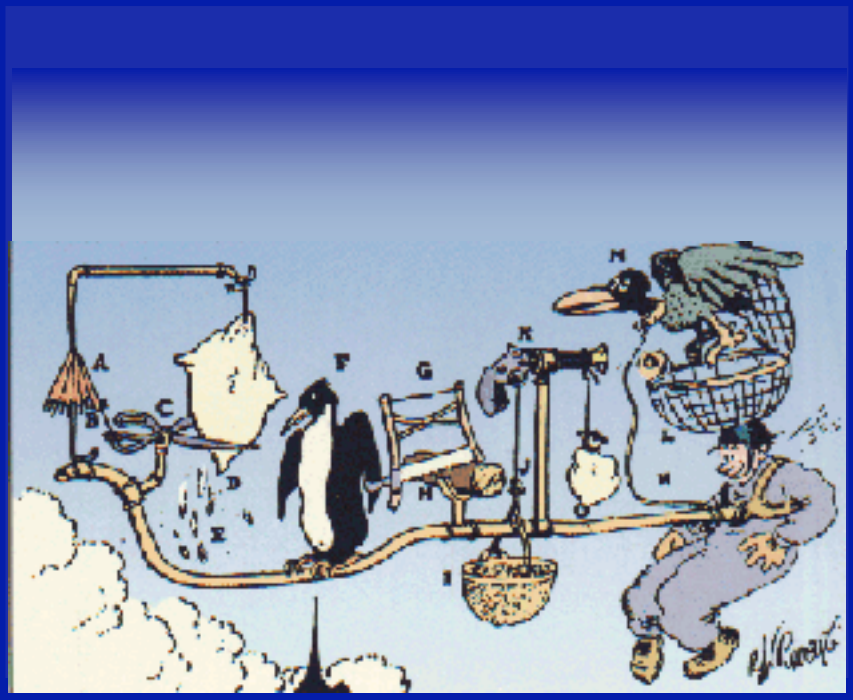
Space Weather: Observational evidence for coupling and feedbacks involving the ITM



Janet Kozyra
University of Michigan

The Sun & Earth form a complex system which has characteristic properties

- ✓Prediction is difficult based on knowledge of components alone

"The whole is greater than the sum of the parts "

The Sun & Earth form a complex system which has characteristic properties

- ✓Prediction is difficult based on knowledge of components alone
- ✓History matters

"Butterfly Effect"

The Sun & Earth form a complex system which has characteristic properties

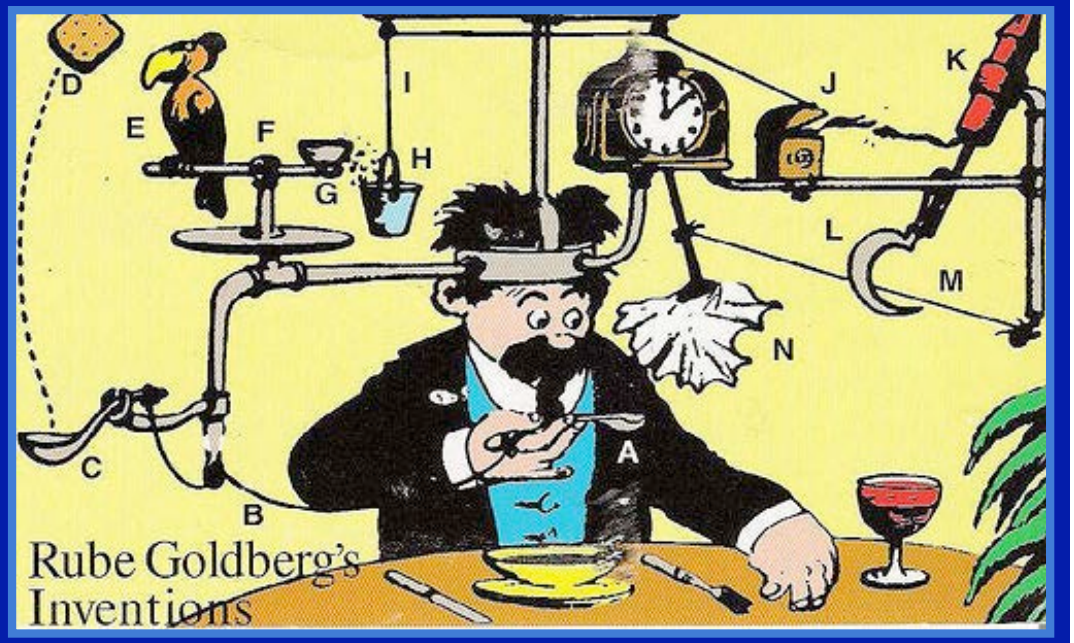
- ✓Prediction is difficult based on knowledge of components alone
- ✓History matters
- ✓Emergent features

Still from "The Mummy"

"Science of Surprise"

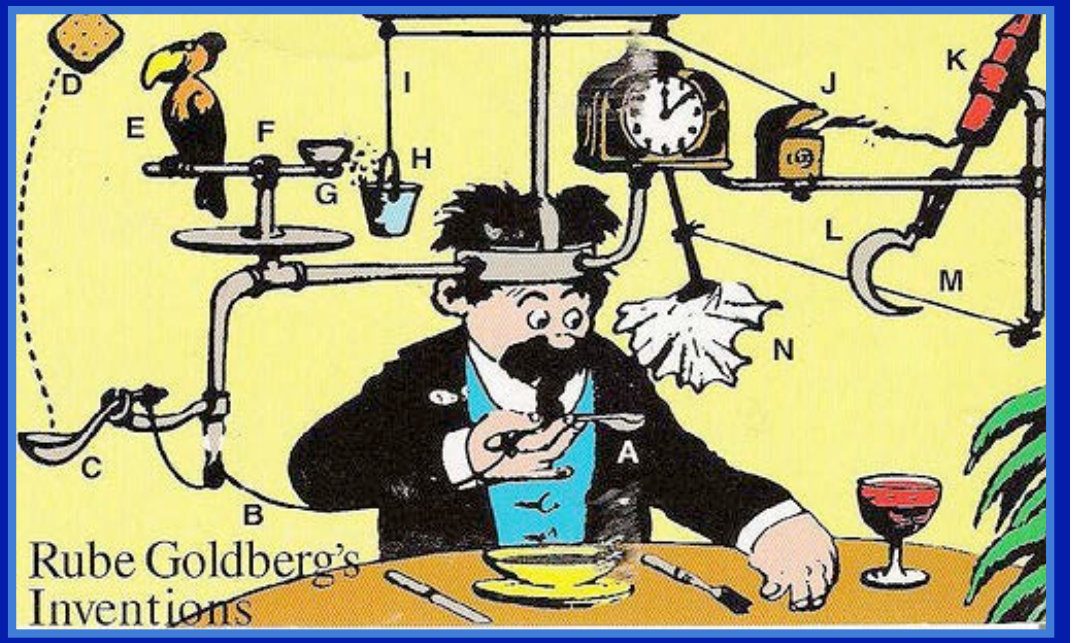
The Sun & Earth form a complex system which has characteristic properties

- ✓Prediction is difficult based on knowledge of components alone
- ✓History matters
- ✓Emergent features
- ✓Negative and positive feedbacks



"Simple cause & effect are rare."

