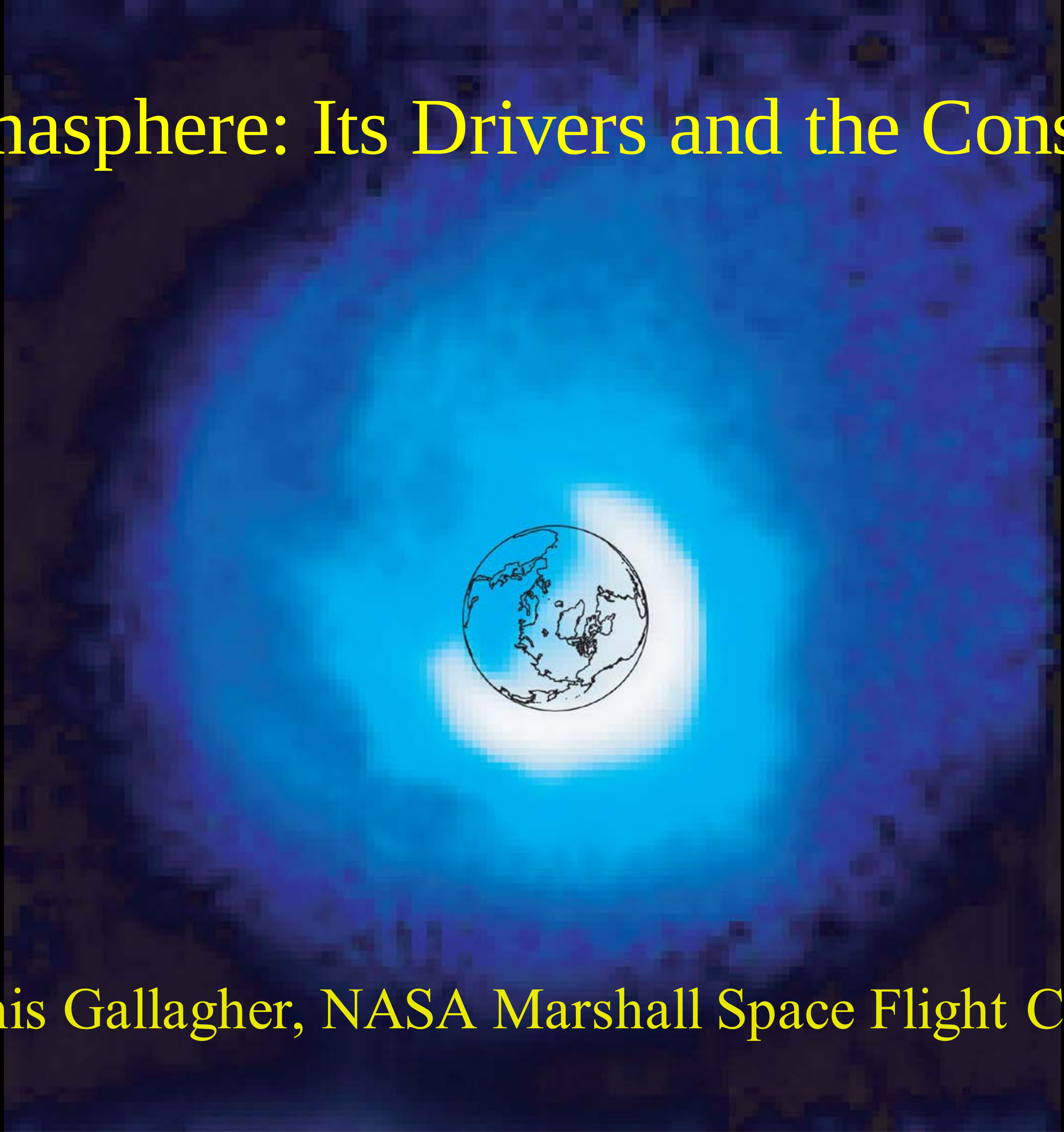
The Plasmasphere: Its Drivers and the Consequences



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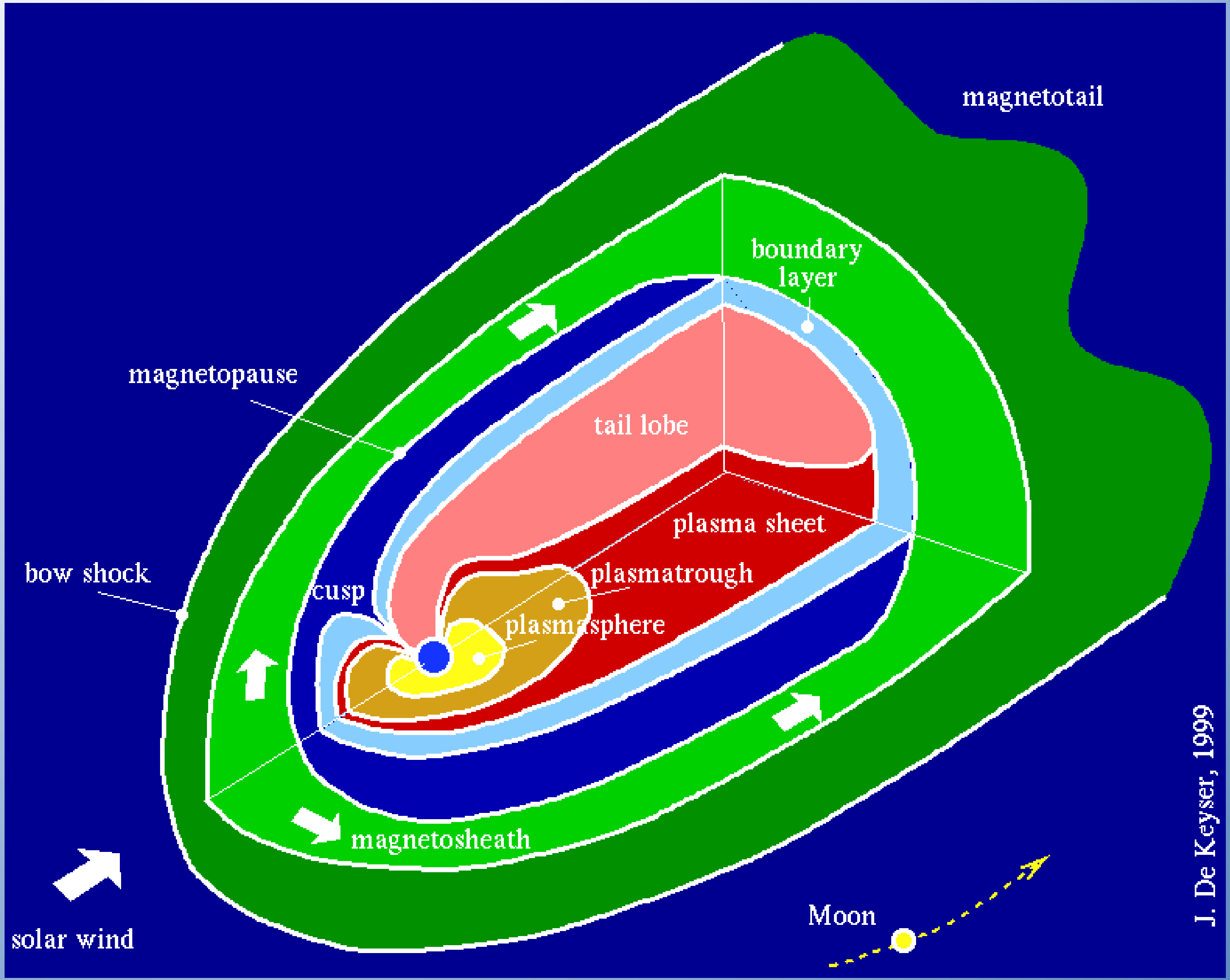
The Magnetosphere

The magnetosphere is a system of plasma where Earth's magnetic field dominates over the Sun's.

