M-I Coupling from the Ionosphere-Thermosphere Perspective: Melting the Frozen-In Flux

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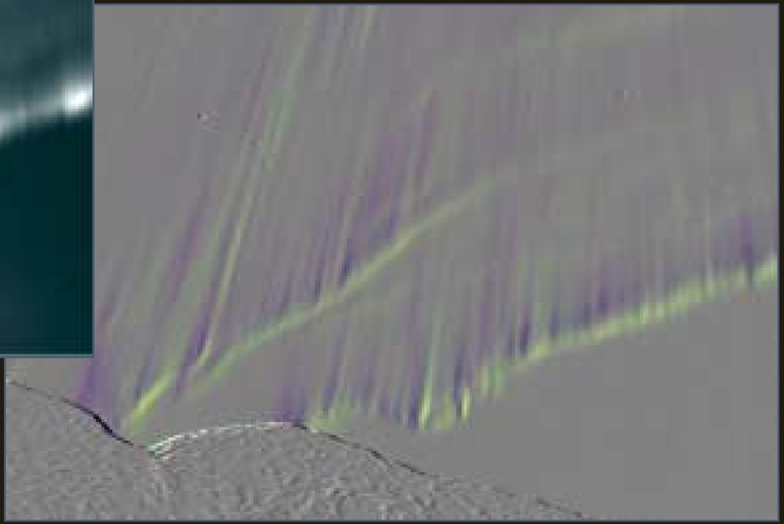
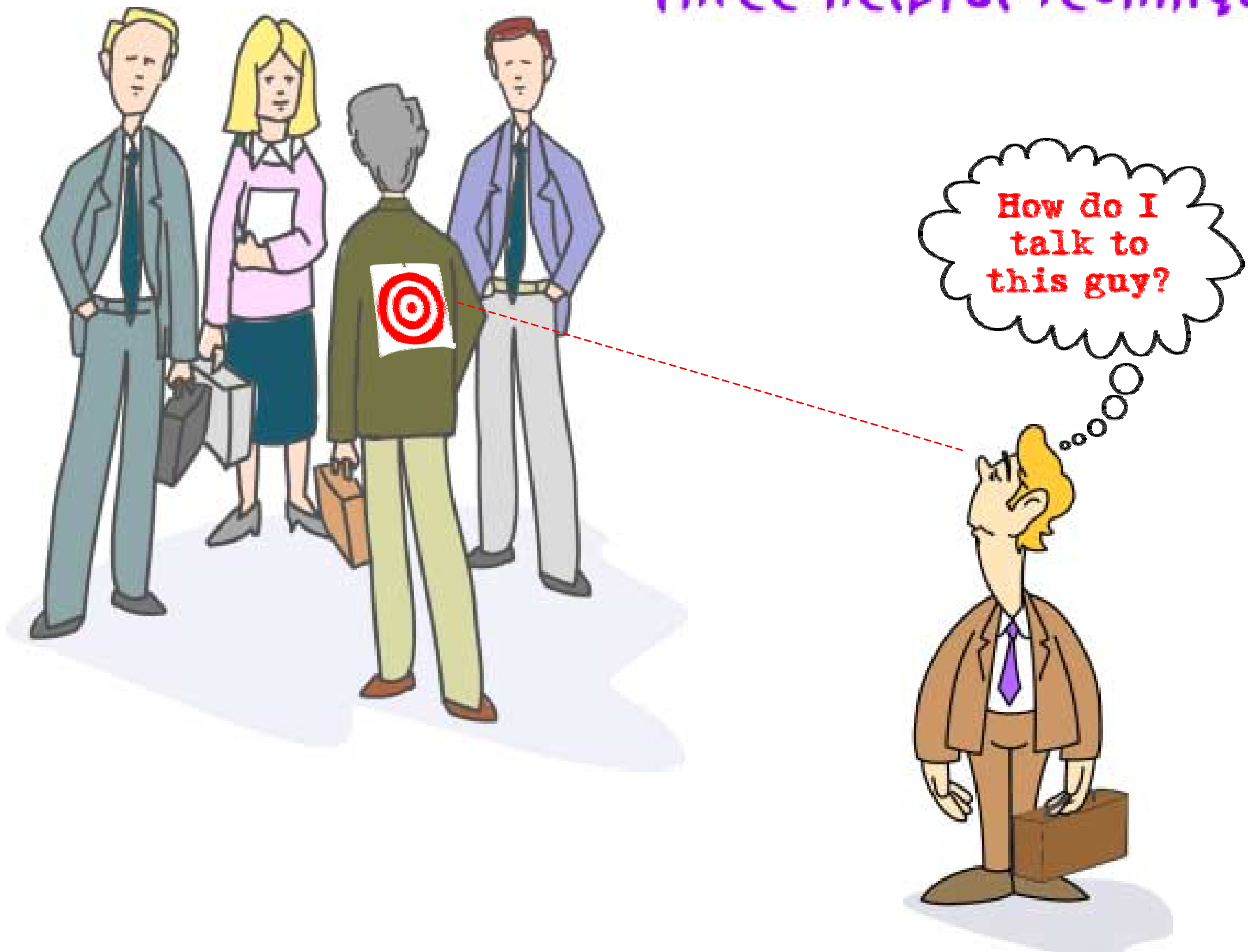
Photo by Craig Heinselman

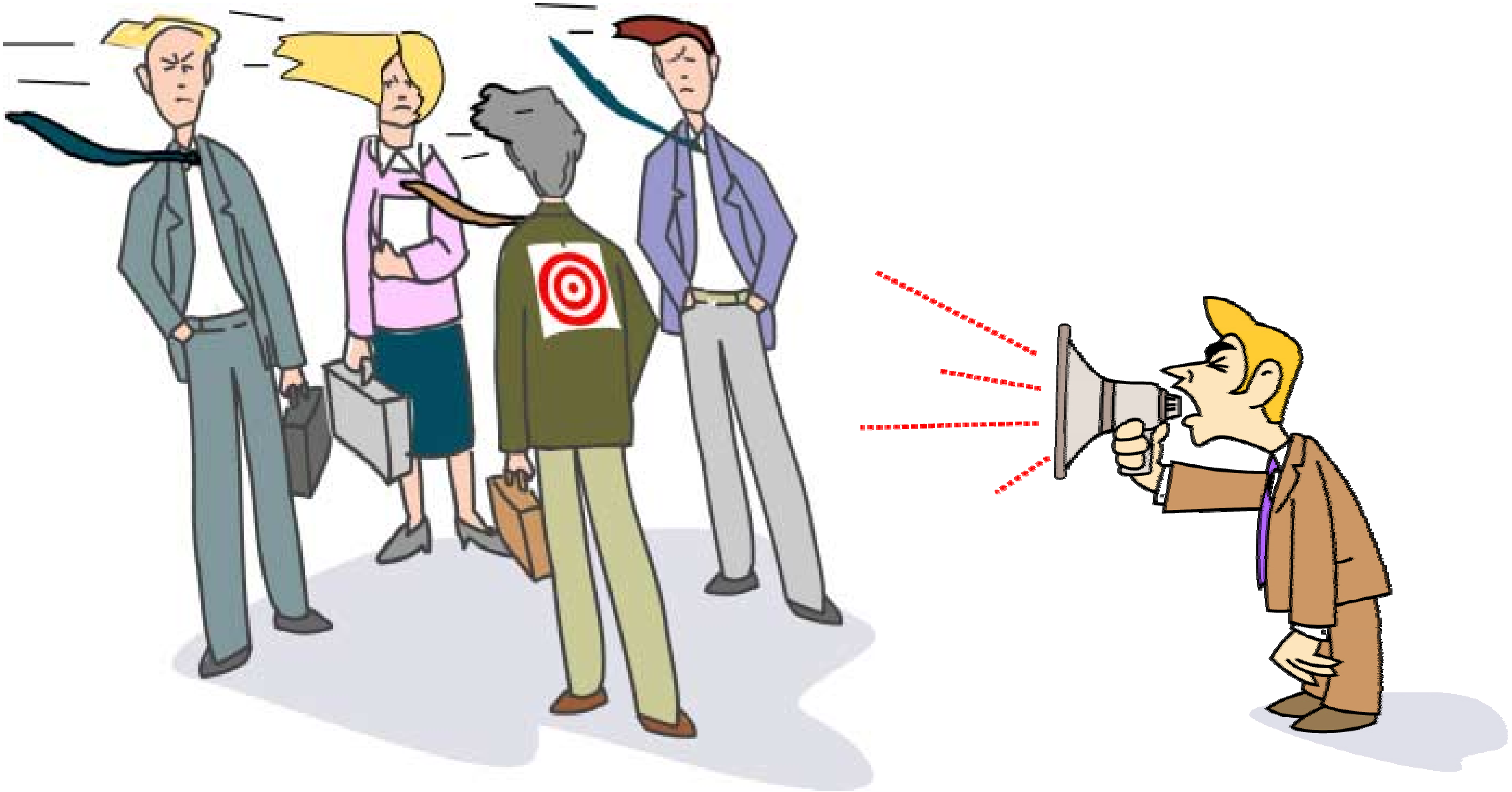


How to Generate Interest in Your Research

Three helpful techniques



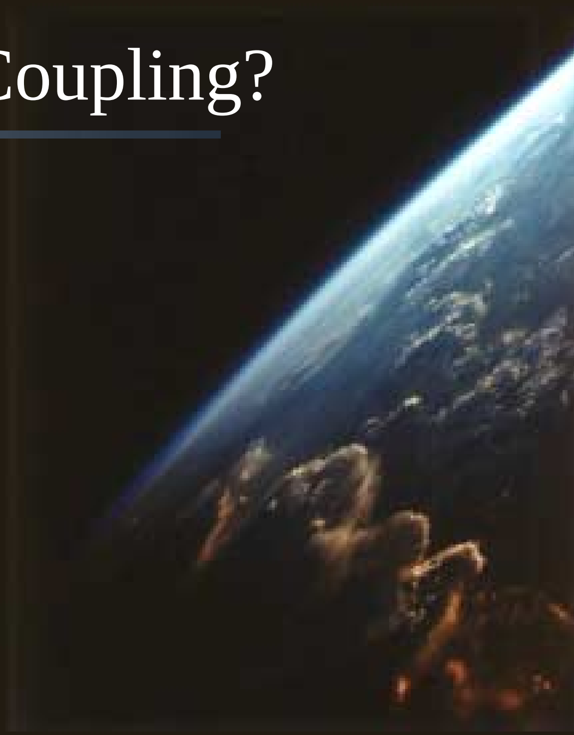
The Brute Force Approach



The Smooth Talker

The Planned Coincidence

What is the Role of the IT system in M-I Coupling?

