Challenges in Polar Aeronomy

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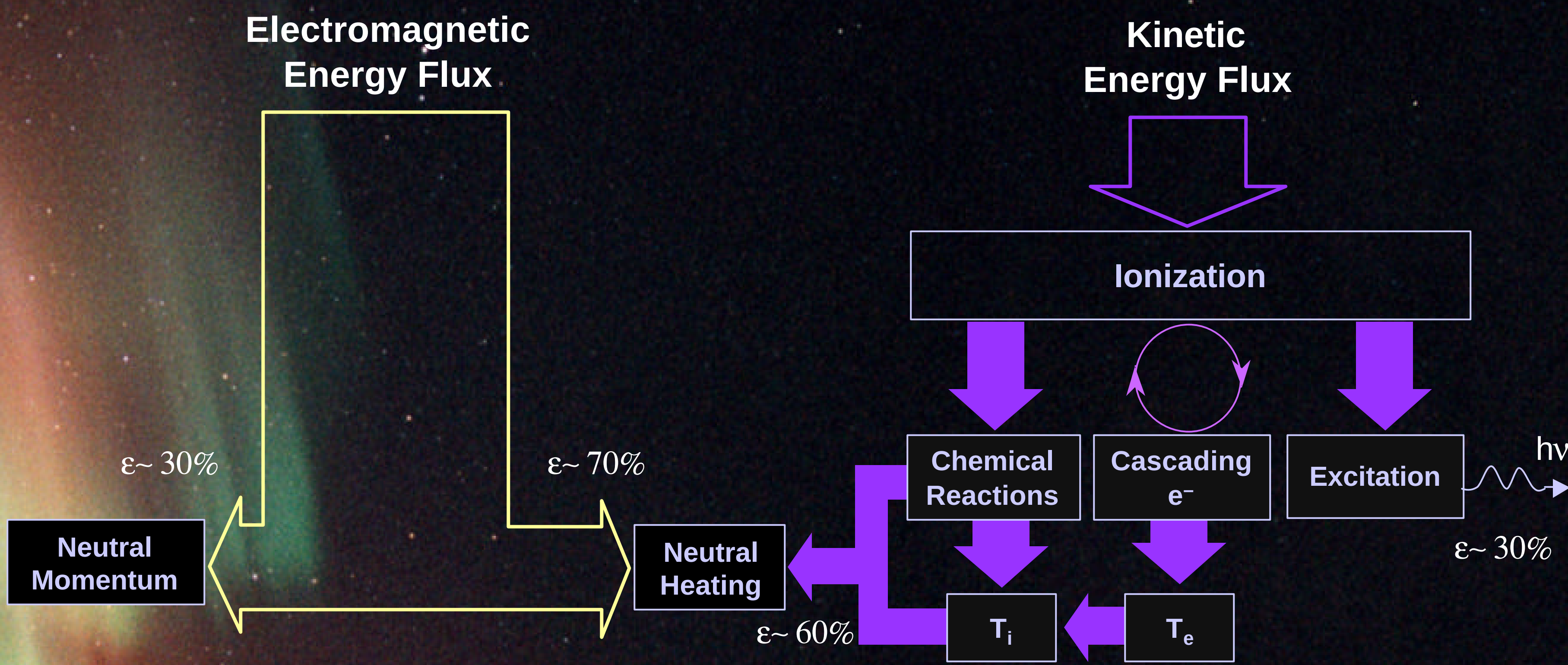
Background photos by Craig Heinselman

A Major Challenge

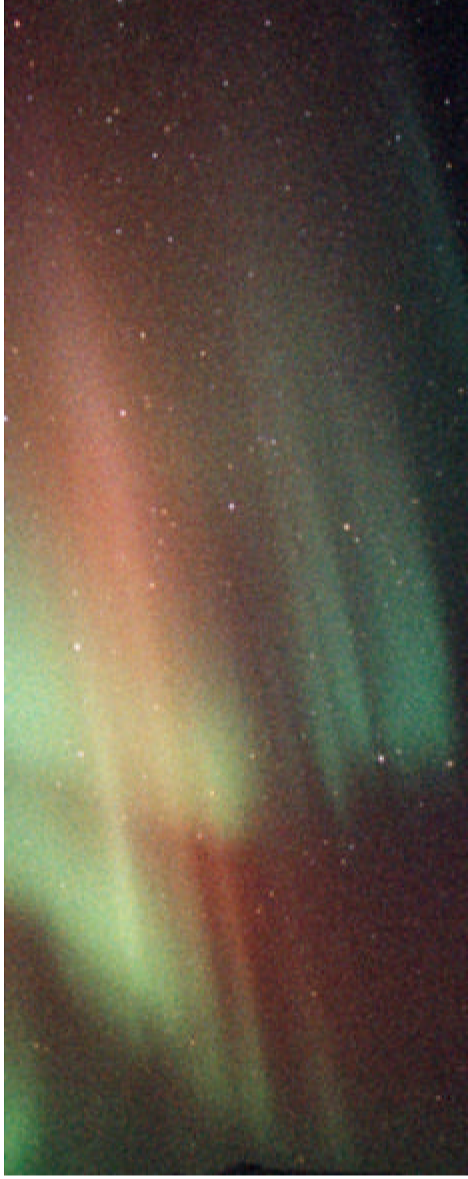
To determine how the polar aeronomic state affects coupling between the ionosphere-thermosphere (IT) system and the magnetosphere

Magnetospheric Energy Transfer to the Polar Atmosphere



Aeronomic State Parameters: neutral winds, ion drift, electron density, temperature and mass

The Importance of the Polar Aeronomic State



Classic Paradigm

The polar ionosphere / thermosphere (IT) system is a passive recipient of magnetospheric energy