Our understanding of this system draws on the observed morphology of densities, energies, temperatures, and motions of the plasma.

A multitude of physical processes are found in the magnetospheric system, with varying importance for each morphological component.

The system is highly coupled between plasma components, much of which appears to have originated in Earth's atmosphere.



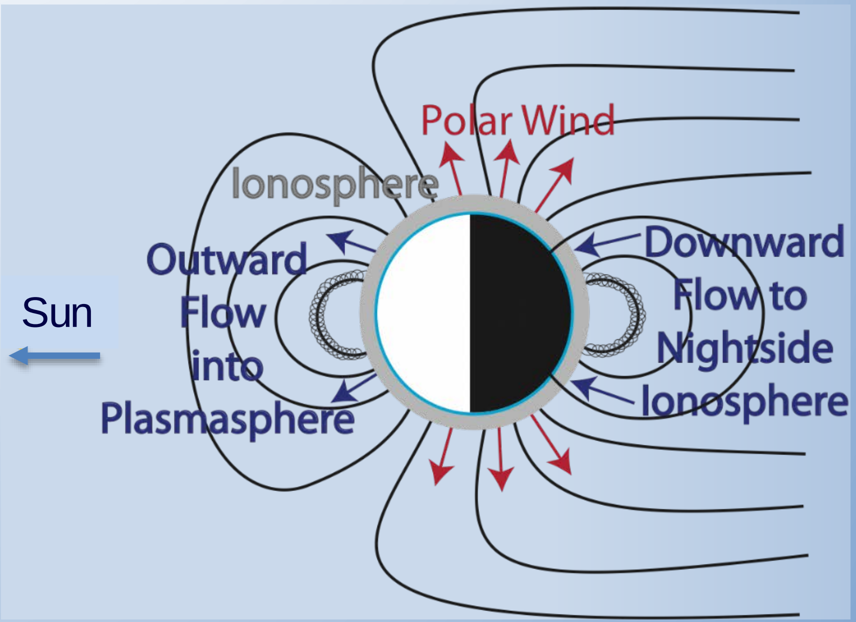
Plasmasphere is One of These Components

- Cold temperature (~ 1eV) *identifies its recent ionospheric origin*
- High density (10 cm^{-3}-1000s cm^{-3}) *requires accumulation*
- Near Co-Rotation with Earth *enables accumulation*
  - Torus-shaped, extends to 4-8 R_E
  - Plasmapause: a sometimes distinct outer boundary
- Characterized often by *complex spatial distribution*
- $\vec{E} x \vec{B}$ transport at all spatial scales *create these distributions*
- Its dominant H^+, He^+, & O^+ composition profoundly influence wave-particle processes and wave propagation that *couple to other components of magnetospheric plasma*

Ionospheric Origin of the Plasmasphere

Ionosphere outflow

- Main causes
  - Ambipolar electric field
  - pressure gradients
  - Mirror force due to gyration of charged particles
- Polar wind: Ionospheric loss at polar latitude
  - Along essentially open geomagnetic field lines
- At mid-latitudes the plasma may flow to the conjugate ionosphere or become trapped to become the plasmasphere



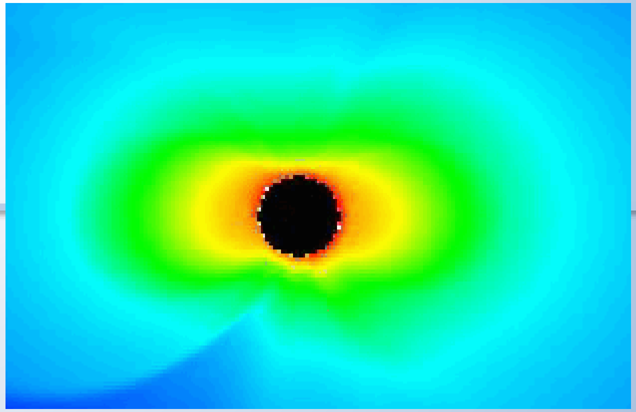
Earth's Upper Atmosphere and Solar Ionizing Radiation to Produce the Ionosphere

Reactions			Common Constituents
$X+\gamma \rightarrow X^{+}+e^{-}$	$XY+\gamma \rightarrow X+Y$	$X^{+}+e^{-} \rightarrow X$	X-rays, EUV, O, N, O_2, N_2, NO, H, O_3
$X^{-}+Y \rightarrow XY+e^{-}$	$X^{+}+YZ \rightarrow YX^{+}+Z$	$X^{+}+e^{-} \rightarrow X+\gamma$	
		$XY+e^{-} \rightarrow Y+X$	
		$X+e^{-} \rightarrow X^{-}$	

- Ionosphere: ionized portion of upper atmosphere
  - Extends from around 60 km to beyond 1000 km
  - Completely encircles the Earth
  - Main Source: photoionization of neutrals
    - Other production processes dominate in different ionospheric regions
  - Loss Mechanism: ionospheric outflow, recombination

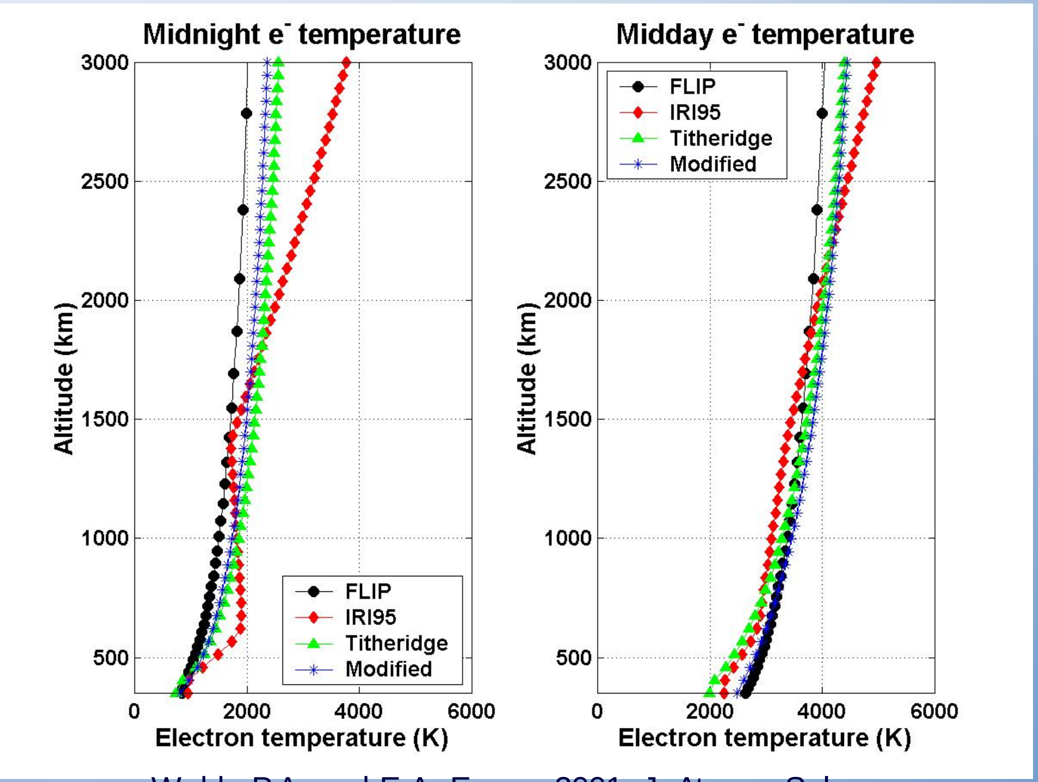
Main regions and transport processes

Plasmasphere Formation: Diffusive Equilibrium



$$H_j = \left(\frac{kT_i}{m_j g}\right)\left(1 - \frac{m_a T_e}{m_j T_t}\right)^{-1}$$