The Sun & Earth form a complex system which has characteristic properties



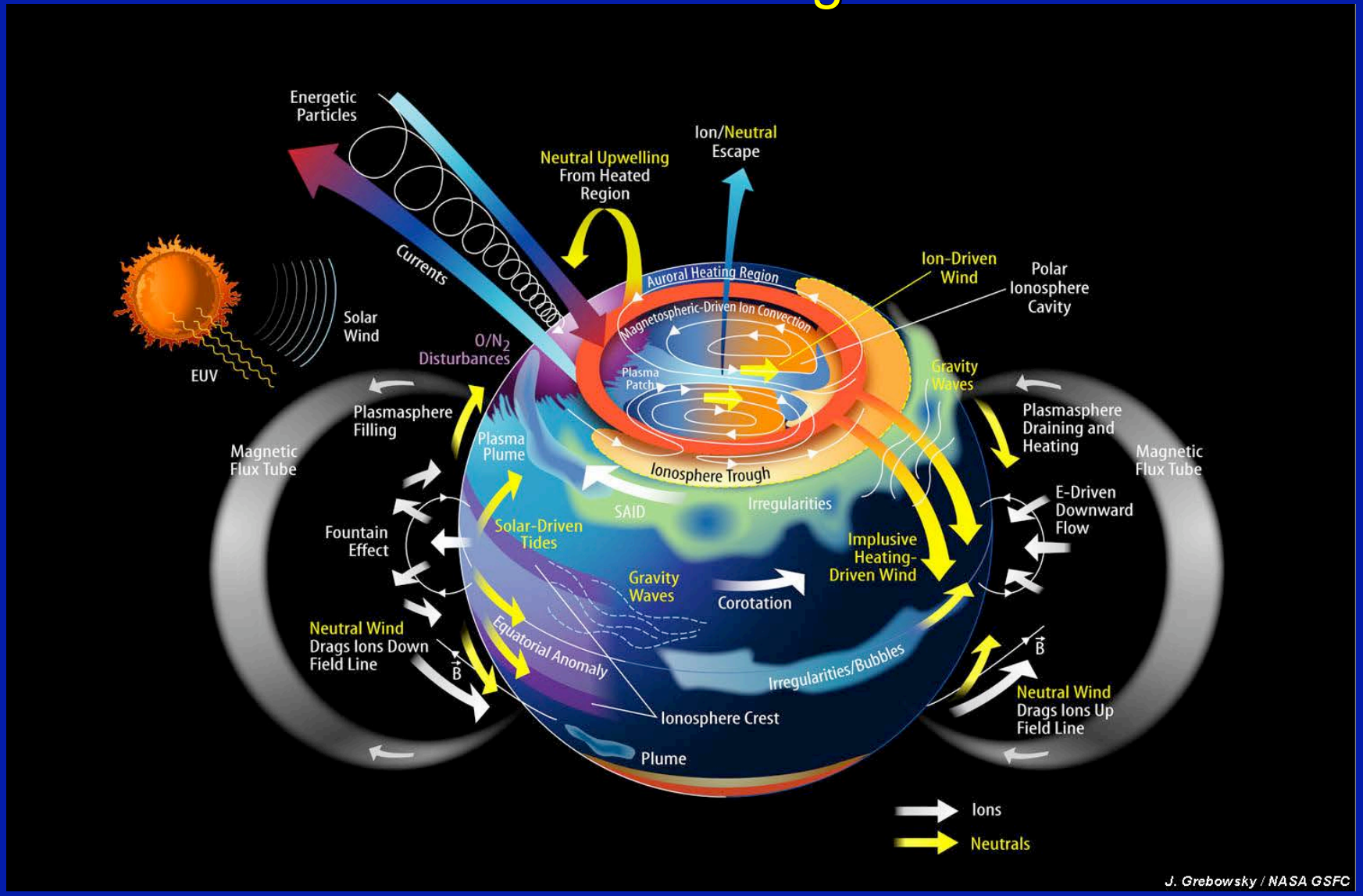
Interactions between components define behavior

Not contained in the individual pieces

Break into smaller digestible pieces -- lose behavior

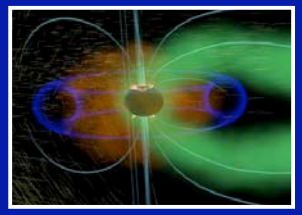
Close-Up on the Upper Atmosphere

Remember what we are dealing with …..



Evidence for Active ITM Influences throughout Geospace

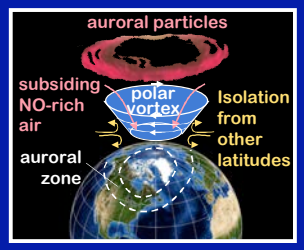
Four coupling pathways:



Mass & momentum outflows

Solar wind energy inflow

Active electrodynamic interactions



Reactive species: production & transport

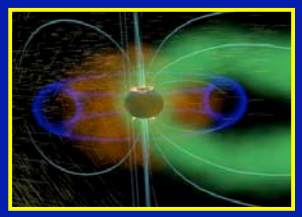
Fundamental physics: Ion-neutral coupling

Cross-scale coupling

Chemical-dynamical coupling

Evidence for Active ITM Influences throughout Geospace

Four coupling pathways:



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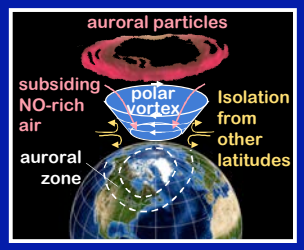

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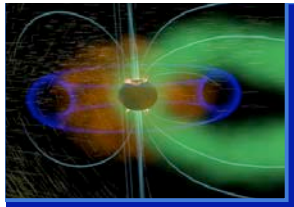
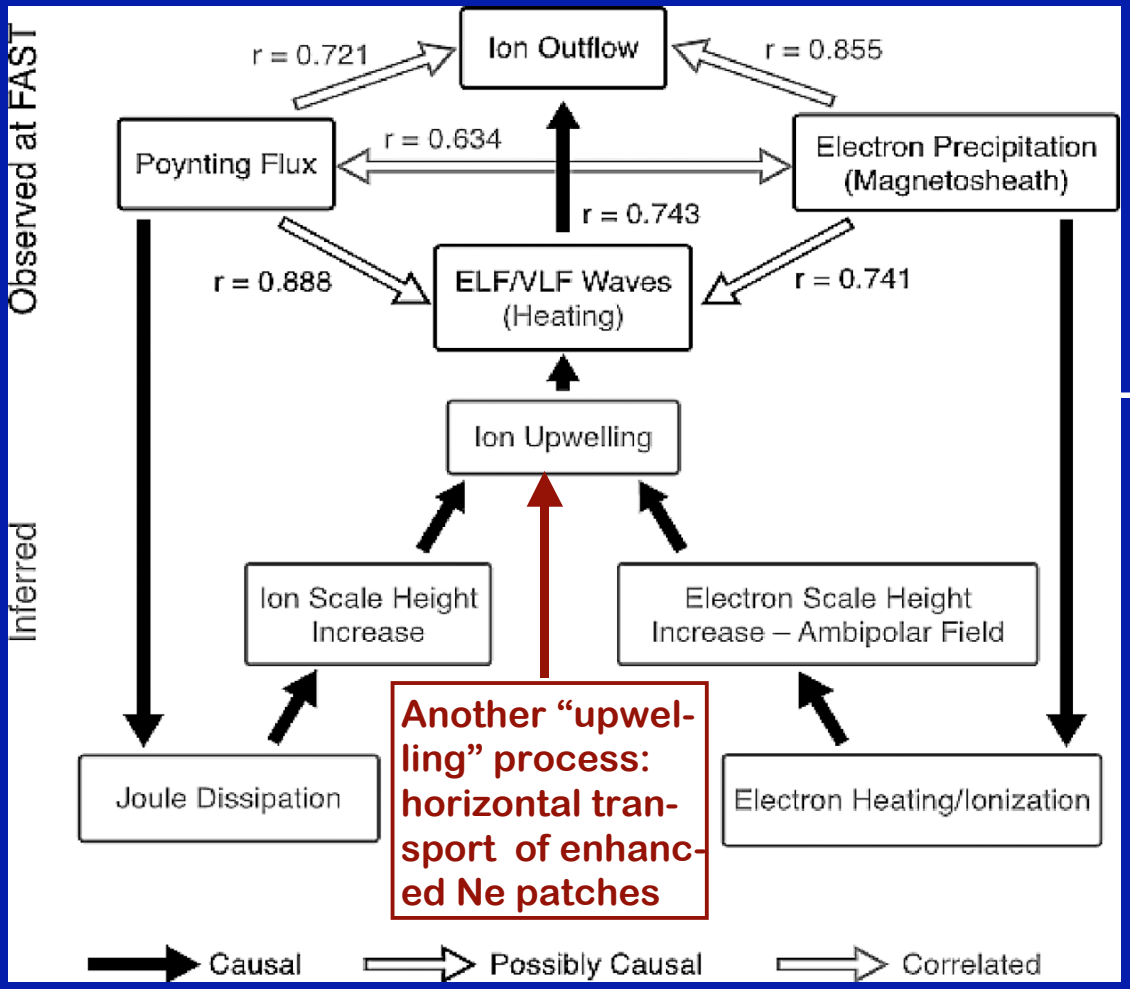