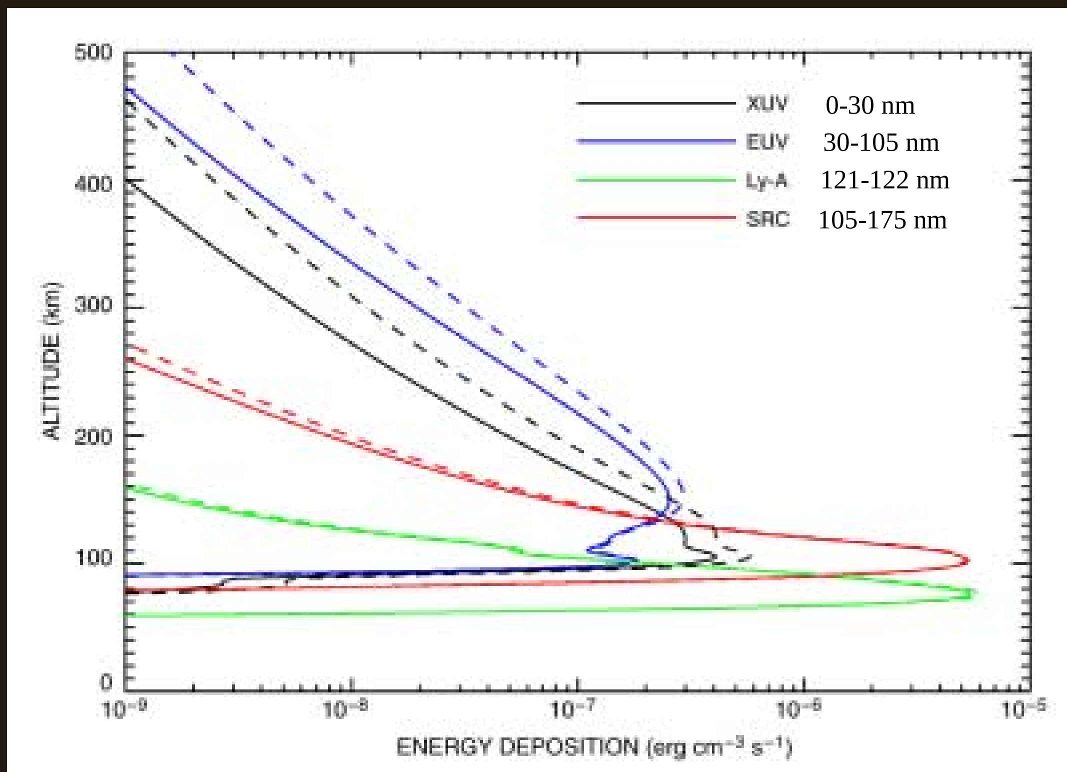


- A Depository for distant sources of energy flux
  - Absorbing VUV solar radiation, magnetospheric Poynting flux and Kinetic energy flux
- An Intermediary for charged and neutral gases
  - Enforcing the physical laws of a multiconstituent, collision dominated, weakly ionized gas
- A Regulator of the magnetosphere
  - Regulating M-I energy exchange through coupled electrodynamic processes

A Depository

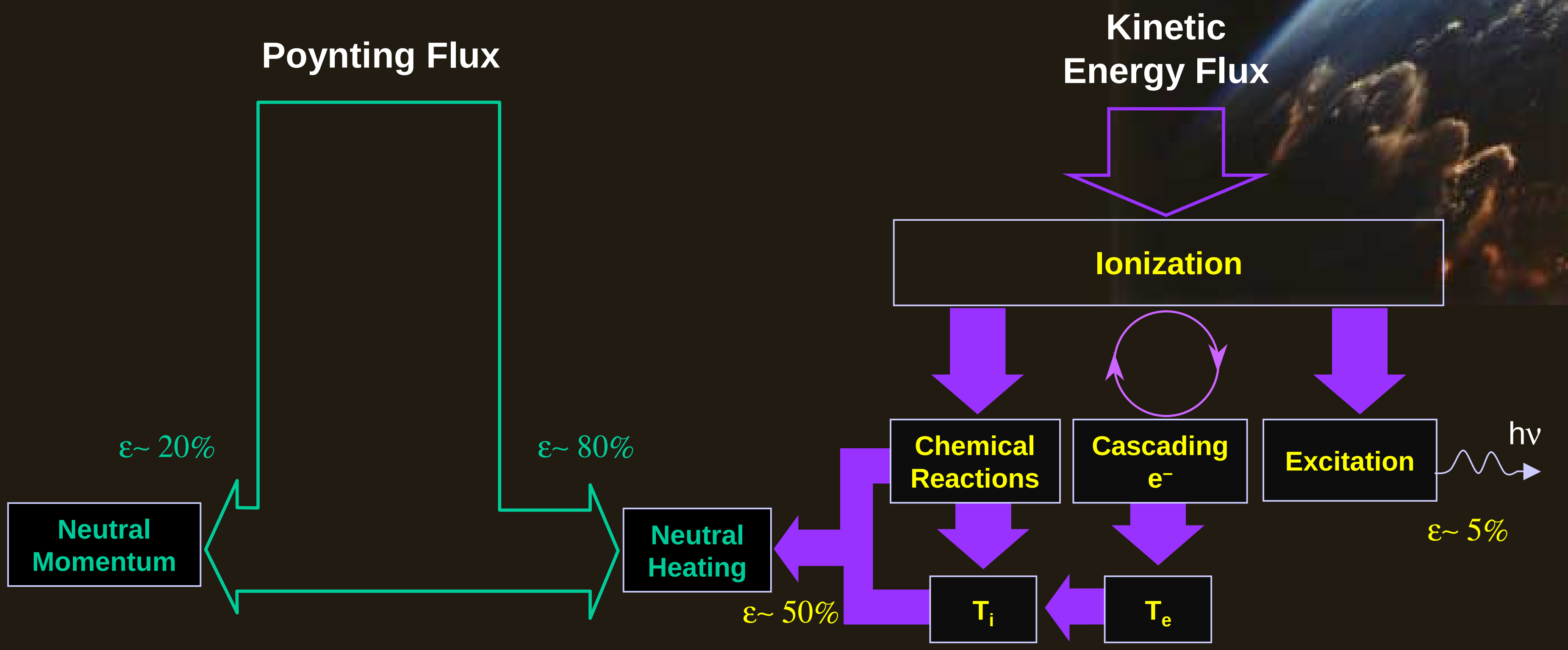
VUV Solar Radiation

TIMED SEE Measurements
July 4, 2002
Solar zenith angle 46 degrees



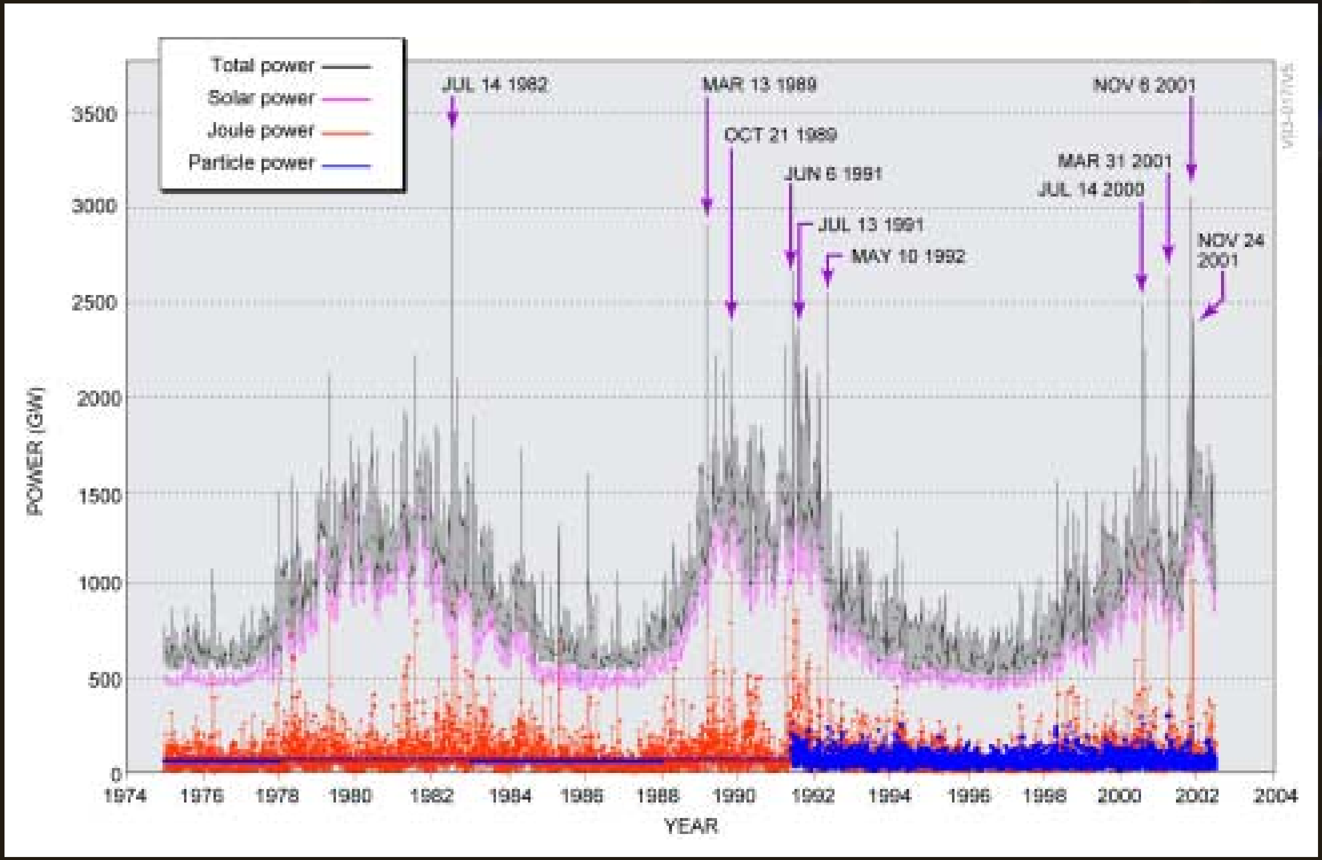
Courtesy of Stan Solomon, NCAR

Magnetospheric Energy Transfer to the Polar IT System



Power Input to the Polar IT System

Solar VUV; Poynting Flux; Kinetic Energy Flux

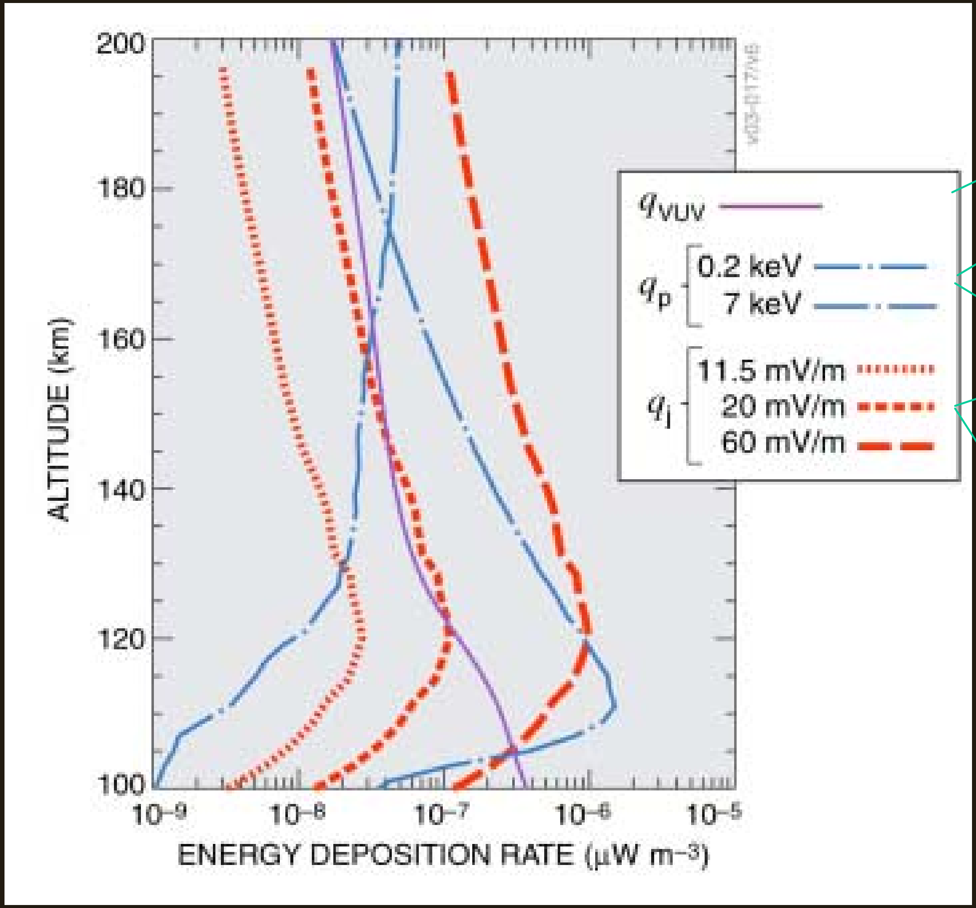


Knipp et al. [2003]

