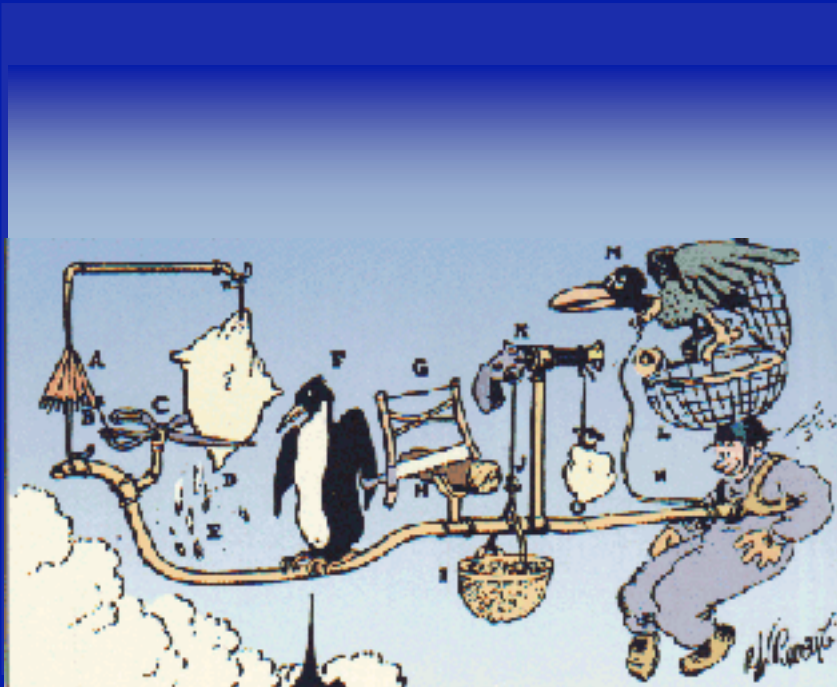


Space Weather: Observational evidence for coupling and feedbacks involving the ITM



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

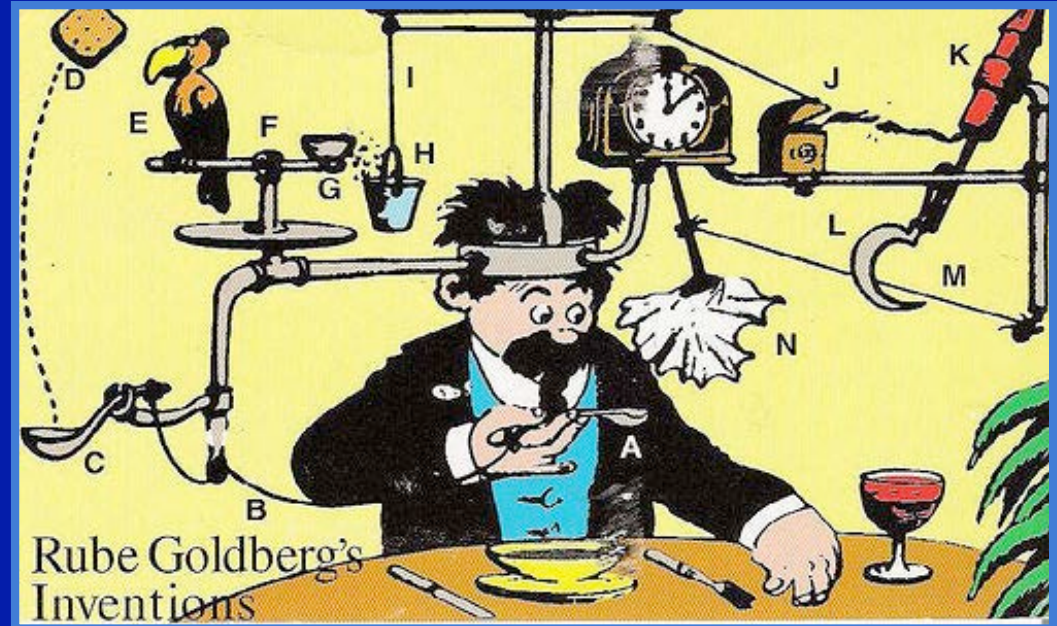


Still from "The Mummy"

"Science of Surprise"

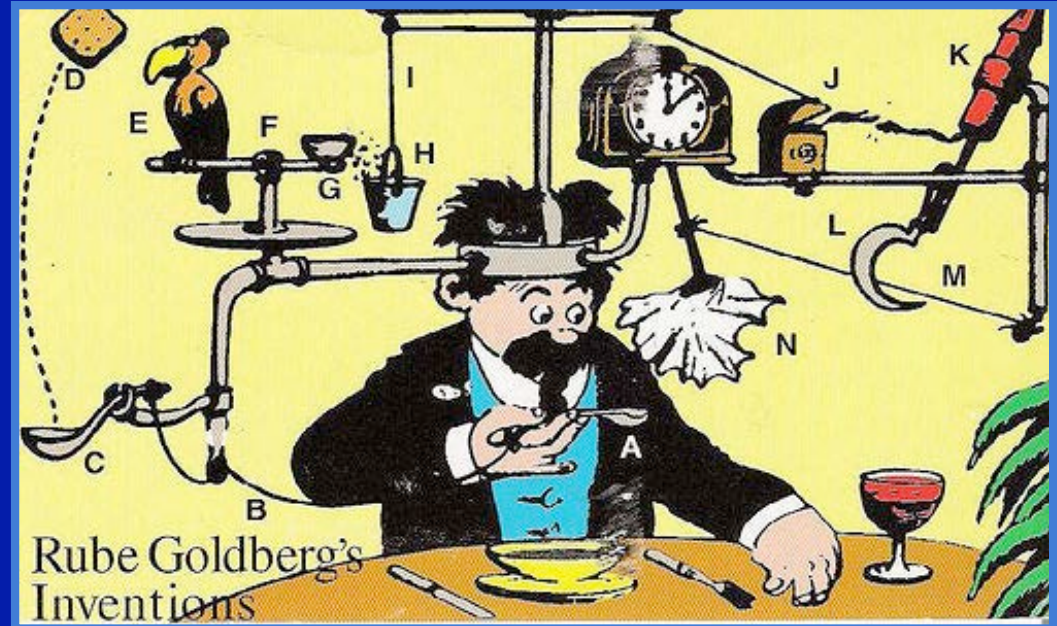
The Sun & Earth form a complex system which has characteristic properties

