

Inner Magnetosphere-Ionosphere (IMI) Coupling

MI Coupling

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IM Coupling

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Reviews of Geophysics distills and places in perspective previous scientific work in currently active subject areas of geophysics. Contributions evaluate overall progress in the field and cover all disciplines embraced by AGU.

Authorship is by invitation, but suggestions from readers and potential authors are welcome. If you are interested in writing an article please talk with me, or write to reviewsgeophysics@agu.org, with an abstract, outline, and explanation of how the paper fits the goals of the journal.

Reviews of Geophysics has an impact factor of 8.021 in the 2009 Journal Citation Reports, highest in the geosciences.

CEDAR (IM) and GEM (MI) perspectives

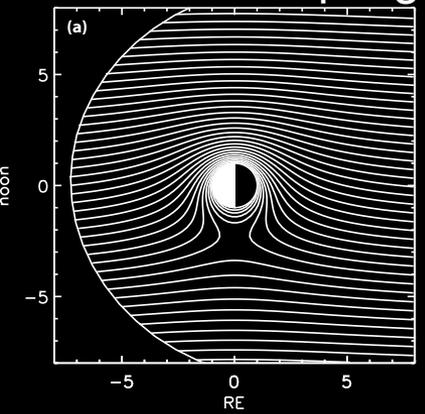
- **We are one/two different communities that attend same/different meetings**
- **Think different physics**
 - *conductivity or resistivity?*
 - *Collisions or collisionless?*
 - *Is the ionosphere a complex 3D system or an infinitely conducting copper sphere?*
- **MI Coupling is where we meet**

MI versus IM coupling

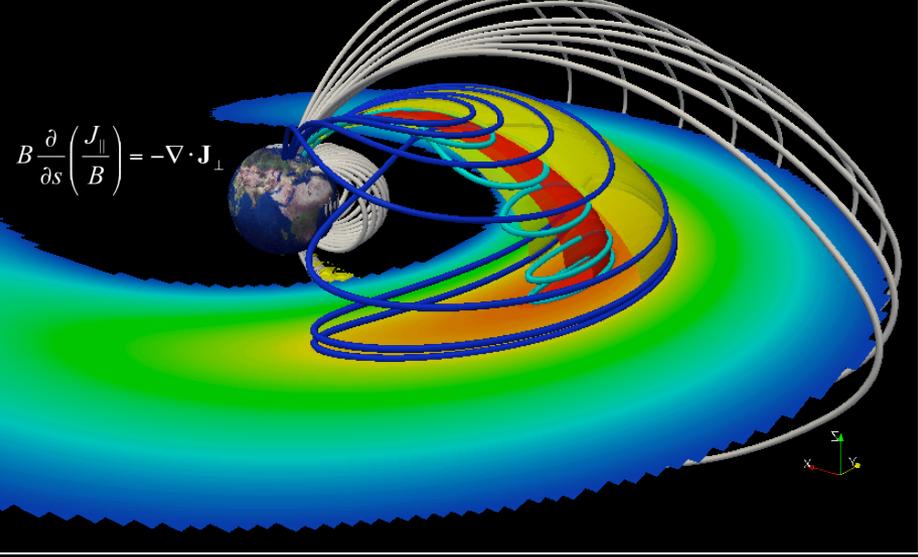
- **(MI) Solar wind driven system with geomagnetic mass-momentum-energy flows into ionosphere**
 - *Critical feedback from ionospheric conductivity*
- **(IM) Neutral Winds, dynamos and gravity wave/tidal energy from below contribute to thermo/ionosphere driven system with mass-momentum-energy flows into magnetosphere**
 - *Critical feedback from magnetospheric FACs*

Macroscopic effects: Magnetospheric perspective

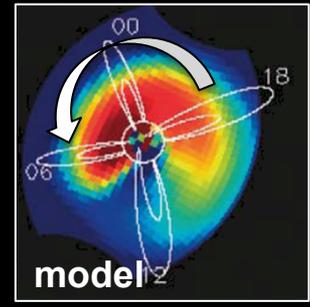
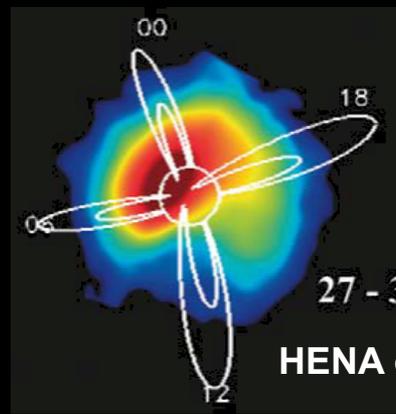
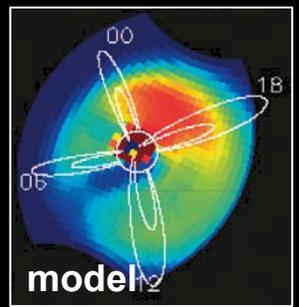
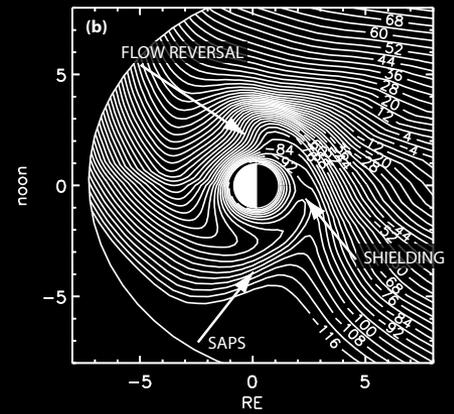
Without coupling