H_j = scale height
k = Boltzmann constant
m_j = j'th ion mass
g = gravitational constant
m_a = mean ion mass
T_e = electron temperature
$T_t = T_i + T_e$ total temperature



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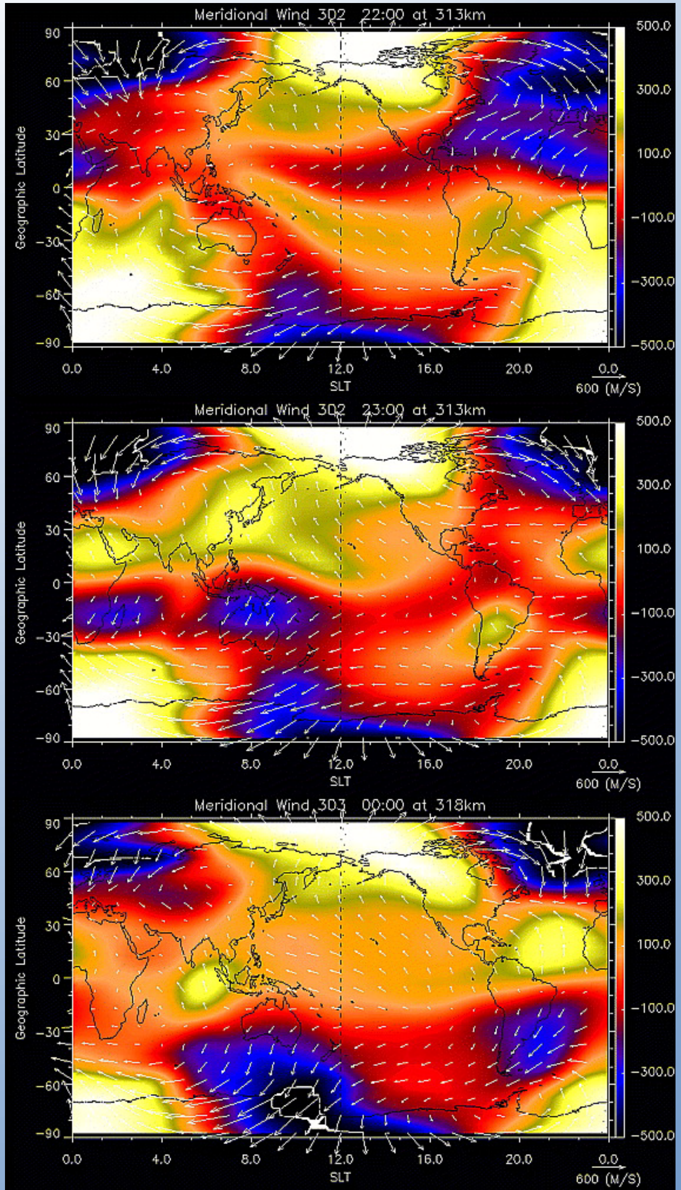
Main regions and transport processes

The Ionosphere-Thermosphere Couple the Magnetosphere and Atmosphere

Neutral wind effect in producing a storm time ionospheric additional layer in the equatorial ionization anomaly region



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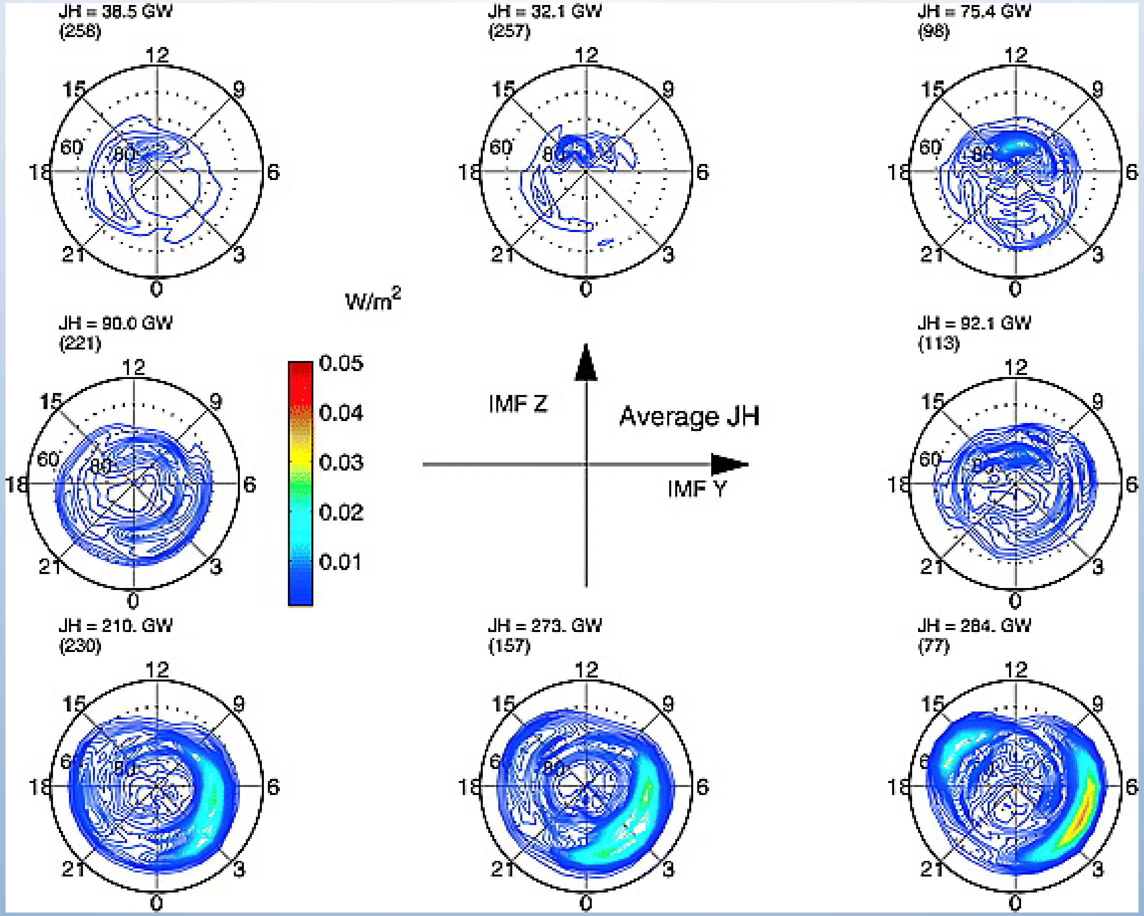
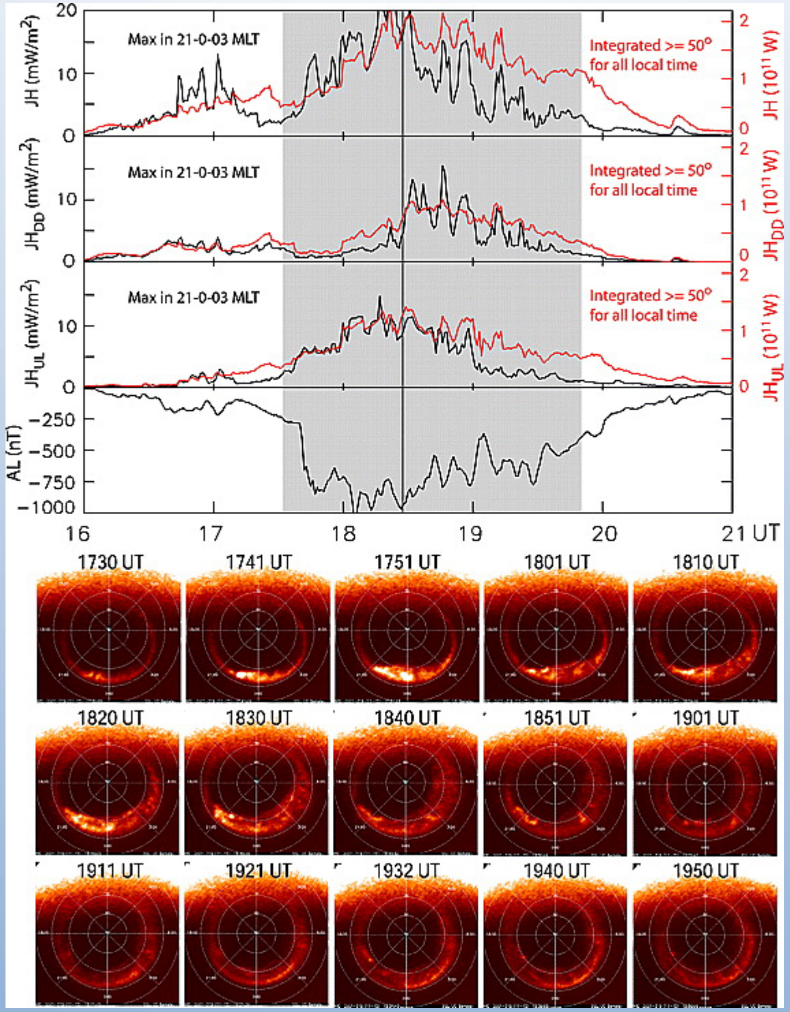
High-latitude Joule heating response to IMF inputs