Local Energy Deposition Rates

Solar VUV ; Poynting Flux; Kinetic Energy Flux

Measured at 67N, solar maximum, summer solstice conditions



Height-Integrated Energy Flux

8.3 mW/m^2

2.5 mW/m^2

35.3 mW/m^2

1.7 mW/m^2

5.1 mW/m^2

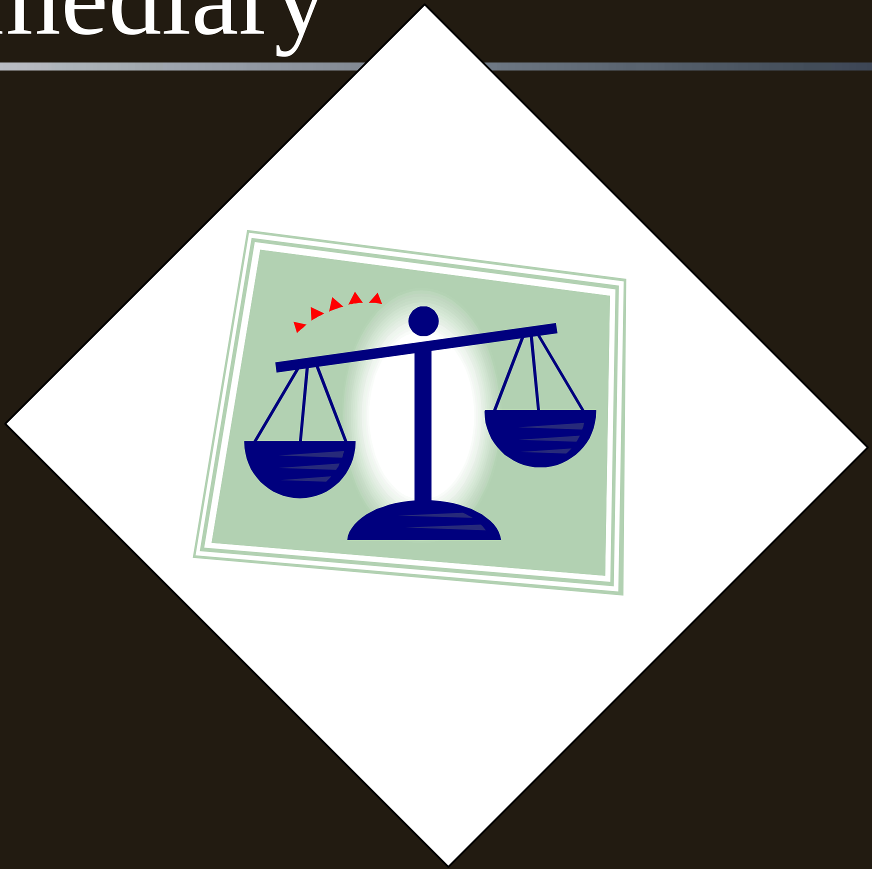
46.3 mW/m^2

Thayer and Semeter, 2003 JASTP

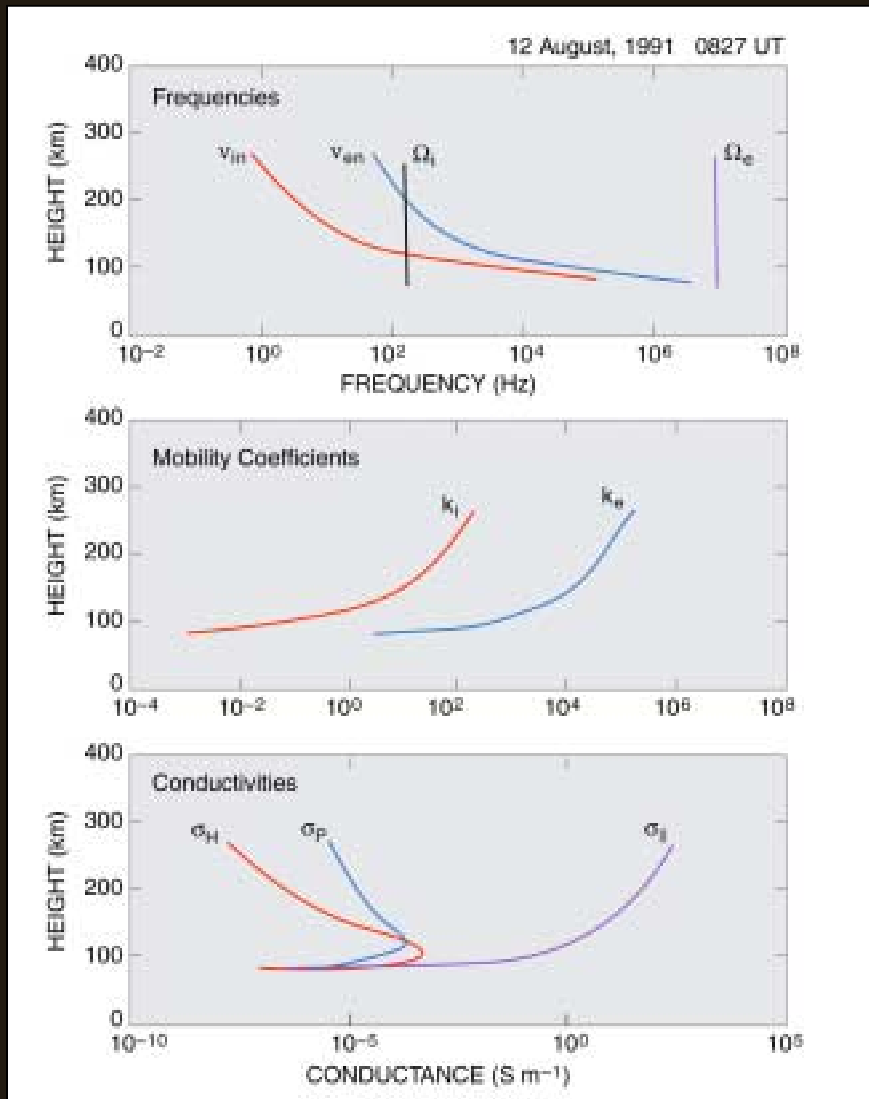
IT System as a Depository

- These fluxes drive the physics and chemistry of the polar IT system
- These fluxes are each processed differently by the polar IT system
- These fluxes can have competing contributions in localized regions

An Intermediary



Ion and Electron Mobility Properties



Ion & Electron Momentum Equations

$$n_i m_i \frac{d\vec{V}_i}{dt} = -\vec{\nabla}\vec{P}_i + n_i m_i \vec{g} + e n_i\left(\vec{E} + \vec{V}_i \times \vec{B}\right) - n_i m_i \upsilon_{in}\left(\vec{V}_i - \vec{U}_n\right)$$

$$\vec{V}_i = \vec{U}_n + \frac{\vec{g}}{\upsilon_{in}} - \frac{\vec{\nabla}\vec{P}_i}{n_i m_i \upsilon_{in}} + \frac{k_i}{B}\left(\vec{E} + \vec{V}_i \times \vec{B}\right) \qquad k_i = \frac{\Omega_i}{\upsilon_{in}}$$

Ion momentum equation in static E- and B-fields with ion-neutral collisions only,

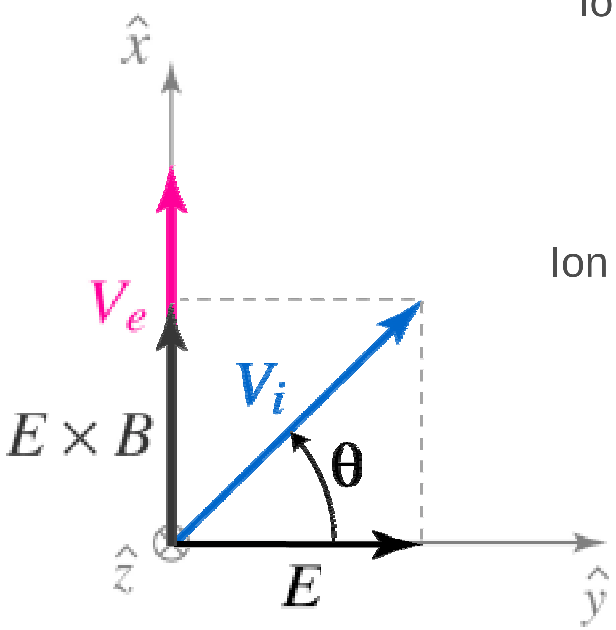
$$\vec{V}_i = \frac{k_i}{B}\vec{E} + \frac{k_i}{B}\vec{V}_i \times \vec{B}$$

$$\vec{V}_i = \frac{1}{1+k_i^2}\left\{\frac{k_i}{B}\vec{E}_\perp + \left(\frac{k_i}{B}\right)^2 \vec{E}\times\vec{B} + \left(\frac{k_i}{B}\right)^3 \left(\vec{E}\bullet\vec{B}\right)\vec{B}\right\}$$

Electron momentum equation in static E- and B-fields with electron-neutral collisions only,

$$\vec{V}_e = \frac{1}{1+k_e^2}\left\{\frac{-k_e}{B}\vec{E}_\perp + \left(\frac{k_e}{B}\right)^2 \vec{E}\times\vec{B} - \left(\frac{k_e}{B}\right)^3 \left(\vec{E}\bullet\vec{B}\right)\vec{B}\right\}$$