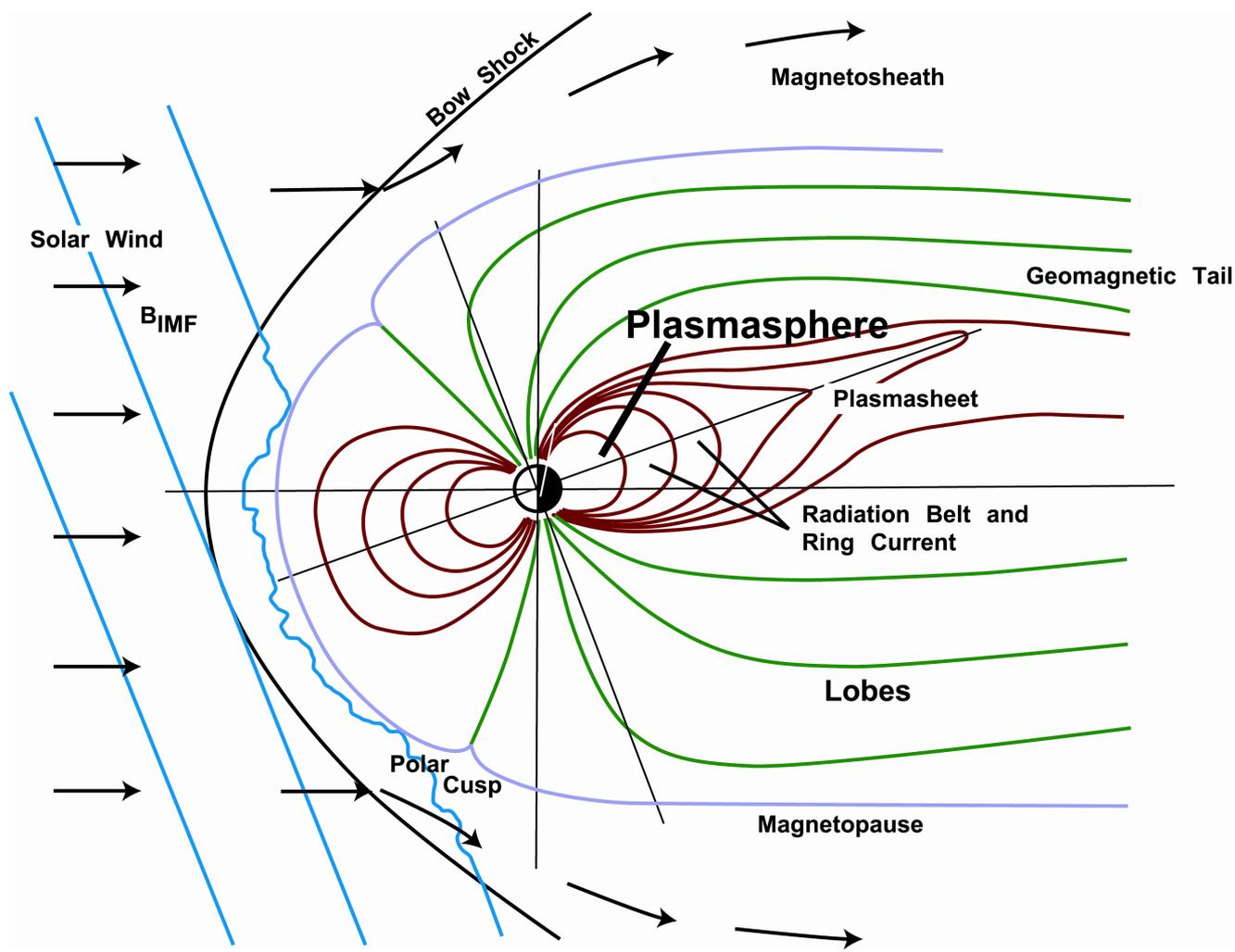
MI-coupling



With coupling

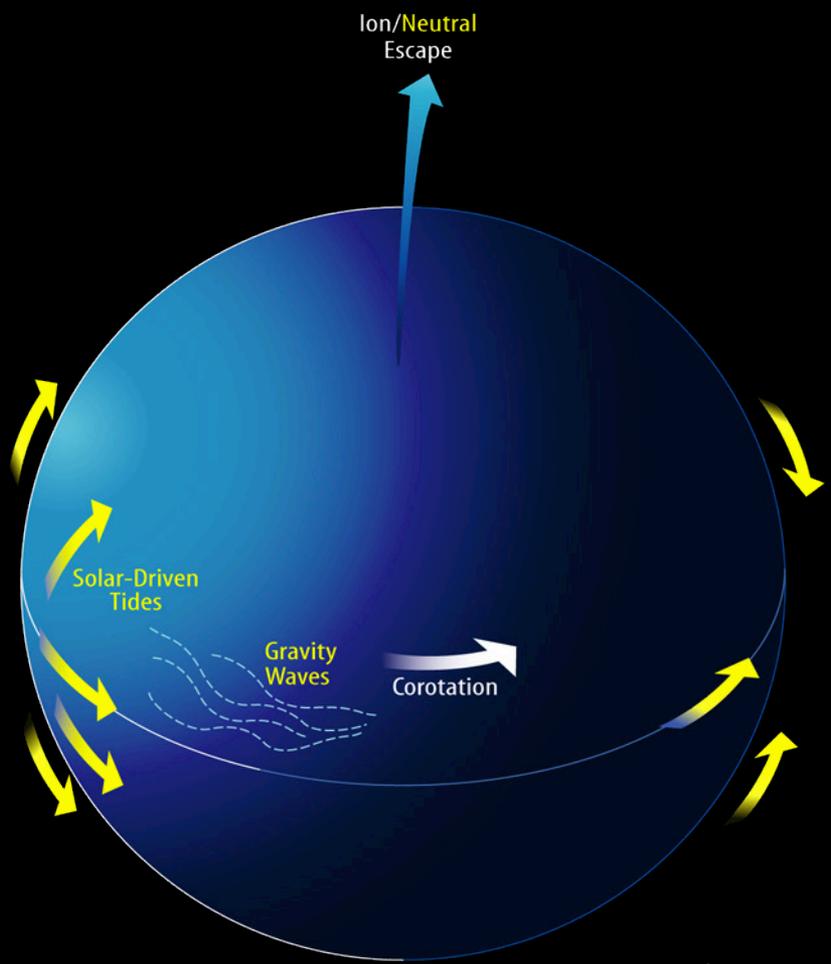
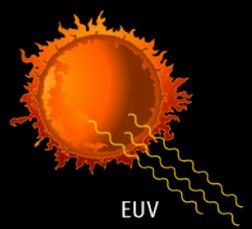


Macroscopic effects: Ionospheric perspective



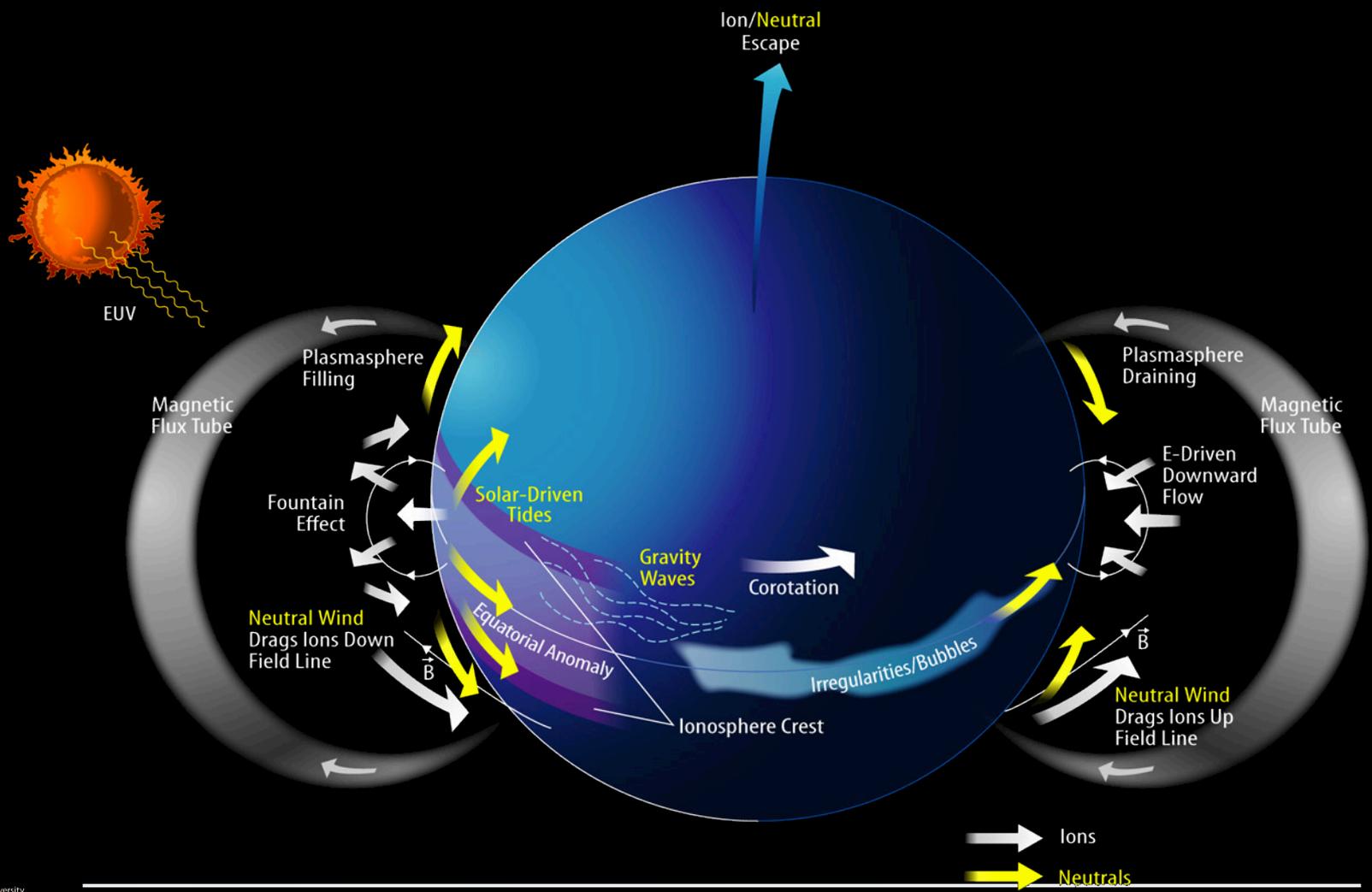
Macroscopic effects: Ionospheric perspective

Solar EUV Effects No Magnetic Fields



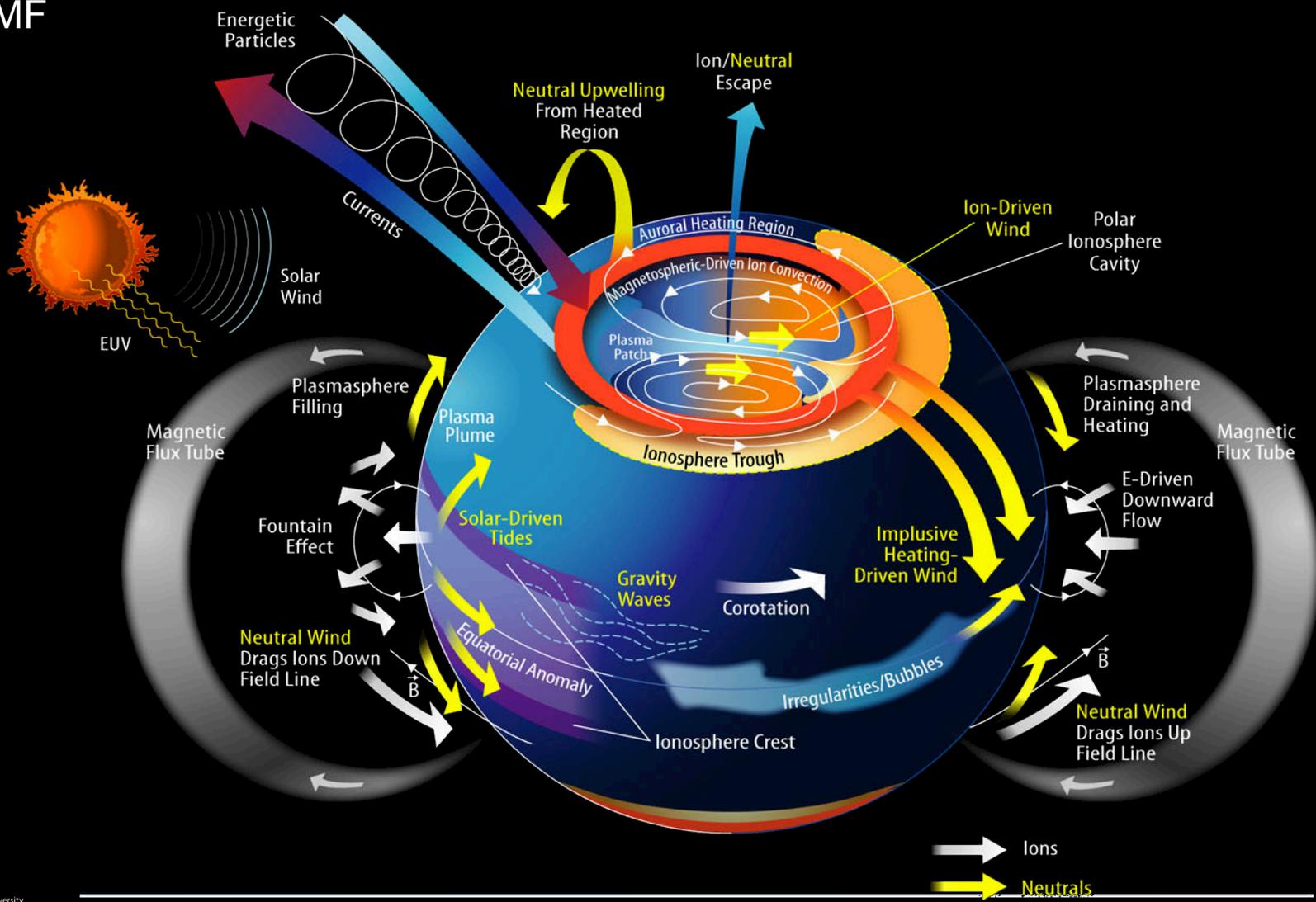
Macroscopic effects: Ionospheric perspective