- ✓ 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



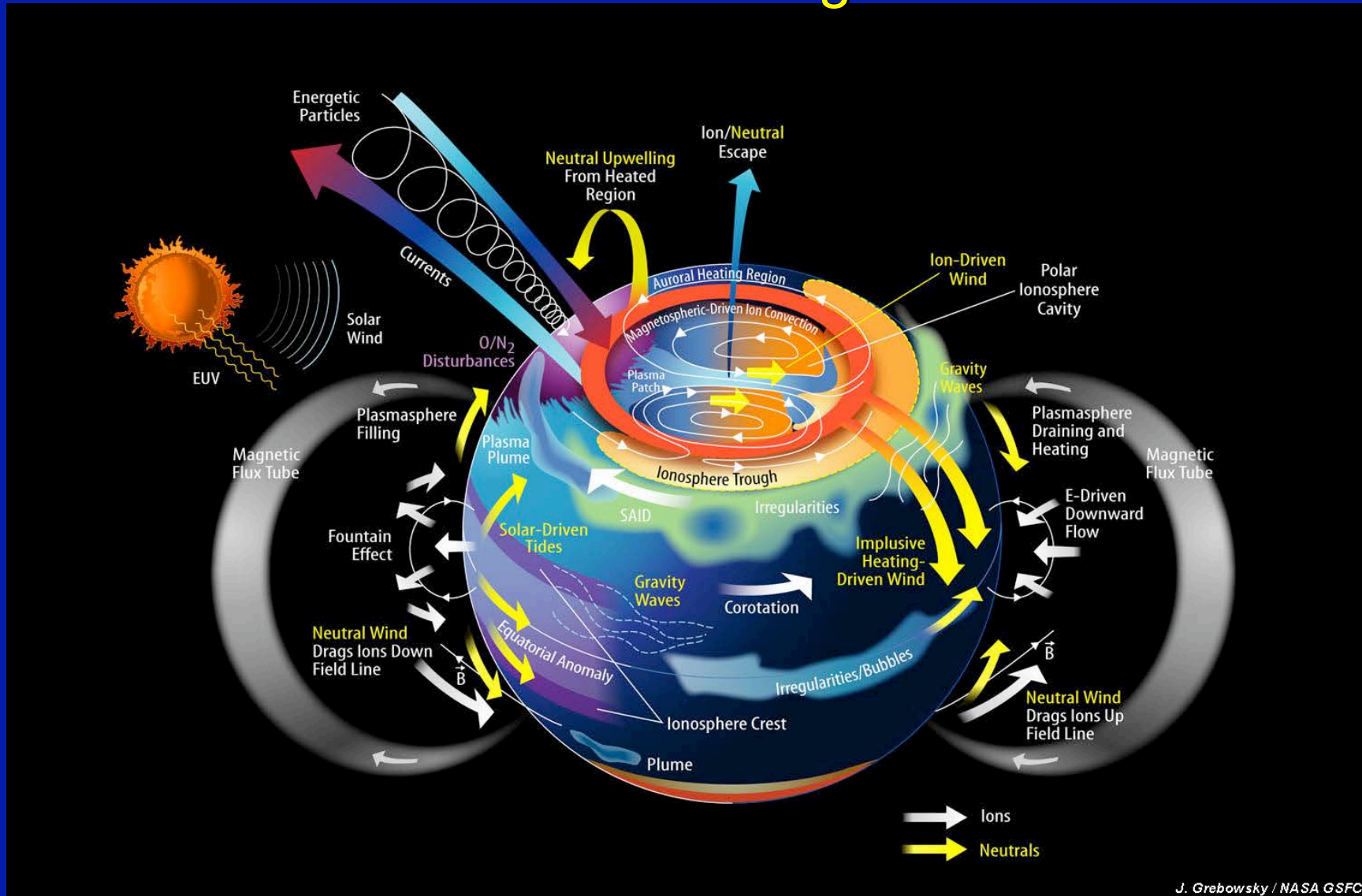
Interactions between components define behavior

Not contained in the individual pieces

Break into smaller digestible pieces -- lose behavior

Close-Up on the Upper Atmosphere

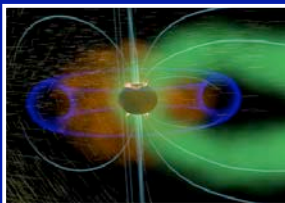
Remember what we are dealing with



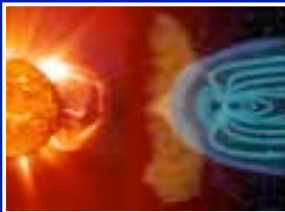
J. Grebowsky / NASA GSFC

Evidence for Active ITM Influences throughout Geospace

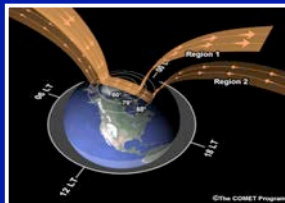
Four coupling pathways:



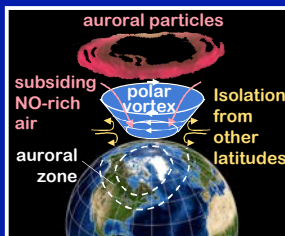
Mass & momentum outflows



Solar wind energy inflow



Active electrodynamic interactions



Reactive species: production & transport

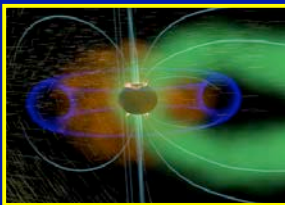
Fundamental physics:
Ion-neutral coupling

Cross-scale coupling

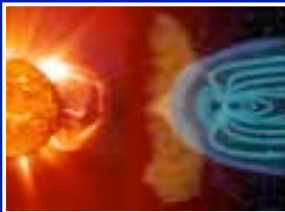
Chemical-dynamical coupling

Evidence for Active ITM Influences throughout Geospace

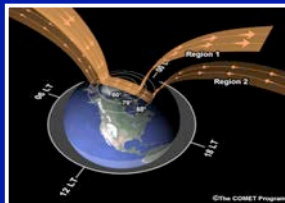
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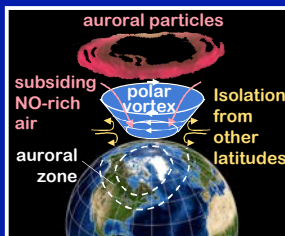
Mass & momentum outflows