Mass and Momentum Outflow

Ionospheric Outflow: 2-Step Process

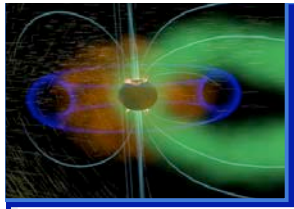


Outflow: Acceleration to > escape velocity

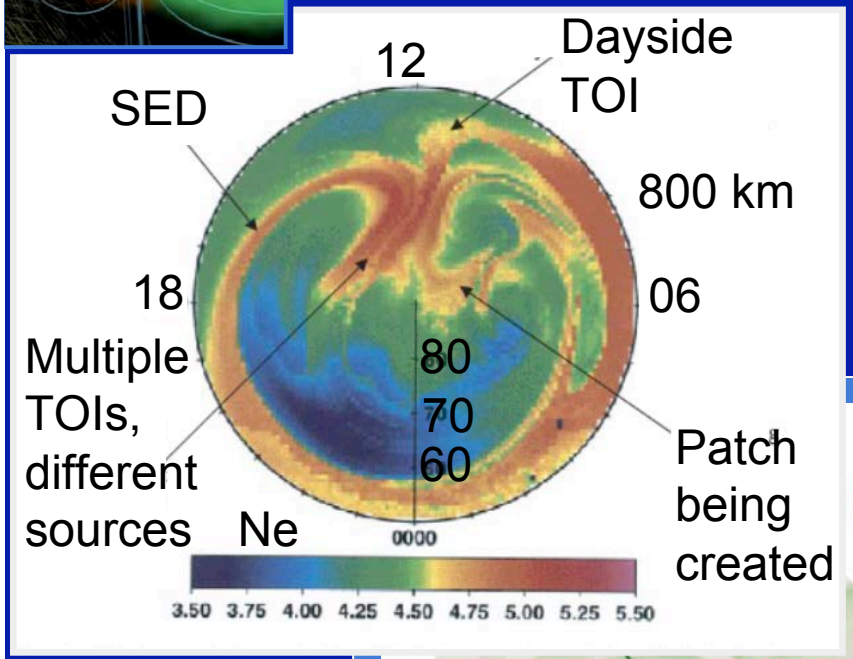
Upwellling: Increase in scale height

Outflows best correlated with solar wind Pdyn fluctuations: Reason Unknown [c.f. Fok et al., 2005]

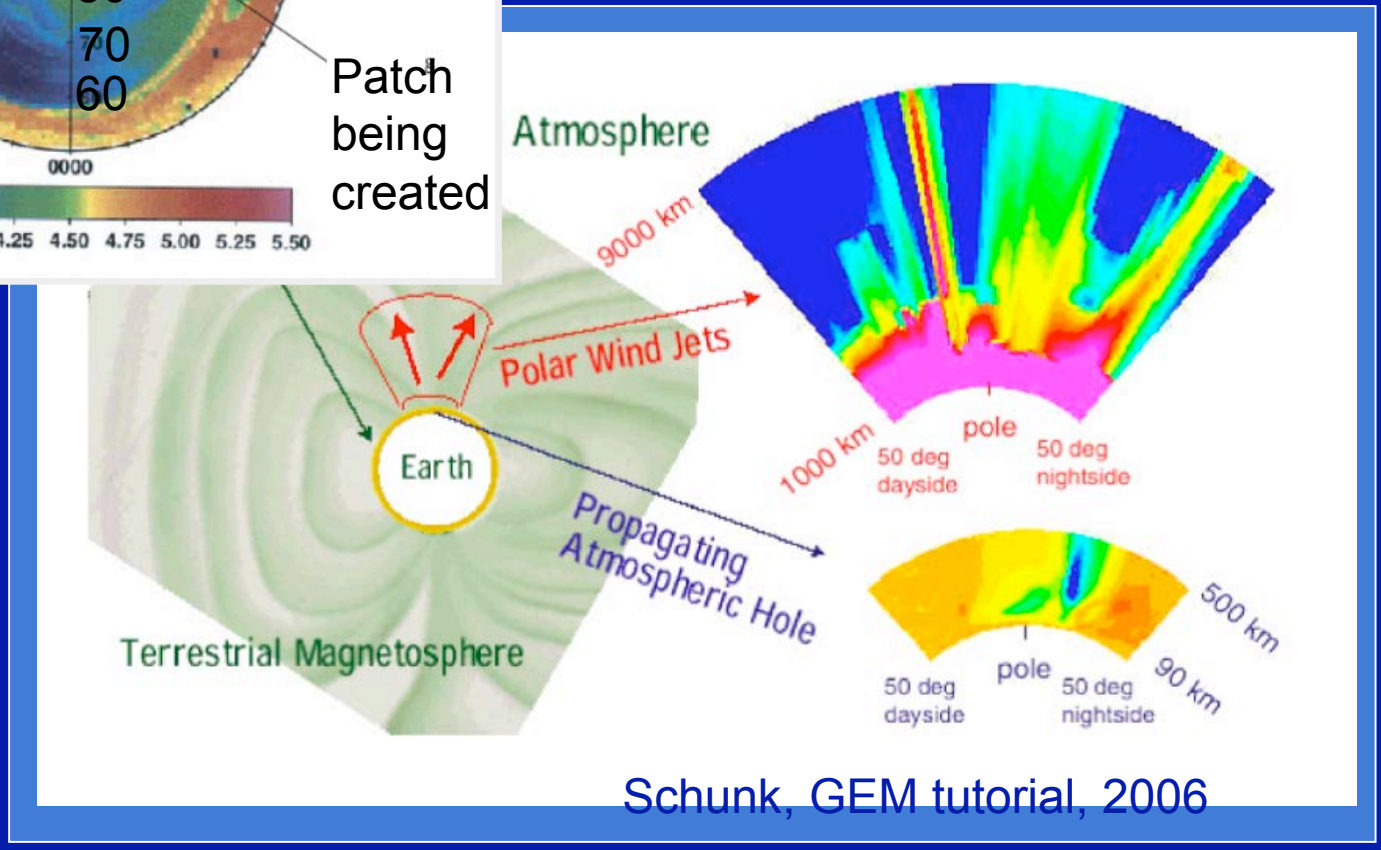
After Strangeway et al., [2005] as summarized in Moore and Horwitz, 2007 and Lotko, 2007