Addition of Earth's Magnetic Field



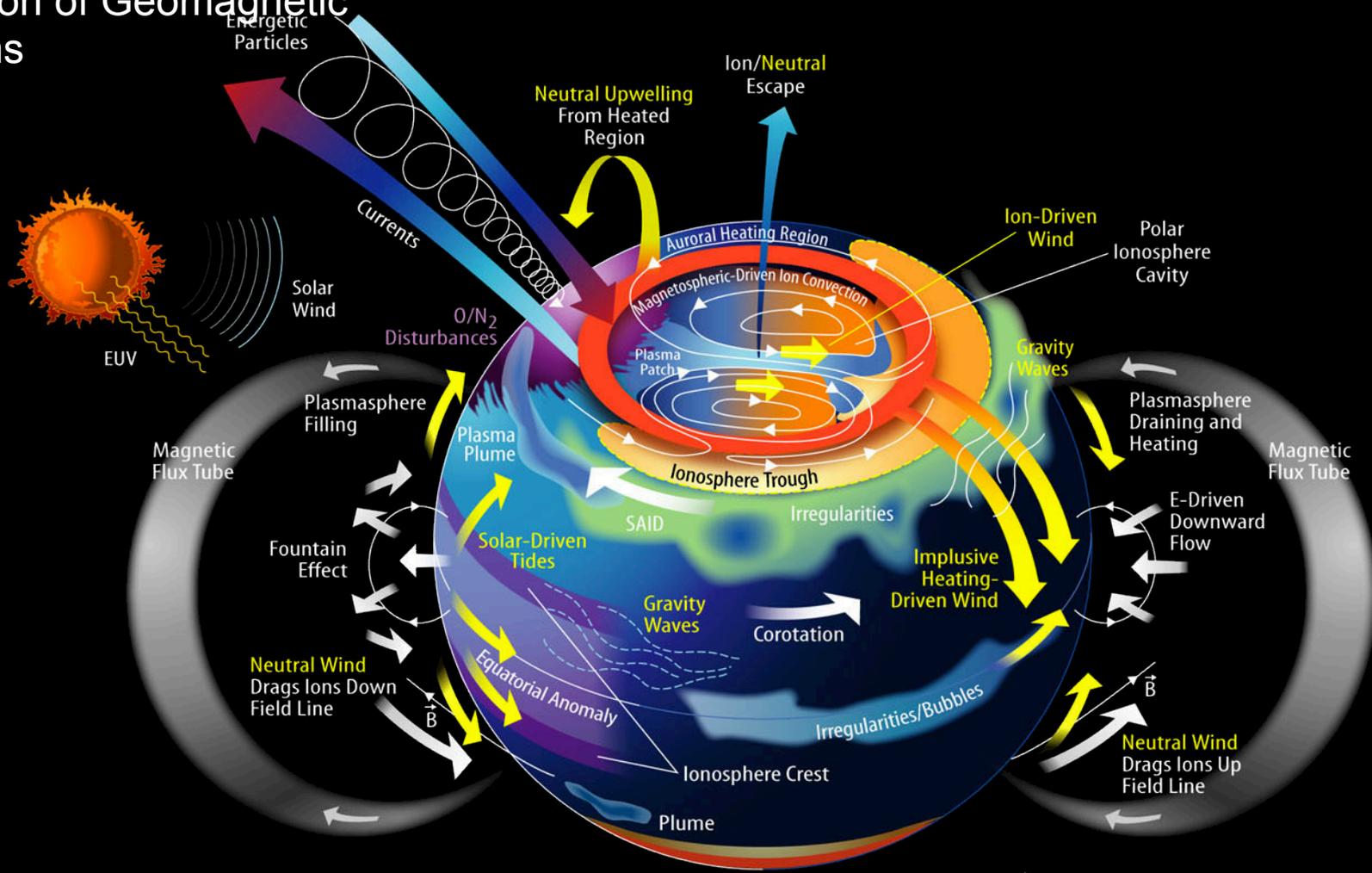
Macroscopic effects: Ionospheric perspective

Addition of Solar Wind And IMF



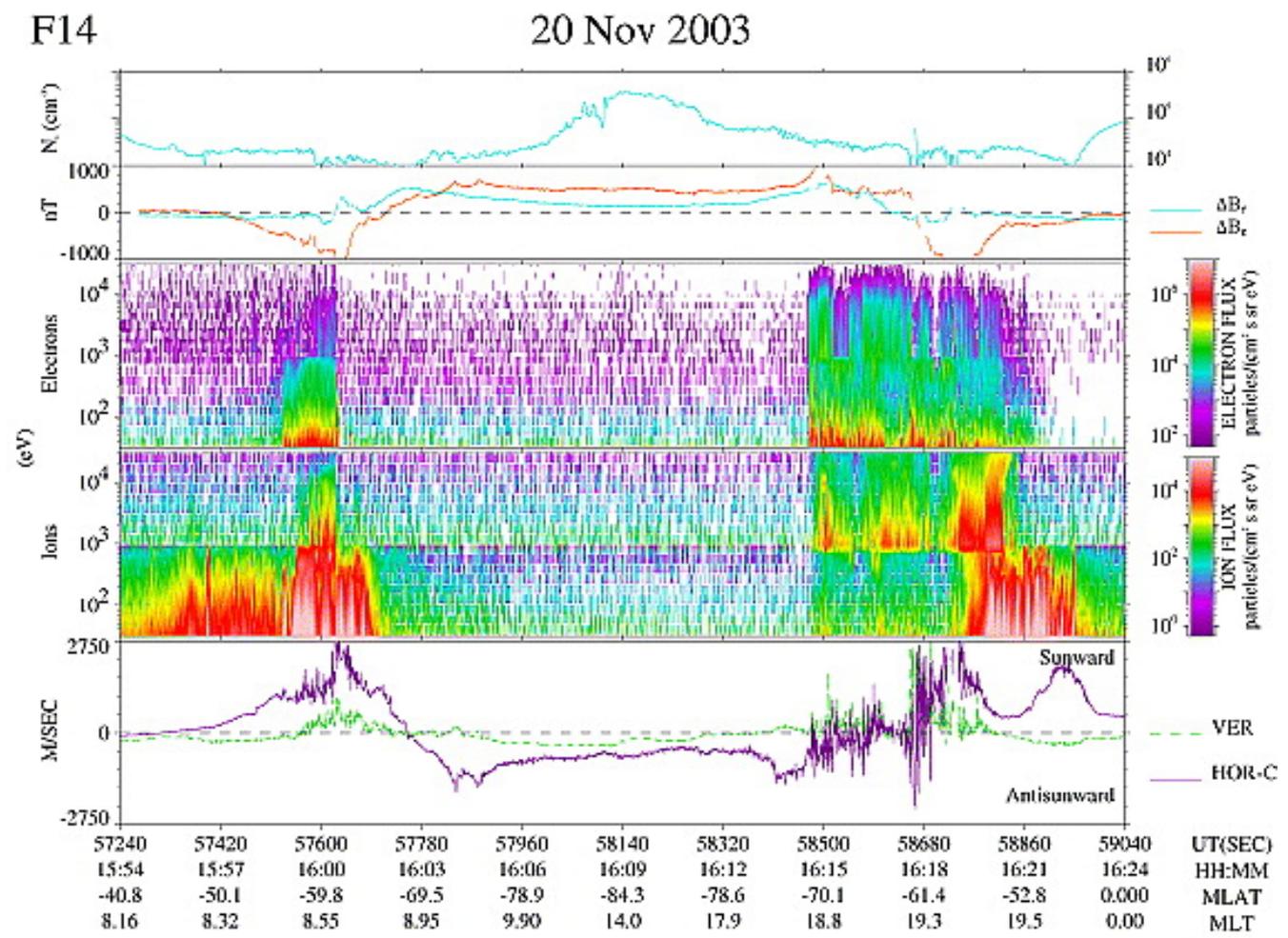
Macroscopic effects: Ionospheric perspective