Solar wind energy inflow



Active electrodynamic interactions

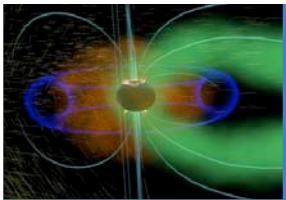


Reactive species: production & transport

Fundamental physics:
Ion-neutral coupling

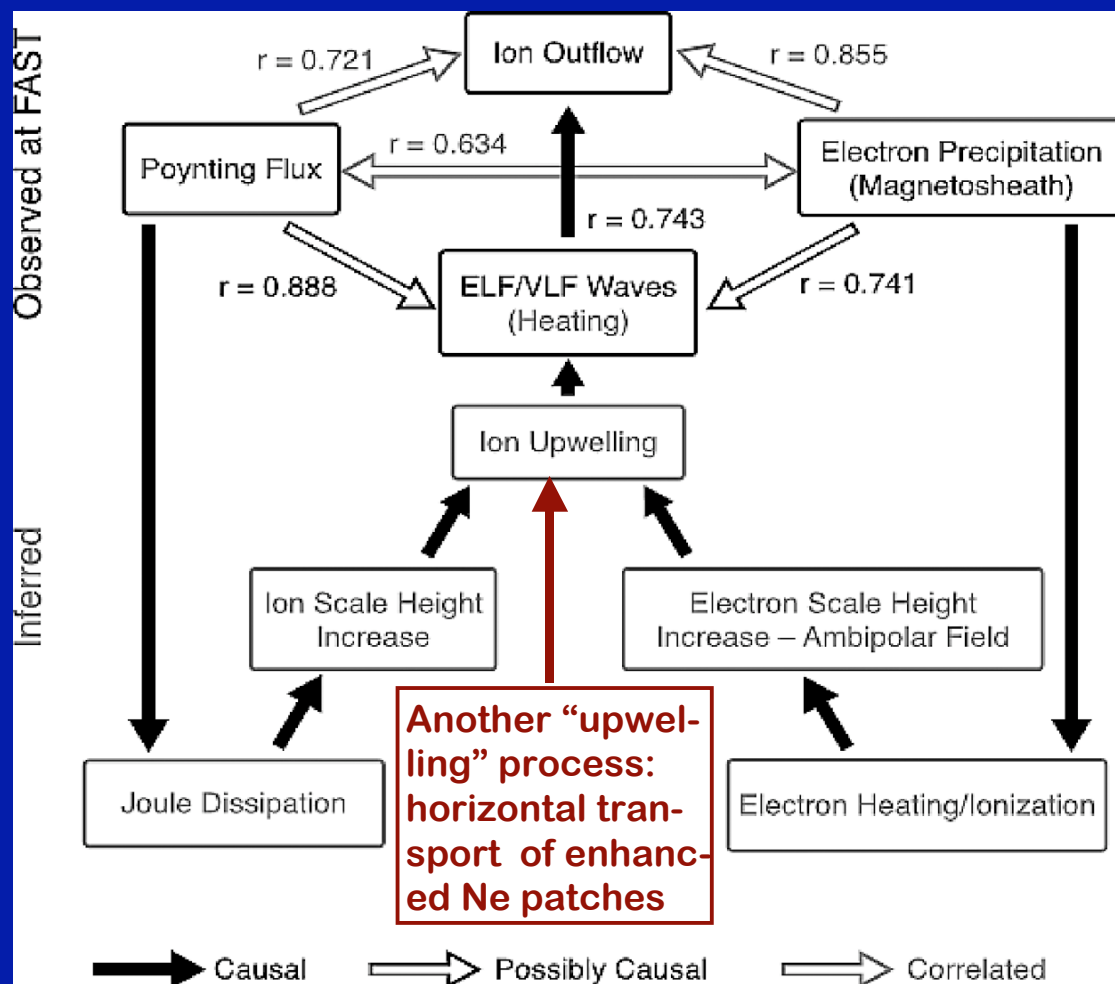
Cross-scale coupling

Chemical-dynamical coupling



Mass and Momentum Outflow

Ionospheric Outflow: 2-Step Process



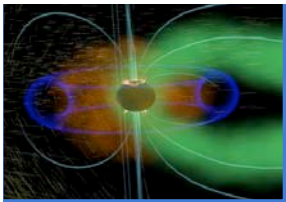
Outflow:
Acceleration
to > escape
velocity

Upwelling:
Increase in
scale height

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

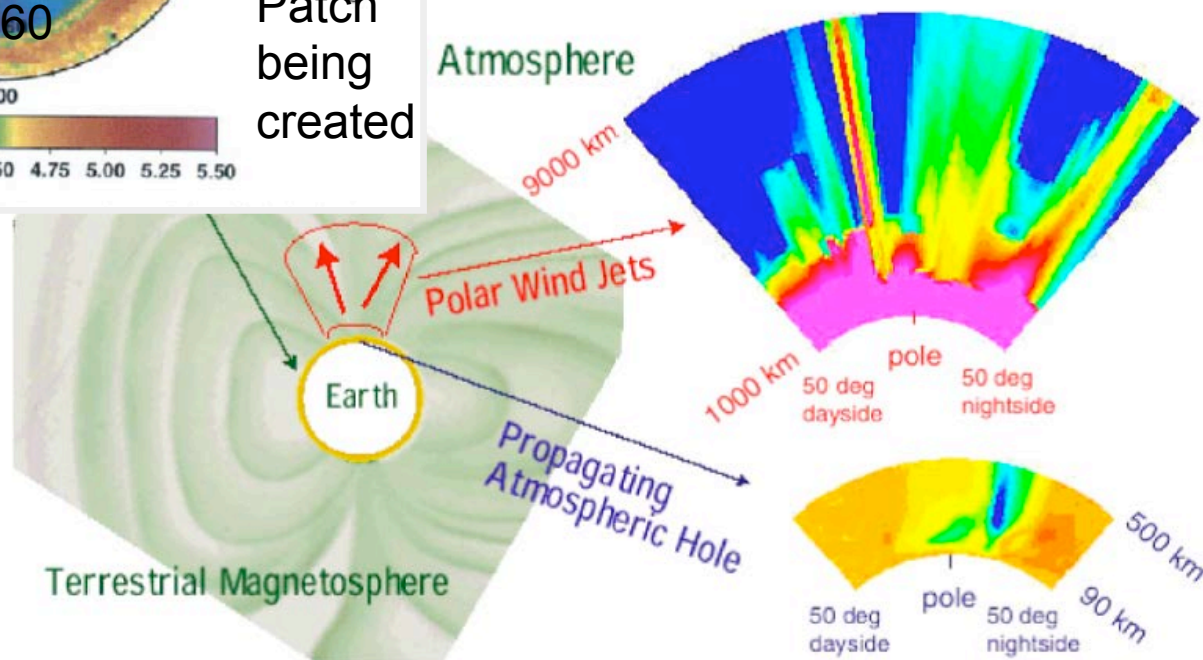
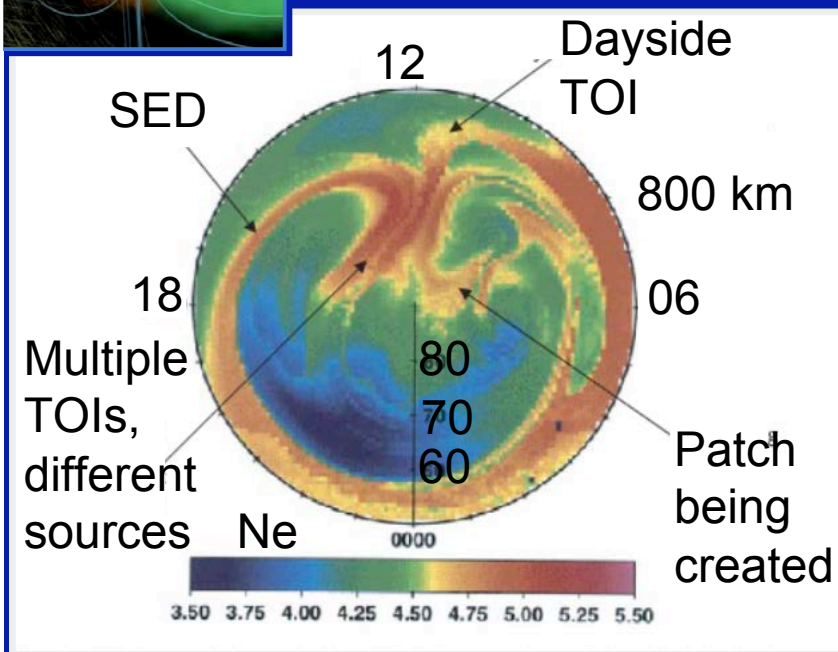
After Strangeway et al., [2005] as summarized in Moore
and Horwitz, 2007 and Lotko, 2007



