:27	144
Mid-latitude Pi2 onset	04:53:05	182
Dipolarization at P3	04:53:05	T_{CD} = 182
Auroral electroject increase	04:54:00	237

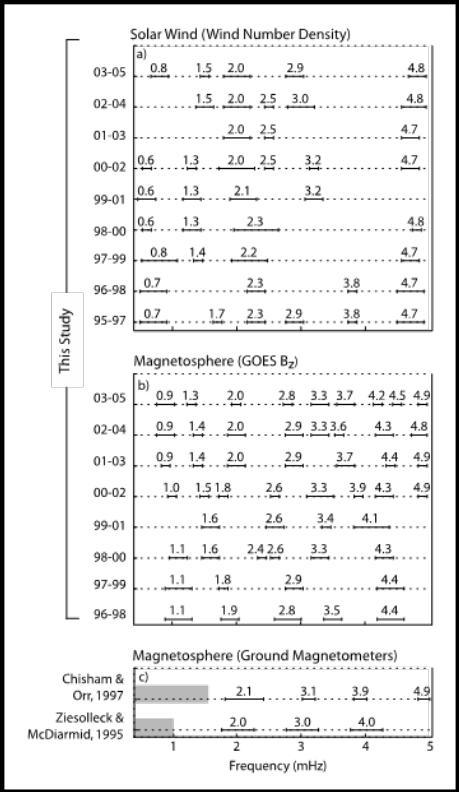
Magnetospheric substorm trigger identified

[Angelopoulos et al., *Science.*, 2008]

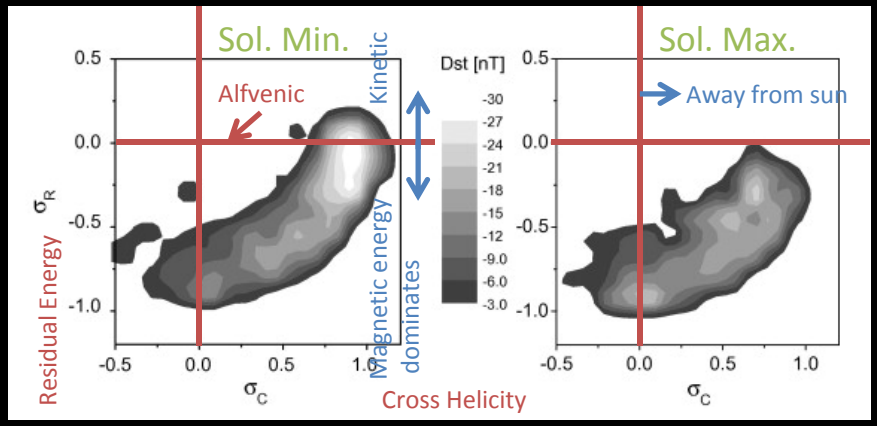
2. Understanding the scale sizes of the solar wind structures that power Earth's magnetosphere

Evidence for an increase in geomagnetic activity attributable to turbulence in the solar wind.

[Viall et al., *J. Geophys. Res.*, 2009]

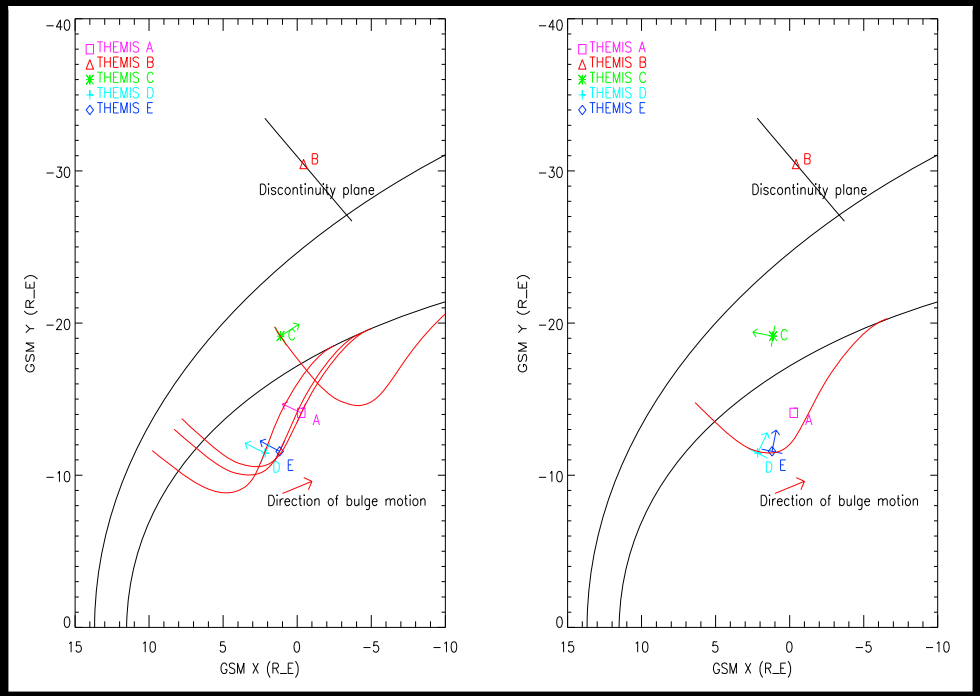


Driving of magnetospheric ULF fluctuations by periodic solar-wind density structures.



[D'Amicis et al., *Adv. Sp. Res.*, 2010]

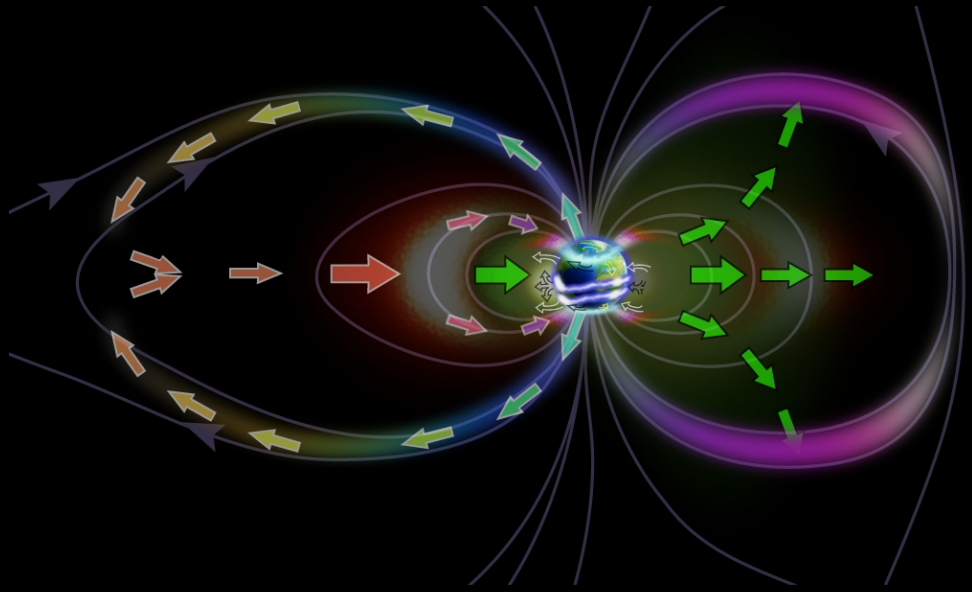
[Jacobsen et al., *J. Geophys. Res.*, 2009]



Hot flow anomalies interact with the dayside magnetosphere.