Addition of Geomagnetic Storms



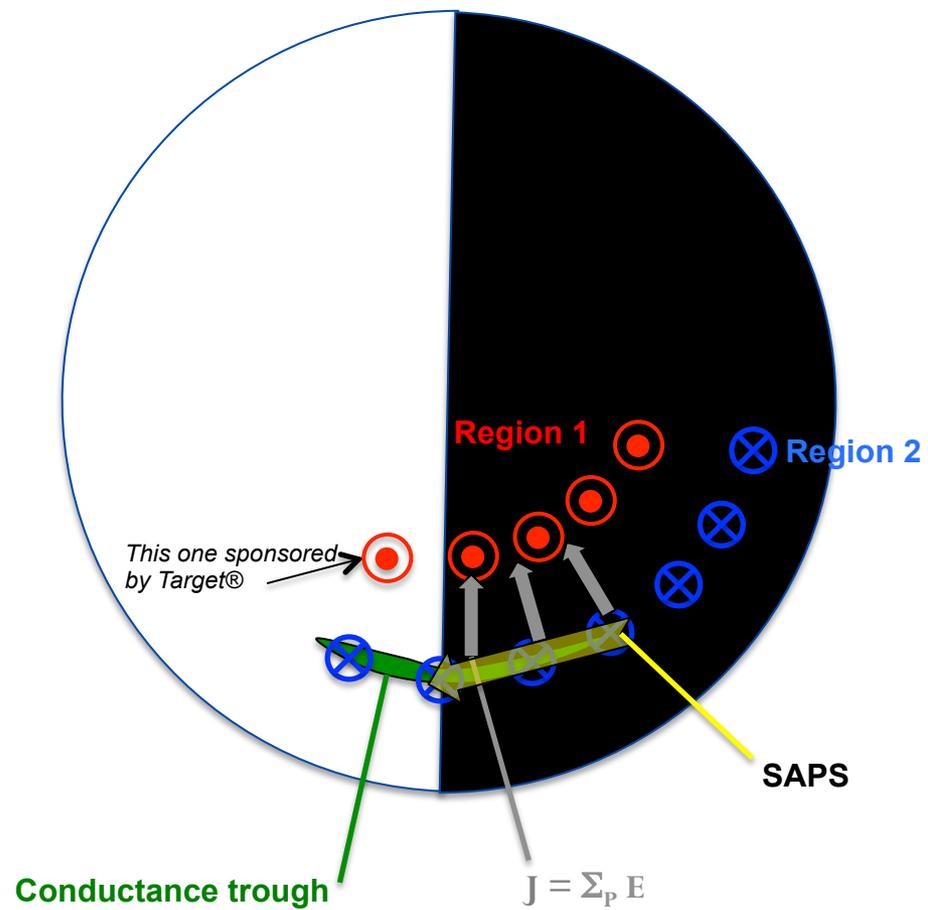
Ions
 Neutrals

SAPS: Ionospheric perspective

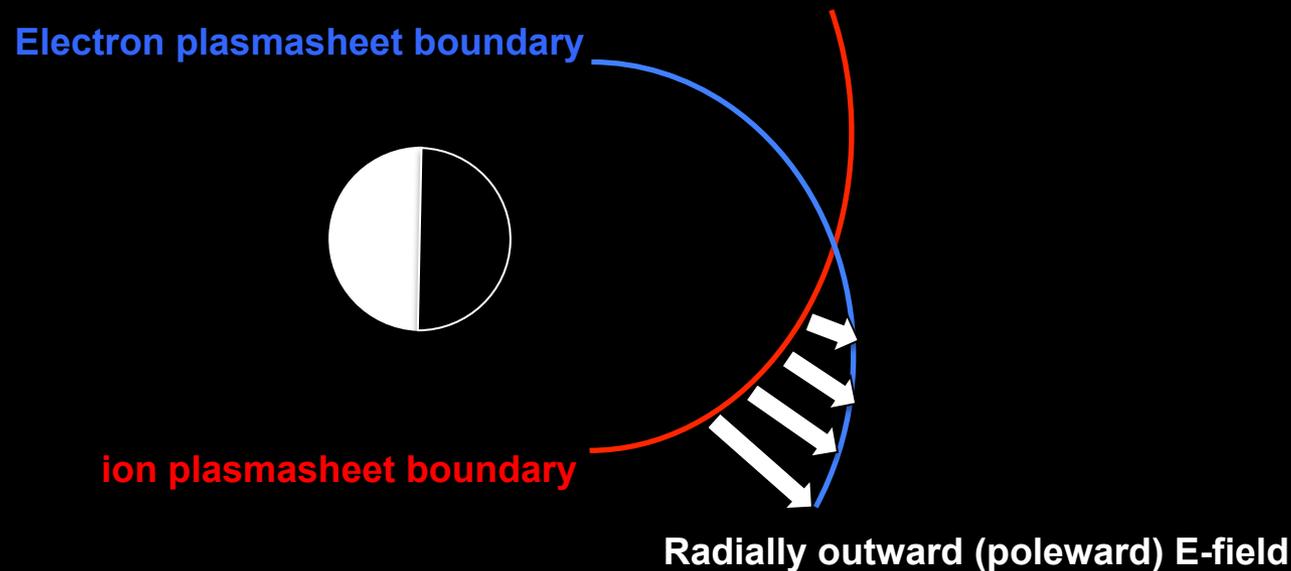


[Huang and Foster, 2007]

SAPS: Ionospheric perspective



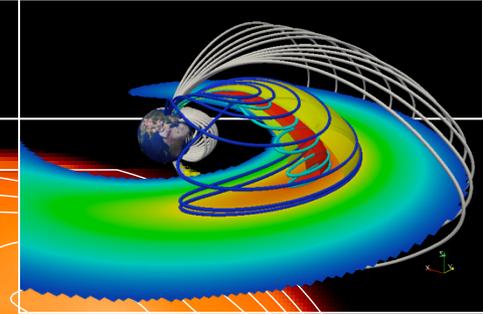
SAPS: Magnetospheric perspective



What's wrong with this picture?

There are no currents...

SAPS: Magnetospheric perspective

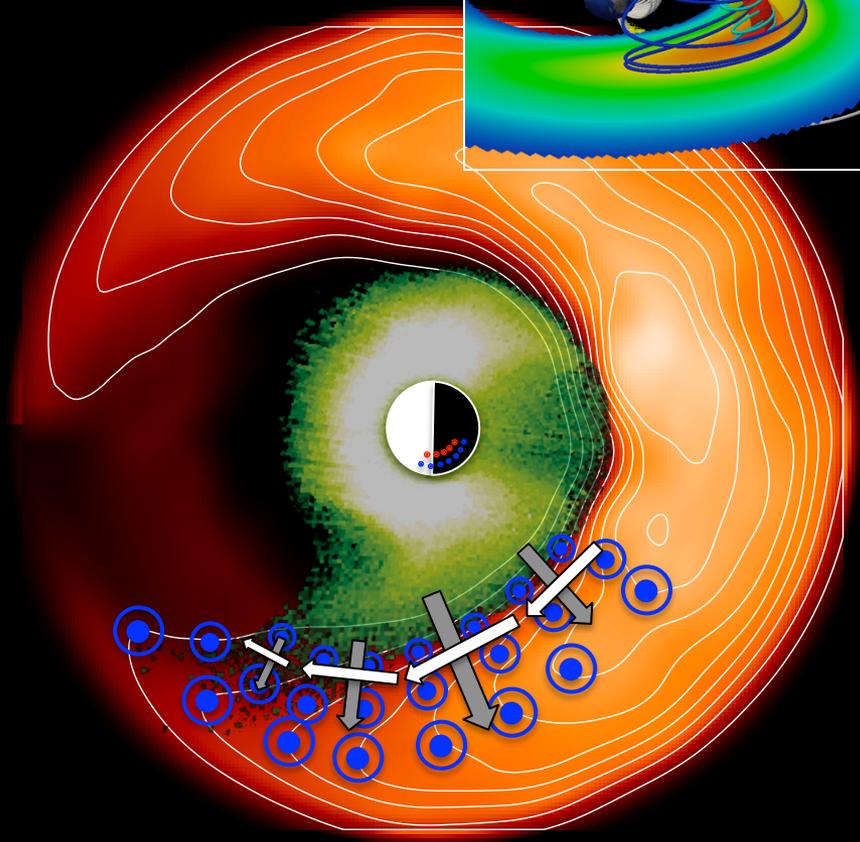


Scenario 1:

1. Pressure gradients “drive” currents
2. Currents “generate” E-field
3. E-field “pushes” plasma
4. E-field maximizes in the trough
5. V maximizes in the trough

Scenario 2:

1. Flows exist
2. Convecting field lines are fastest where conductance is the lowest (in the trough)



← $v = \frac{\mathbf{E} \times \mathbf{B}}{B^2}$

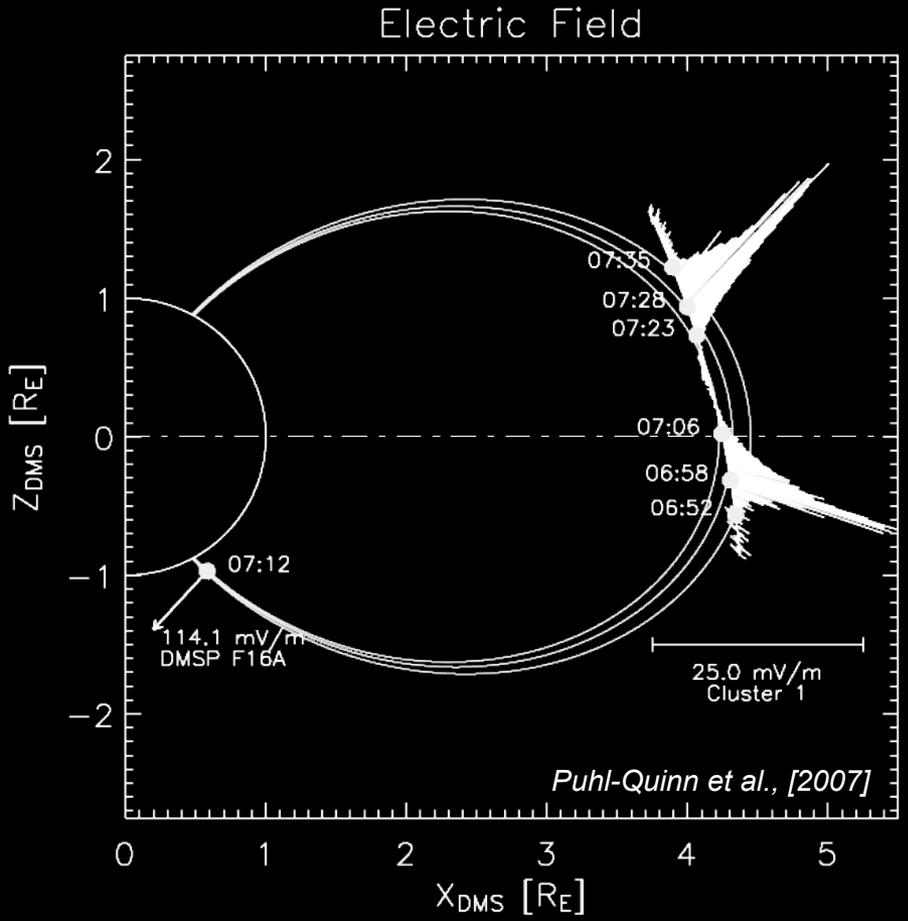
← Electric field

⊙ FAC into ionosphere

$$B \frac{\partial}{\partial s} \left(\frac{J_{\parallel}}{B} \right) = -\nabla \cdot \mathbf{J}_{\perp}$$

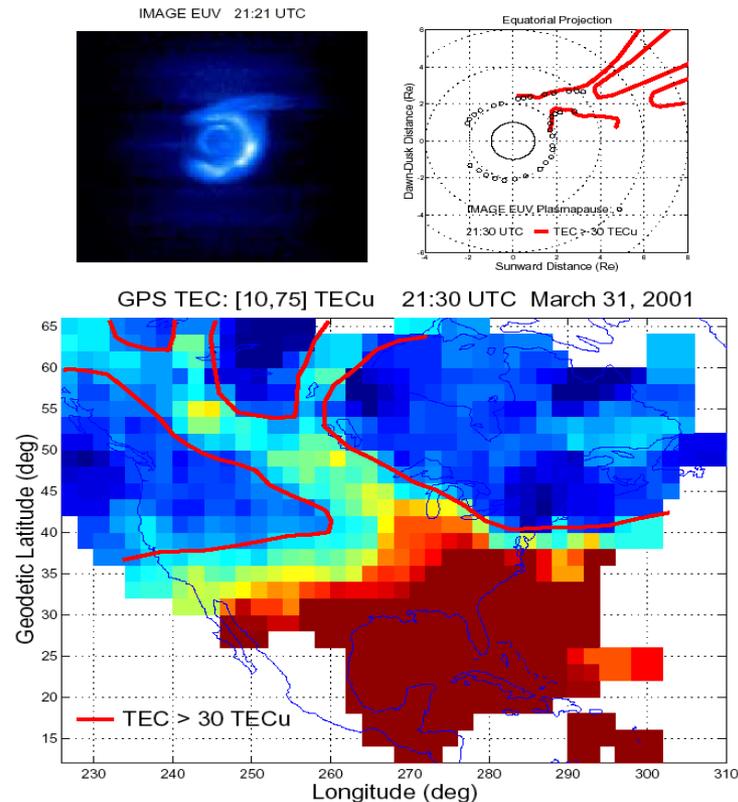
SAPS: Open questions

- **How similar is the E-field/ flow evolution in the IT and IM system? When does it break down and why?**
- **How does ring current pressure gradients, currents and the ionospheric trough evolve together?**
- **What creates the narrower SAIDs? What makes the trough deepen?**
- **Where is the trough in the magnetosphere?**



SED: Ionospheric perspective

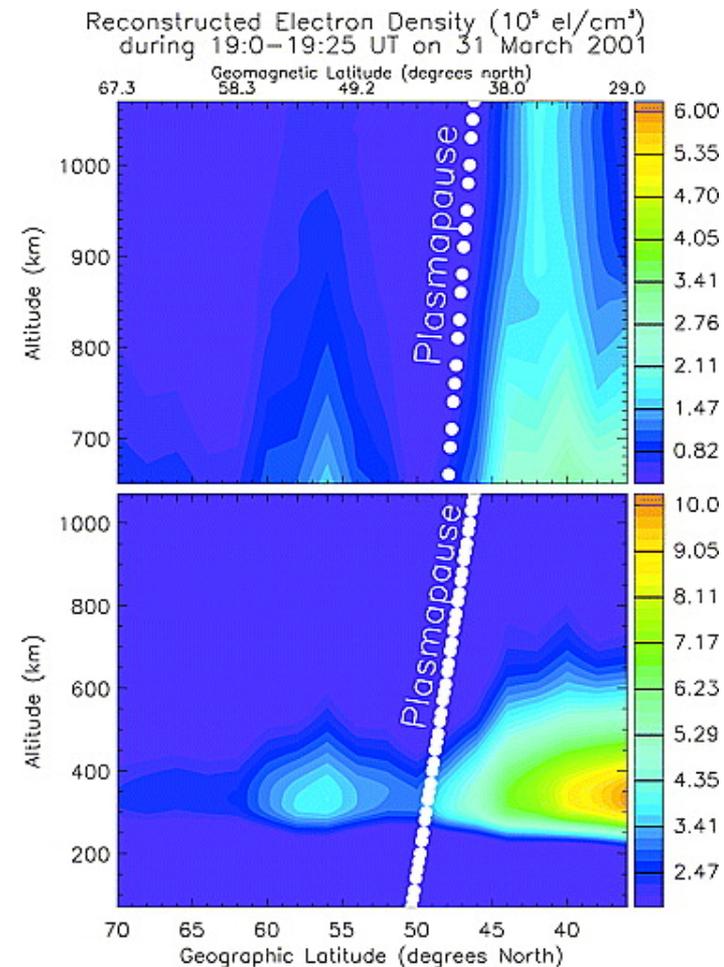
- **Storm Enhanced Density observed in TEC, ISR...**
- **Maps to plumes**
- **Is TEC enhancement due primarily to F region or topside/plasmasphere?**



[Foster et al., 2002]

SED: Ionospheric perspective

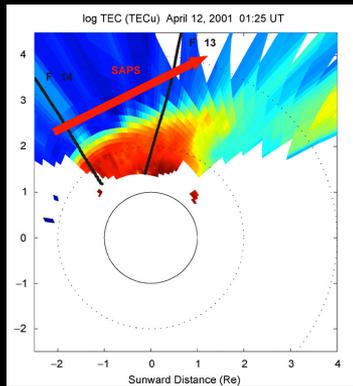
- **Trough marks plasmasphere boundary and density is field aligned extending into plasmasphere**
- **Plume should too**