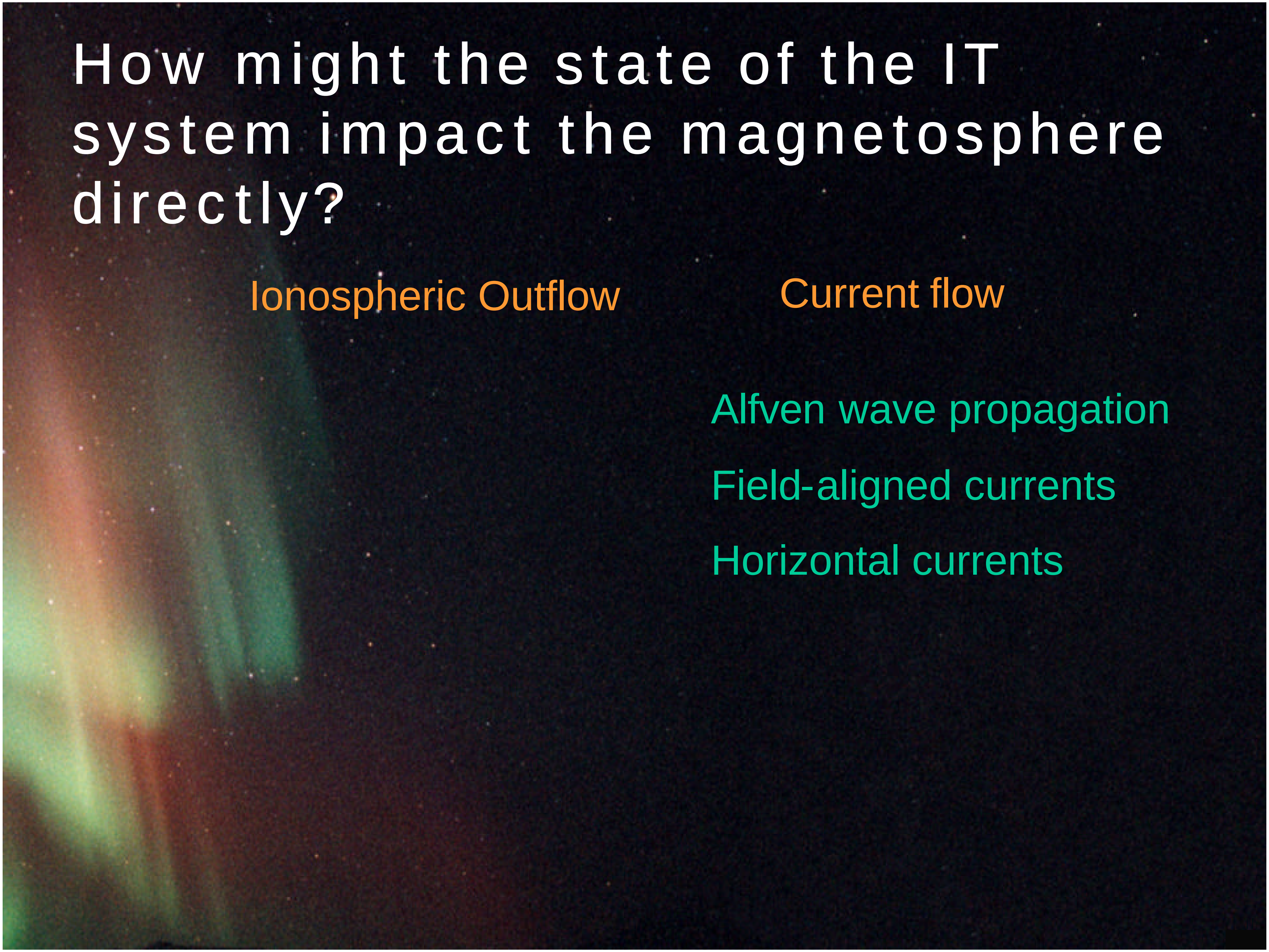
New Paradigm

The polar IT system is an active participant in determining the energy exchange between the magnetosphere and the IT system

How might the state of the IT system impact the magnetosphere directly?

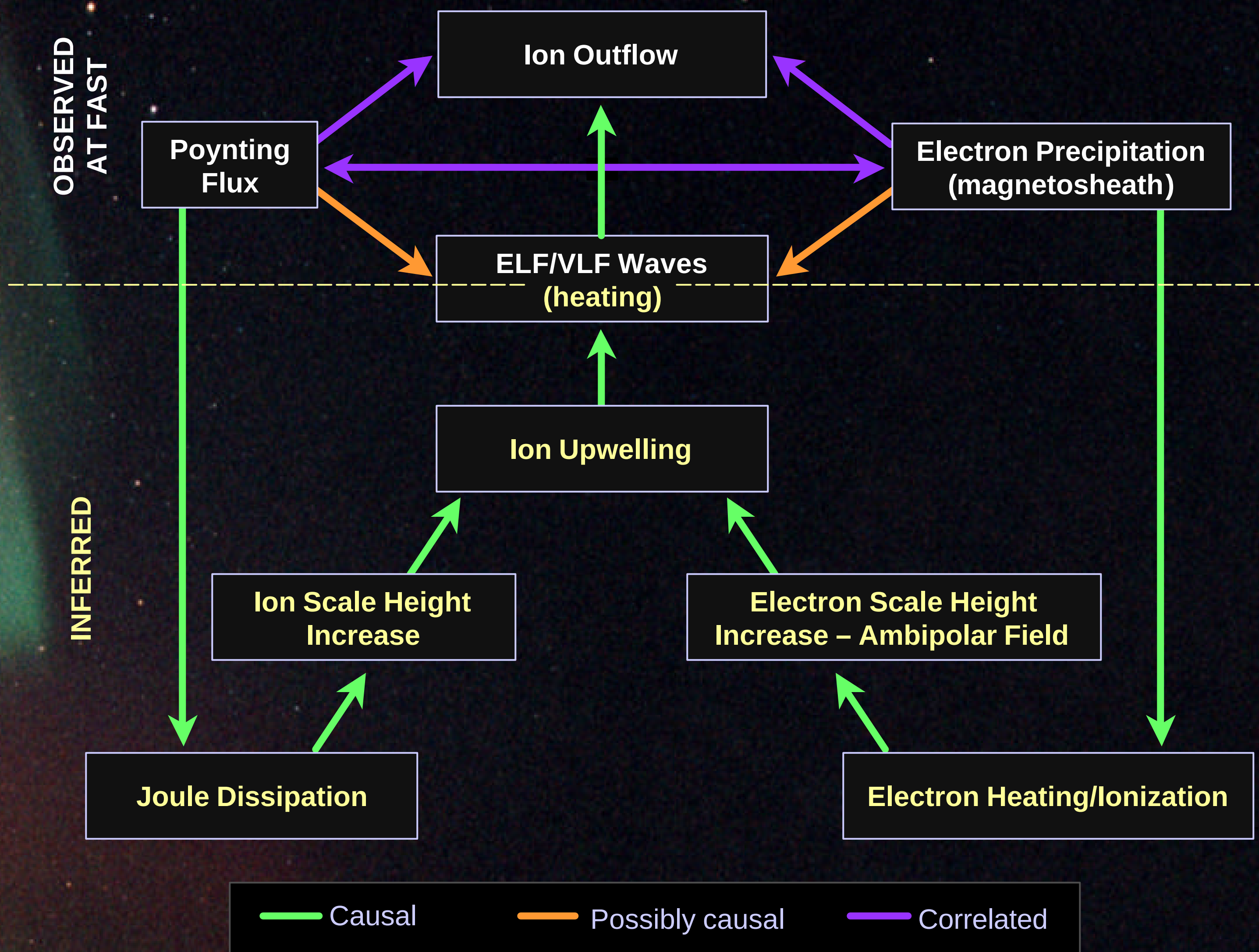
How might the state of the IT system affect the level of coupling with the magnetosphere?