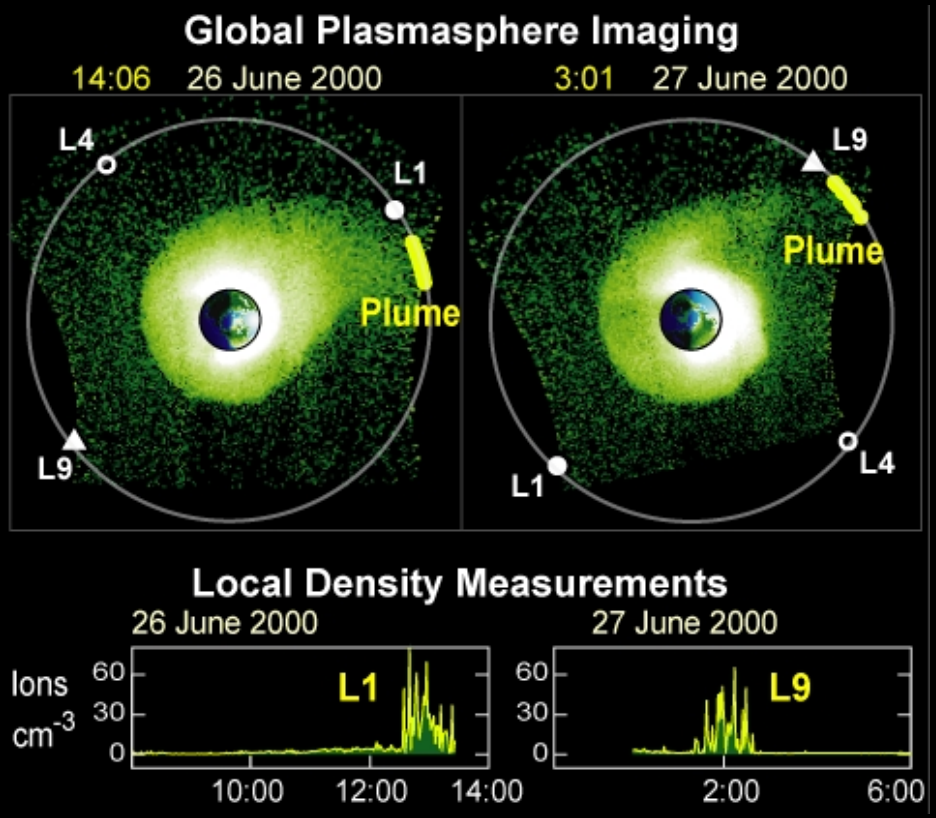
3. Understanding the dynamics of the coupled magnetospheric system and of space weather

System-level science awakened



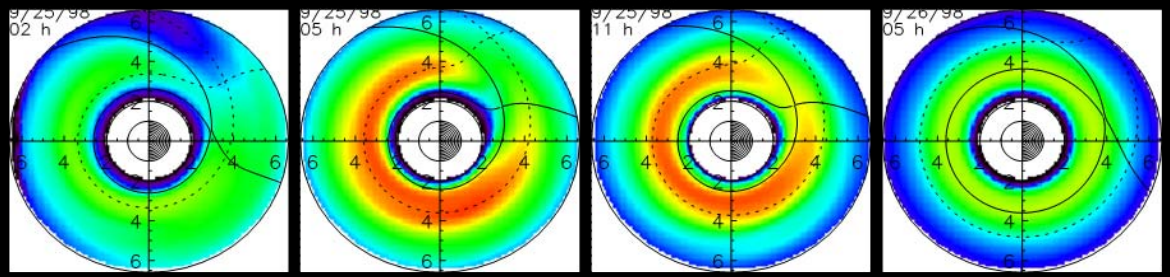
- Global imaging
  - IMAGE, TWINS
- Multi-point measurements
  - Cluster
  - THEMIS
  - “Great Observatory”
  - Ground networks
- Global numerical simulations

Plasmaspheric dynamics: plumes, shoulders, etc.



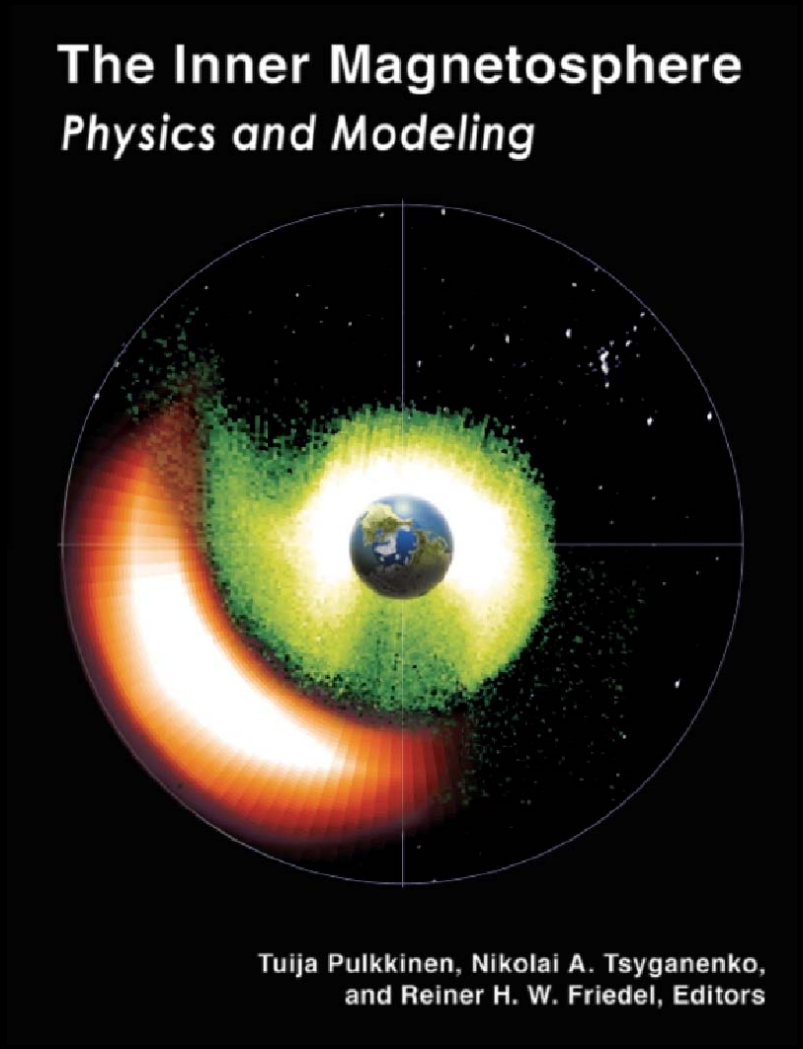
[after Goldstein et al., *J. Geophys. Res.*, 2004]

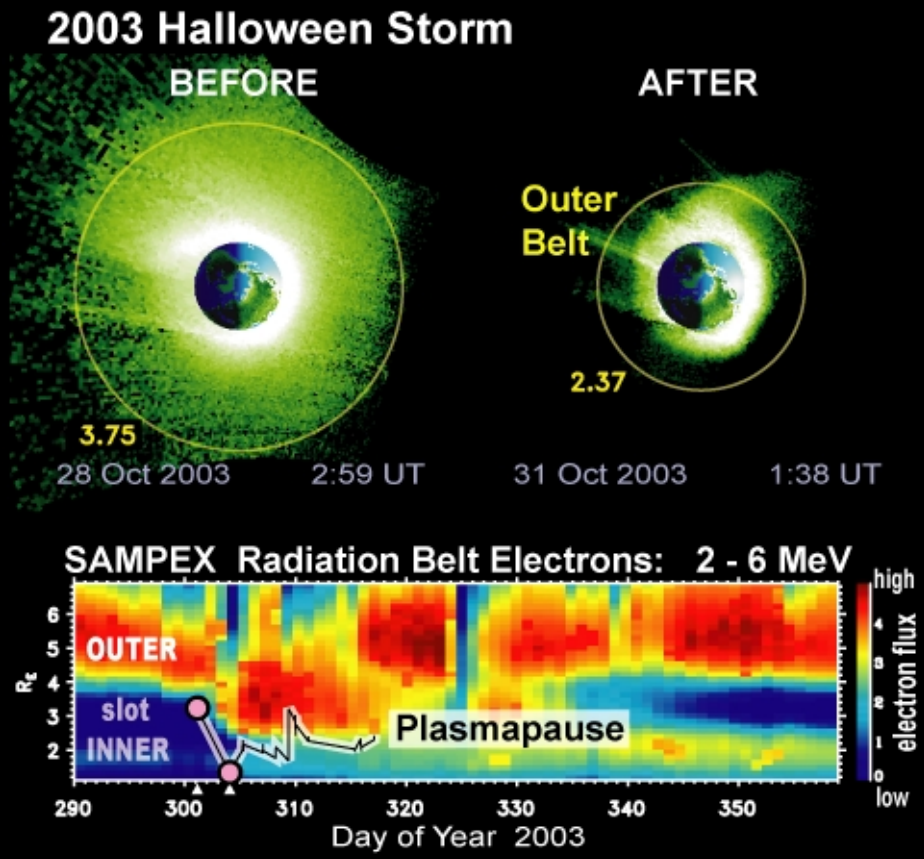
Inner magnetospheric electric field and its importance for ring current development