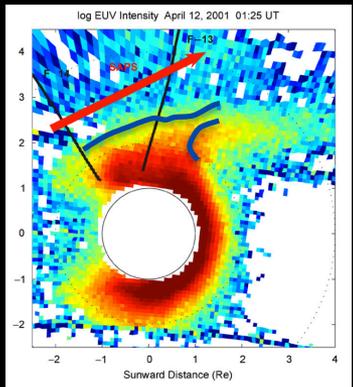
Yizengaw and Moldwin, GRL

SED: Coupled perspective

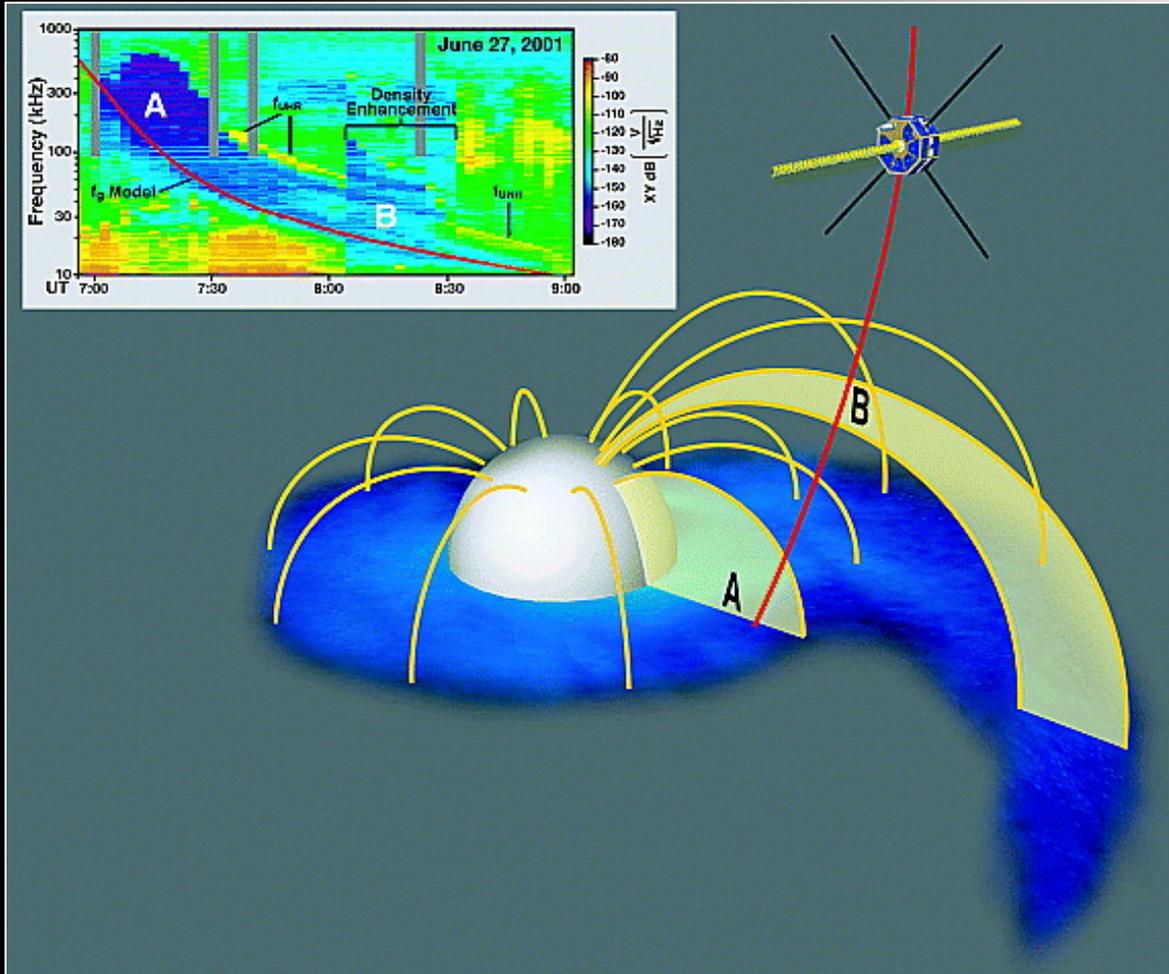
Ionospheric TEC



Plasmasphere



Foster et al., [2006]



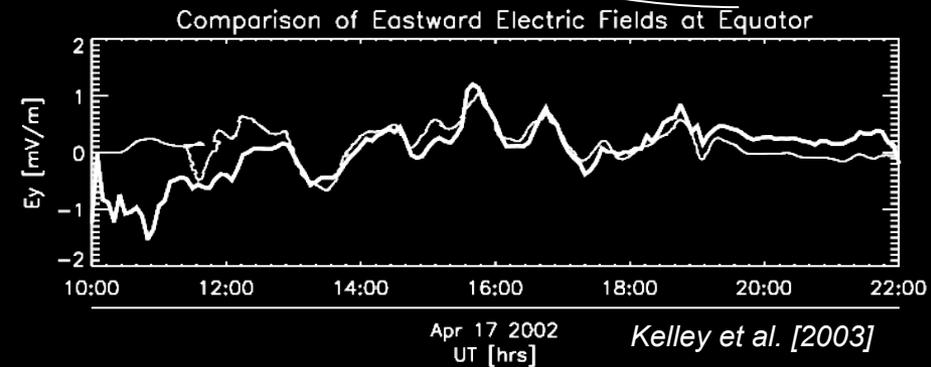
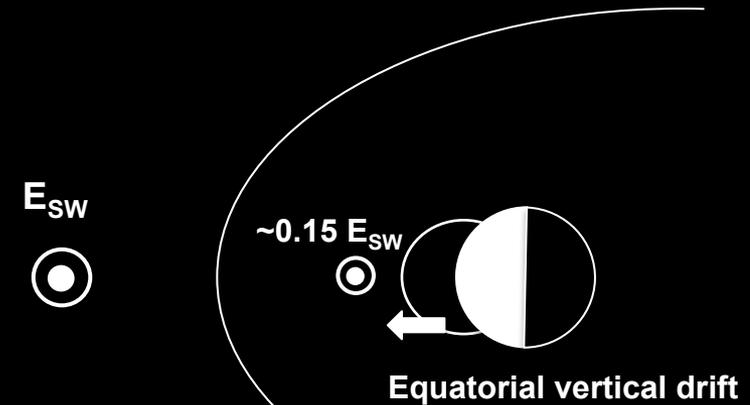
Garcia et al.

SED: Open questions

- **What is field-aligned density profile of SED/Plume flux tube?**
- **Relative role of SED/Plume plasma in magnetospheric mass density budget**
- **Is the O^+ outflow from the plasmasphere a significant source for the ring current?**

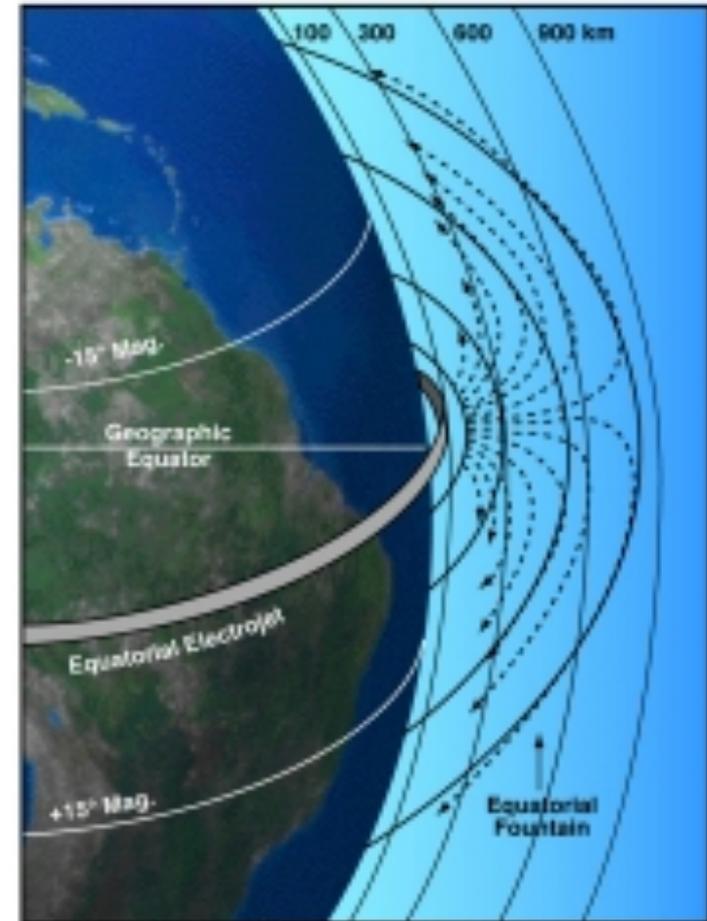
Penetration: Magnetospheric perspective

- **Vertical drifts at Jicamarca track IEF well with about a 10 min lag [Kelley et al., 2003]**
- **Why?**
- **Does IEF “penetrates” the magnetosphere through the changing magnetospheric convection (FTEs)?**
- **...but wait....it takes about 15-30 min to change magnetospheric convection**



Penetration: Ionospheric perspective

- **Kikuchi et al. [1996]** concludes that the magnetospheric E-field propagates from the polar to equatorial ionosphere in $<25s$
- **Proposes wave guide** between ionosphere and ground
- **Chi et al. [2001]** use Tamao's MHD model [1964] to explain near simultaneous response across globe of magnetic signatures opposed to super-Alfvénic (speed of light) EM mode
- **How are equatorial electrodynamics coupled to magnetosphere?**



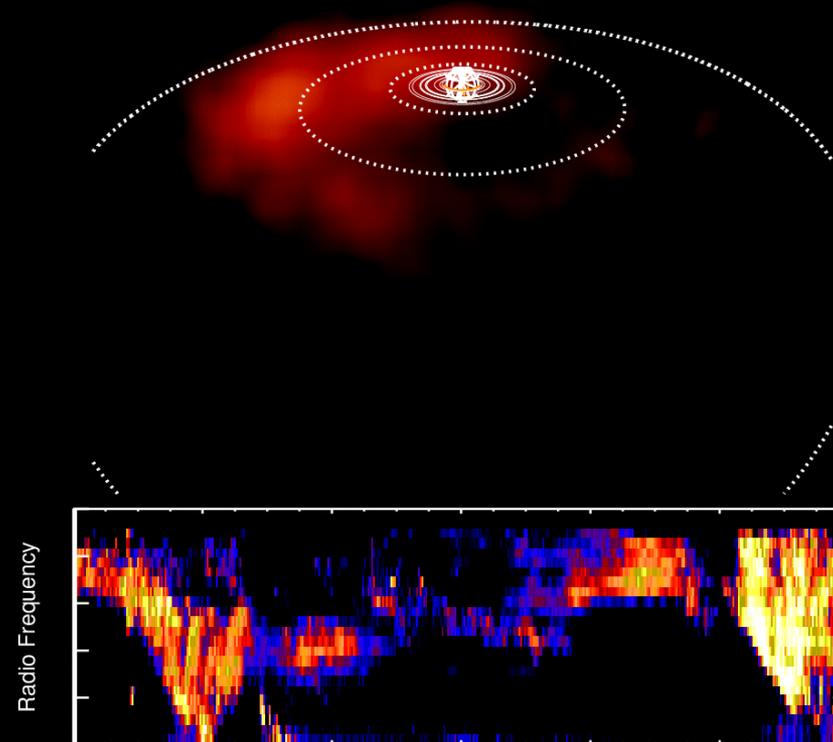
Penetration: Open questions

- **How does the E-field propagate to mid and low-latitude that quickly?**
- **How to separate dynamo-driven E-fields and penetration?**
- **How does the ring current modulate the penetration?**

UT effects on magnetospheric dynamics?