What is the spatial and temporal behavior of the polar aeronomic state?


How might the state of the IT system impact the magnetosphere directly?
Ionospheric Outflow
Current flow
Alfven wave propagation
Field-aligned currents
Horizontal currents

Ion Outflow Mechanism

Courtesy of Robert Strangeway



How might the state of the IT system affect the level of coupling with the magnetosphere?

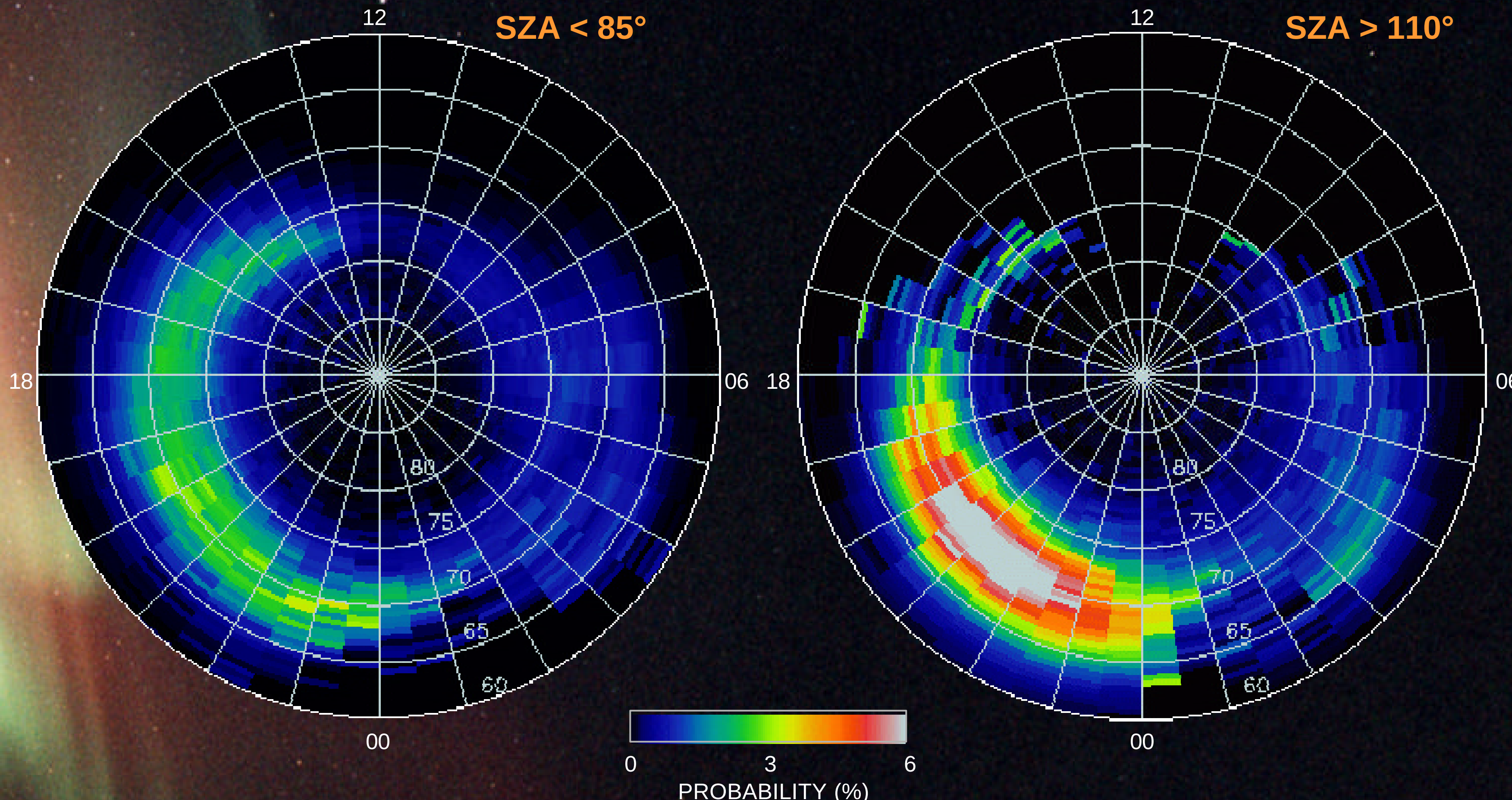
By influencing,

- **Kinetic Energy Flux**
- **Electromagnetic Energy Flux**

Kinetic Energy Flux

Newell et al., *Reviews of Geophysics*, 39, May 2001

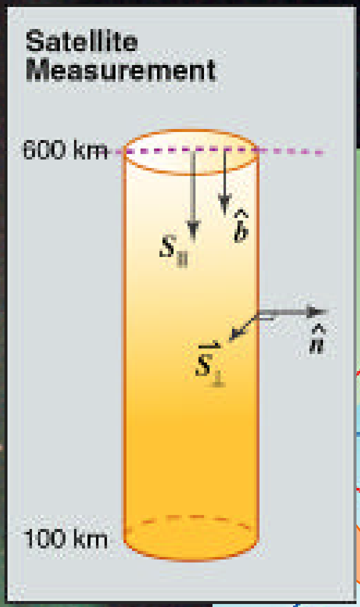
Suppression of intense aurora in sunlight