Ion & Electron Behavior in the E-region



Ion direction perpendicular to B

$$\theta = \arctan\left(\frac{\Omega_i}{\upsilon_{in}}\right)$$

Ion magnitude perpendicular to B

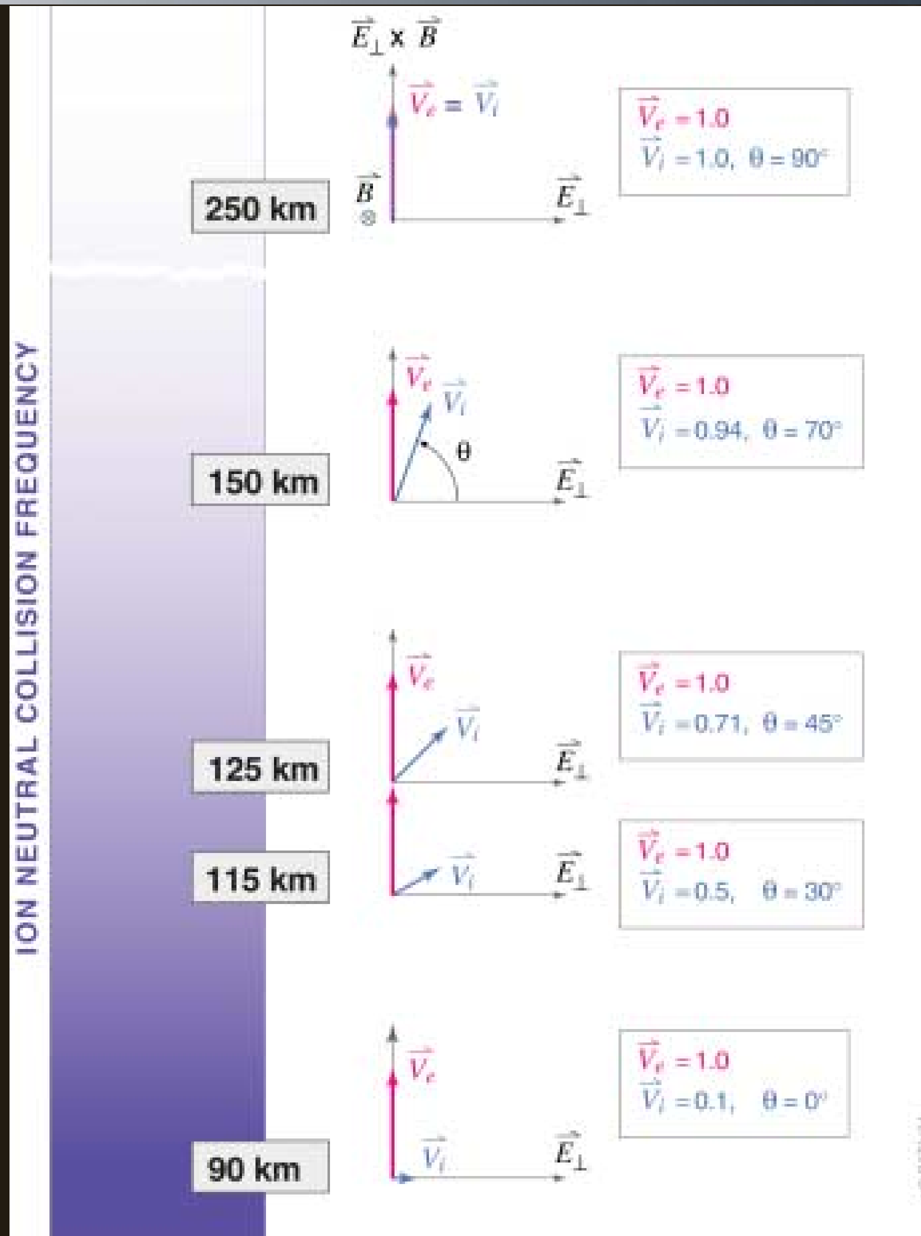
$$\left|V_{i\perp}(z)\right| = \frac{k_i}{\sqrt{1+k_i^2}}\left|\frac{E_\perp}{B}\right|$$

$$\left|V_{i\perp}(z)\right| = \sin(\theta_i)\left|\frac{E_\perp}{B}\right|$$

Electron magnitude and direction perpendicular to B

$k_e \gg 1$ $\quad\quad$ $\theta_e = 90^\circ$ $\quad\quad$ $\left|V_{e\perp}\right| = \frac{\left|E_\perp\right|}{B}$

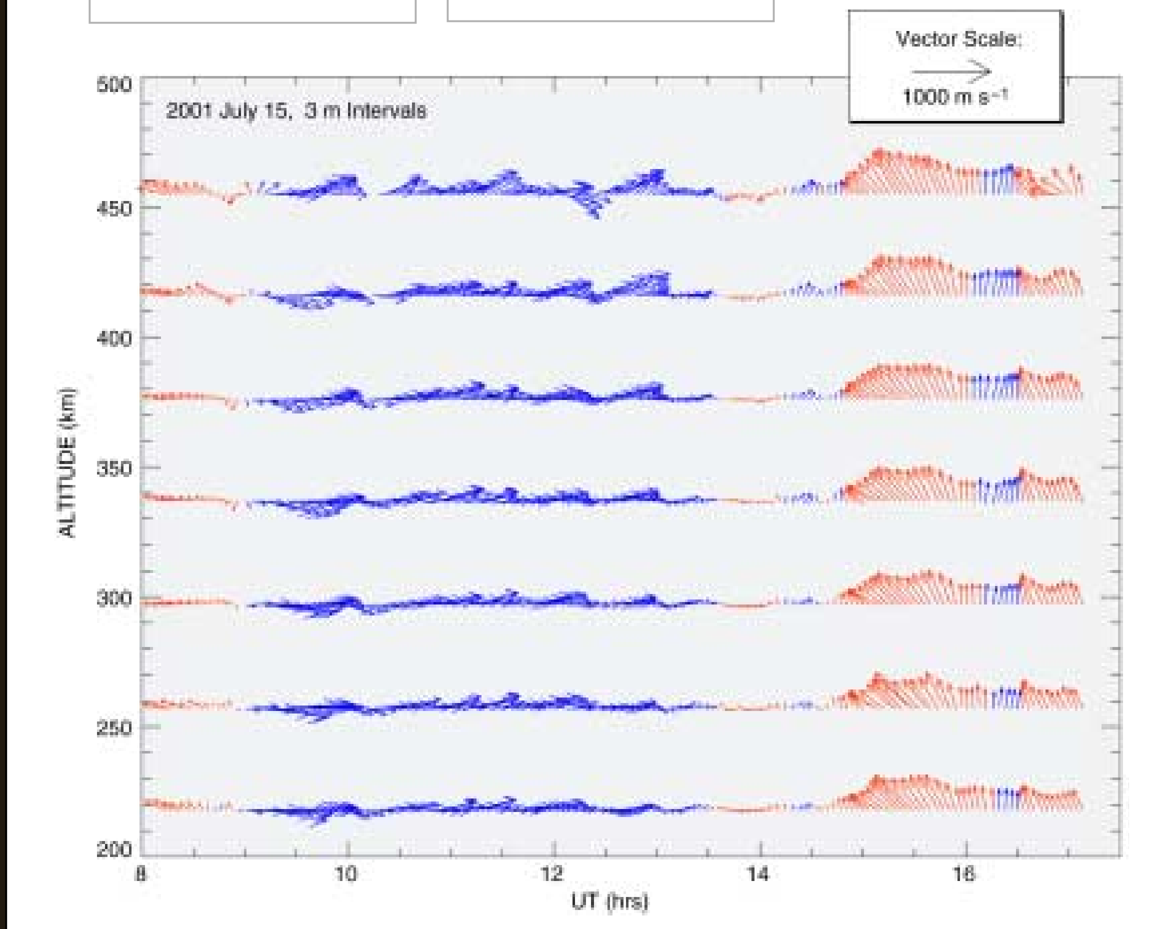
Ion & Electron Motion through the E-region

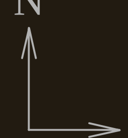


F-region Plasma Motion & Frozen-in Flux

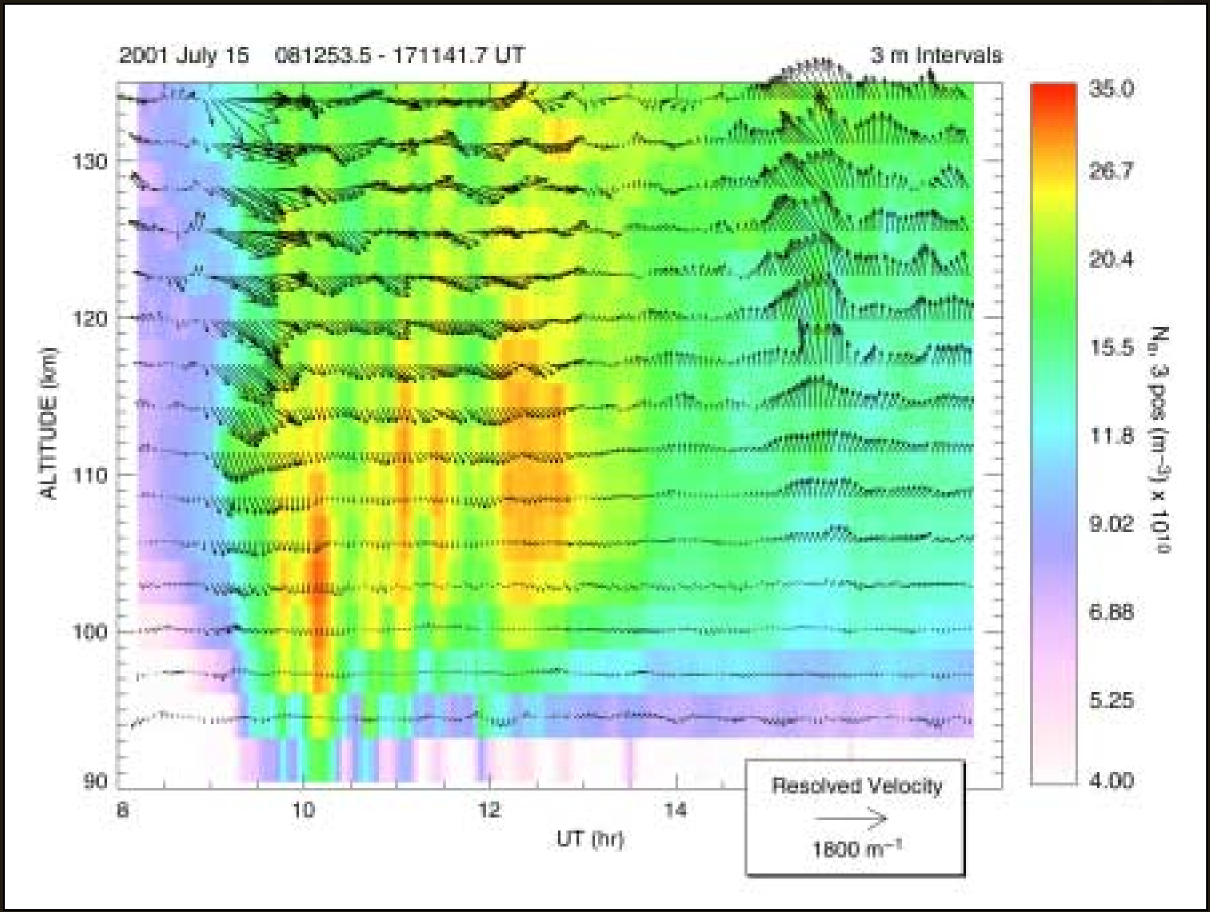
$$\vec{V}_{e,i} = \frac{\vec{E} \times \vec{B}}{B^2}$$

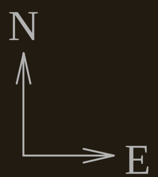
$$\vec{E} = -\vec{V} \times \vec{B}$$





E-Region Ion Motion – Where the Frozen-In Flux gets Slushy





E-region Current Behavior

$$\vec{j} = en_e\left(\vec{V}_i - \vec{V}_e\right)$$

Assuming $k_e \gg 1$

$$\vec{j}_\perp = en_e\left(\frac{k_i}{1+k_i^2}\frac{\vec{E}_\perp}{B} - \frac{1}{1+k_i^2}\frac{\vec{E}_\perp \times \vec{B}}{B^2}\right)$$