Saturn

00:01 UTC



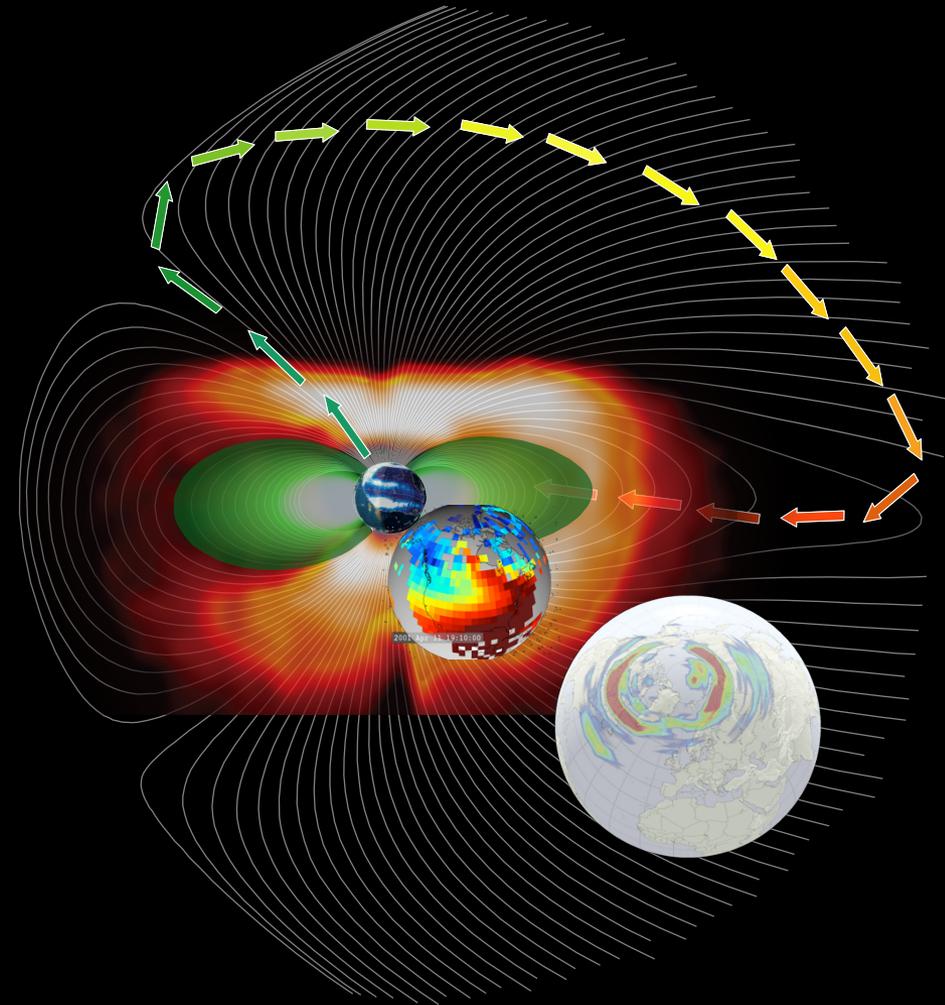
Brandt et al., 2010

Needs

- **Magnetosphere needs realistic conductances, especially in the trough**
- **Ionosphere needs to know what the magnetospheric currents are doing**
- **...plus everything else above and below.**
 - *Mass and energy flow*
 - *Gravity waves, tides, chemistry...*

Future

- **System-level view**
 - *Studies and observations that follow global dynamics of the ionosphere and the magnetosphere simultaneously*
- **Global modeling and data assimilation**
 - *No understanding without modeling*
 - *No nowcasting without assimilation*
- **Comparative planetary ionospheric and magnetospheric science**
 - *Lessons go both ways*
 - *Interest there, funding not*
 - *GEM is the right forum*
 - *Planetary tutorials is a good start*



Extra slides

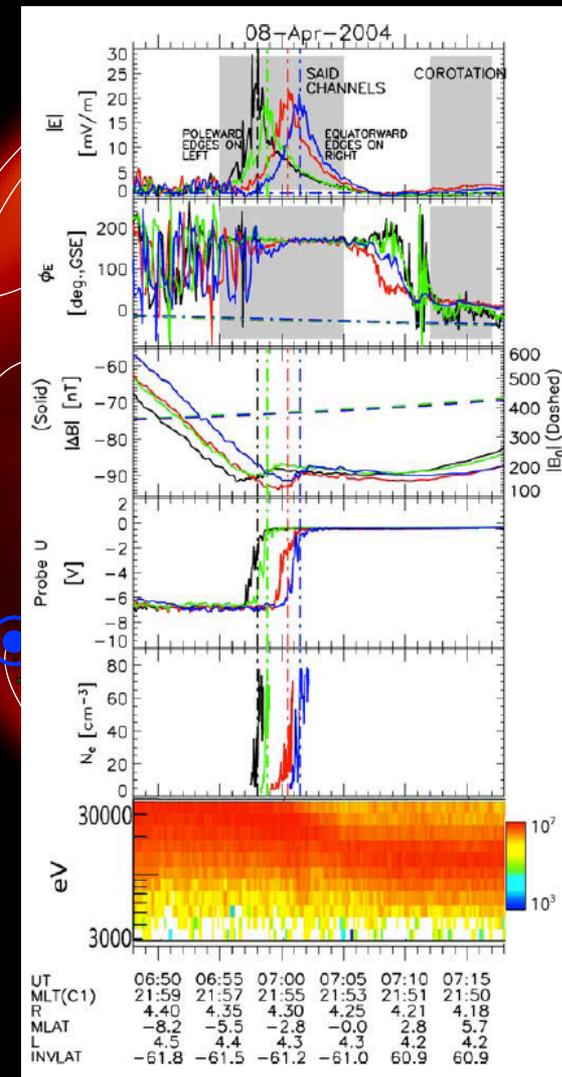
SAPS: Magnetospheric perspective

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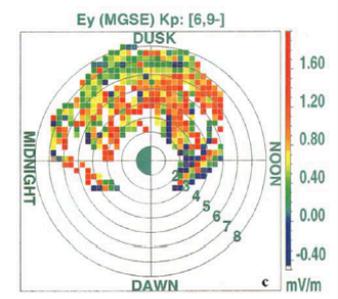
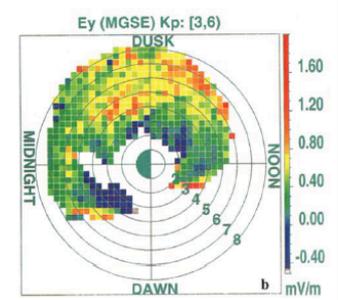
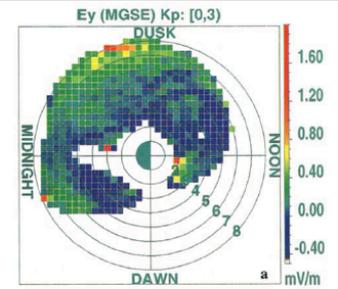
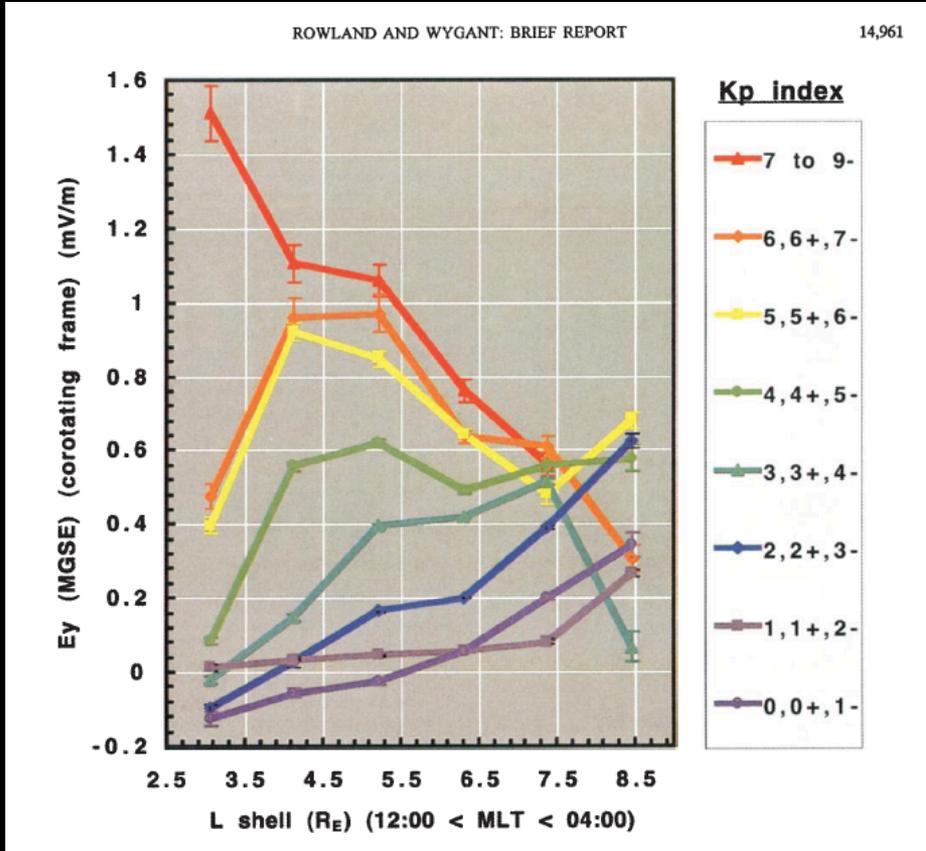
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$\mathbf{v} \times \mathbf{B}$
 B^2
 electric field
 into ionosphere