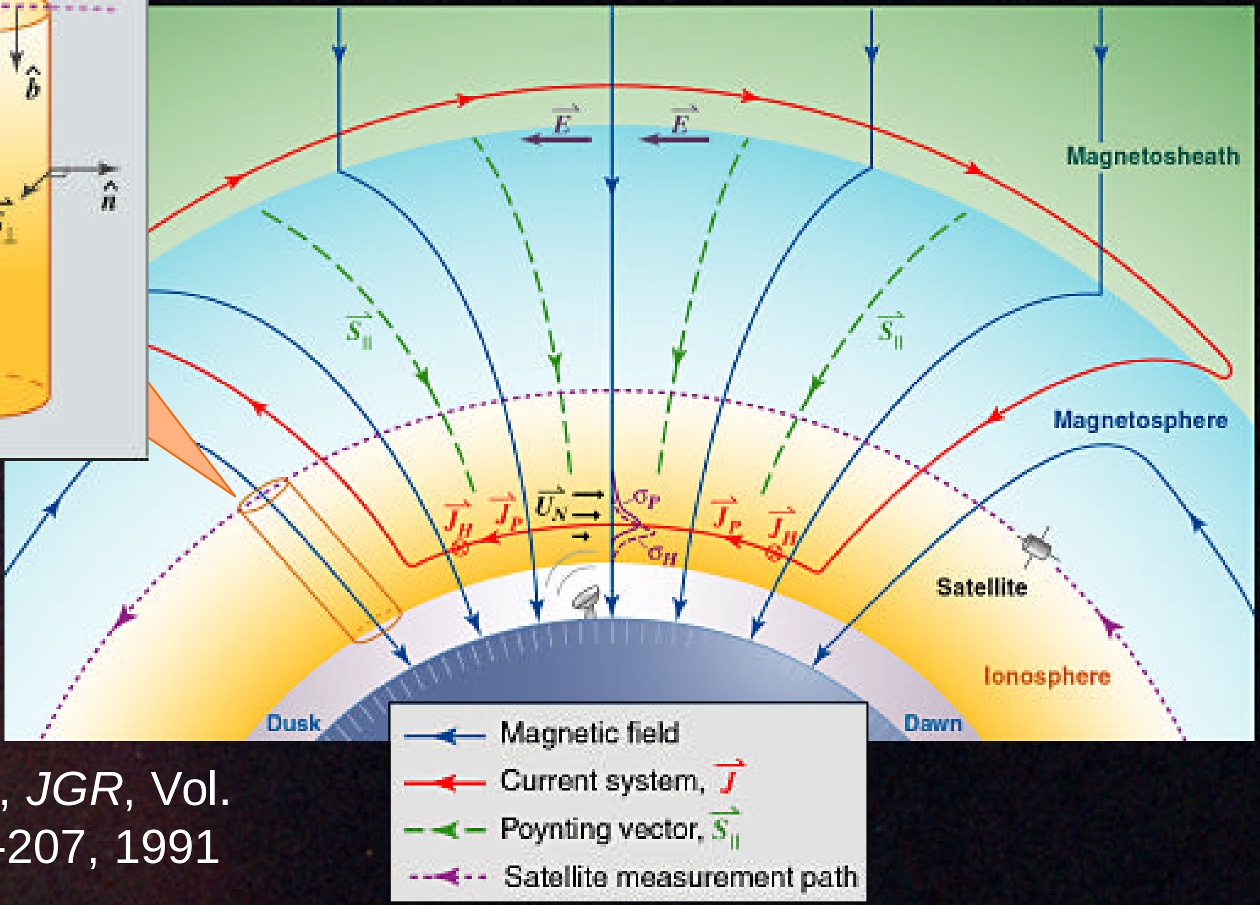


Total electron flux threshold: 5 ergs cm^{-2} s^{-1}

Electromagnetic Energy (Poynting) Flux

$$\int_A \vec{S} \bullet \hat{n}\, dA = \int_V \vec{J} \bullet \vec{E}\, dV$$





Kelley et al., *JGR*, Vol. 96, pp. 201-207, 1991

Summary of DE-2 Field-Aligned Poynting Flux

Gary et al., GRL, Vol. 22, No. 14, pp. 1861-1864, July 1995

576 orbits over DE-2 lifetime

On a statistical average,

- The Poynting flux was directed downward throughout the high latitude region
- Dayside values were 20-50% higher than nightside values

Upward Poynting flux was observed in 147 passes
(about 1 in every 4th pass included in the study)

- Upward fluxes were noticeaby smaller than compared to downward-directed fluxes
- Upward fluxes were more prevalent in the dawn and postmidnight sector with many events occurring during southward IMF and $K_p > 3$

What is the Spatial and Temporal Behavior of the Polar Aeronomic State?

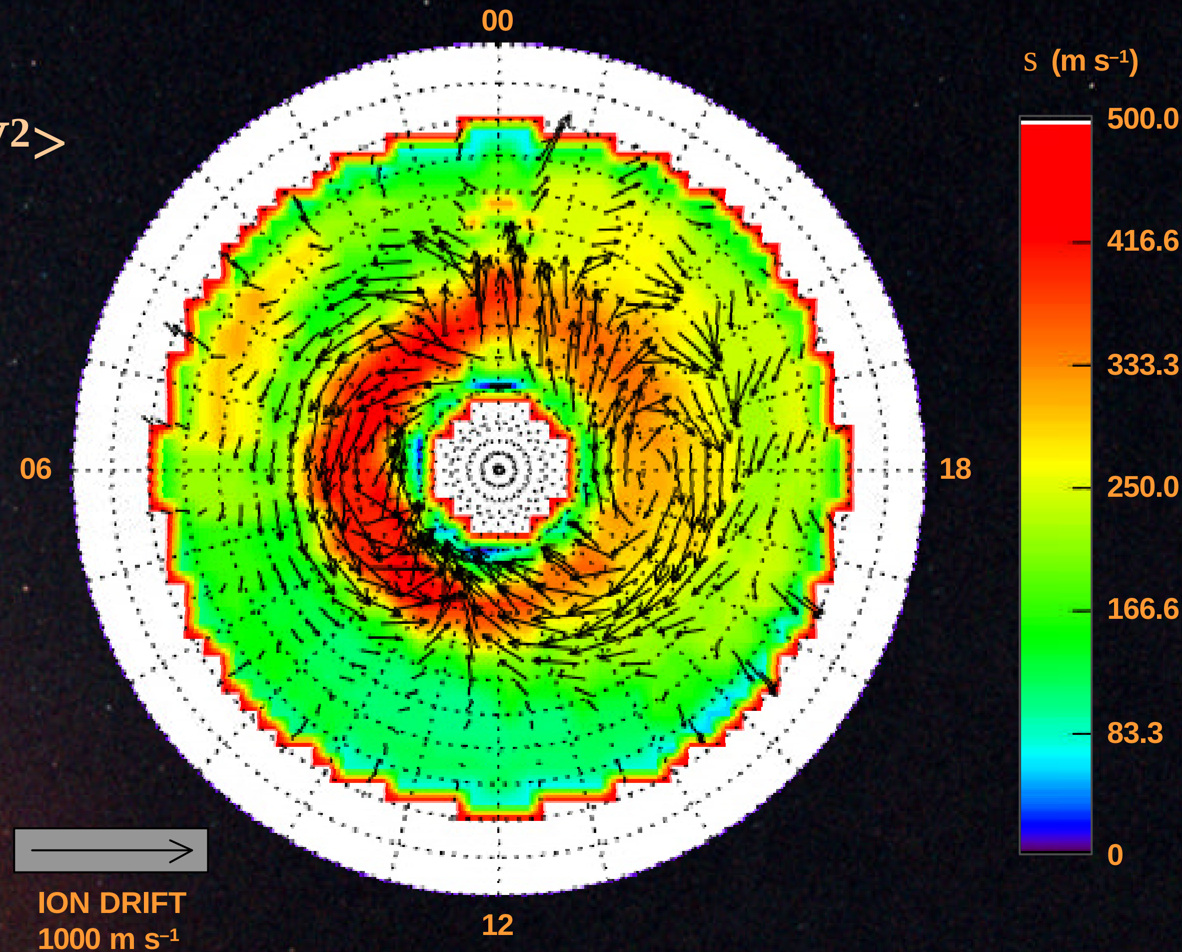
State Parameters:

- Ion drift
- Conductivity
- Neutral Wind

Ion Drift Variability

$$\langle \mathbf{V}^2 \rangle = \langle \mathbf{V} \rangle^2 + s^2$$

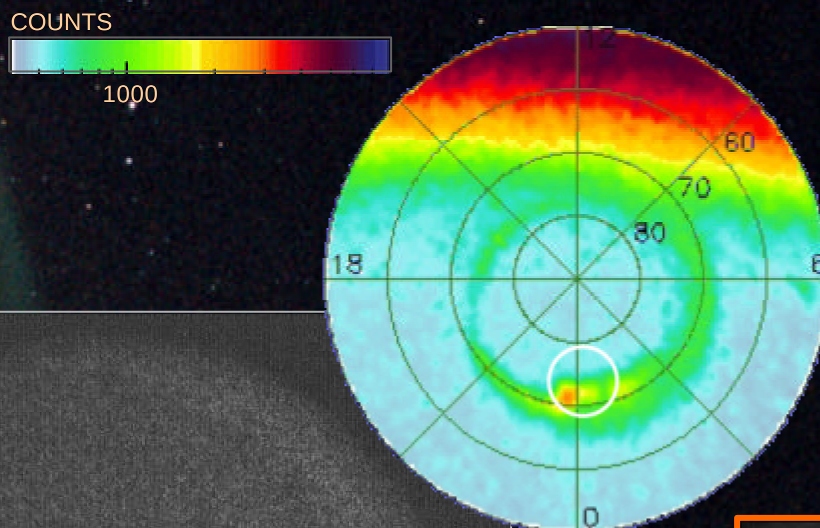
$$\mathbf{Q}_j \ a \ \langle \mathbf{V}^2 \rangle$$



Codrescu et al. 2000, JGR

Conductivity Variability

Geomagnetic Coordinates



Geographic Coordinates

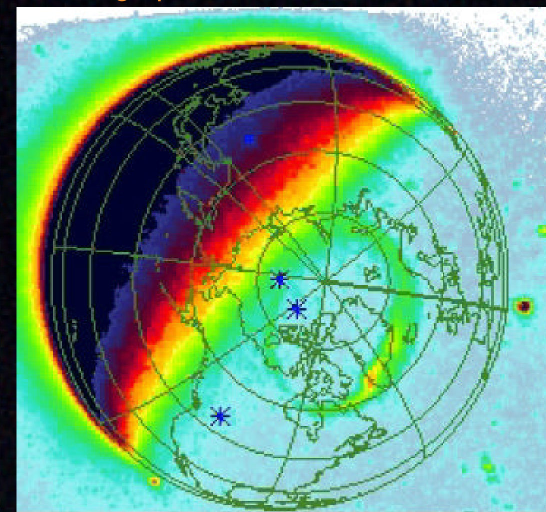
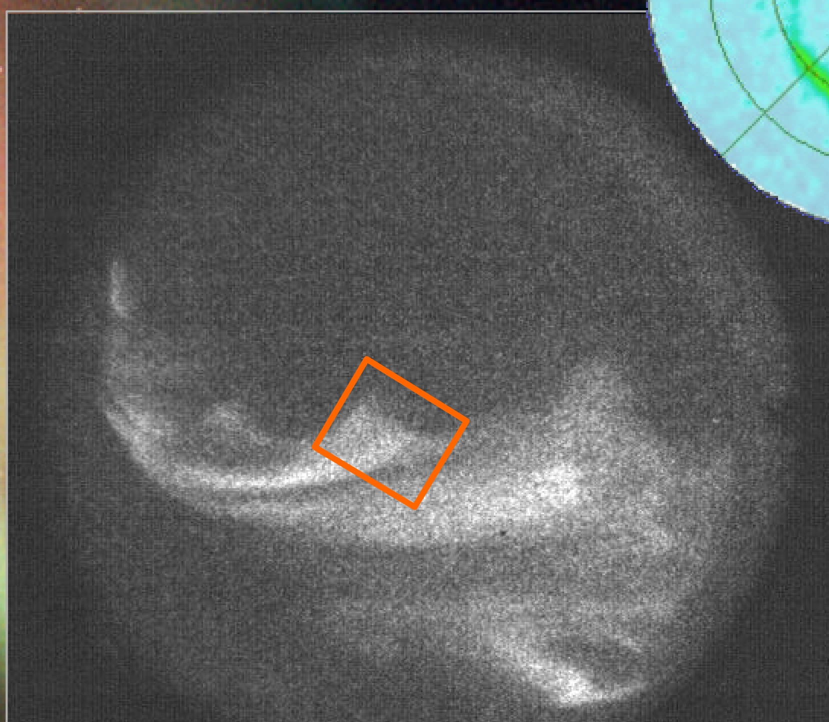


IMAGE Spacecraft (Stephen Mende)