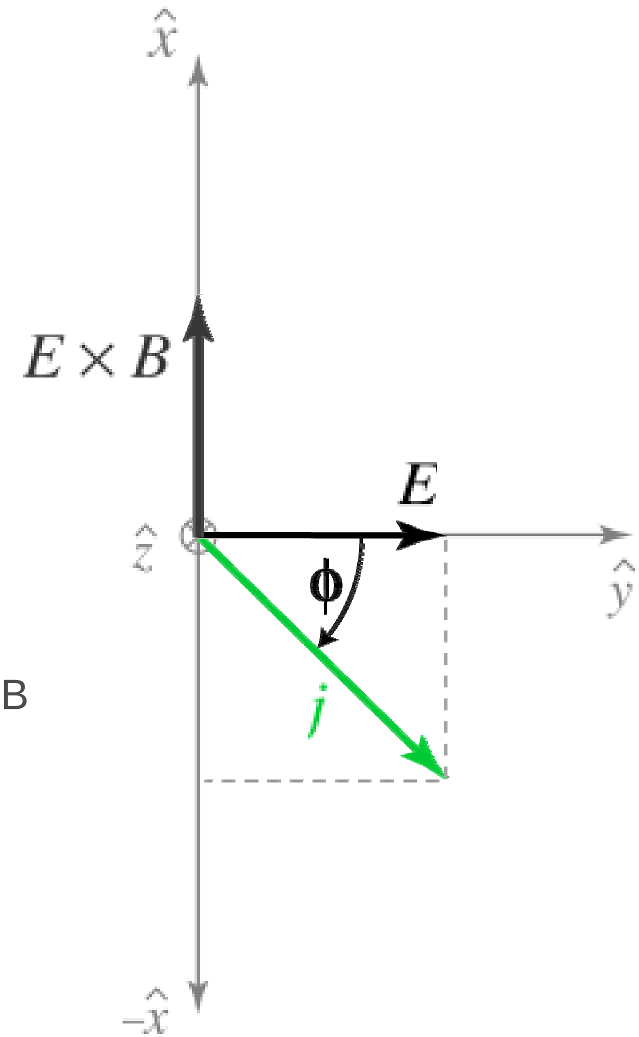
Current direction perpendicular to B

$$\phi = \arctan\left(\frac{-\upsilon_{in}}{\Omega_i}\right)$$

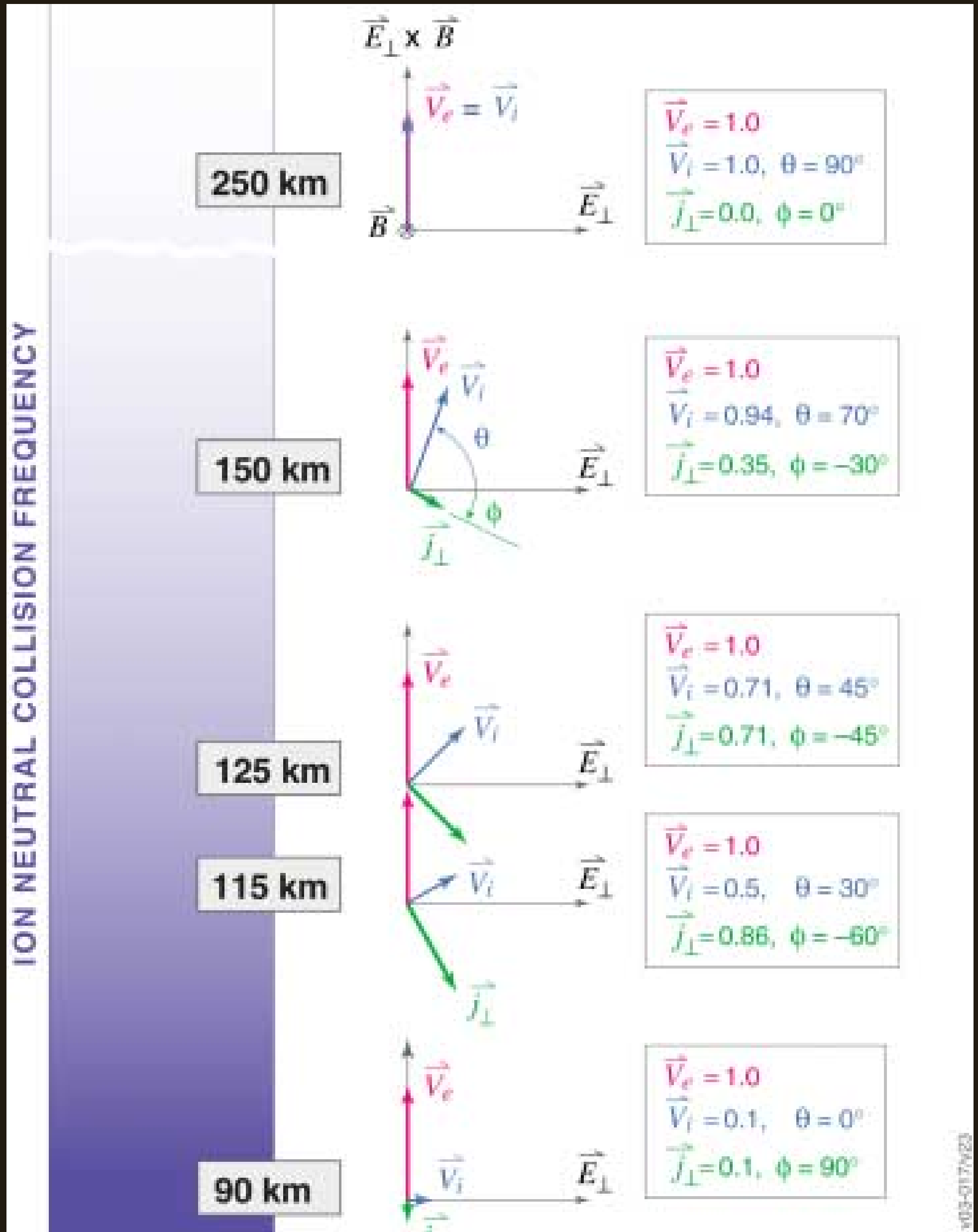
Current magnitude perpendicular to B

$$|j_\perp| = \frac{en_e}{B}\frac{1}{\sqrt{1+k_i^2}}|E_\perp|$$

$$|j_\perp| = \frac{en_e}{B}|\sin\phi||E_\perp|$$

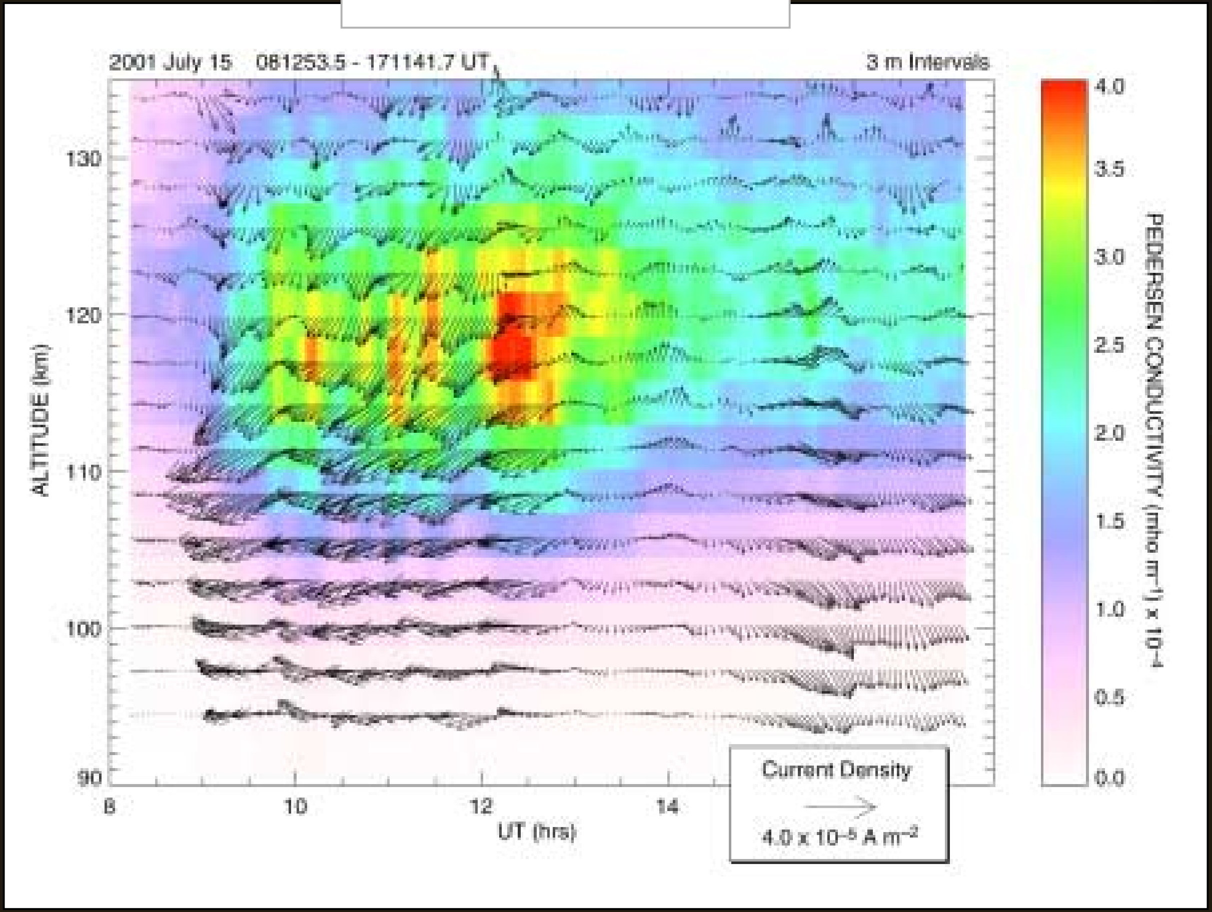


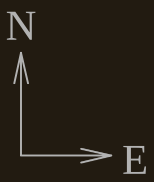
Currents in the E-region



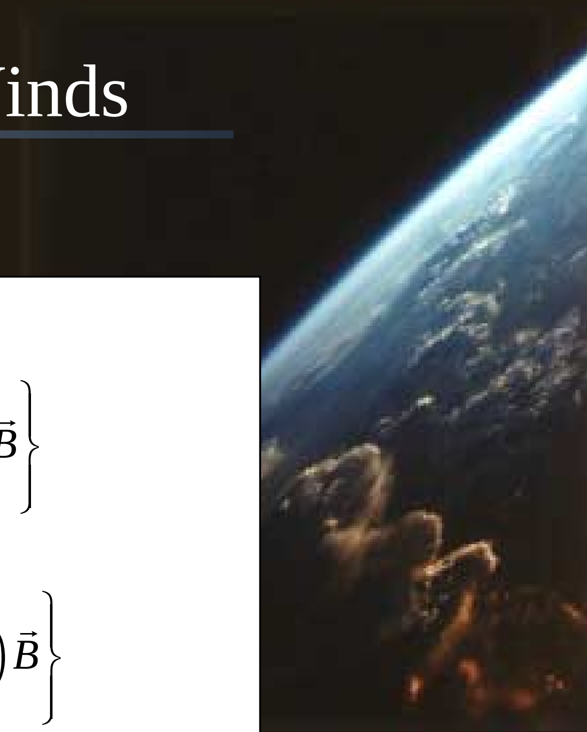
E-Region Currents

$$\vec{j}(z) = en_e(z)\left(\vec{V}_i - \vec{V}_e\right)$$





E-region Electrodynamics with Neutral Winds



Ion momentum equation

$$\vec{V}_i' = \vec{V}_i - \vec{U}_n = \frac{1}{1+k_i^2}\left\{\frac{k_i}{B}\vec{E}_\perp' + \left(\frac{k_i}{B}\right)^2 \vec{E}'\times\vec{B} + \left(\frac{k_i}{B}\right)^3 \left(\vec{E}'\bullet\vec{B}\right)\vec{B}\right\}$$