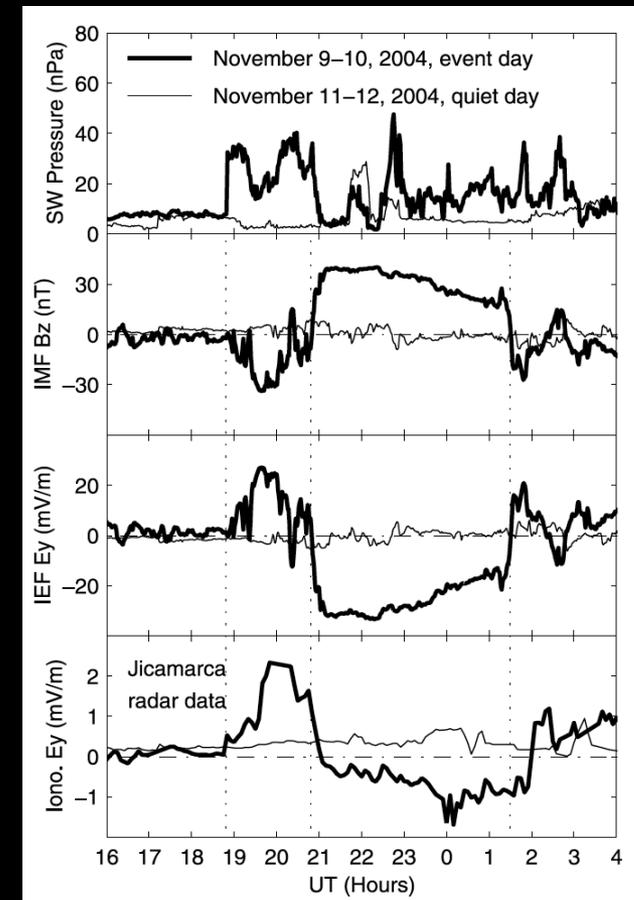
$$B \frac{\partial}{\partial s} \left(\frac{\mathbf{v}}{B} \right) = -\nabla \cdot \mathbf{J}_{\perp}$$

Macroscopic effects: Magnetospheric electric field

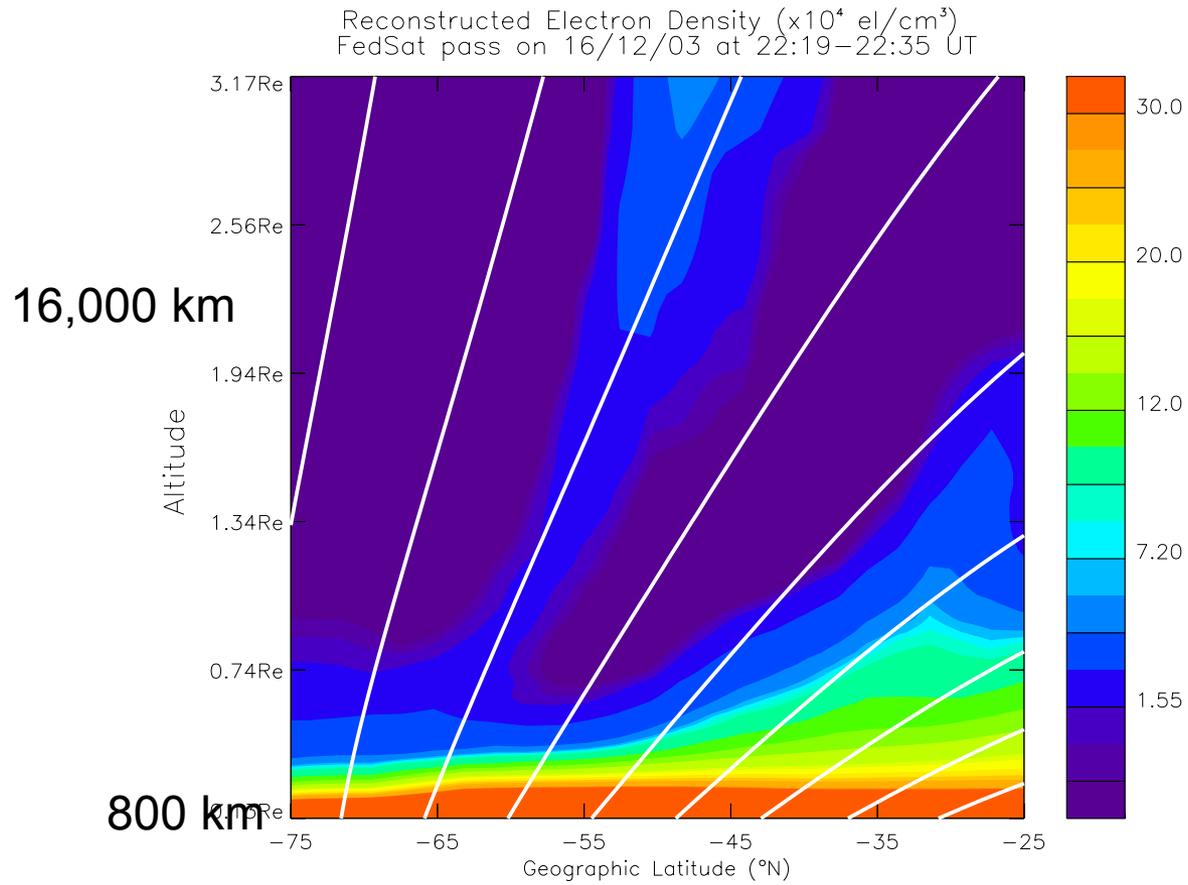


Penetration: Role of ring current

- [Possible additional penetration/shielding examples that could be used to segway into shielding...]
- Huang et al. [2007] show long-duration penetration of the IEF with no apparent shielding effects
- Kikuchi et al. [2010] showed that the solar wind does not penetrate. It is consistent with ring current shielding.



Outflow

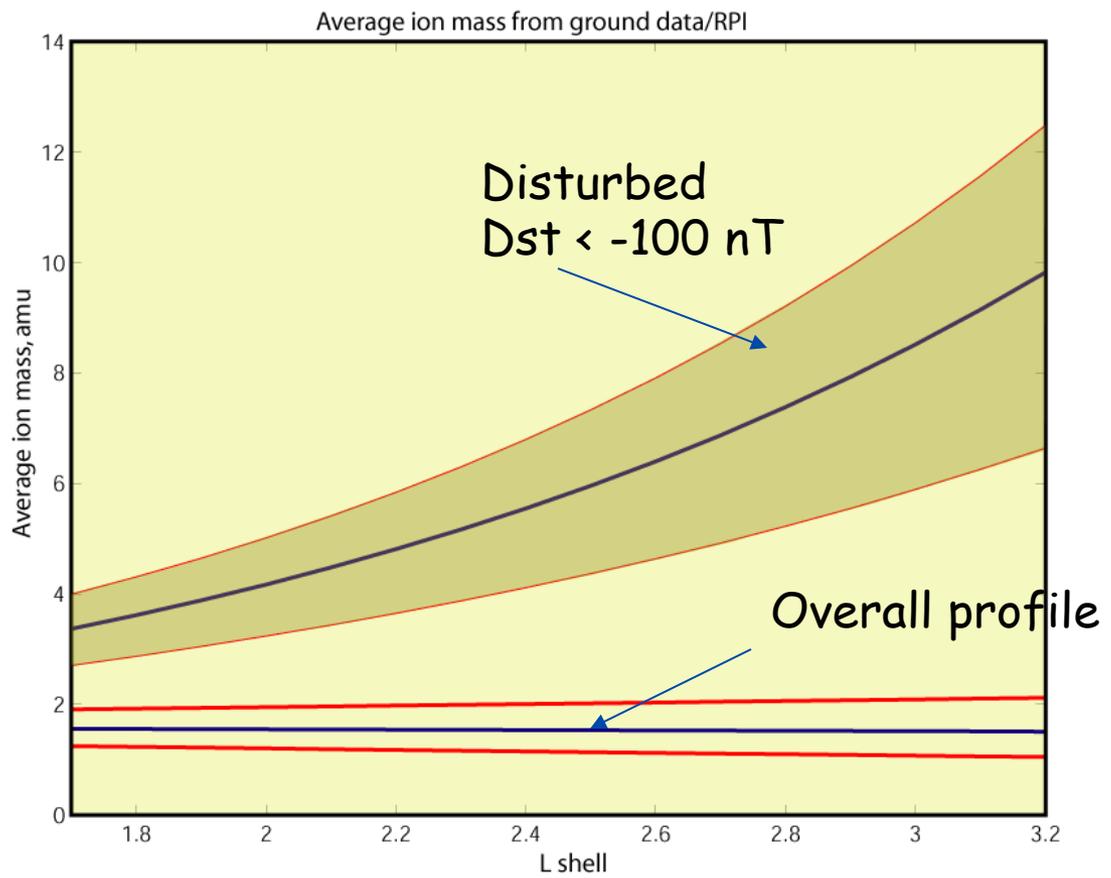


Yizengaw et al., 2006 GRL

Outflow: "O⁺ torus", "warm ion cloak", ...

Combine average equatorial mass and electron density models to estimate the average ion mass as a function of L. ($M_{avg} = \rho_{eq}/n_{eq}$)

Empirical $n_{eq}(L)$ determined by Fung et al. (2001) from database of IMAGE/RPI electron density.



APL Berube et al., 2005; and DE results