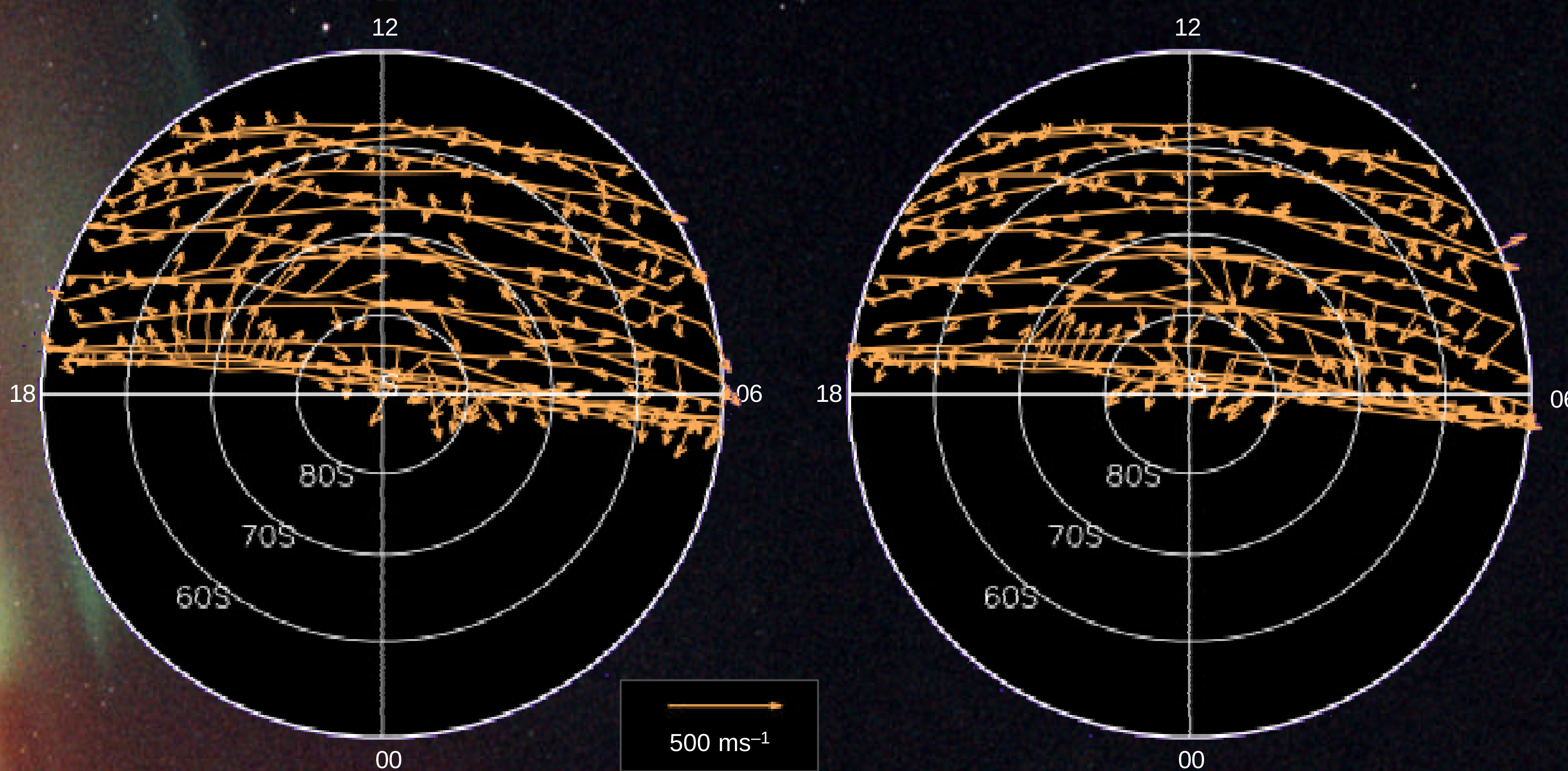
Allsky Imager (Rick Doe)

SMI (Josh Semeter)

Neutral Wind Variability

April 8, 1993 Recovery Phase

Zhang and Shepherd, *GRL*, Vol. 27, No. 13, pp. 1855-1858, July 2000



130 km **180 km**

WINDII O(^{1}S) derived winds

Making Progress

IT Observations

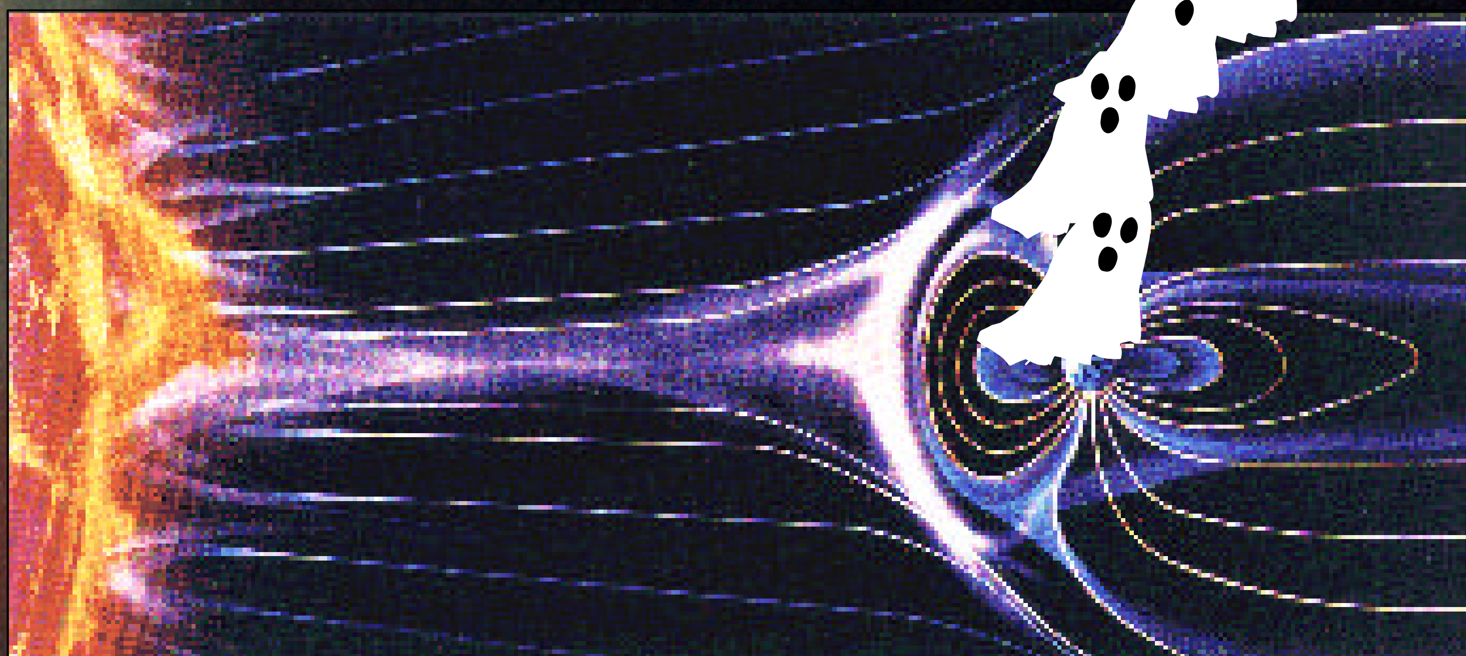
- NASA TIMED (2001)
- NSF Relocatable Atmospheric Observatory (2003)
- NASA Geospace Electrodynamic Connections (2009)

Modeling

- Self-consistent M-I-T Coupling Models without parameterizations

Polar Aeronomy:
“The Graveyard of Space Weather”

Polar Aeronomers can take a more promising view as the ghost of space weather events from the past may come back to haunt the magnetosphere



Poynting's Theorem

- Conservation of electromagnetic energy flux
- Directly derivable from Maxwell's Equations
- Links Maxwell's Equations to Newton's Laws

$$\frac{\partial W}{\partial t} + \nabla \bullet \vec{S} = -\vec{J} \bullet \vec{E}$$

Electric & Magnetic Energy Density

$$W = \frac{e_0 E^2}{2} + \frac{B^2}{2m_0}$$

Poynting's Flux Vector

$$\vec{S} = \frac{\vec{E} \times \vec{B}}{m_0}$$

Electromagnetic Energy Transfer Rate

$$\vec{J} \bullet \vec{E}$$

Apply to Polar Ionosphere / Thermosphere System

Changes in the Electromagnetic Energy Flux	=>	Joule Heating Rate	+	Mechanical Energy Transfer Rate