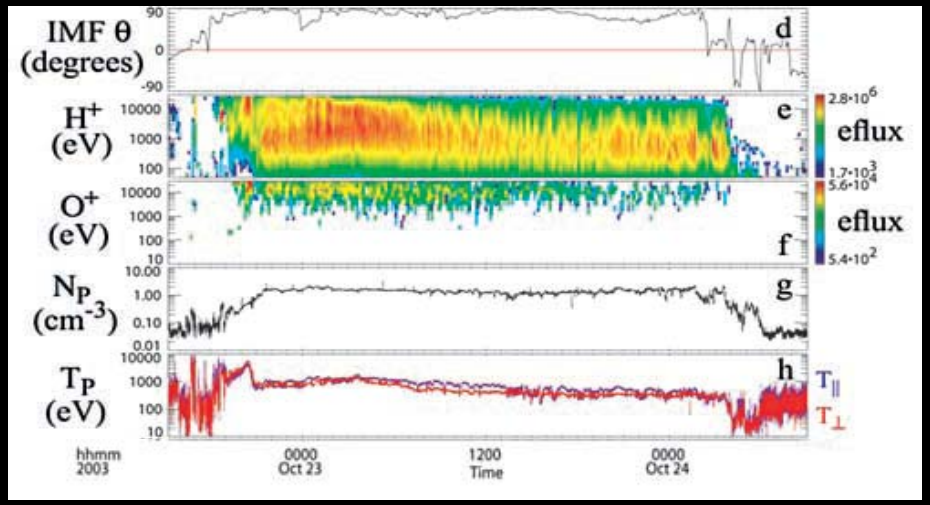
[Liemohn et al., *J. Geophys. Res.*, 2001]

Hot-cold plasma interactions and space weather





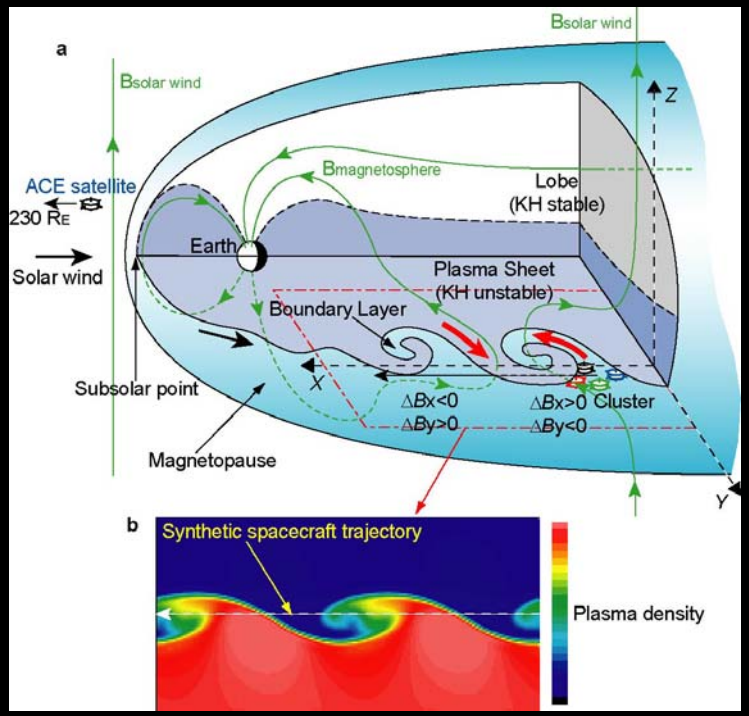
[Giles et al., *AGU press conf.*, 2004; adapted from Baker et al., *Nature,* 2004]



[after Øieroset et al., *Geophys. Res. Lett.*, 2005]

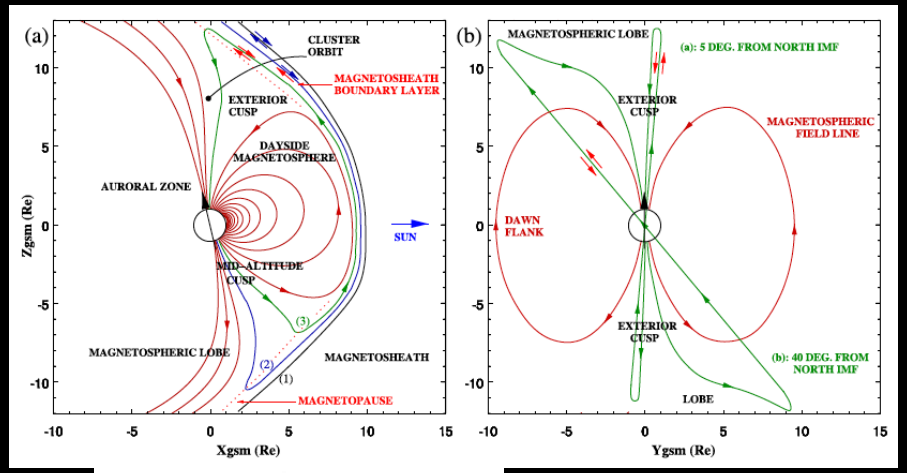
Plasma entry under northward IMF

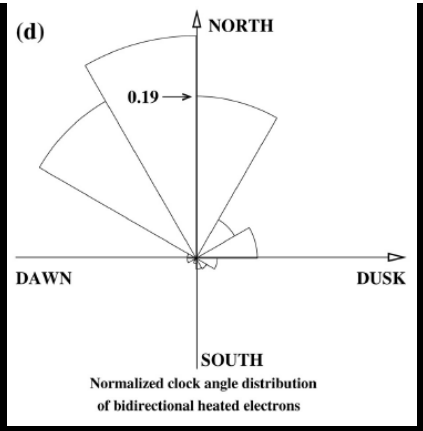
Kelvin-Helmholtz



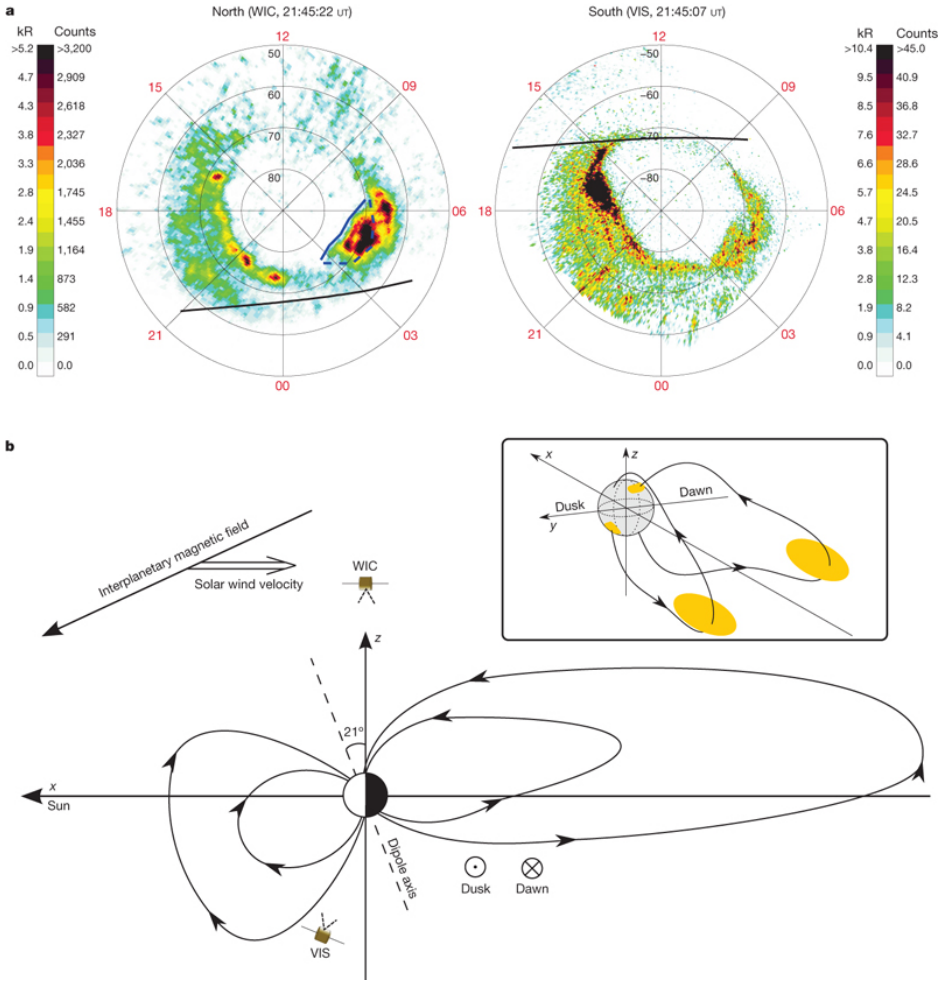
[Hasegawa et al., *Nature*, 2004]