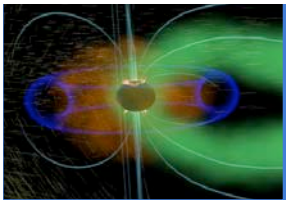


Mass and Momentum Outflow

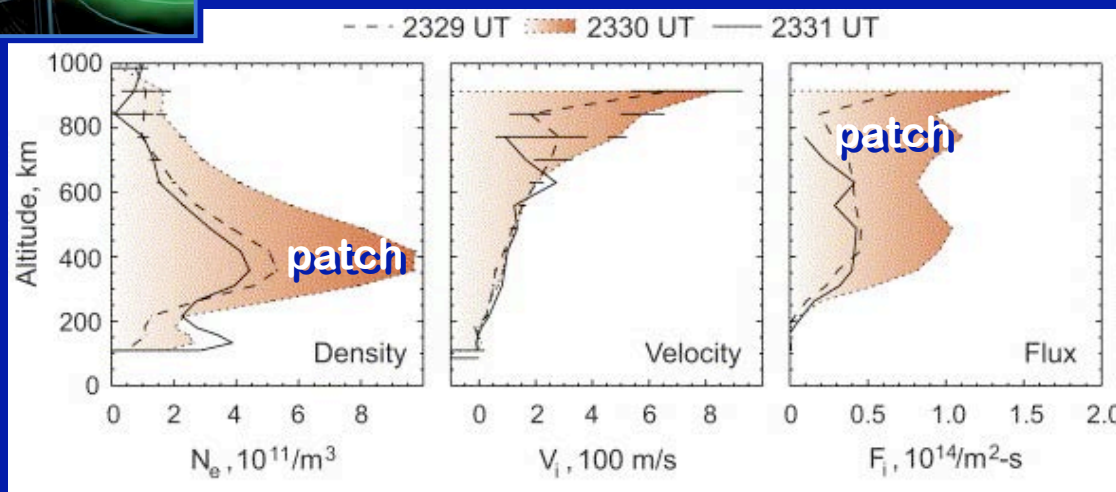
Accumulating evidence that most of the mass, momentum, and energy coupling occurs on relatively small spatial scales.



Schunk, GEM tutorial, 2006

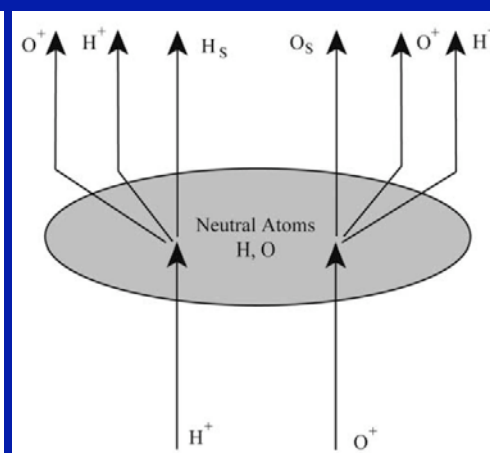
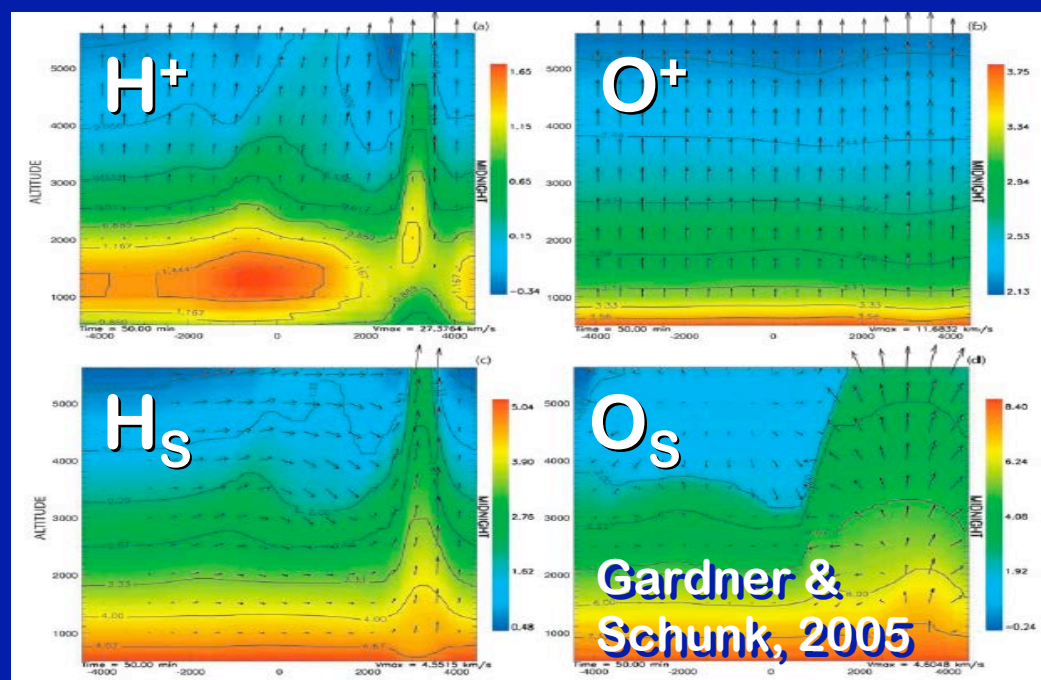