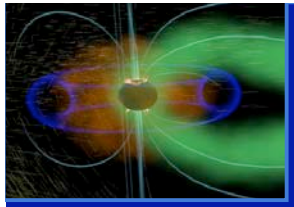
Mass and Momentum Outflow



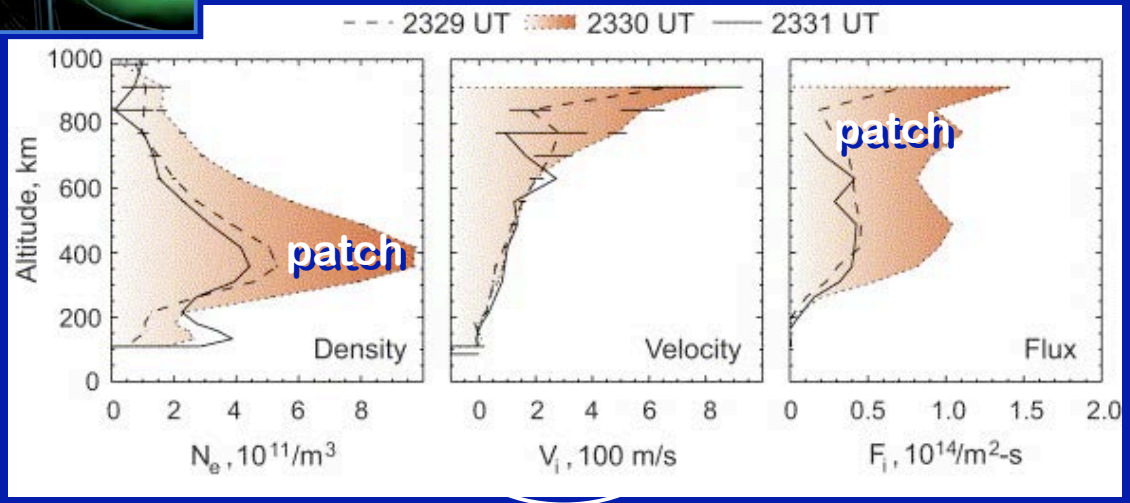
Accumulating evidence that most of the mass, momentum, and energy coupling occurs on relatively small spatial scales.



Schunk, GEM tutorial, 2006

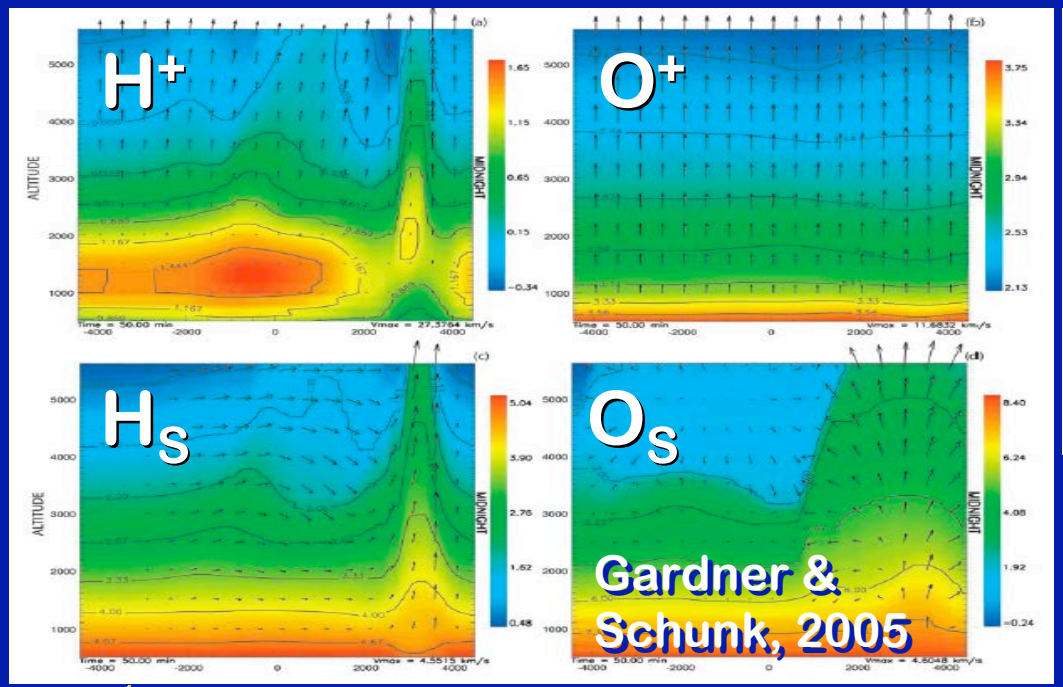


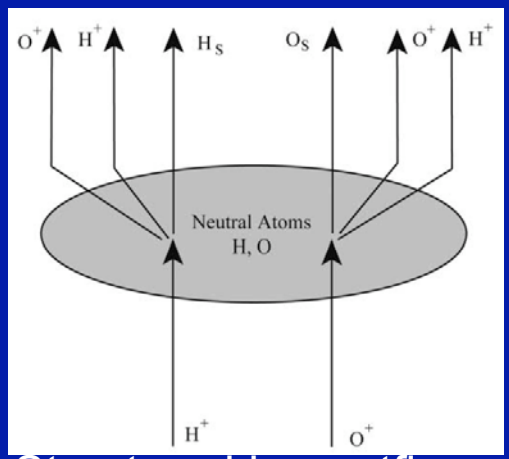
Mass and Momentum Outflow



Sondrestrom view of polar cap patch ions energized in nightside auroral zone.