McHarg, M., F. Chun, D. Knipp, G. Lu, B. Emery, & A. Ridley, Journal of Geophysical Research: Space Physics, Volume: 110, Issue: A8, First published: 27 August 2005, DOI: (10.1029/2004JA010949)

Joule heating associated with auroral electrojets during magnetospheric substorms



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Previous Studies Cited as Providing Plasmasphere Refilling Rates

Source	L	Refilling Rate ($cm^3 d^{-1}$)	Filling Phase
Gallagher et al. 2005	2-2.5	5.5-75	Early to late
	2.5-3	46.8-139	
	3-3.5	49.4-80	
Reinisch et al. 2004	3.1	~120	Early to late
Sandel & Denton 2007	2.75	334	Early to late
	3.25	439	
	3.75	407	
	4.25	411	
	4.75	377	
	5.25	265	
	5.75	157	
	6.25	78	
	6.75	58	
Park 1974	3	290-570	Late
	3.5	140-390	
	4	66-420	
	4.5	64-280	
	5	36-180	

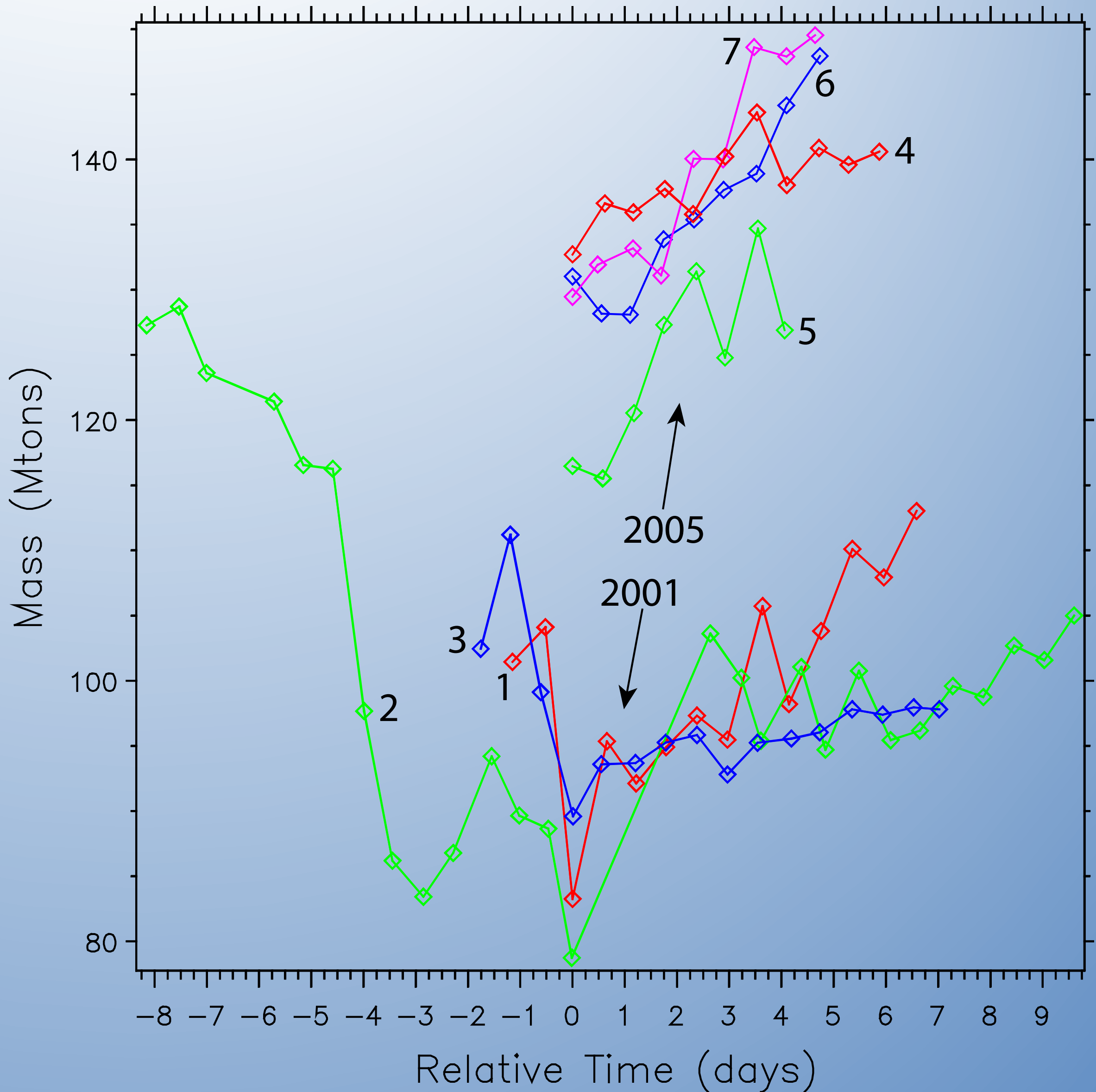
Source	L	Refilling Rate ($cm^{-3} d^{-1}$)	Filling Phase
Dent et al. 2006	4.12	~11-180	Late
Park 1973	4.5	30-40	Late
Carpenter et al. 1993	4.5	~80	Late
Farrugia et al. 1989	4.5 & 5	150	Late
Sojka & Wrenn 1985	6.6	30-50	Early to late
Décréau 1983, Décréau et al. 1986	6.6	8	Early
Song & Caudal 1987	6.6	4.9-13.0	Late
Song et al. 1988	6.6	7-25	Late
Gallagher et al. 1998	6.6	13.4	Early
Lawrence et al. 1999	6.6	~0.6-12	Early
		10-50	Late

Accumulation of Ionospheric Plasma to become the Plasmasphere

The highest densities and most massive magnetospheric component results from the formation of the plasmasphere.