Double-lobe reconnection



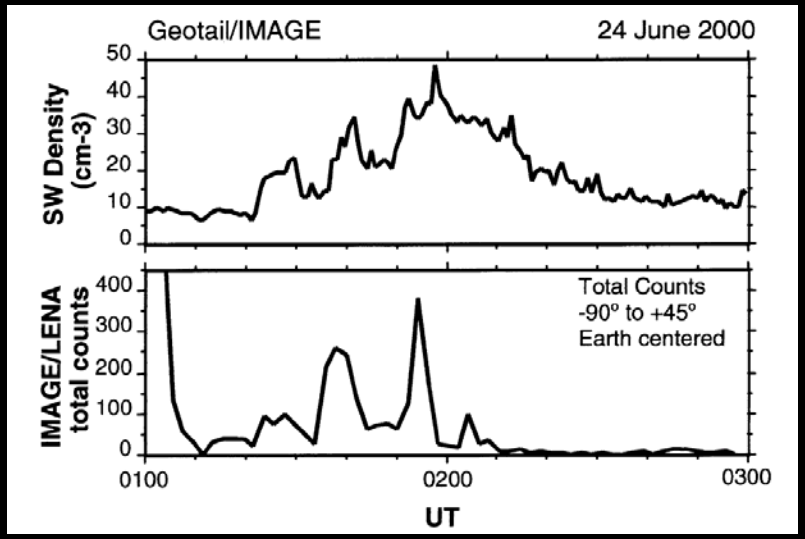


[Lavraud et al., *J. Geophys. Res.*, 2006]


a
North (WIC, 21:45:22 UT)
South (VIS, 21:45:07 UT)
kR
Counts
>5.2
>3,200
4.7
2,909
4.3
2,618
3.8
2,327
3.3
2,036
2.8
1,745
2.4
1,455
1.9
1,164
1.4
873
0.9
582
0.5
291
0.0
0.0
>10.4
>45.0
9.5
40.9
8.5
36.8
7.6
32.7
6.6
28.6
5.7
24.5
4.7
20.5
3.8
16.4
2.8
12.3
1.9
8.2
0.9
4.1
0.0
0.0
12
09
06
03
00
15
18
21
50
60
70
80
b
Interplanetary magnetic field
Solar wind velocity
WIC
VIS
Sun
21°
Dipole axis
Dusk
Dawn
x
y
z

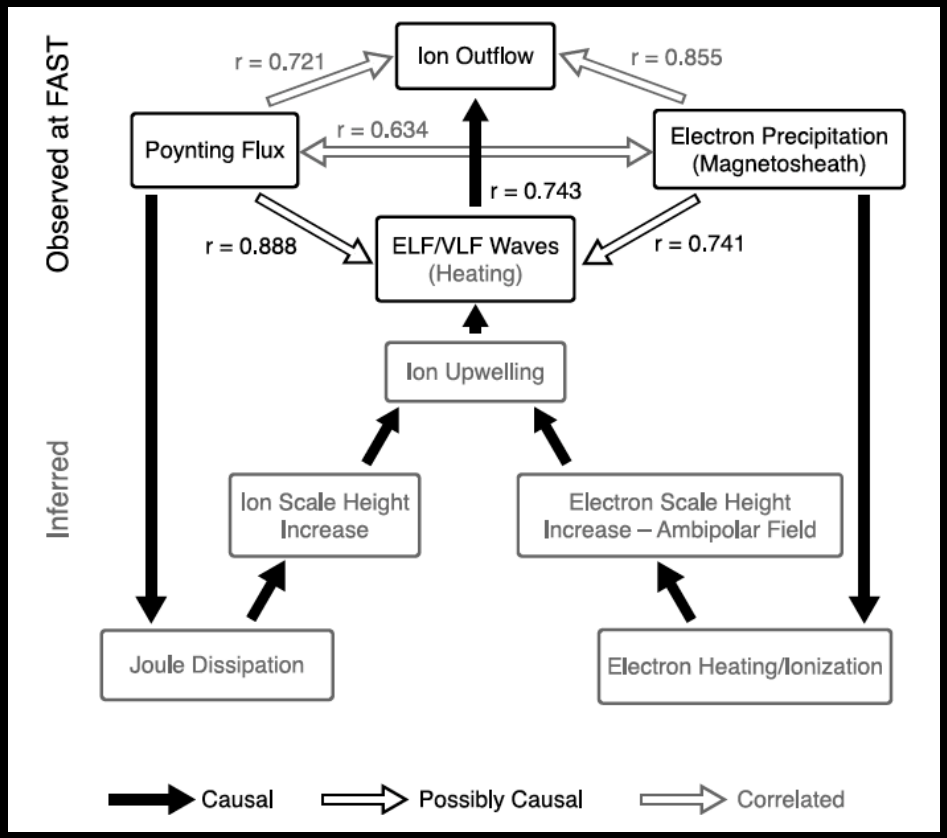
4. Understanding the complex interaction between the solar wind and the polar ionosphere

Extensive observations of ionospheric ion outflow: Dependence on solar wind properties and magnetospheric activity



[Fuselier et al., *Sp. Sci. Rev.,* 2003]

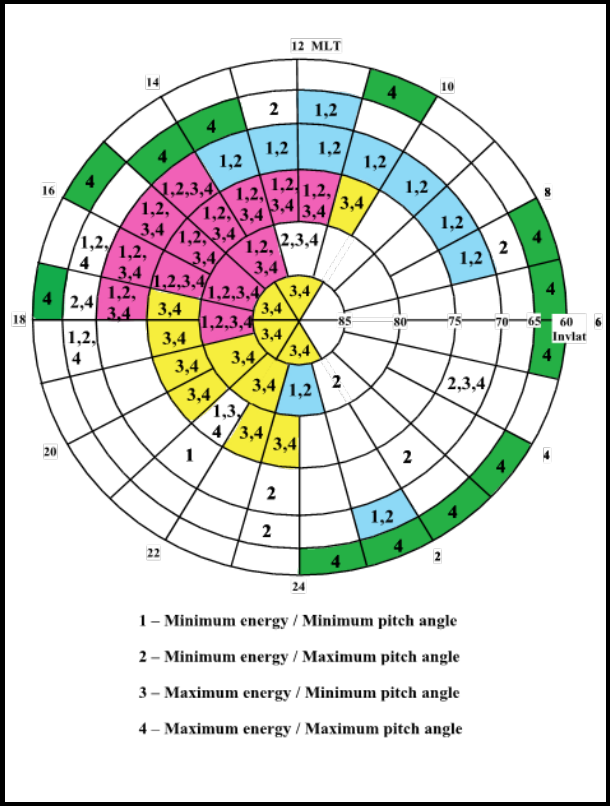
Theoretical developments on the causes of ion outflow



[Strangeway et al., *J. Geophys. Res.,* 2005]