Electron momentum equation

$$\vec{V}_e' = \vec{V}_e - \vec{U}_n = \frac{1}{1+k_e^2}\left\{\frac{-k_e}{B}\vec{E}_\perp' + \left(\frac{k_e}{B}\right)^2 \vec{E}'\times\vec{B} - \left(\frac{k_e}{B}\right)^3 \left(\vec{E}'\bullet\vec{B}\right)\vec{B}\right\}$$

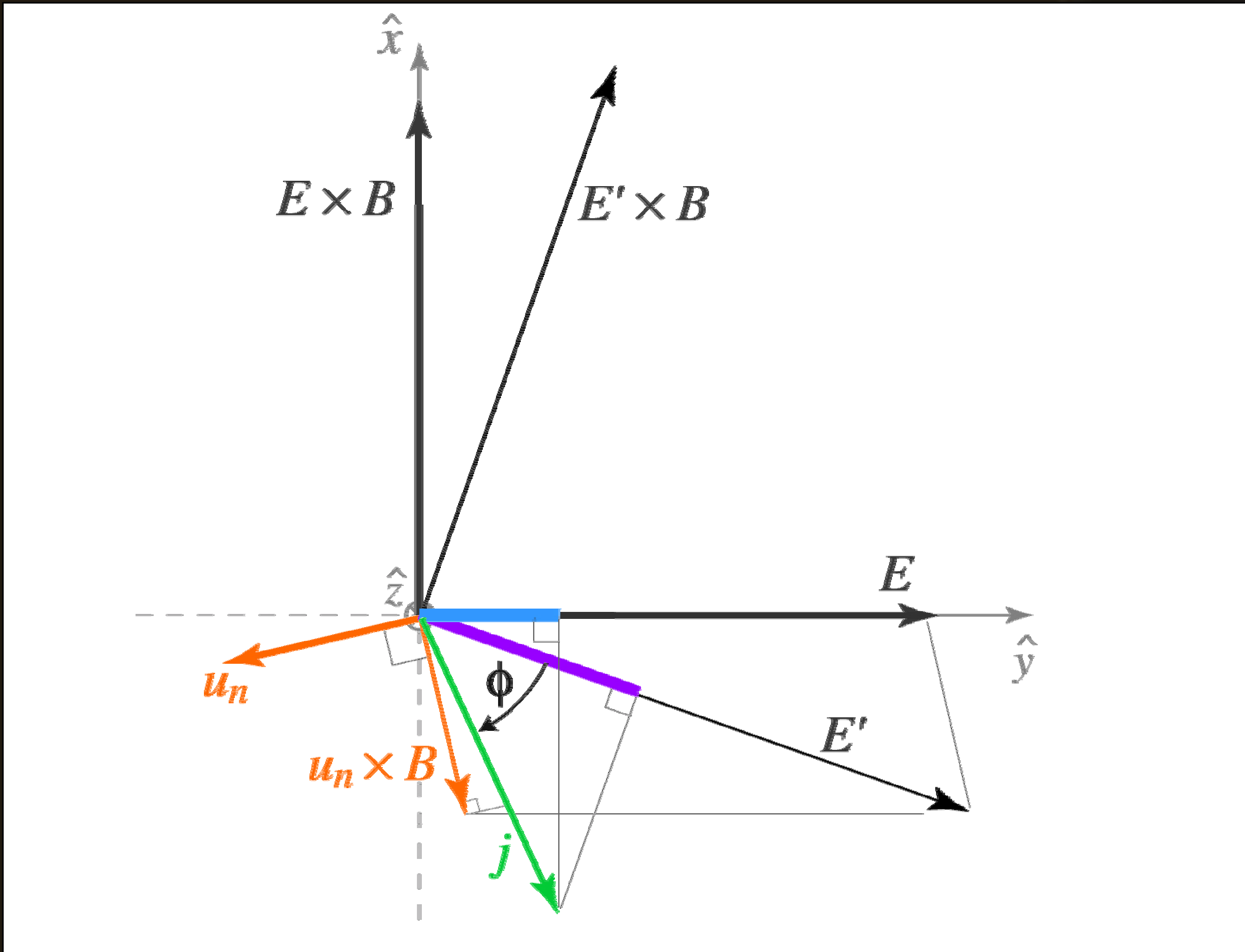
Current density

$$\vec{j} = en_e\left(\vec{V}_i - \vec{V}_e\right) = en_e\left(\vec{V}_i - \vec{U}_n - \left(\vec{V}_e - \vec{U}_n\right)\right) = en_e\left(\vec{V}_i' - \vec{V}_e'\right) = \vec{j}'$$

$$\vec{j} = en_e\left\{\left(\frac{k_e}{1+k_e^2} + \frac{k_i}{1+k_i^2}\right)\frac{\vec{E}_\perp'}{B} - \left(\frac{k_e^2}{1+k_e^2} - \frac{k_i^2}{1+k_i^2}\right)\frac{\vec{E}'\times\vec{B}}{B^2} + \left(\frac{k_e^3}{1+k_e^2} + \frac{k_i^3}{1+k_i^2}\right)\frac{\left(\vec{E}'\bullet\vec{B}\right)\vec{B}}{B^3}\right\}$$

$$\vec{j} = \sigma_P \vec{E}_\perp' - \sigma_H \frac{\vec{E}'\times\vec{B}}{B^2} + \sigma_{||}\vec{E}_{||}'$$

Currents including neutral winds



Poynting Flux to Energy Deposition

Poynting's Theorem

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

Energy Equation

$$\frac{d\left(\rho u + \rho U_n^2 / 2\right)}{dt} = -\nabla \bullet \left(\vec{P} \bullet \vec{U}_n + \vec{q}\right) + \rho \vec{U}_n \bullet \vec{g} + \rho Q + \boxed{\vec{j} \bullet \vec{E}}$$

Kinetic Energy Equation

$$\frac{d\left(\rho U_n^2 / 2\right)}{dt} = -\vec{U}_n \bullet \vec{\nabla} \bullet \vec{P} + \rho \vec{U}_n \bullet \vec{g} + \boxed{\vec{U}_n \bullet \vec{j} \times \vec{B}}$$

Internal Energy Equation

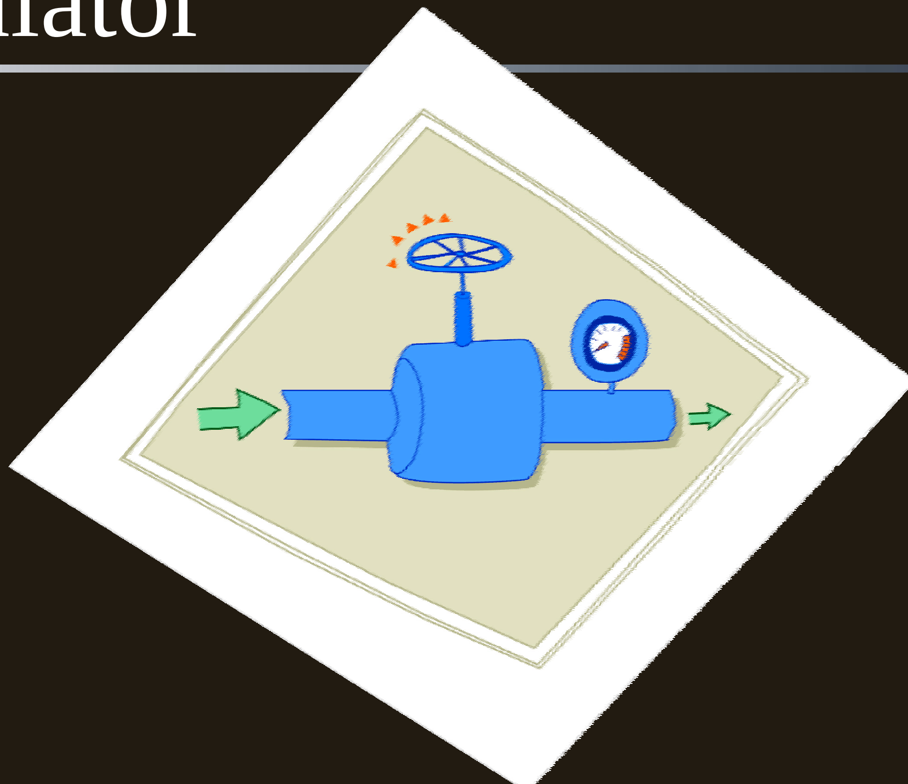
$$\frac{d\left(\rho u\right)}{dt} = -\nabla \bullet \vec{q} + \rho Q - \vec{P} : \vec{\nabla} \vec{U}_n + \boxed{\vec{j} \bullet \vec{E}'}$$

IT System as an Intermediary

- Determining the relative roles of the neutral and charged particles of the IT system