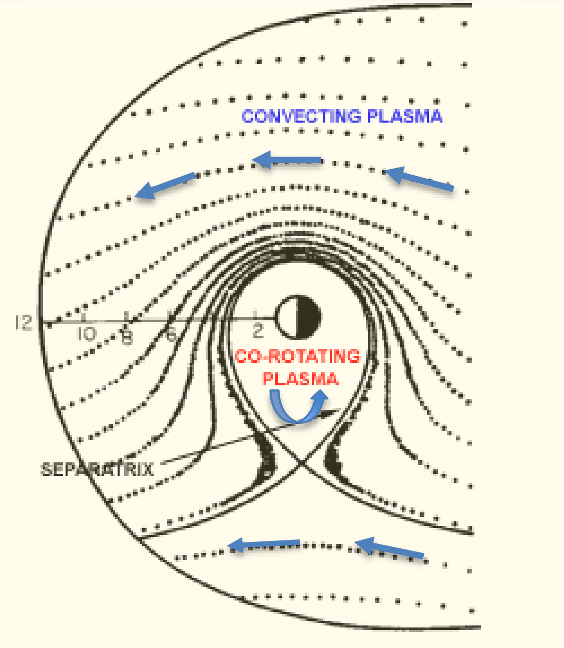
Without further influence the plasmasphere would become no more than a donut-like magnetic field-shaped region cold plasma reservoir in the inner magnetosphere.

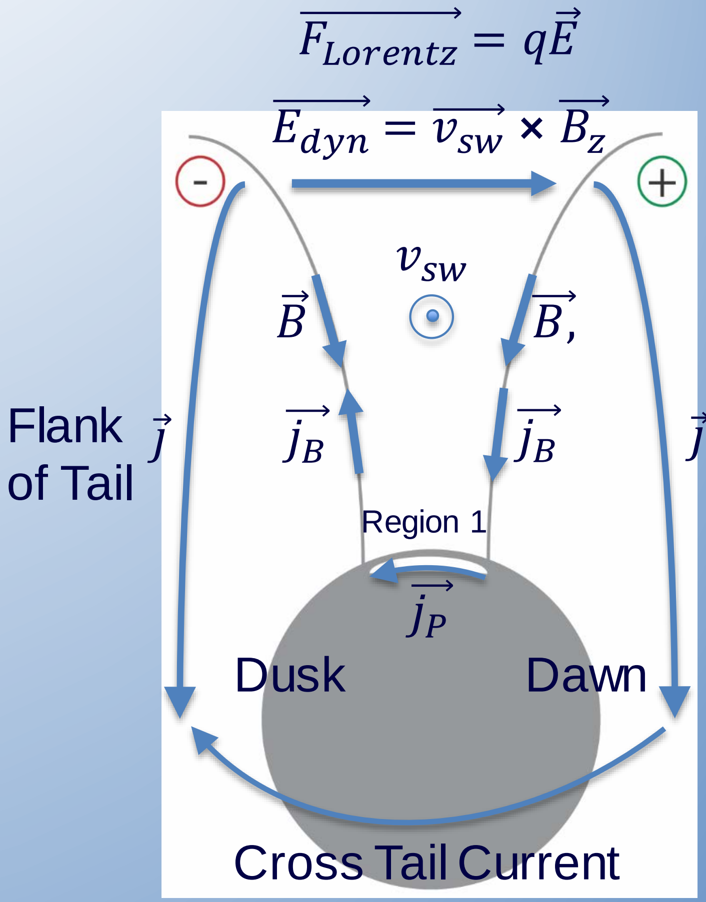
However, it is often found to have considerable spatial structure that varies dynamically and be a strong influence on the transport and energization of energy and plasma in the magnetosphere.



Large-scale $\vec{E} x \vec{B}$ created spatial distribution "Solar wind dynamo"

- Highly conducting plasma in the solar wind flows across polar geomagnetic field lines
  - Induces an electric dynamo field
  - Plasma and B-field lines are transported: Frozen-in flux concept

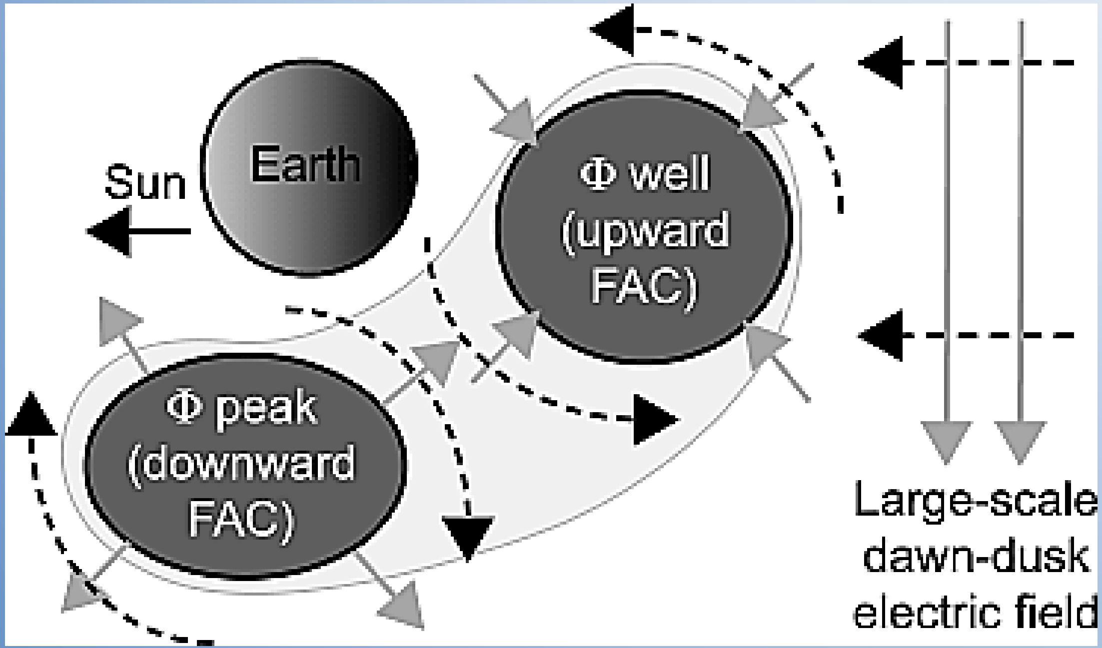


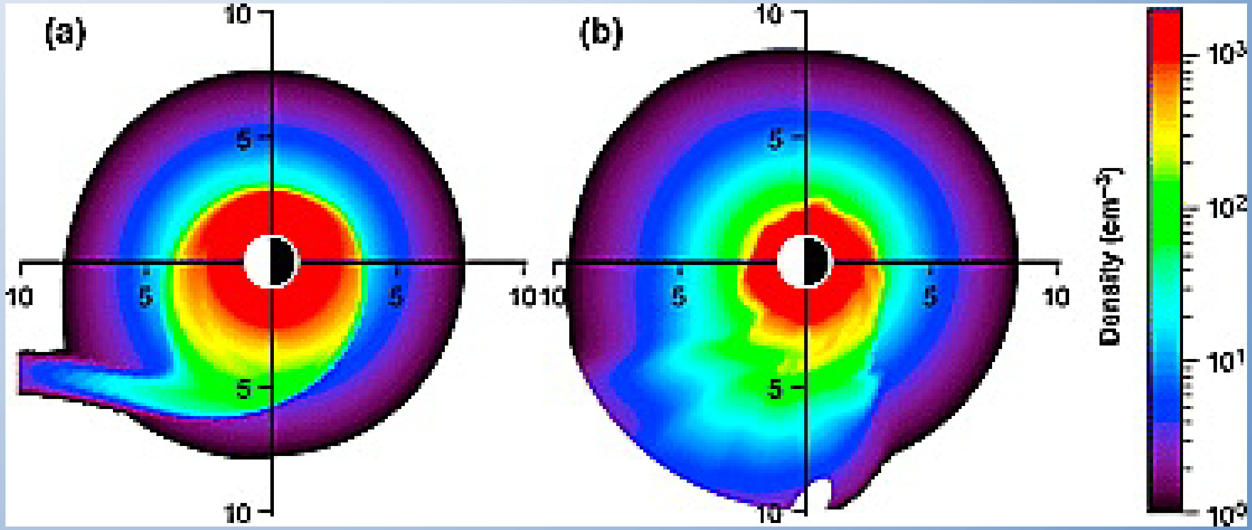


Small-scale $\vec{E} x \vec{B}$ created spatial distribution

"Charge Separation"