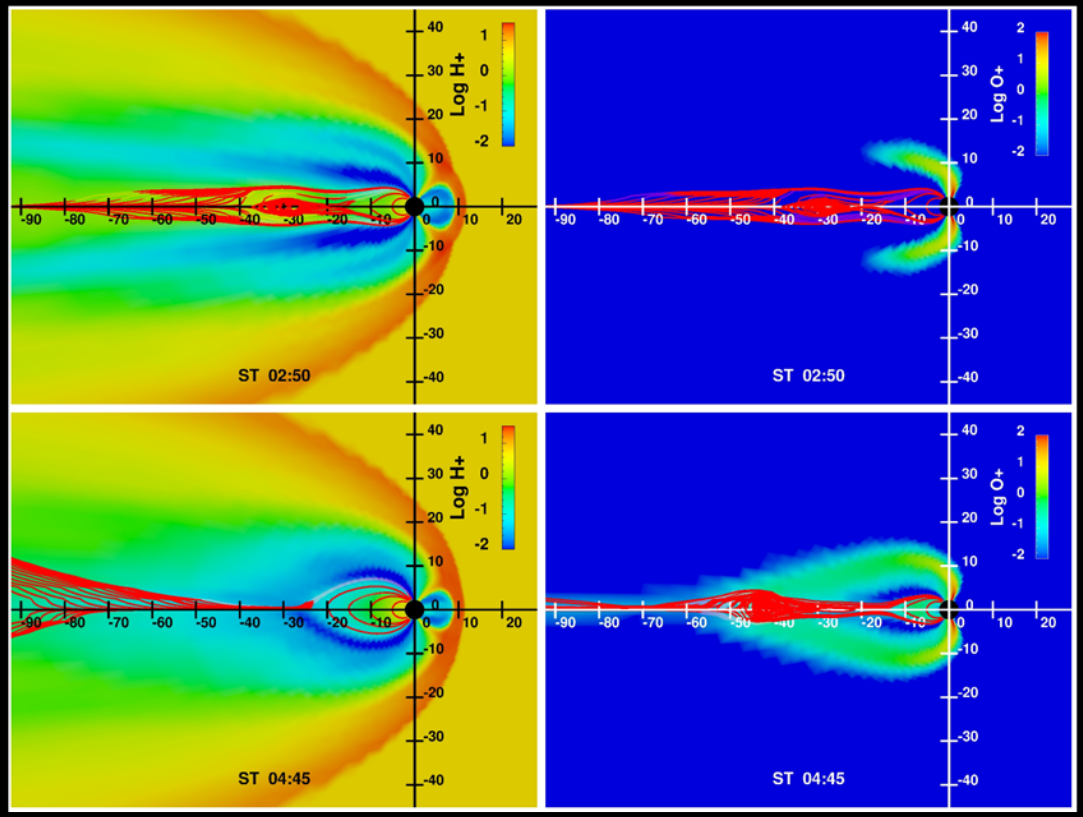
Importance of the ionosphere as a source and regulator

Numerical tracing of outflow trajectories



[Huddleston et al., *J. Geophys. Res.*, 2005]

[Wiltberger et al., *J. Geophys. Res.*, 2010]



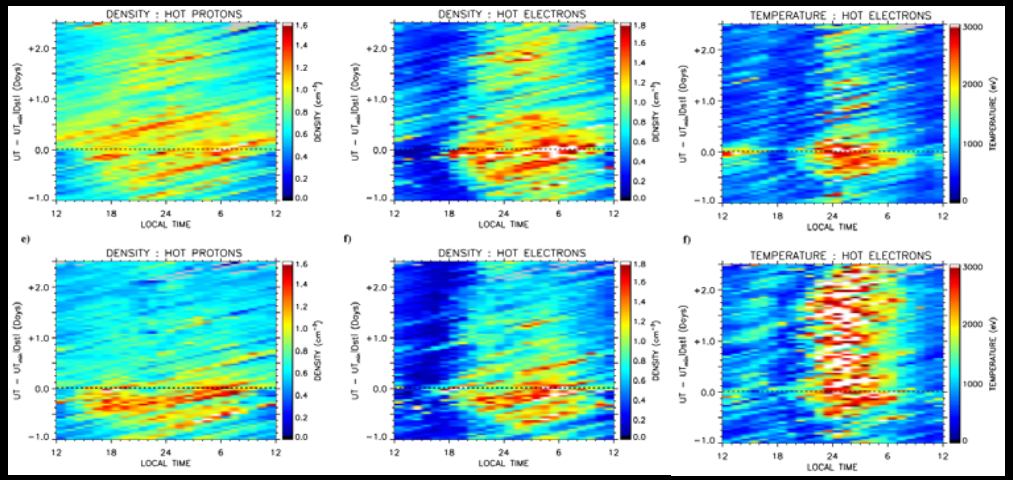
Demonstration from multifluid simulation that ionospheric outflow can produce repeated substorms

5. Measurement of the density of the invisible populations within the magnetosphere

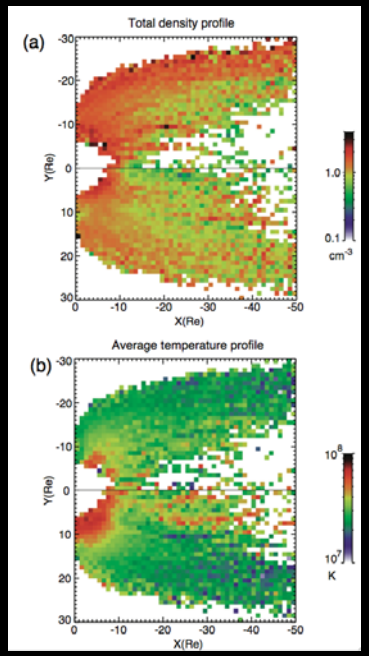
Statistical surveys of plasma properties

CME

CIR

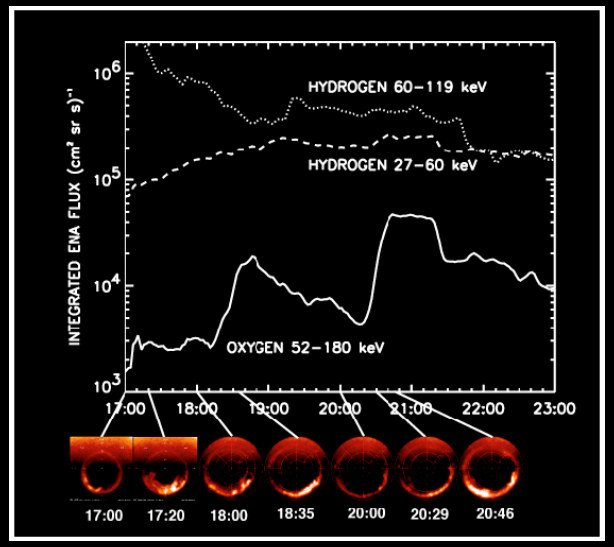


[Denton et al., *J. Geophys. Res.*, 2006]

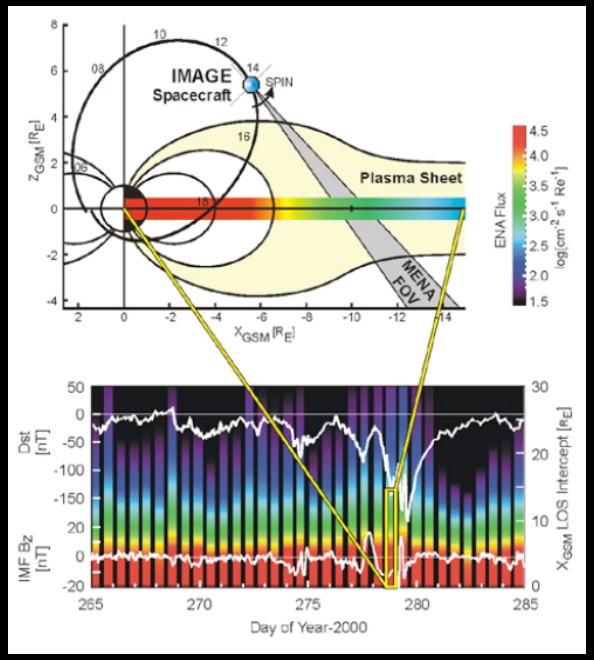


[Wing et al., *J. Geophys. Res.*, 2005]