Mass and Momentum Outflow



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

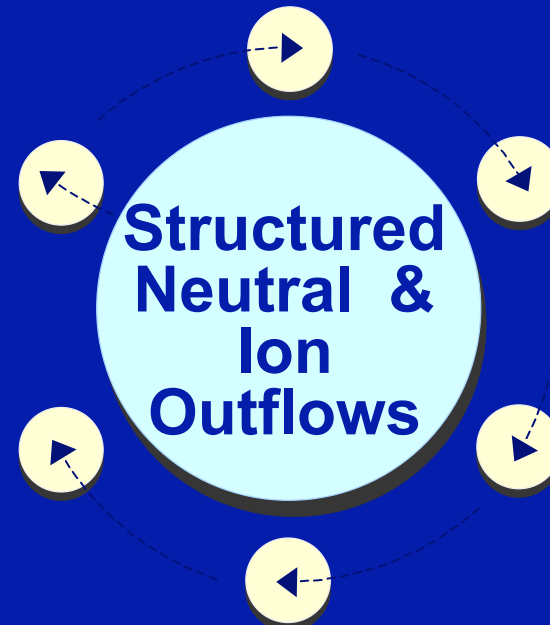
**Solar wind -
energy inflow**



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



16 June 2008

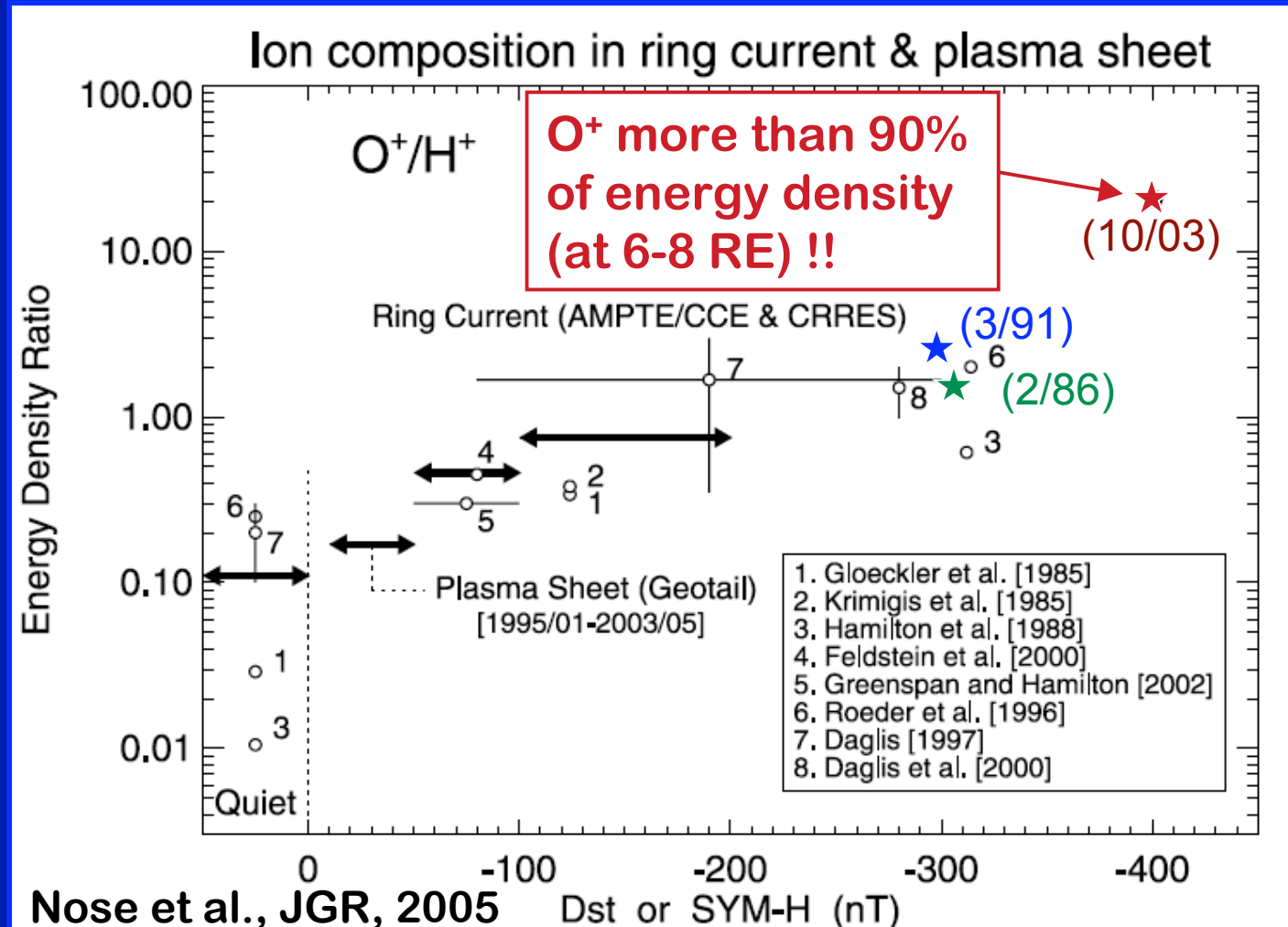
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Oxygen ions dominate the magnetospheric plasma during extreme events in the inner region. Patchy composition.

O^+ can dominate even for more moderate solar and magnetic activity levels. Variability due to multiple drivers.