- Understanding the processes that govern the response of the IT system

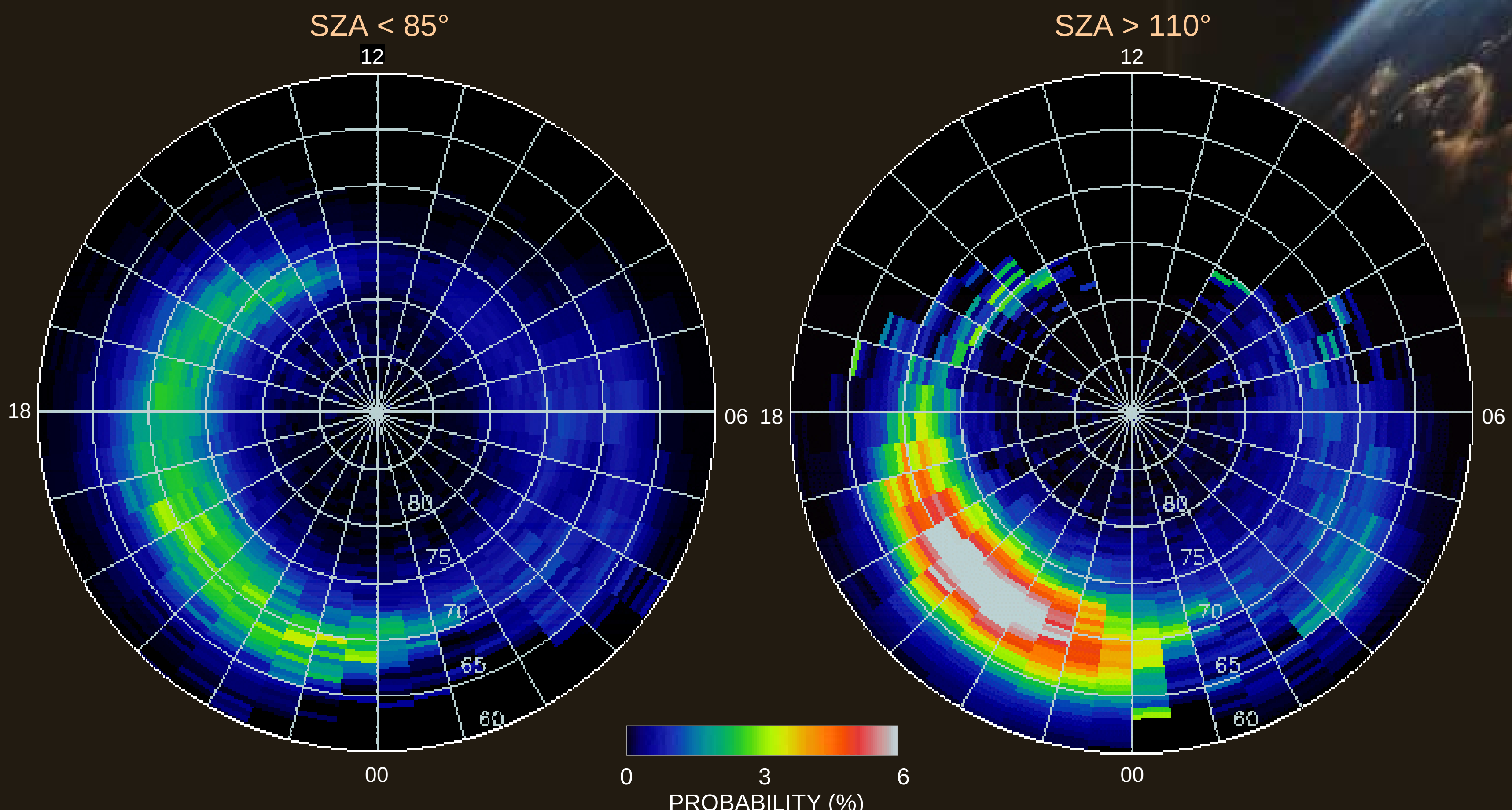
A Regulator



Kinetic Energy Flux

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

Suppression of intense aurora in sunlight

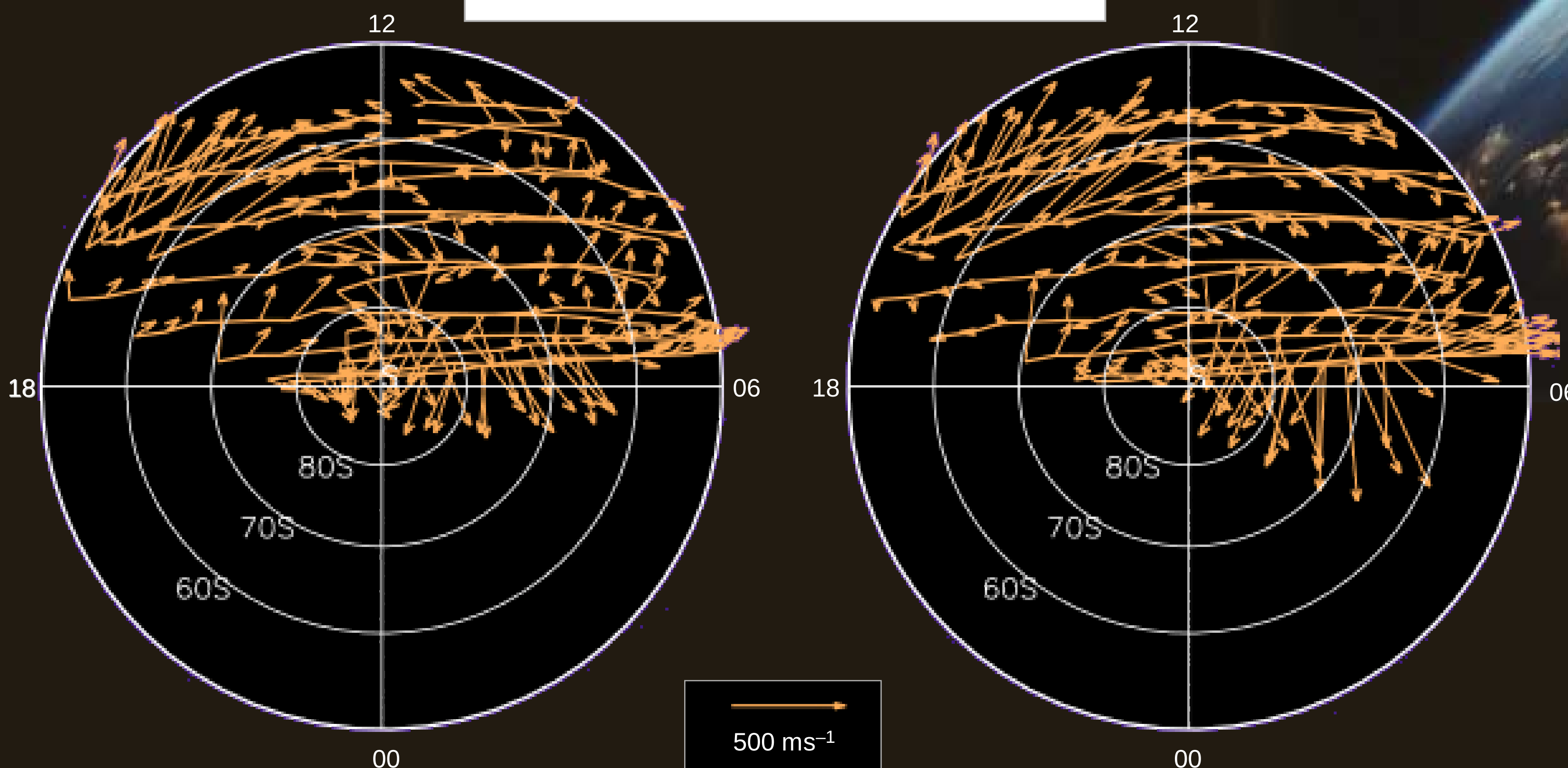


Total electron flux threshold: 5 ergs cm^{-2} s^{-1}

Neutral Wind Observations

$$\nabla \bullet \left(\vec{\vec{\sigma}} \bullet \vec{E} \right) + \nabla \bullet \left(\vec{\vec{\sigma}} \bullet \vec{U}_n \times \vec{B} \right) = -\frac{\partial j_{\|}}{\partial z}$$