Global ring current and plasma-sheet images during storm development

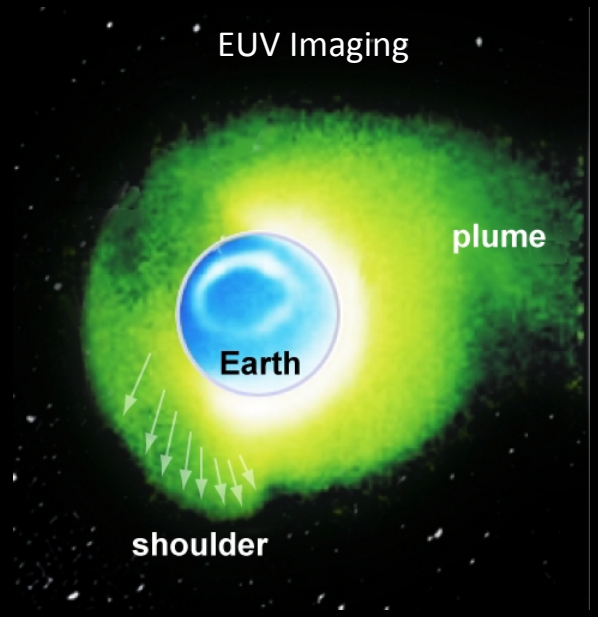


[Mitchell et al., *Sp. Sci. Rev.*, 2003]



[McComas et al., *Geophys. Res. Lett.*, 2002]

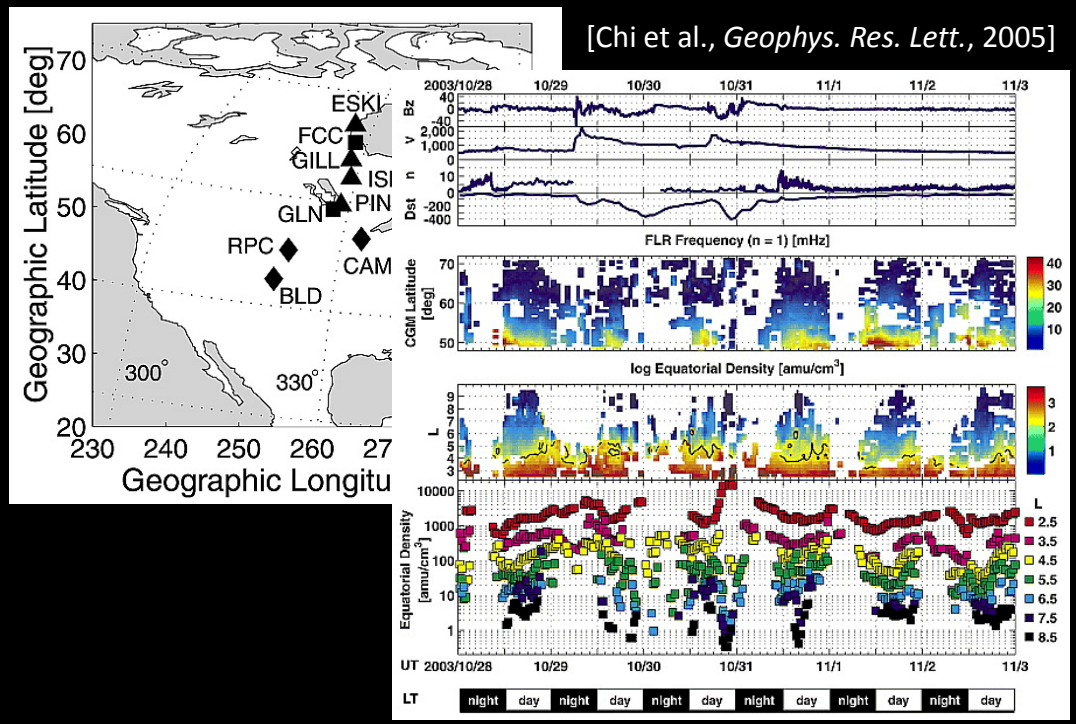
New techniques for observing cold plasmas



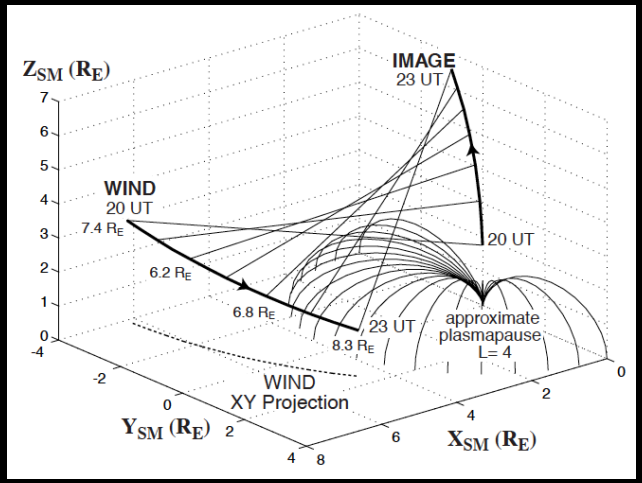
[from Sandel et al., *Sp. Sci. Rev.*, 2003]

Field-Line Resonances from Ground Magnetometers

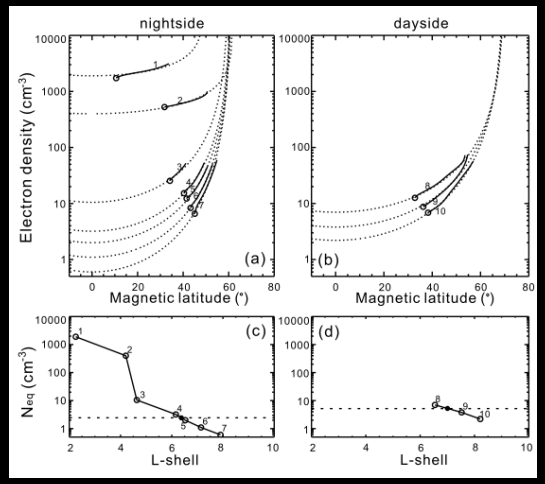
[Chi et al., *Geophys. Res. Lett.*, 2005]



Faraday Rotation



[Cummer et al., *Geophys. Res. Lett.*, 2001]



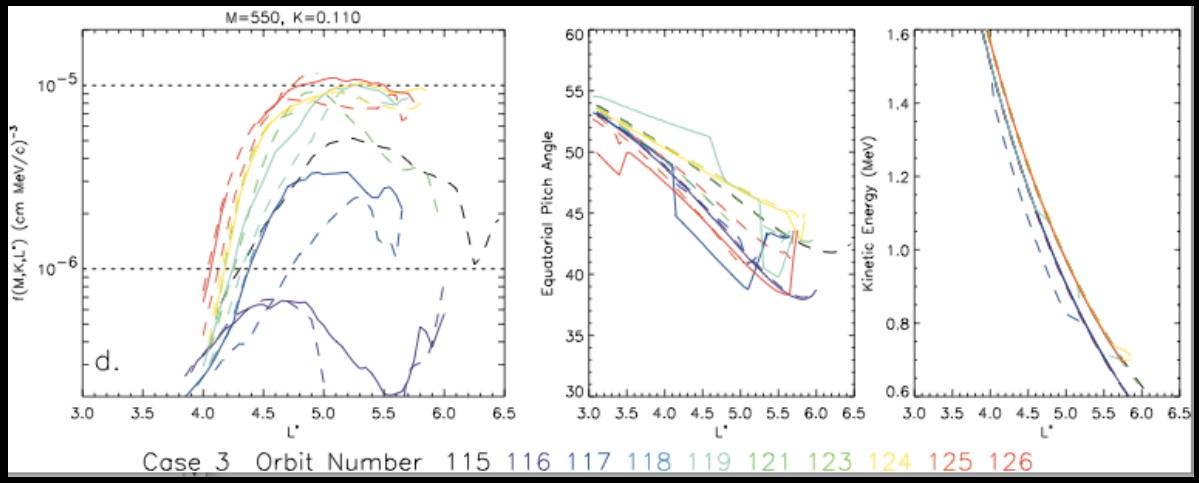
Active Radio Sounding Along the Field (IMAGE/RPI)

[Fu et al., *J. Geophys. Res.*., 2010]