Adapted from Semeter et al. 2003 in Lotko 2007 review





Structured ion outflow creates structured neutral outflow through charge exchange

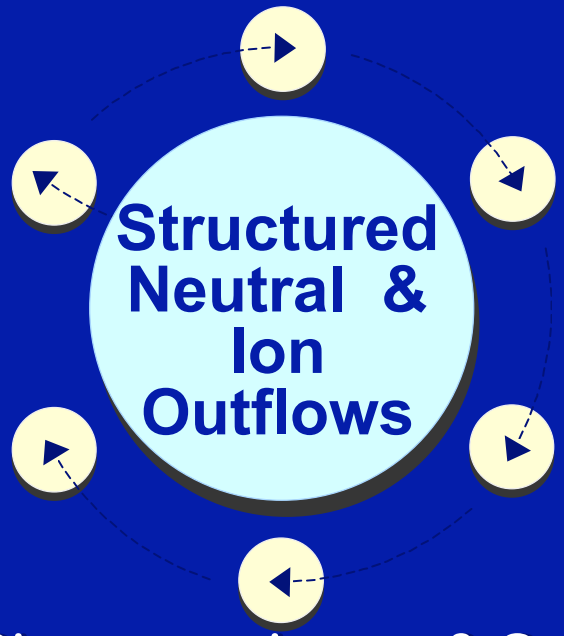
Mass and Momentum Outflow

Solar wind - energy inflow →

Structured energy inputs (Poynting flux, Joule heating, soft precipitation) and convecting ionospheric density structures

Effects plasma waves, ring current & rad belt composition, charge exchange losses & atmospheric loss

Patchy plasma sheet composition. Variable oxygen geocorona



Cause structured "upwelling" of ions, polar wind jets, neutral holes

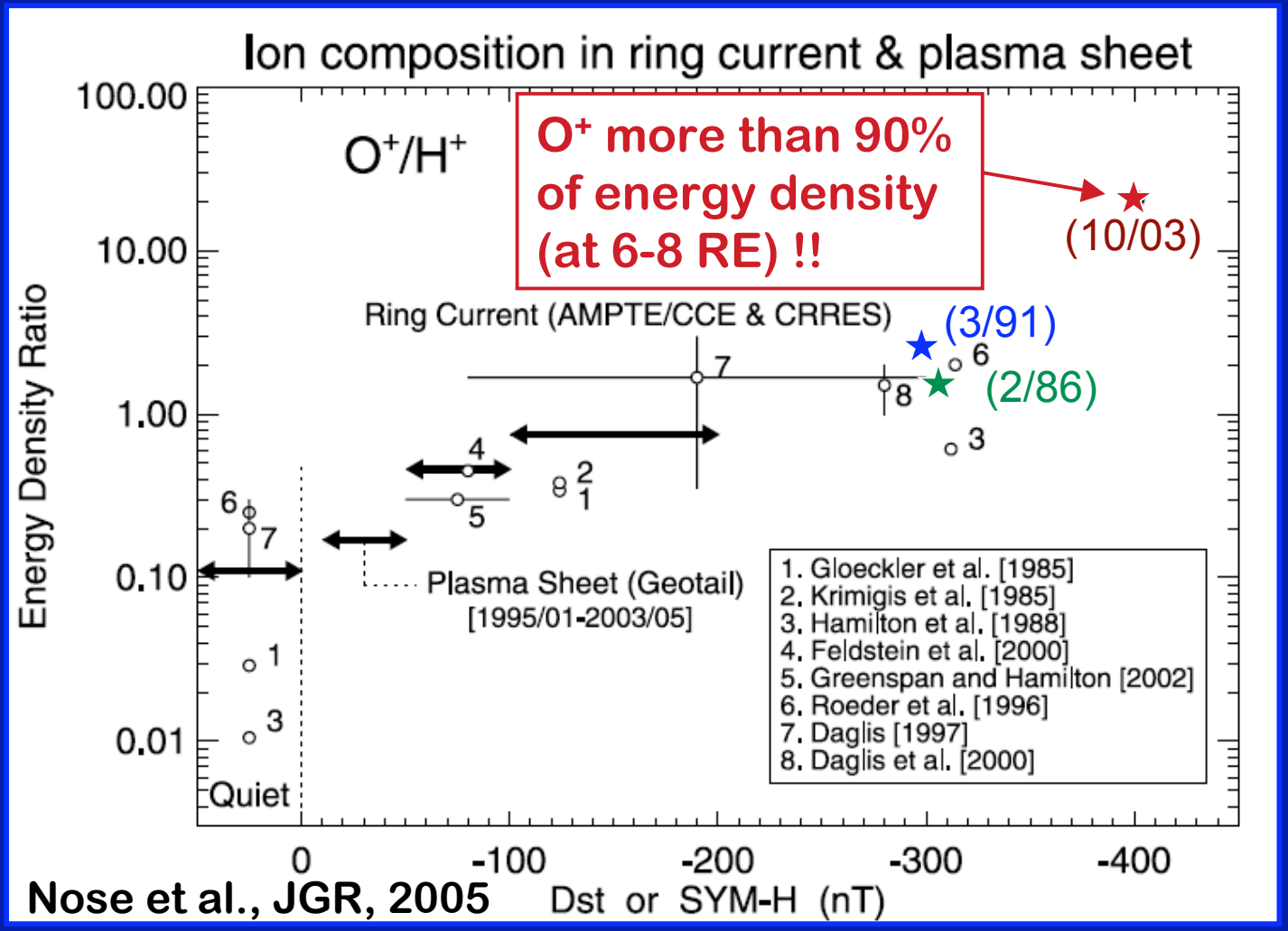
Further acceleration by waves and field-aligned potentials at high altitude cause oxygen outflows

Charge exchange & O backsplash from H/H^+ auroras creates neutral O outflows

Lotko [2007], Sojka and Schunk references

Oxygen ions dominate the magnetospheric plasma during extreme events in the inner region. Patchy composition.

O^+ can dominate even for more moderate solar and magnetic activity levels. Variability due to multiple drivers. [***Greenspan & Hamilton, JGR, 2002***]