[*Greenspan & Hamilton, JGR, 2002*]



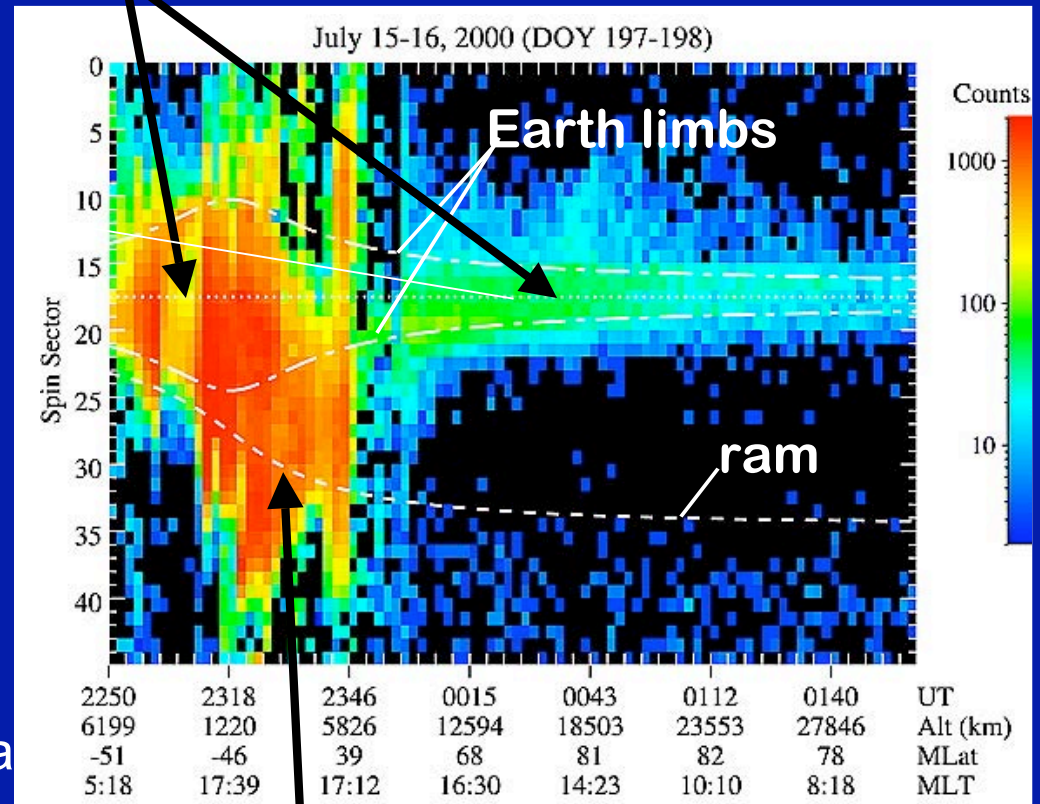
Ever-present <50 eV oxygen outflow

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 backslash O from H/H⁺ auroral precipitation [Shematovich, et al., 2006]

These upward O fluxes increase in intensity with increasing magnetic activity to a few $\times 10^9$ cm⁻²s⁻¹.