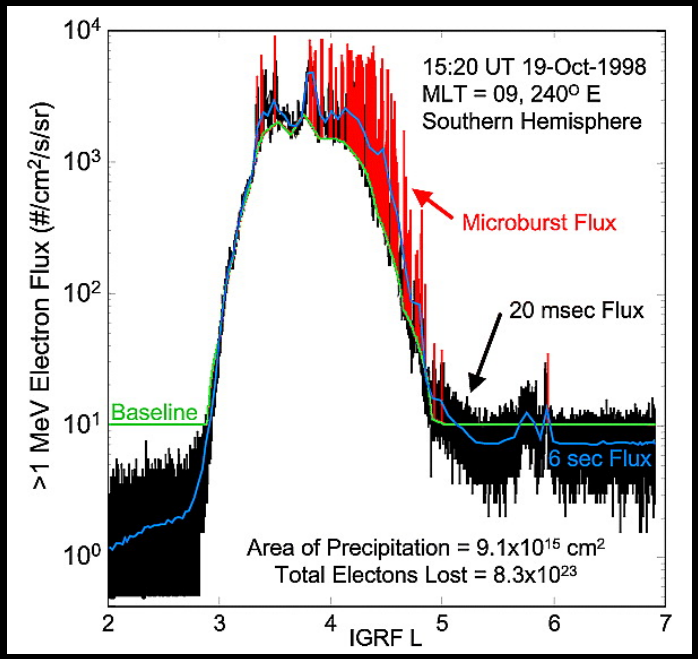
6. Understanding the energization of the radiation belts

Evidence for nonadiabatic local acceleration processes

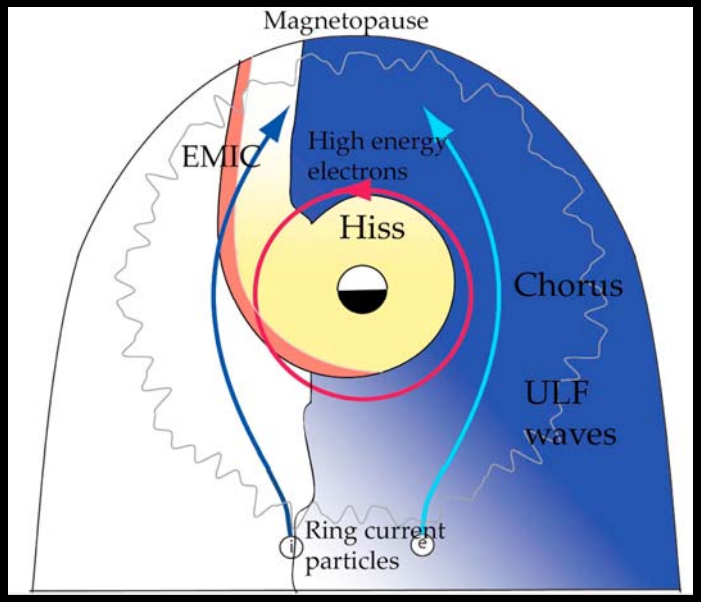
[after Iles et al., *J. Geophys. Res.*, 2006]



Quantification of losses, sources, acceleration



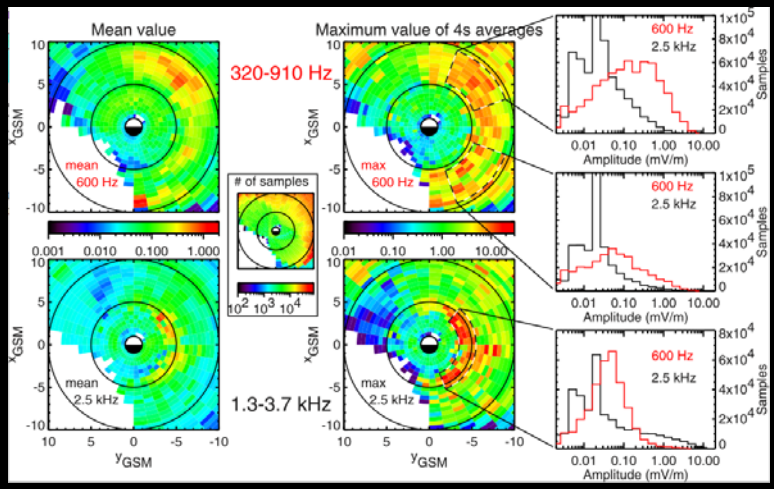
[O'Brien et al., *Geophys. Res. Lett.*, 2004]



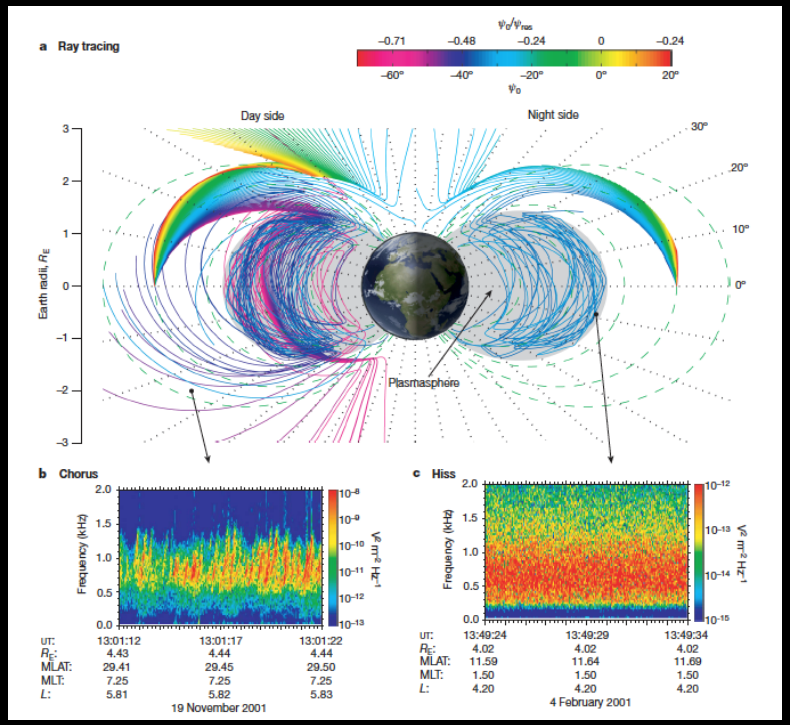
[Shpritz et al., *J. Geophys. Res.*, 2006]

Recognition of the importance of wave-particle interactions

Discovery of large-amplitude whistler-mode waves



[Cully et al., *Geophys. Res. Lett.*, 2008]

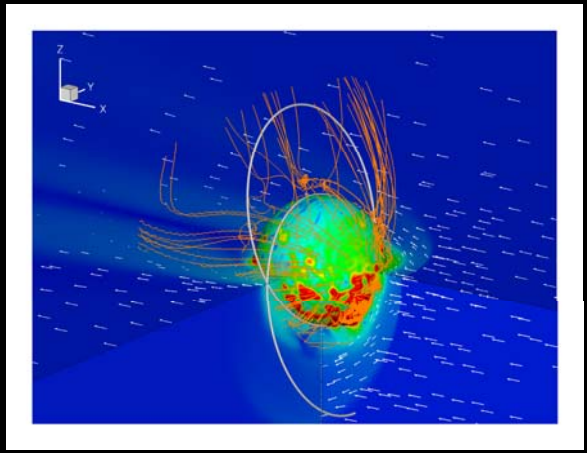


Source of plasmaspheric hiss

[Bortnik et al., *Nature*, 2008]