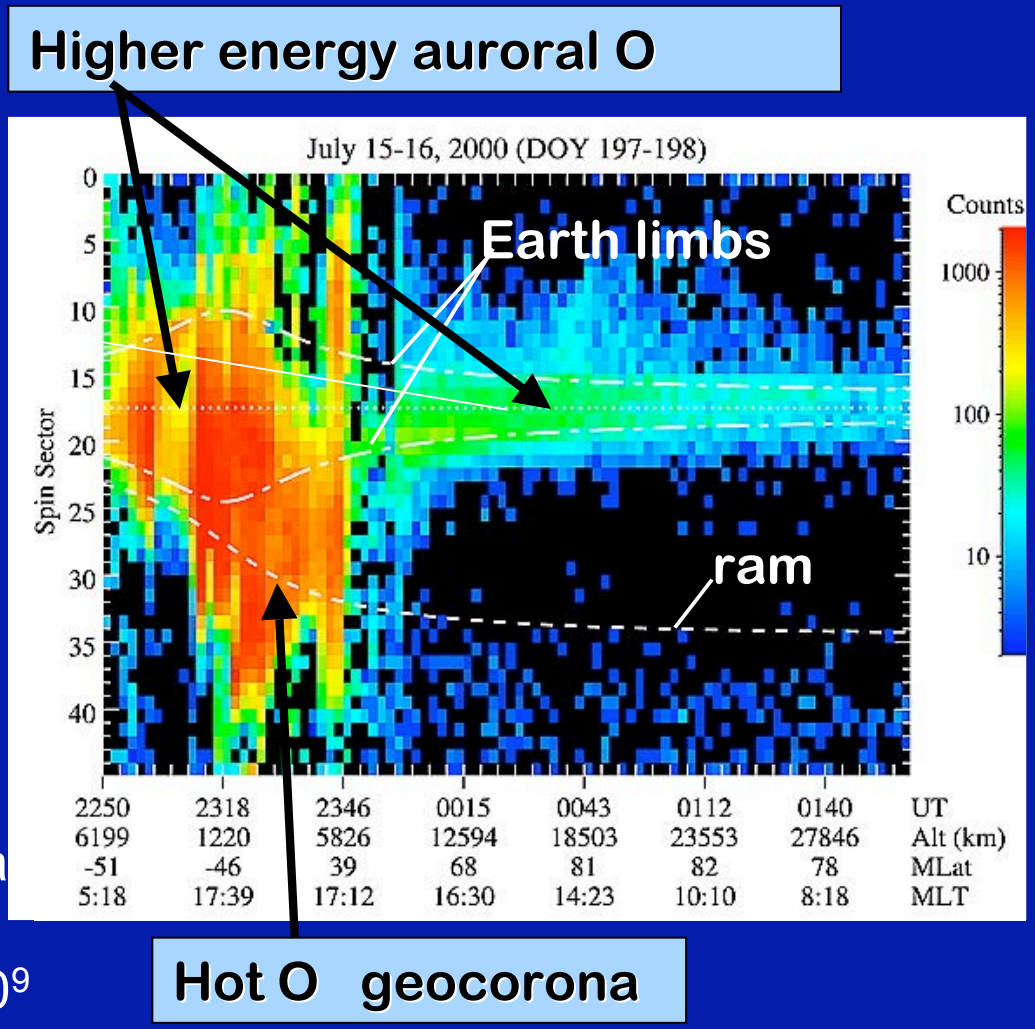


Ever-present <50 eV oxygen outflow

LENA sees at least 2 neutral O populations under all conditions:

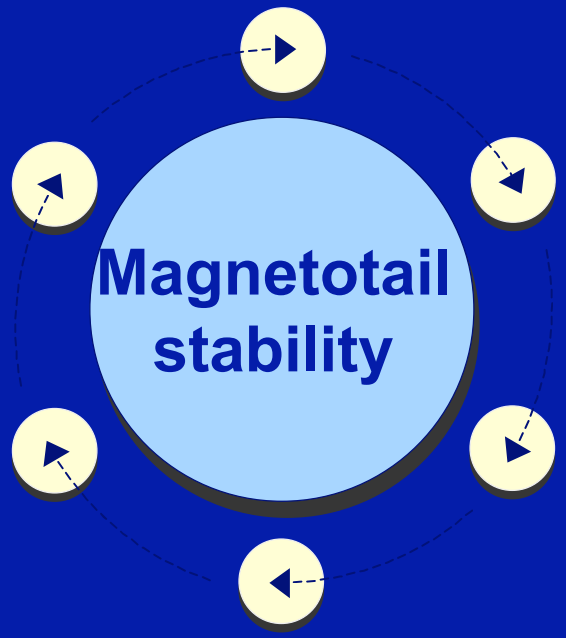
- A neutral hot O geocorona
- A higher energy upflowing O population originating from the auroral zone. Possibly due to backsplash O from H/H^+ auroral precipitation [*Shematovich, et al*., 2006]

These upward O fluxes increa in intensity with increasing magnetic activity to a few x 10^9 $cm^{-2}s^{-1}$.



Wilson et al., 2003; 2005

Suggested positive feedbacks on magnetotail stability



Ionospheric outflow from auroral activity feeds O^+ into magnetotail

Mass loads convection in magnetosphere, slows reconnection rate

Less O^+ in dayside plasma sheet implies faster dayside merging

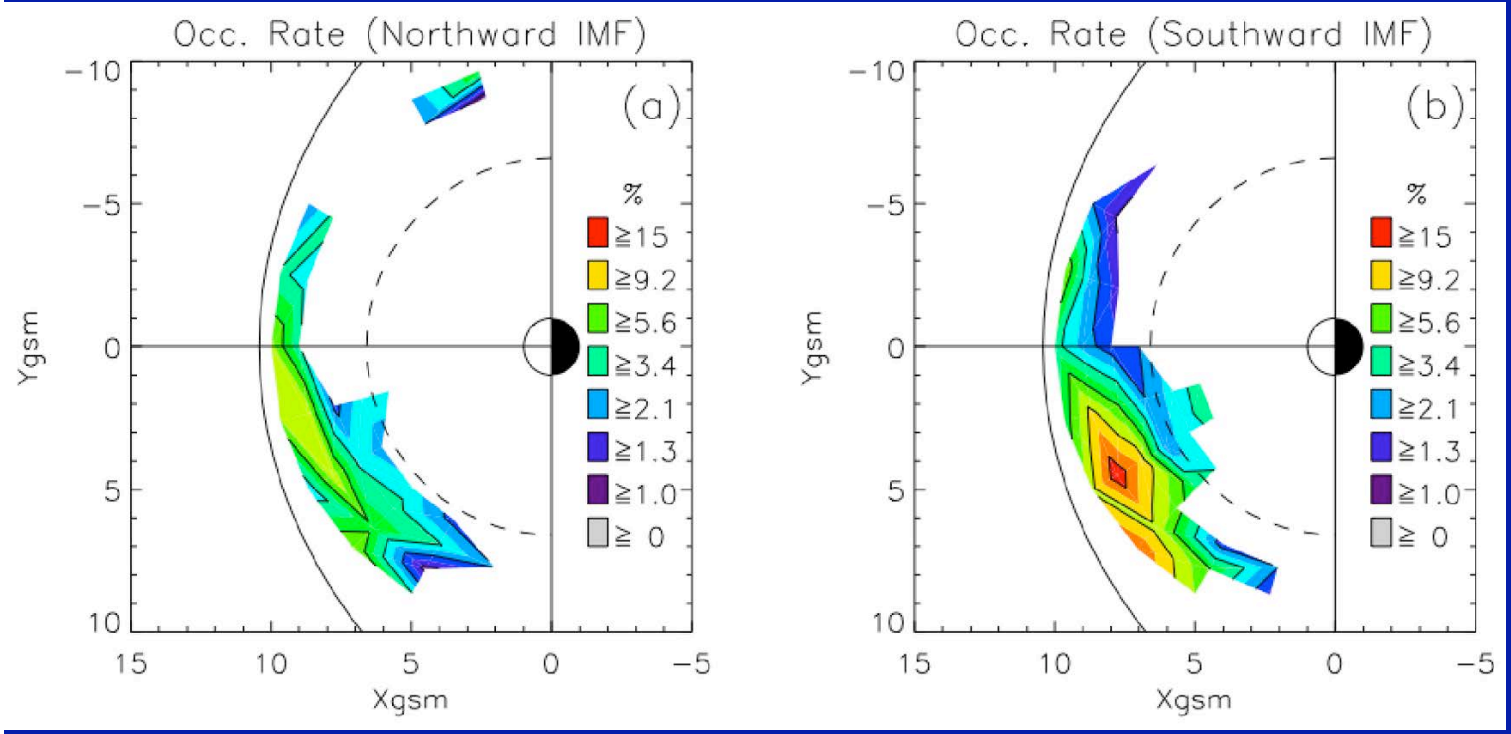
Slower nightside reconnection rate cannot balance the dayside rate