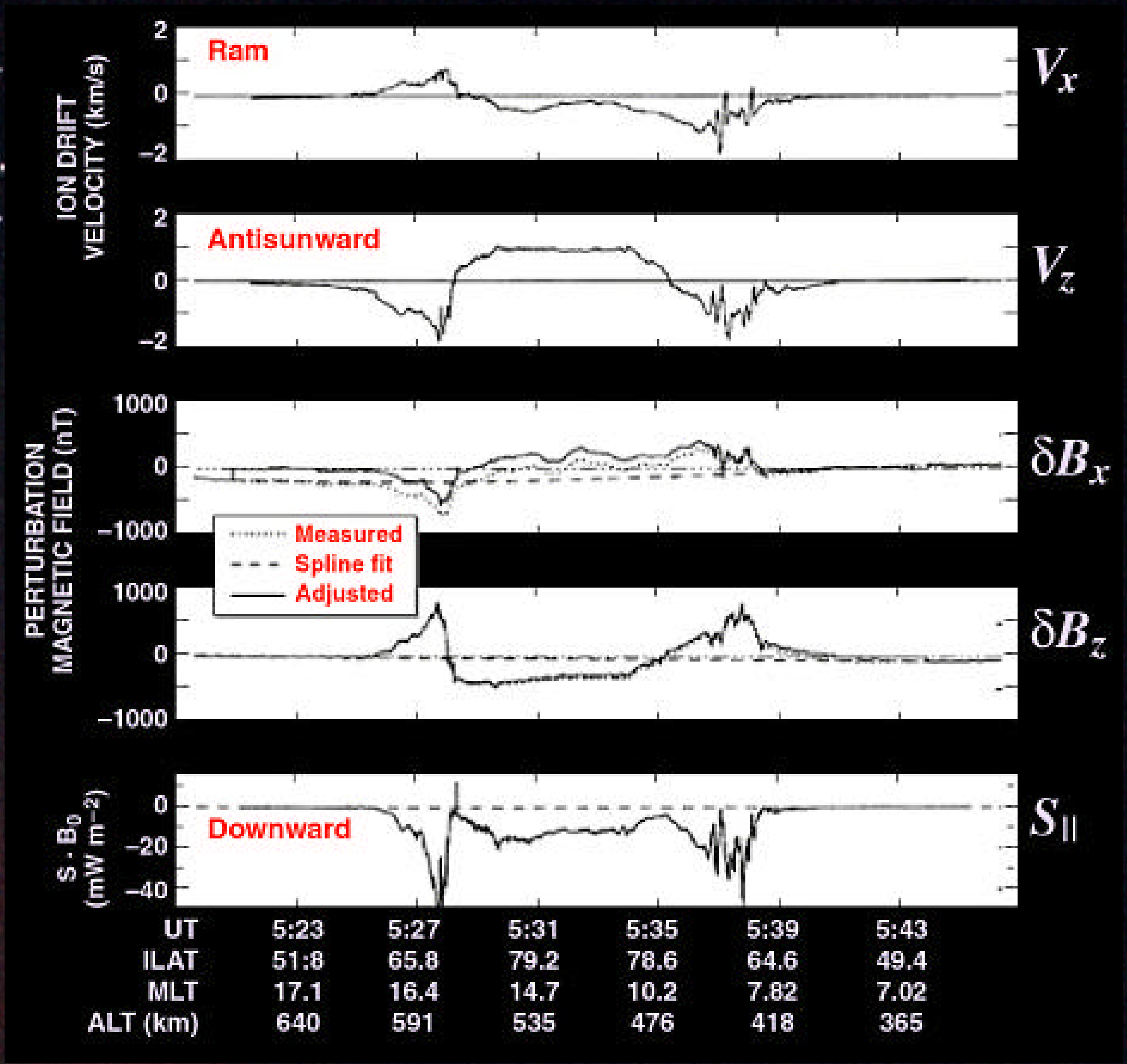
$$\frac{\partial(W)}{\partial t} + \nabla \bullet (\vec{S}) = -\left\{ \vec{J} \bullet \left(\vec{E} + \vec{U}_n \times \vec{B}\right) + \vec{U}_n \bullet \vec{J} \times \vec{B} \right\}$$

Changes in the Kinetic Energy Flux	=>	Collisional Heating Rate	+	Photon Loss Rate

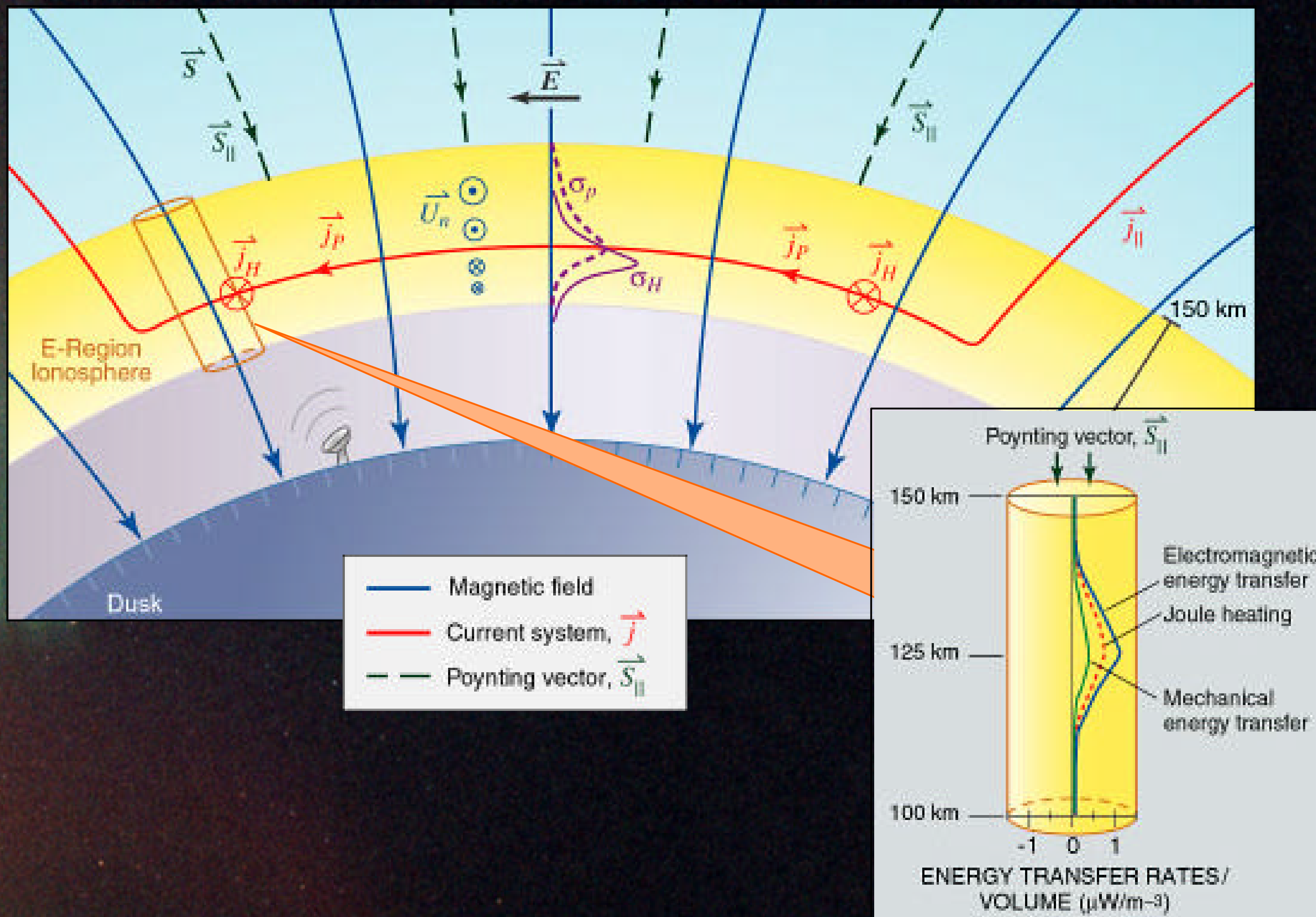
$$\frac{\partial(K)}{\partial t} + \nabla \bullet (\vec{M}) = Q_e + L_e$$