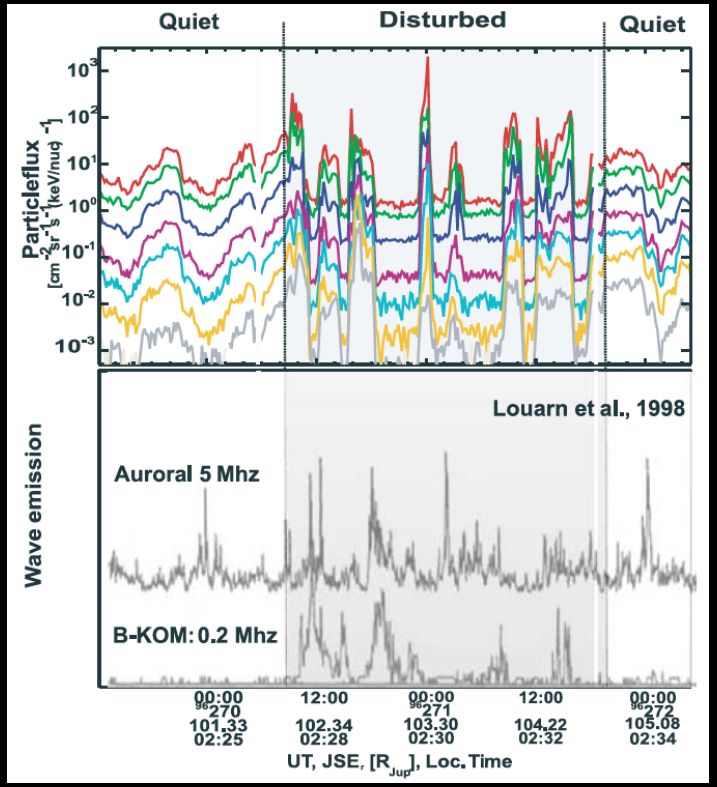
7. Understanding planetary magnetospheres;
8. Understanding the complex interactions of the solar wind and planetary magnetospheres and atmospheres

Mars: Modeling of Atmospheric Loss



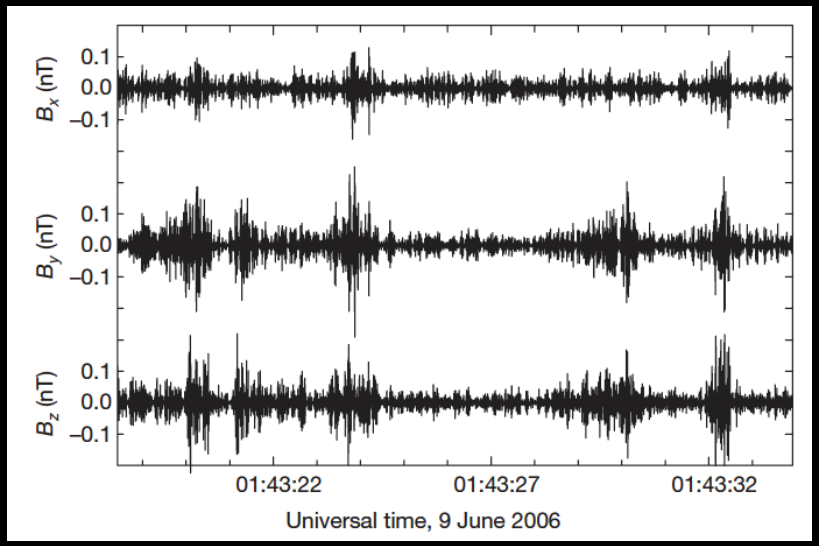
[Ma and Nagy, *Geophys. Res. Lett.*, 2007]

Jupiter: Substorm-like tail reconfiguration events



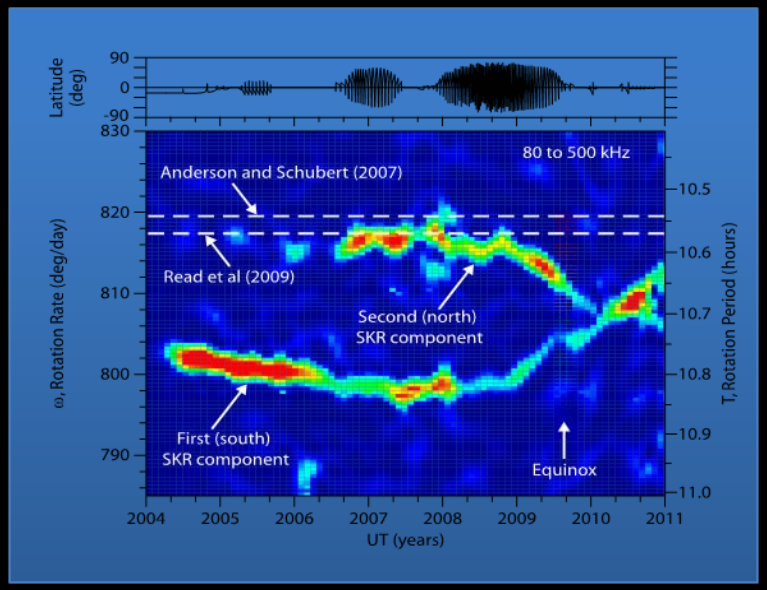
[Kronberg et al., *J. Geophys. Res.*., 2005]

Venus: Detection of Lightning-Generated Whistler Waves

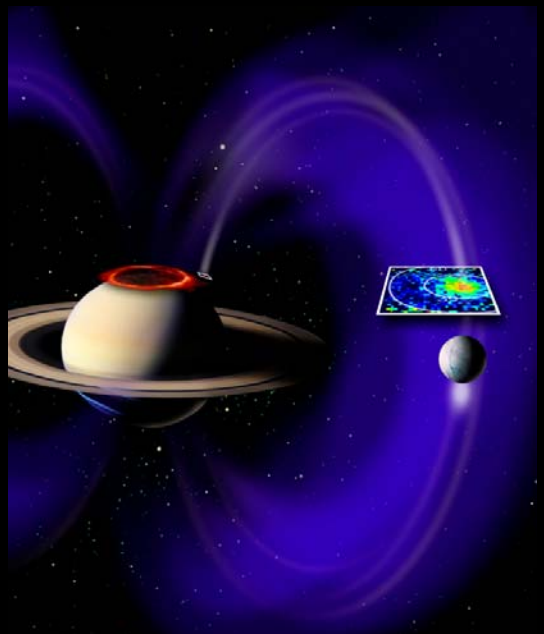


[Russell et al., *Nature.*, 2007]

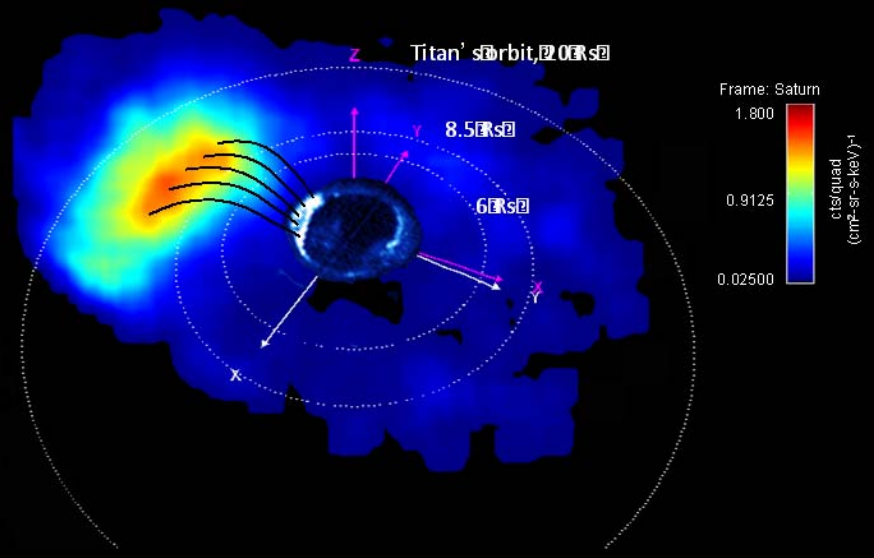
Saturn: SKR Periodicity ≠ Planetary Rotation Rate



[Gurnett et al., *Geophys. Res. Lett.*, 2010]



Saturn: Periodic Plasmoid Release and Energetic Particle Injections



[After Mitchell et al., *Plan. Sp. Sci.*, 2009]

Saturn: Crucial Role of Enceladus

[Pryor et al., *Nature*, 2011; image credit Ken Moscati and Abi Rymer, JHUAPL]

Summary

- There has been an amazing amount of progress over the past decade, covering the full range of high-priority objectives identified in the previous decadal survey.
- Major accomplishments have come from new spacecraft missions, exploitation of the existing multi-spacecraft “Great Observatory”, ground-based observations, non-NASA data sources, numerical simulations, analytical theory, and laboratory studies. Both targeted efforts and serendipity.
- Expect a similar pace in the coming decade.