Increased demand for episodic unloading of tail flux

Produces more frequent and/or more intense auroral activity

Saturation of the polar cap potential breaks positive feedback loop. Lotko, 2007

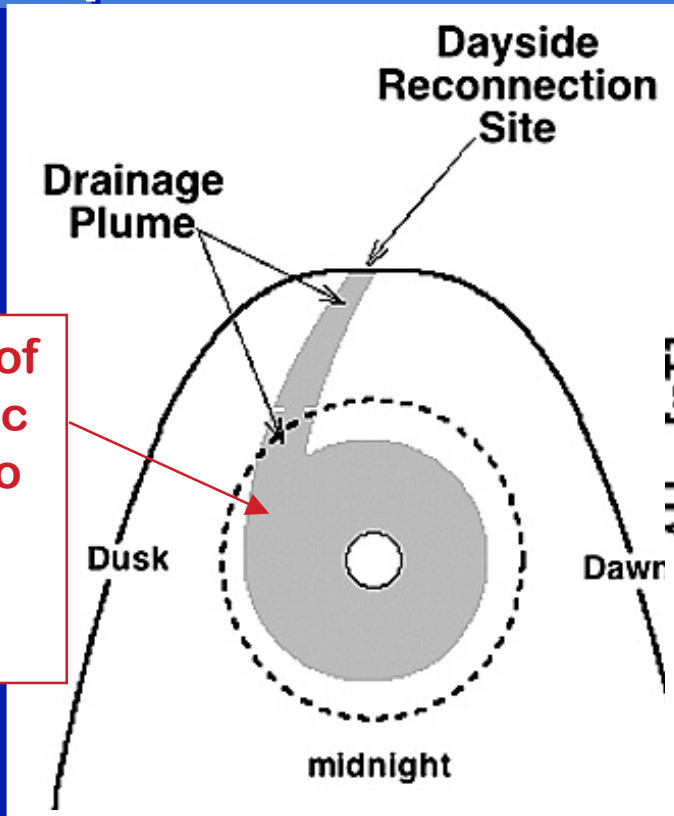
Evidence for the mass-loading of reconnection flows



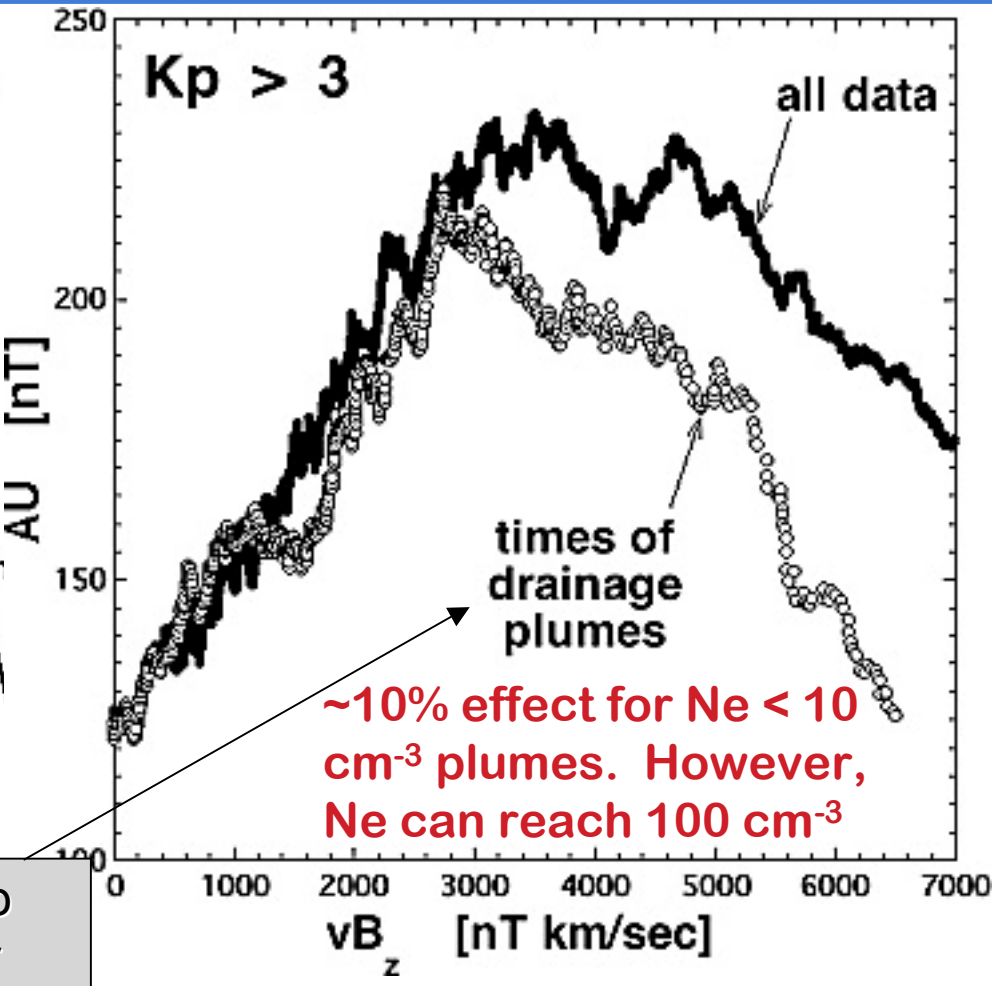
Observed occurrence rate of cold convecting ions at the dayside magnetosphere for northward (left) and southward (right) IMF [*Chen and Moore* 2006].

Consequences (review *Moore & Horwitz*, 2007): (1) reduces Alfven speed of inflow to the dayside reconnection region, (2) slows reconnection, (3) reduces convection

Evidence mass-loading by drainage plume slows reconnection



Extension of ionospheric plasma into the inner magneto-sphere



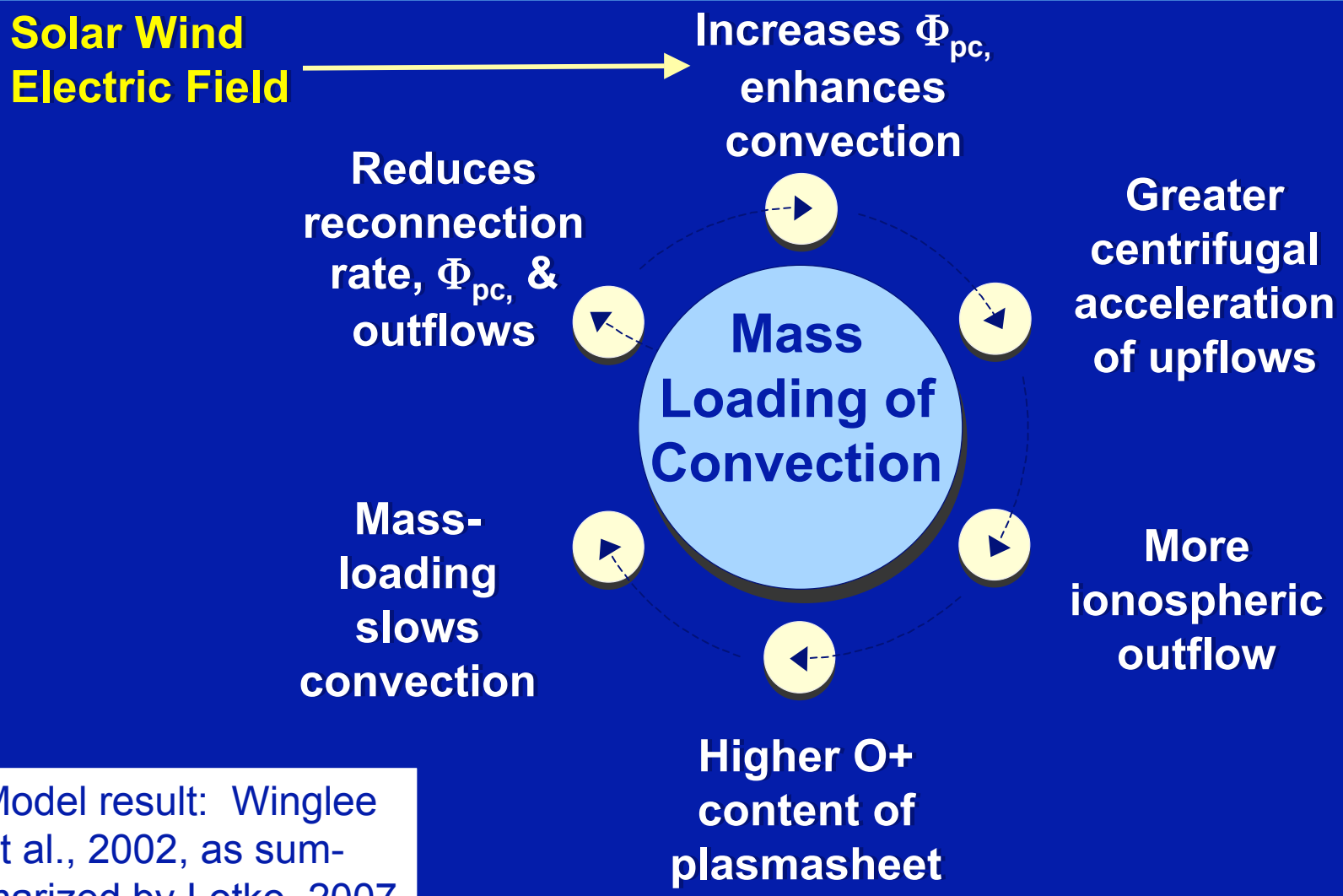
~10% effect for Ne < 10 cm^{-3} plumes. However, Ne can reach 100 cm^{-3}