DE-2 Poynting Flux Measurements

Gary et al., Vol. 99, pp. 11417-11427, J. Geophys. Res., 1994



Ground-Based Observations



How does the polar aeronomic state affect the coupling between the ionosphere-thermosphere (IT) system and the magnetosphere?

How well we meet this major challenge depends on the progress made in concurrent understanding of, for example:

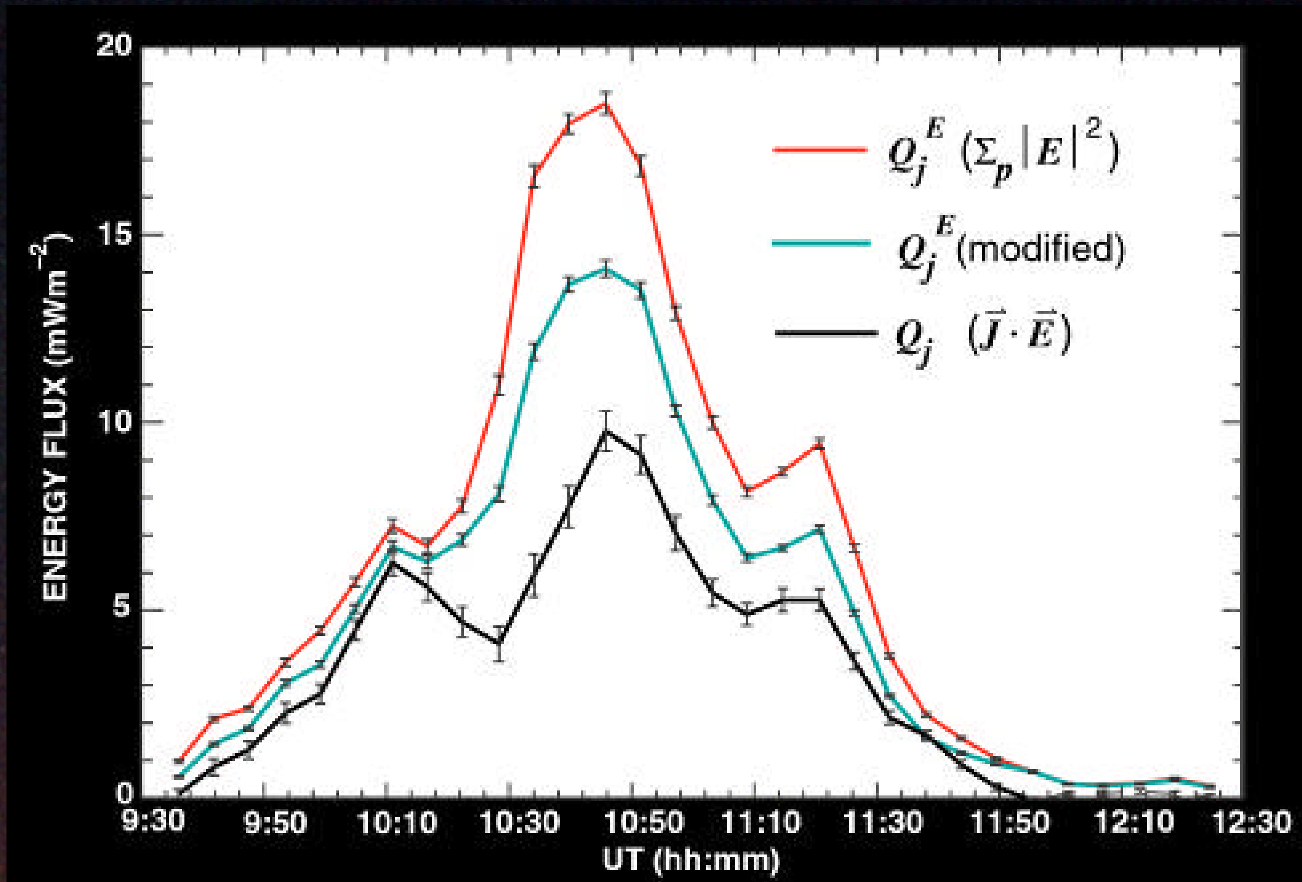
- Ion Outflow
- Current Closure
- Kinetic Energy Flux
- Poynting Flux
- Neutral Dynamo
- Alfven wave propagation

These advancements rely on enhancements to models and measurements of key parameters without spatial / temporal ambiguities:

- Electric Fields
- Conductivities
- Neutral winds
- Composition (ion and neutral)
- plasma and neutral state parameters

Electromagnetic Energy Transfer Events

Thayer, J. Geophys. Res., Vol. 105, No. A10, pp. 23015-23024, Oct. 2000



Polar Processes and Vertical Coupling

- **Middle Atmosphere / Lower Atmosphere Coupling**
  - Cold summer polar mesopause
  - Vortex dynamics in polar winter
  - Polar mesospheric cloud formation and evolution
- **(Ionosphere - Thermosphere) - Magnetosphere Coupling**
  - Current flow and closure
  - Auroral particle precipitation
  - Electric field mapping