Origin and evolution of deep plasmaspheric notches





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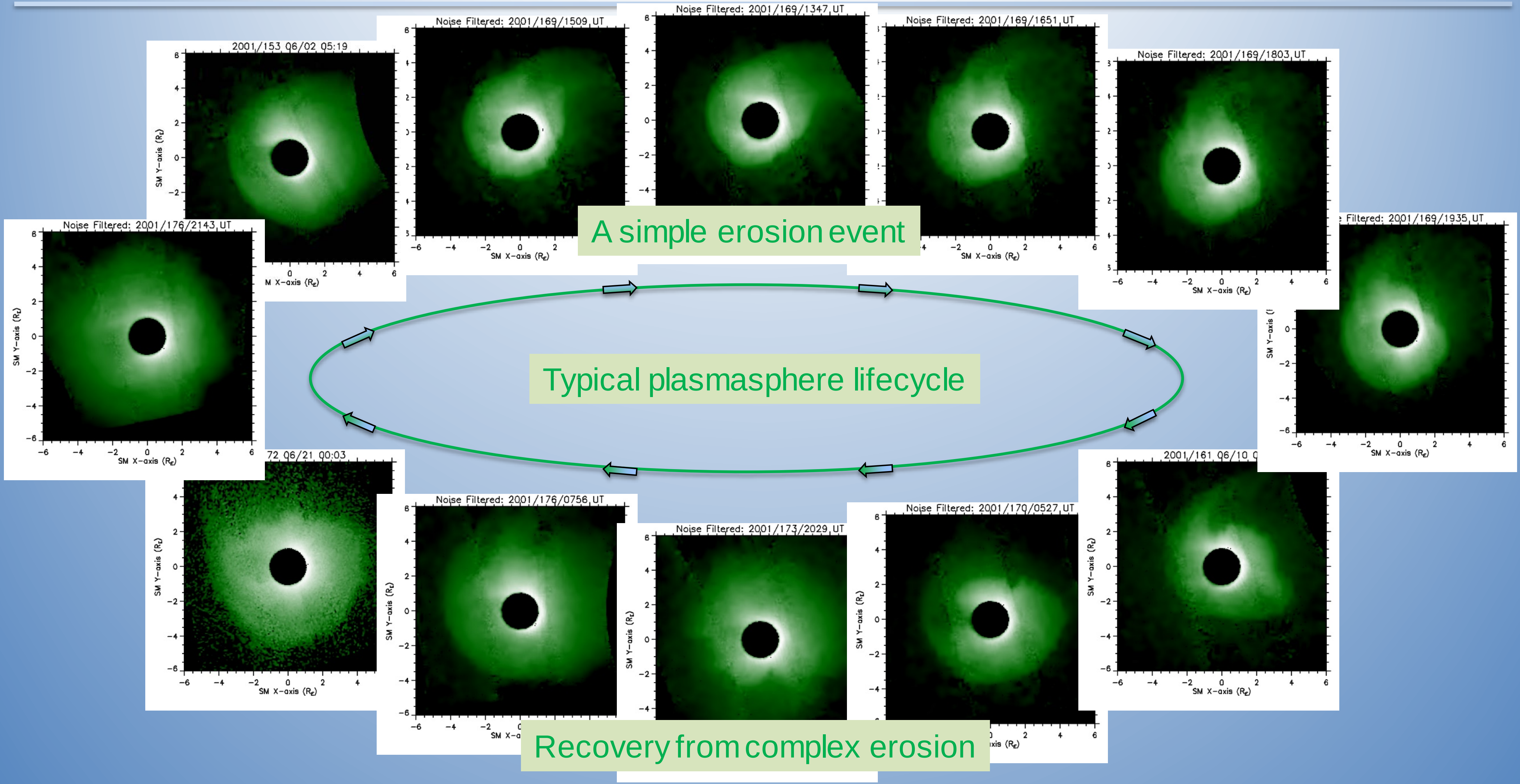
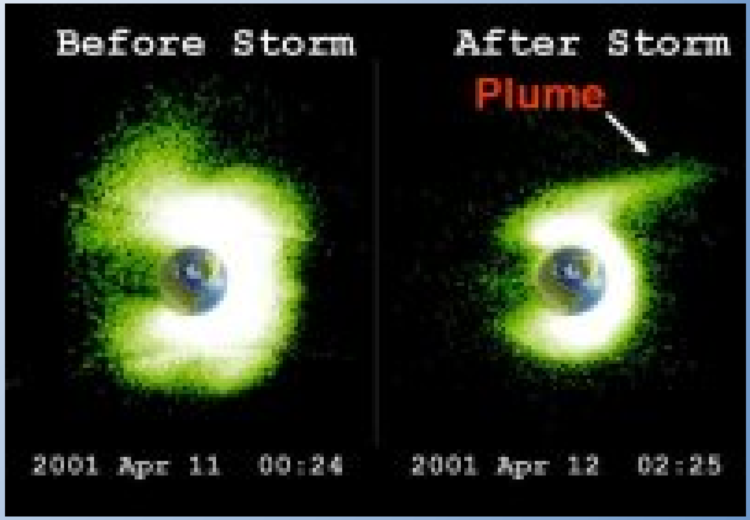
Complex Plasmasphere Distributions