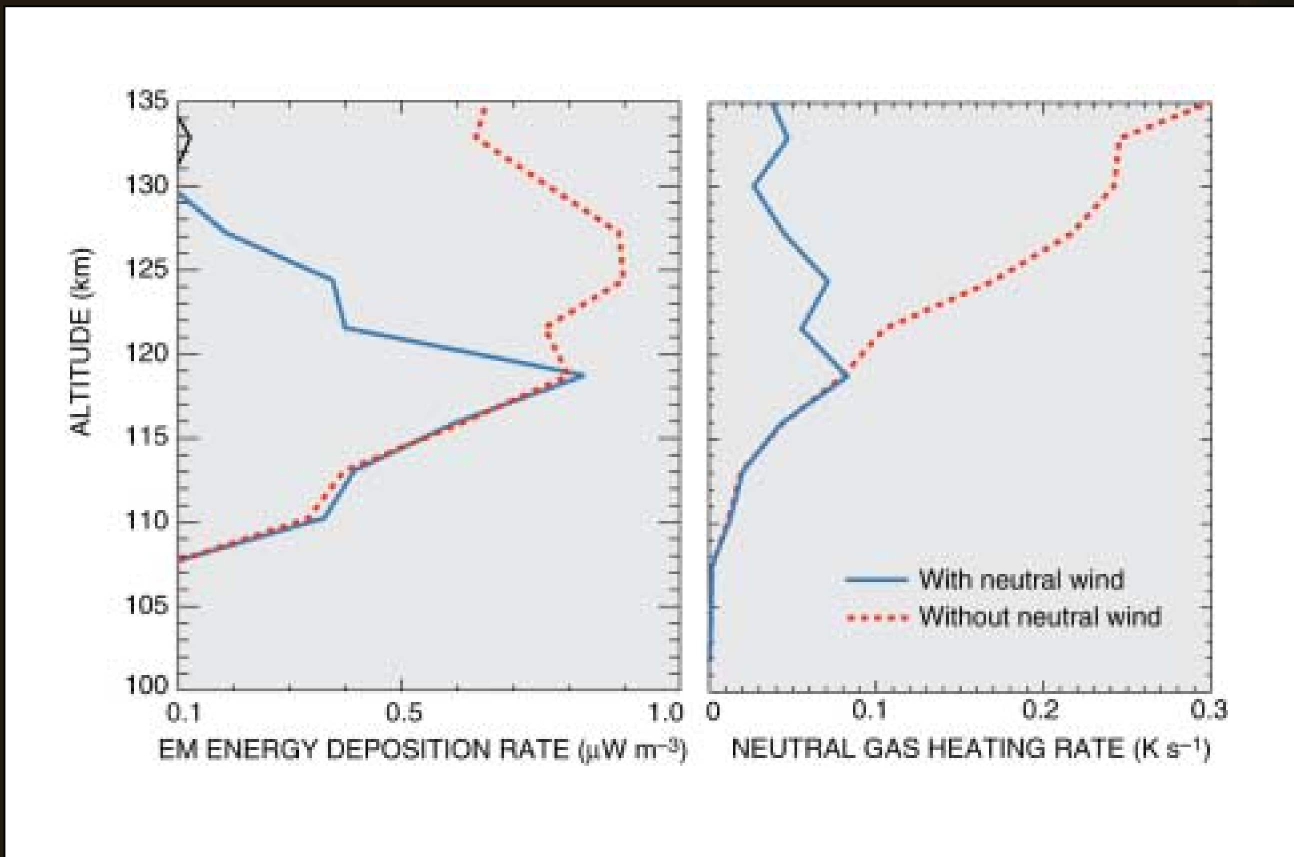
130 km | 180 km



WINDII O(^{1}S) derived winds

Zhang and Shepherd, 2000, JGR

Neutral Wind Influence on EM Energy Deposition

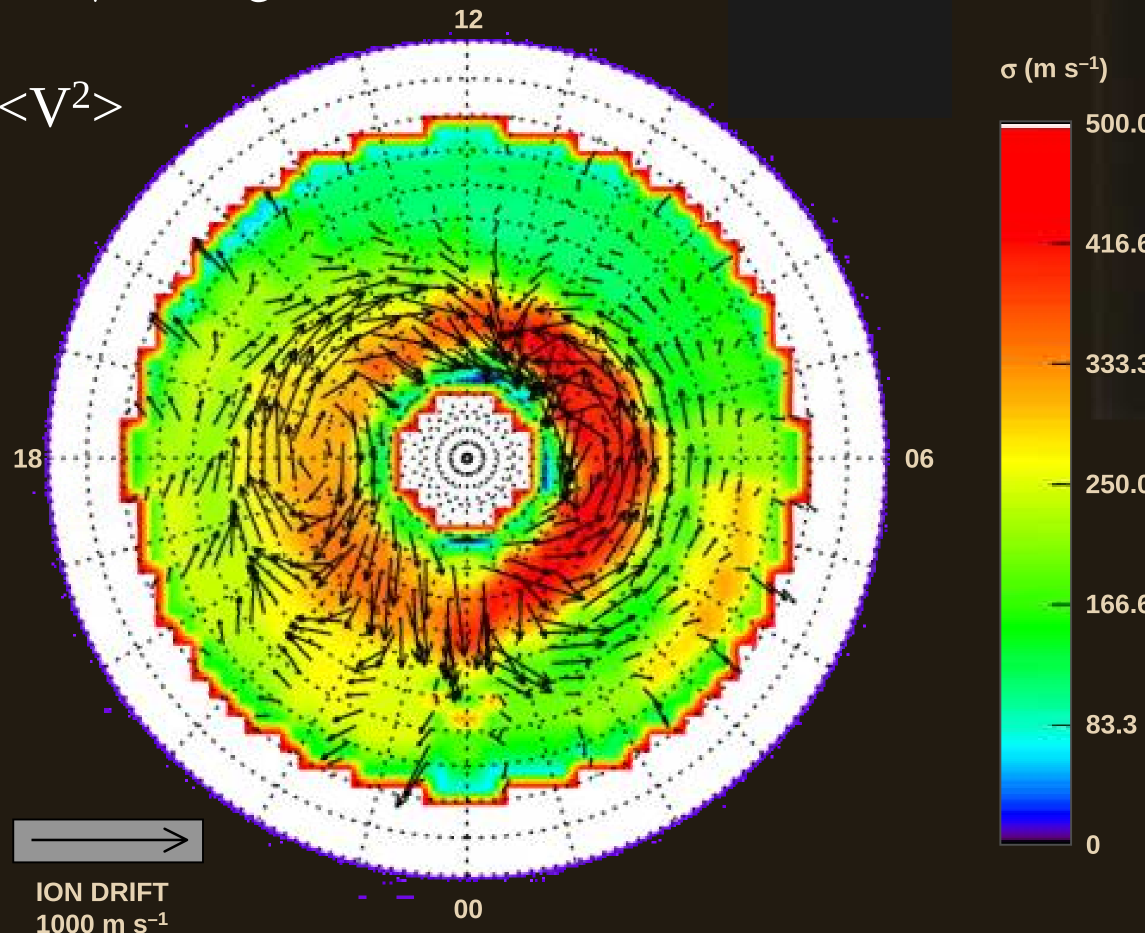


Thayer and Semeter, 2003 JASTP

Electric Field Variability

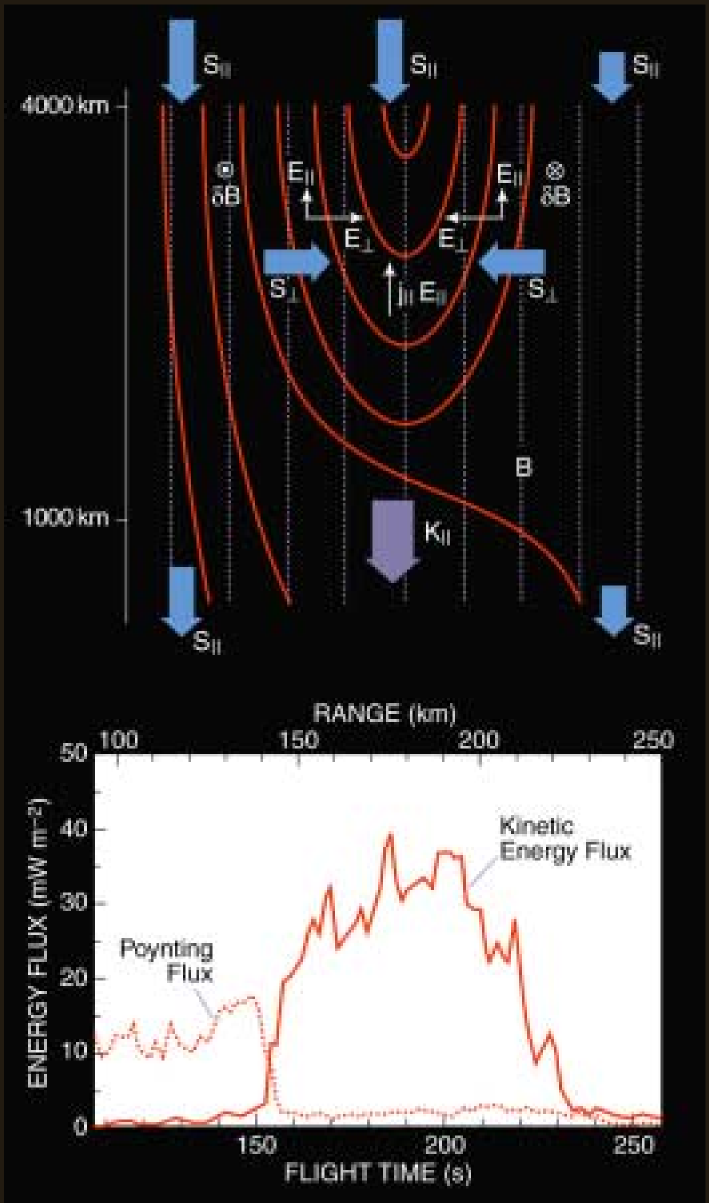
$$\langle V^2 \rangle = \langle V \rangle^2 + \sigma^2$$

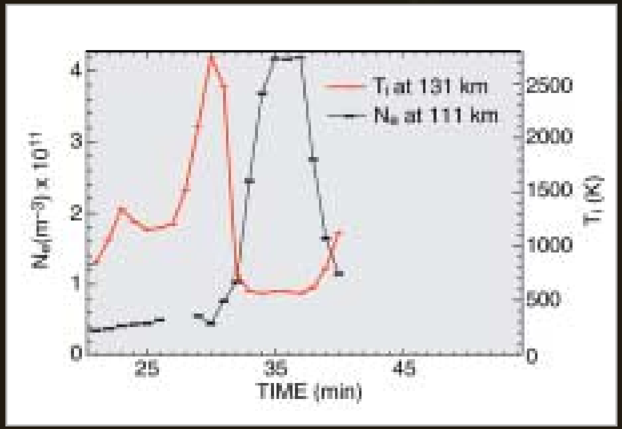
$$Q_j \; \alpha \; \langle V^2 \rangle$$



Codrescu et al. 2000, JGR

Poynting Flux and Kinetic Energy Flux Exchange

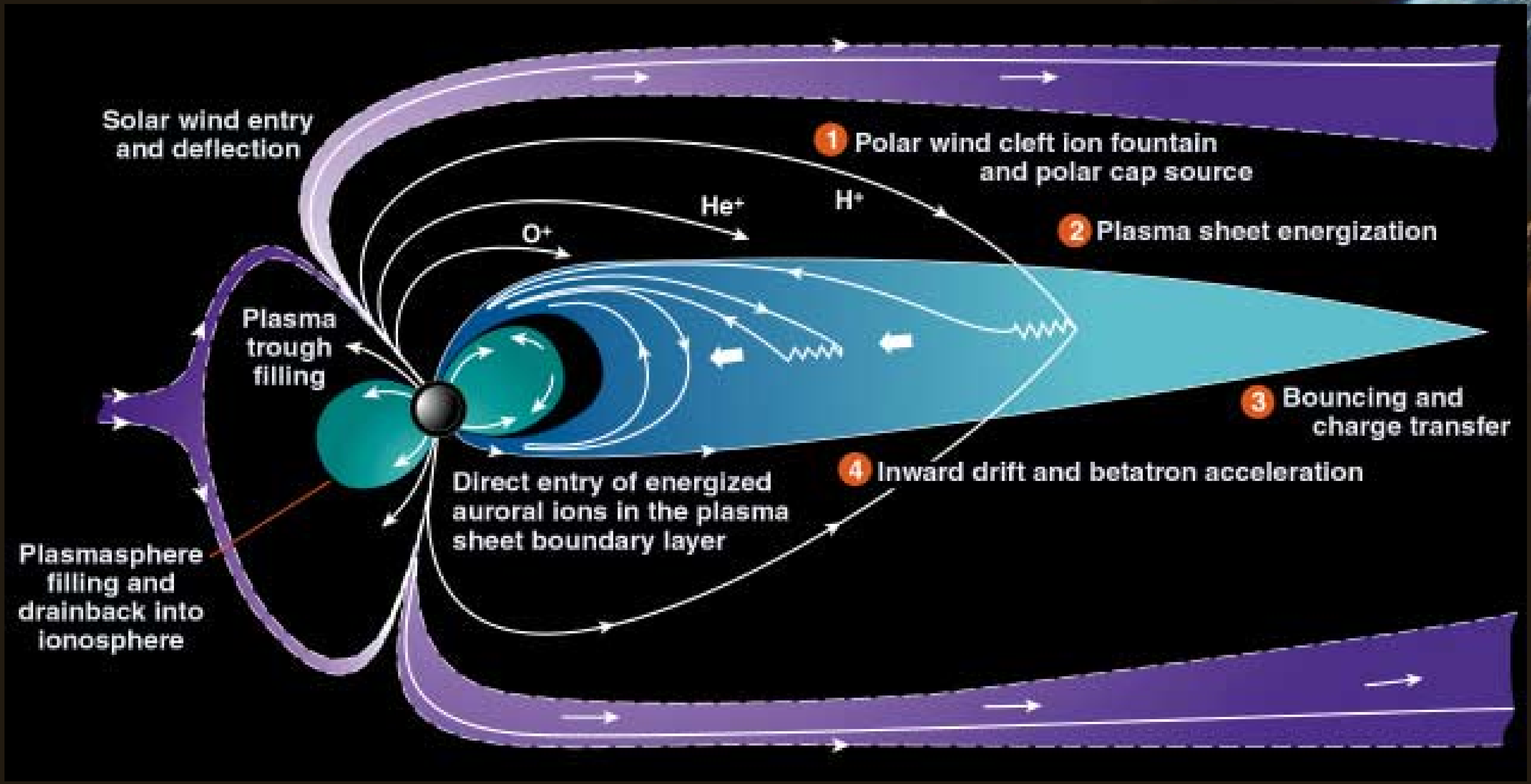




Ionospheric Response

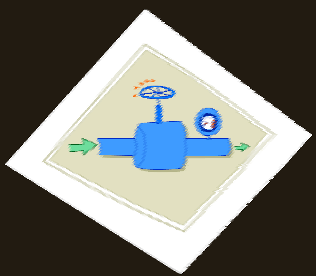
Thayer and Semeter, 2003 JASTP

IT Mass Loading of Magnetosphere

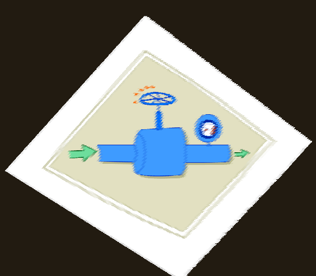


Courtesy of R. Chappell

IT System as a Regulator



Determining how the preconditioned state of the IT system impacts future coupling



Determining how the the energy flux of one source impacts the flux of another

Upcoming Observing Programs

Observing Programs

NASA Missions

- LWS geospace probes (IT Mappers ; Radiation Belt Mappers) 2008-2010
- MIDEX THEMIS mission – 2007 (PI Vassilis Angelopoulos)
- Solar-Terrestrial Probes (TIMED, MMS, GEC, MAGCON)

Ground-based Initiatives

- Advanced Modular Incoherent Scatter Radar (AMISR) NSF program approved
- Improved SuperDarn coverage of the southern polar region
- Enhanced auroral imaging network to support THEMIS

Geospace Electrodynamic Connection Mission

- Solar Terrestrial Probe mission within NASA SEC program (planned launch date 2010)
- Three or four deep dipping spacecraft (perigee ~130 km)

Advanced Modular Incoherent Scatter Radar (AMISR)

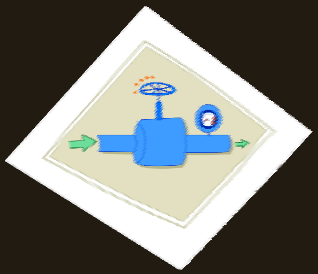
A Transportable Ionospheric Radar

- Poker Flat, Alaska 2004
- Resolute Bay, Nunavut 2006

Issues in I-T Coupling to the Magnetosphere

- Mass Loading
- Current Closure
- Regulation
- Source spectrum and interplay

Summary of Polar IT System Contributions

 +  +  + 

M-I Coupling from the I-T perspective?

YES! I-M Coupling

When Nature Calls…

Opportunity Knocks