Sign of weakened coupling to the solar wind & evidence for decreased reconnection rate.

Borovsky & Denton, 2006

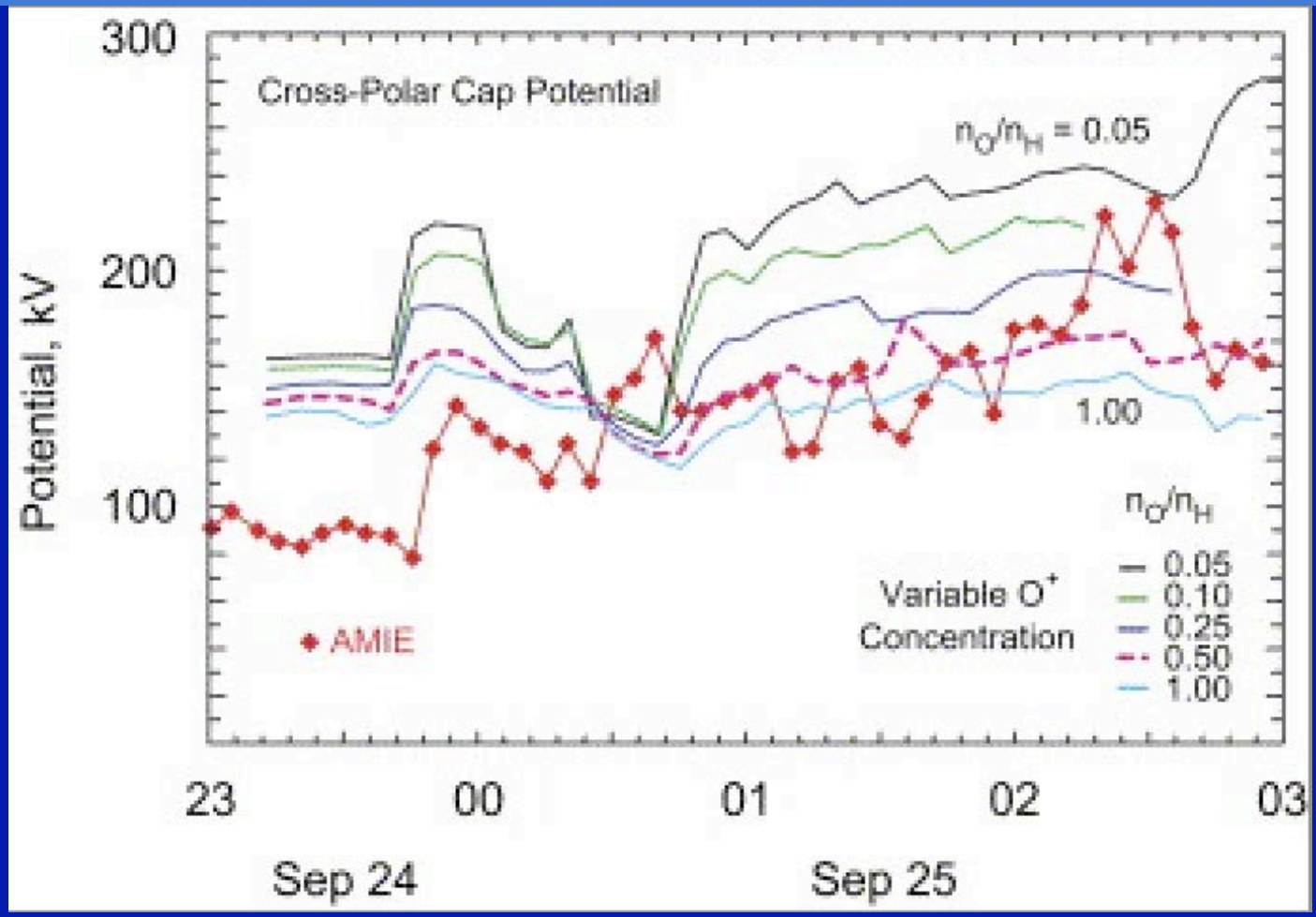
Important component of mass circulation not included in MHD models

ITM Mass Loading of Magnetospheric Convection



Model result: Winglee et al., 2002, as summarized by Lotko, 2007

ITM Mass Loading of Magnetospheric Convection



As mass-loading increases in multi-fluid model, the convection potential drops toward values predicted by AMIE model based on magnetometer data [Winglee et al., 2002]

Summary

- ITM is an active participant in Geospace system. Not just a boundary condition.
- Growing evidence that mass & momentum flows and electrodynamic parameters are all structured by the ITM.
- Coupling occurs on small spatial & temporal scales.
- Structured ion outflows produce structured neutral outflows
- Coupling involves a broad range of scales, fluid & kinetic processes & varies in complicated ways with solar wind drivers
- Fundamental questions in the magnetosphere and middle atmosphere cannot be answered without a more complete knowledge of ITM processes

Highest priority ITM problems related to Geospace system science

- Understand how fundamental ITM processes work so we can recognize their signatures at the system level
- New ways of observing global patterns of energy inputs, basic state parameters, and electrodynamic quantities. Climatologies are not sufficient.
- Determine what spatial and temporal scales are needed
- Tackle the challenges & take the steps that will lead to a revolution in our understanding of geospace as a tightly coupled system of systems

Future Measurement Requirements

- Multi-point observations connecting solar driving to auroral field-aligned transport
- Connection between ionospheric (also plasmaspheric) structures, transport & outflows.
- Ion - neutral interactions
- NOx in the polar night. Quantities related to transport
- ITM Complex System: Instantaneous global patterns of energy inputs and electrodynamic parameters.