Plasmaspheric Plumes

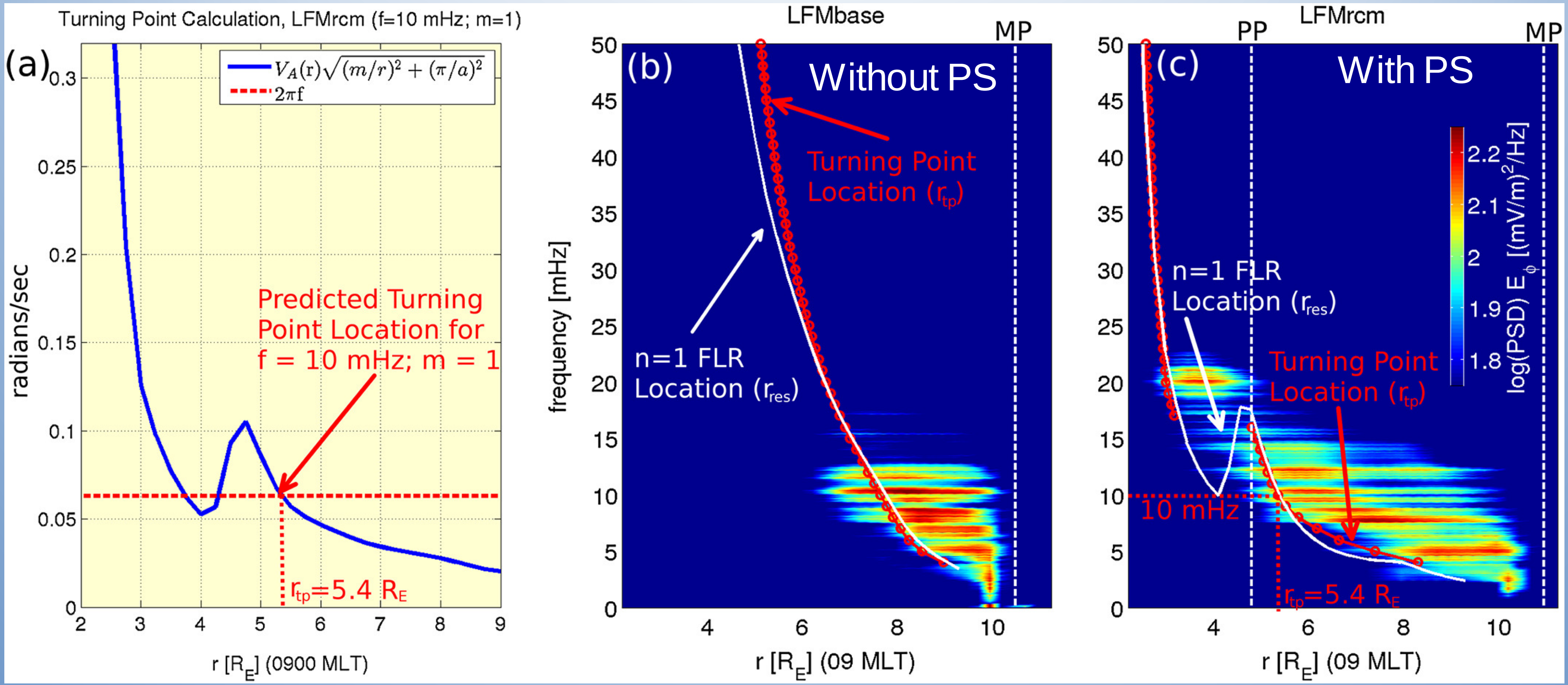
- Enhanced convection also causes the co-rotating plasmaspheric material to surge sunward
  - Decreasing the night-side plasmapause radius
  - Extending the dayside plasmapause radius
- Creates a plume extending from ~12 to 18 MLT
- For continued enhanced convection less material remains to feed the plume and it narrows in MLT
  - Dusk edge remains almost stationary
  - Western edge moves eastward
- Cold dense plasma is delivered to the dayside reconnection region



The Role of the Mass of the Plasmasphere

"Wave Propagation"

Global MHD modeling of resonant ULF waves: Simulations with and without a plasmasphere



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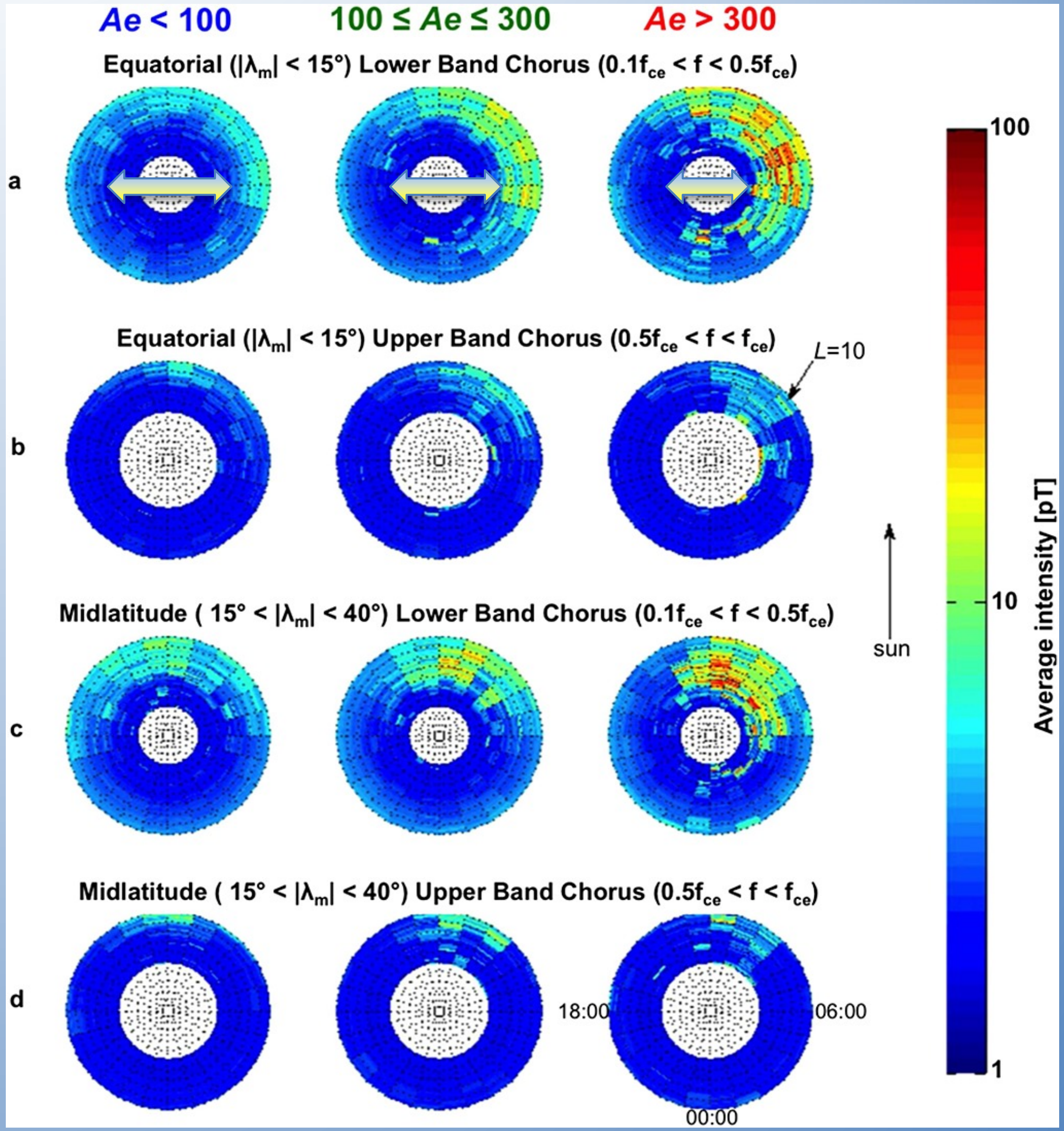
The Role of the Mass of the Plasmasphere

"Wave-Particle Instabilities"

Outside the PS

Statistical study of chorus wave distributions in the inner magnetosphere using Ae and solar wind parameters