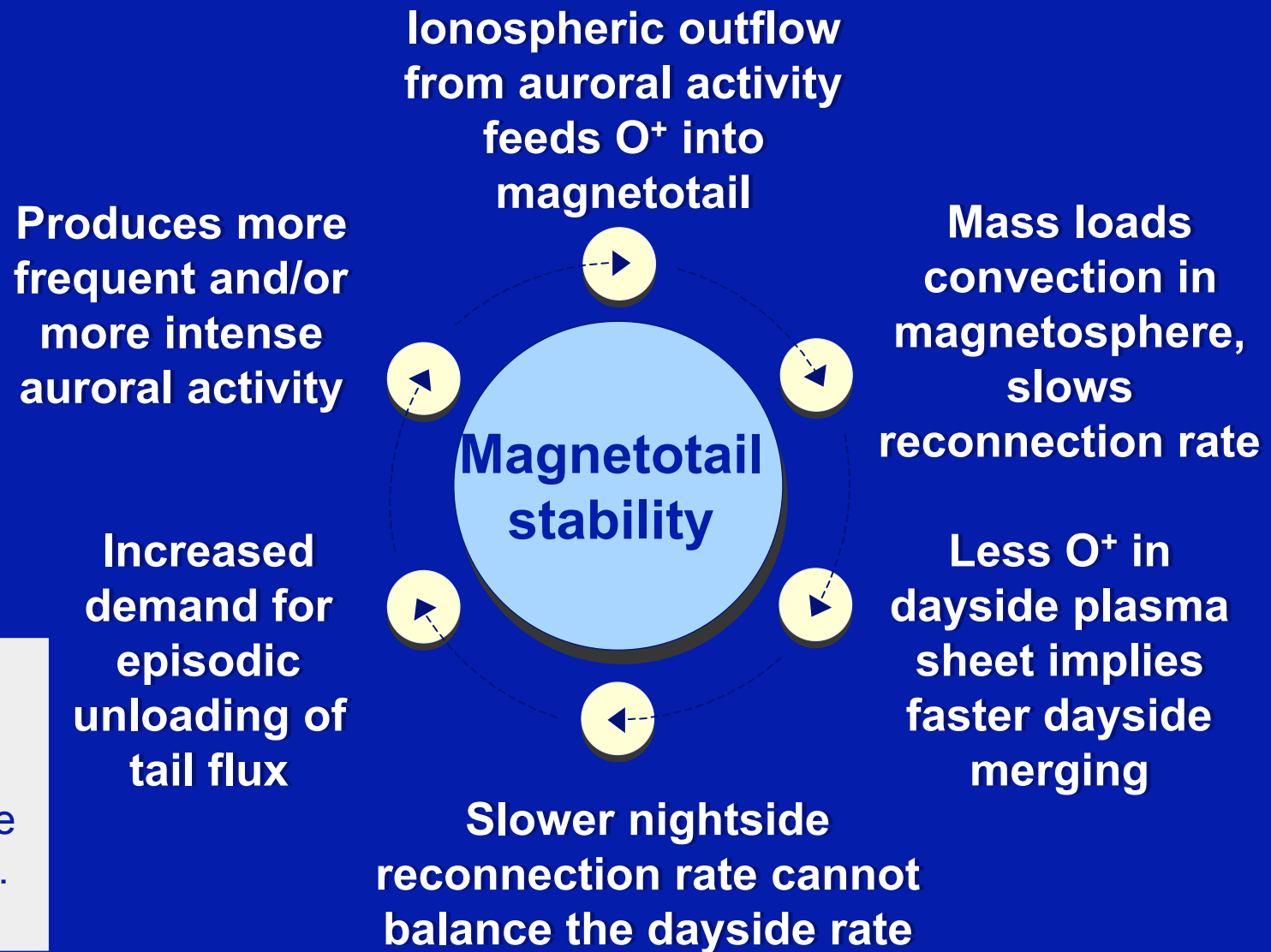
Higher energy auroral O



Hot O geocorona

Wilson et al., 2003; 2005

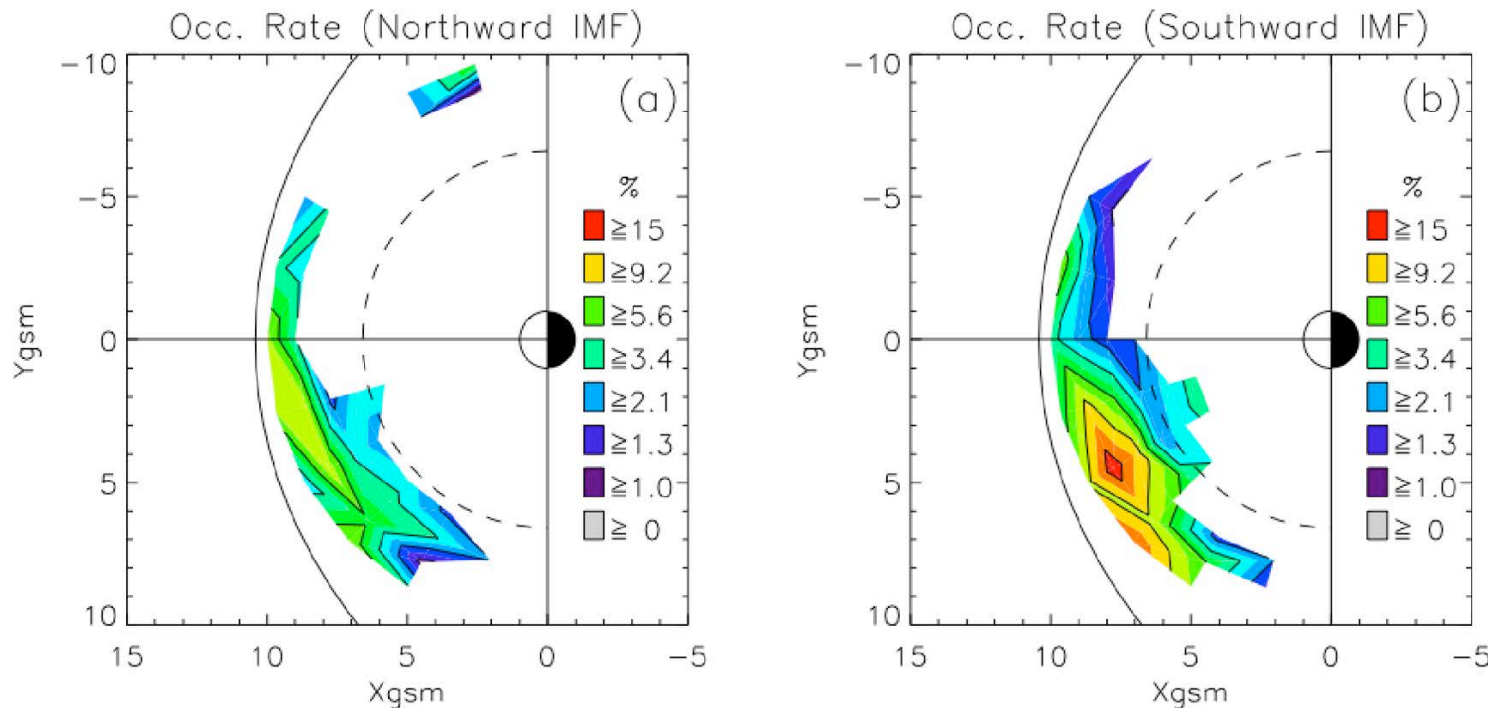
Suggested positive feedbacks on magnetotail stability



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



Evidence for the mass-loading of reconnection flows

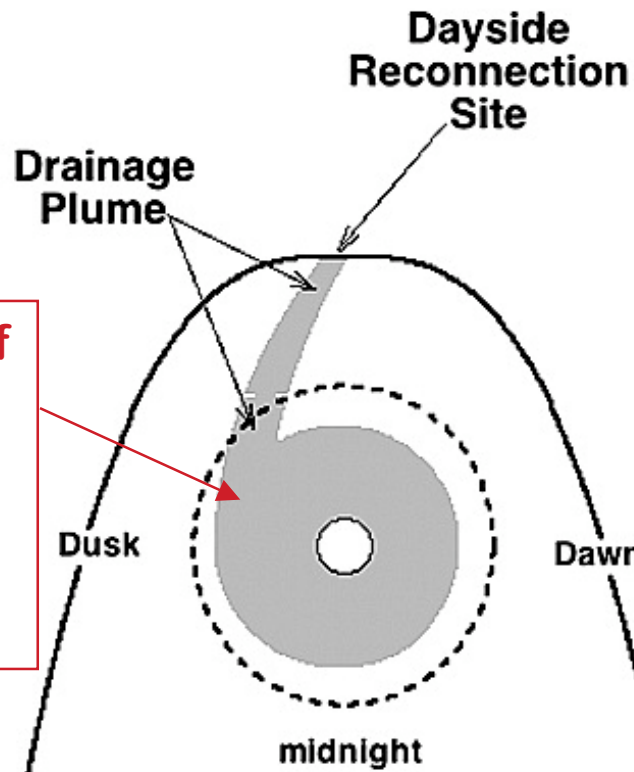


Observed occurrence rate of cold convecting ions at the dayside magnetosphere for northward (left) and southward (right) IMF [Chen and Moore 2006].