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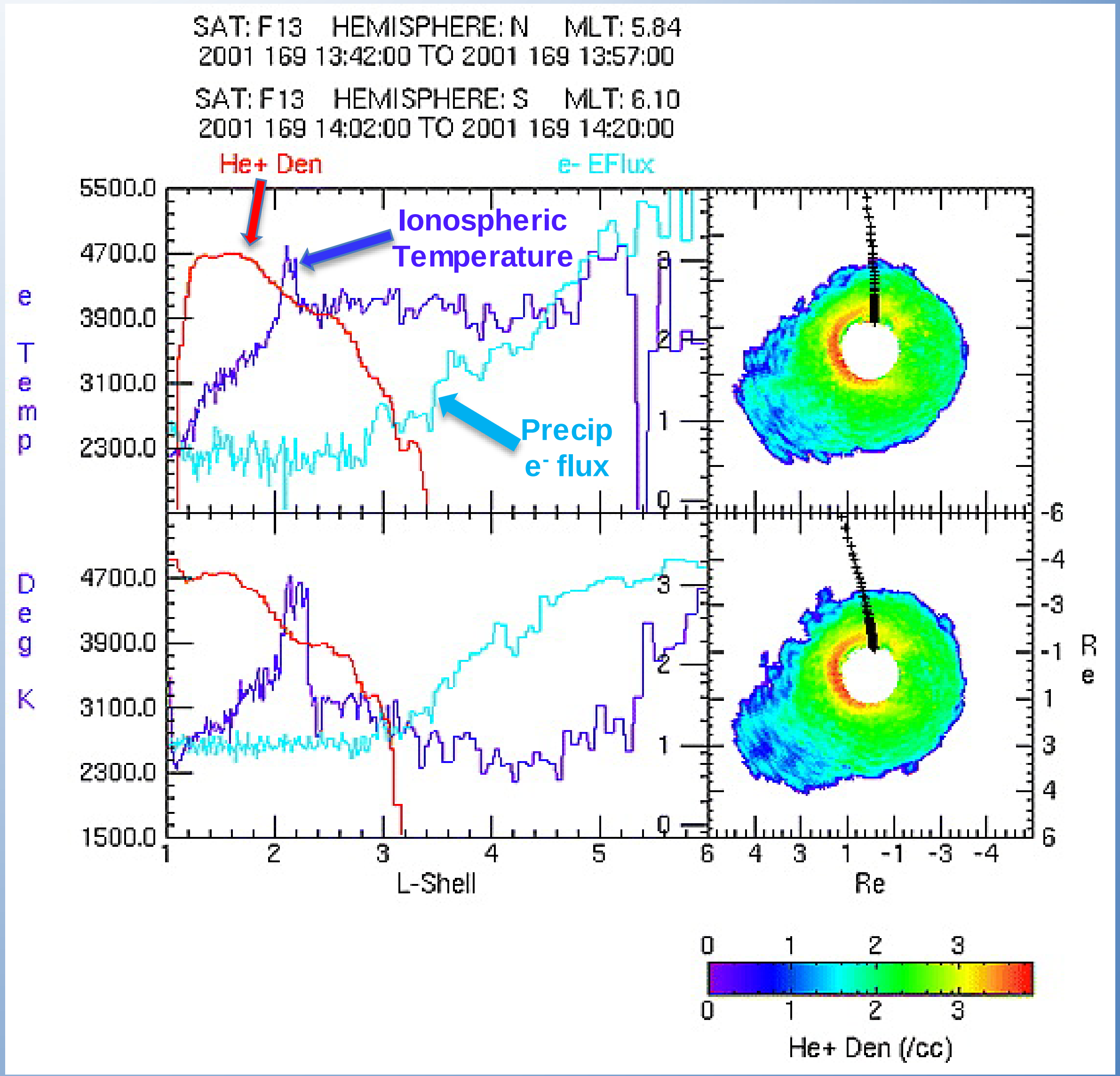
The Role of the Mass of the Plasmasphere

"Coulomb Scattering"

Overlap of the plasmasphere and ring current: Relation to subauroral ionospheric heating



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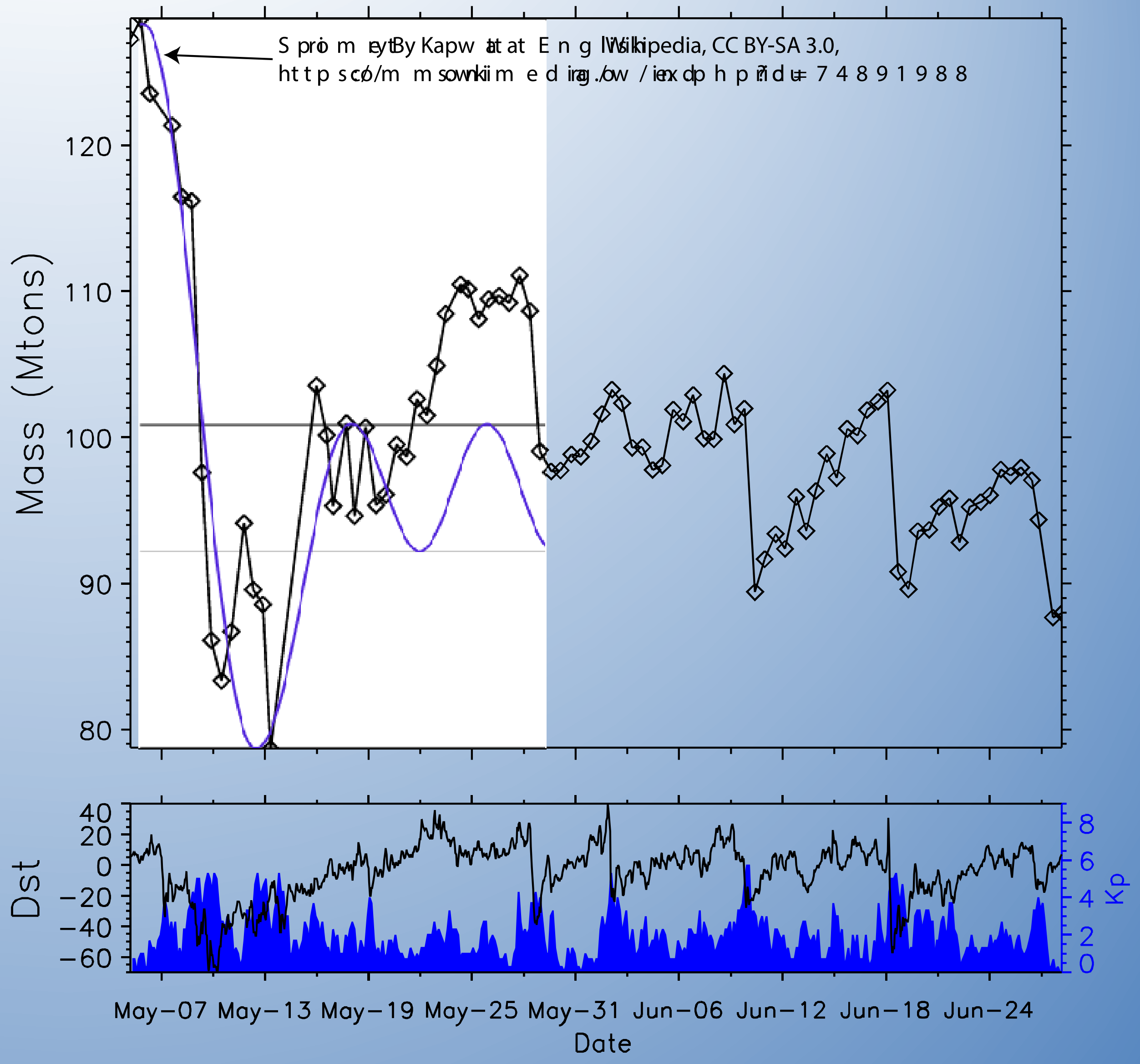
Techniques to Quantify the State and Behavior of the Plasmasphere are Still needed

Magnetospheric research has and is changing to a system-level approach for resolving the unknowns that remain in our knowledge.

The path for forward progress needs experimental missions and analysis techniques with a system-level focus.

This paper is a rather blatant attempt to seek that approach for using remote imaging to study the plasmasphere. Maybe it will work; maybe it won't.



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