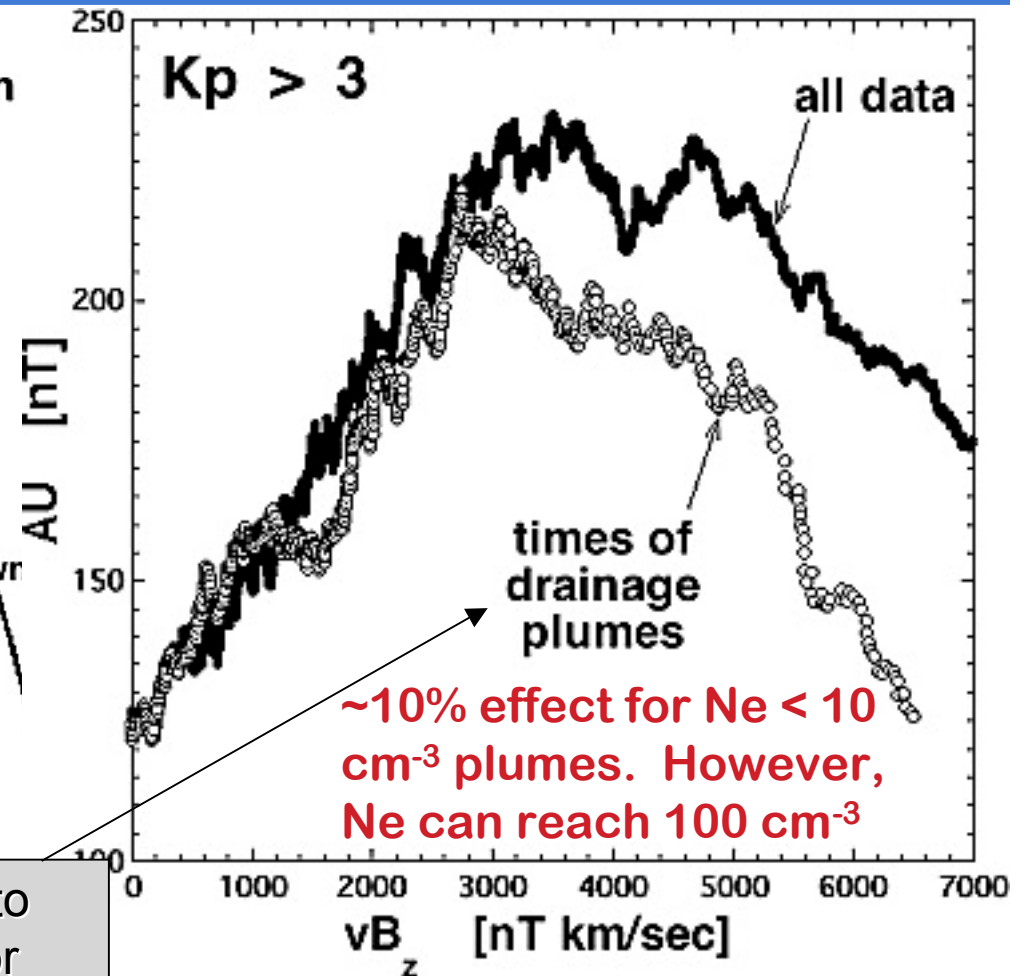
Consequences (review *Moore & Horwitz, 2007*): (1) reduces Alfvén speed of inflow to the dayside reconnection region, (2) slows reconnection, (3) reduces convection

Evidence mass-loading by drainage plume slows reconnection

Extension of ionospheric plasma into the inner magnetosphere



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



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ITM Mass Loading of Magnetospheric Convection

**Solar Wind
Electric Field**

Increases Φ_{pc} ,
enhances
convection

Reduces
reconnection
rate, Φ_{pc} , &
outflows

Greater
centrifugal
acceleration
of upflows

More
ionospheric
outflow

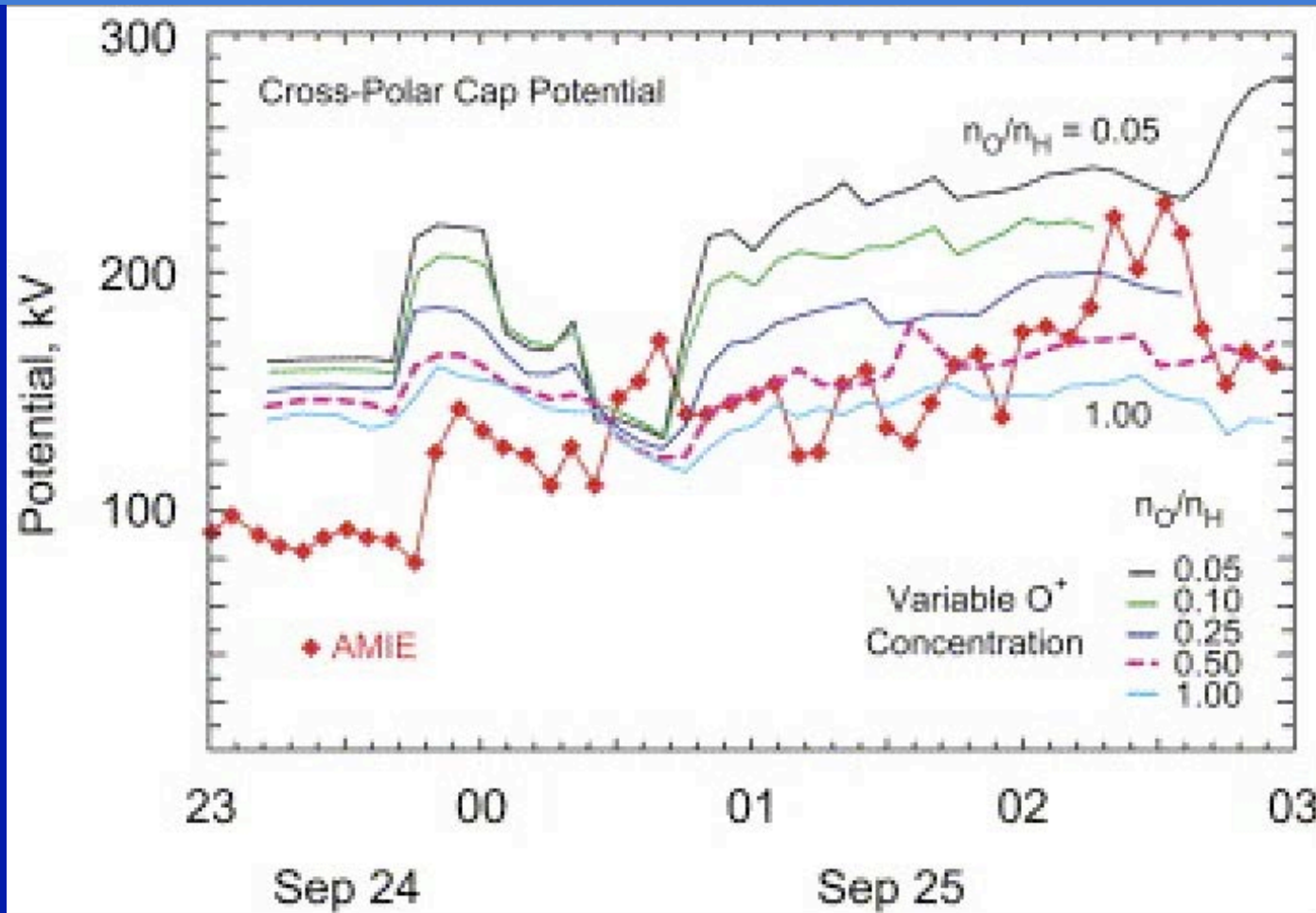
Mass-
loading
slows
convection

Higher O+
content of
plasmasheet

**Mass
Loading of
Convection**

Model result: Winglee
et al., 2002, as sum-
marized 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
- NO_x in the polar night. Quantities related to transport
- ITM Complex System: Instantaneous global patterns of energy inputs and electrodynamic parameters.