What Processes Influence Plasmaspheric Refilling?

(Really, I'd like to know)

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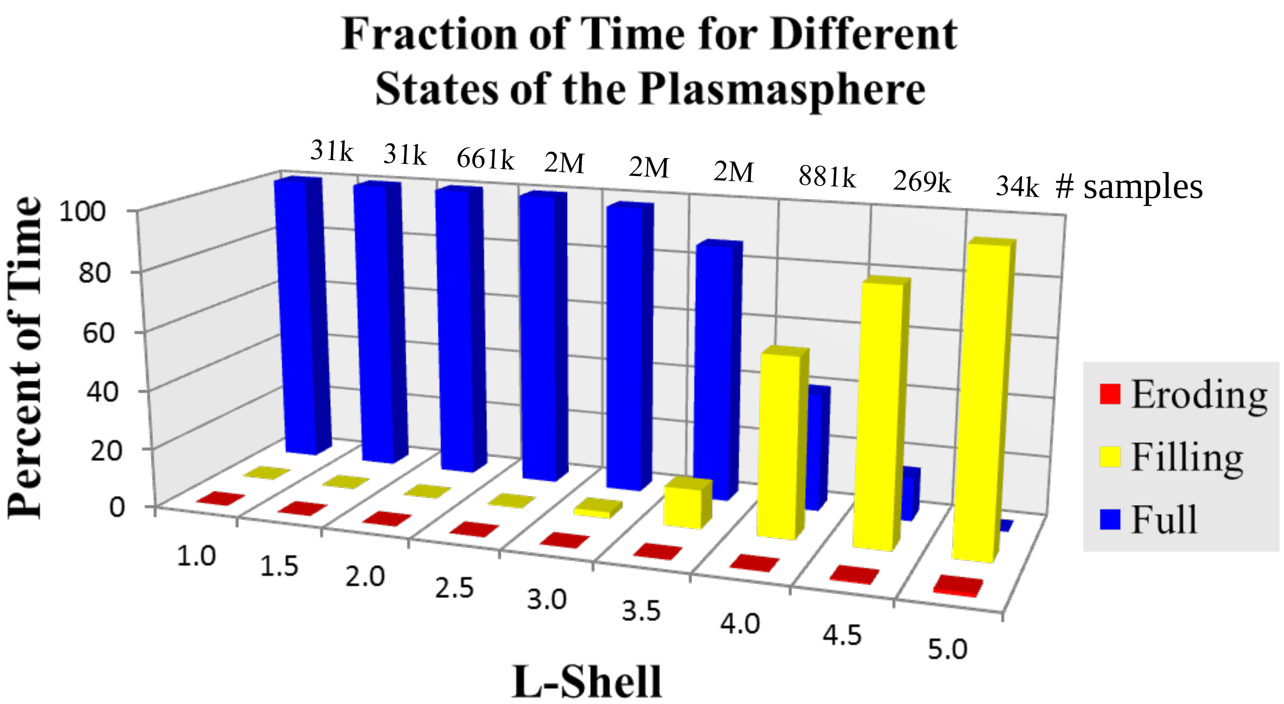
- Not so much new physics, but determining what is important to include?
- Cannot be complete. Where not, feel invited to help make it more so.
- Densities can vary by 4 orders in magnitude; boundary locations vary much?

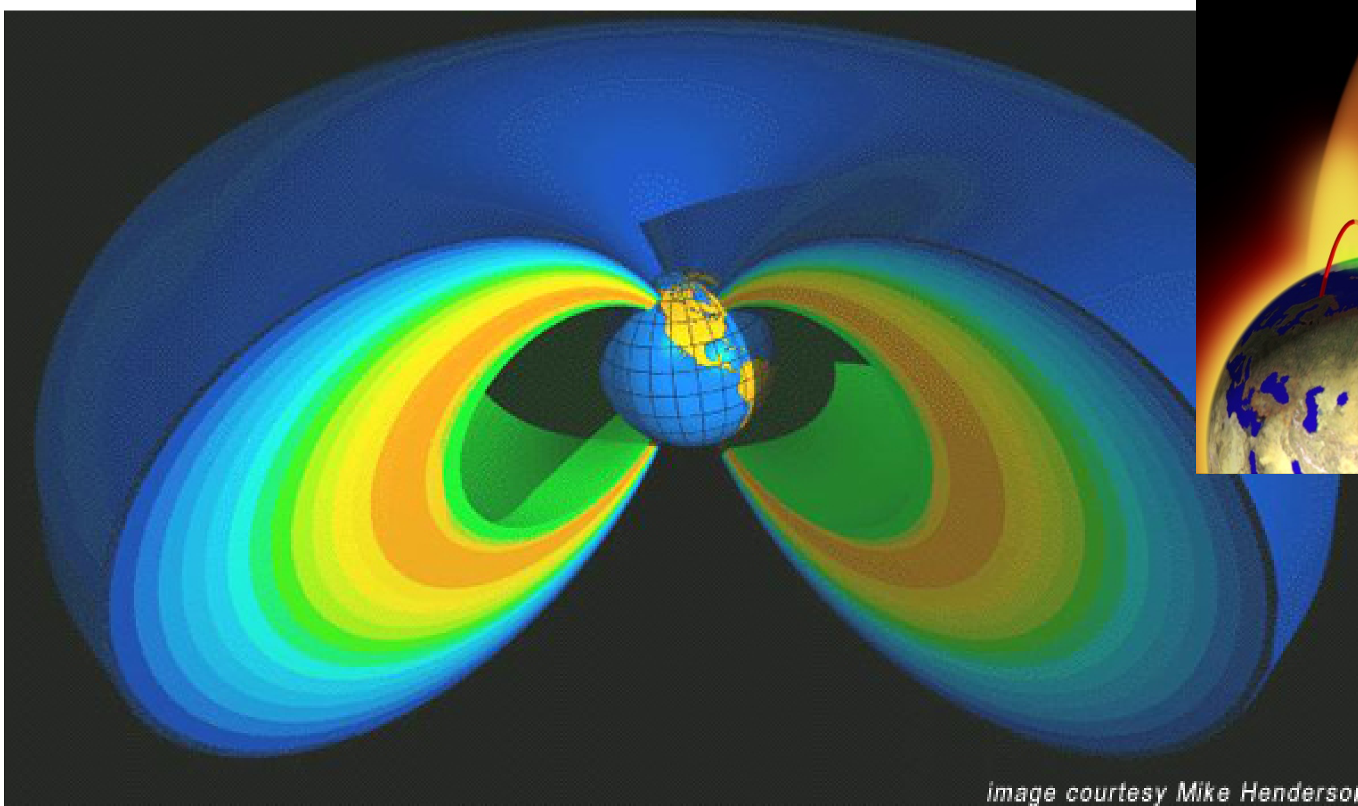
Outer Plasmasphere in Continuous Transition

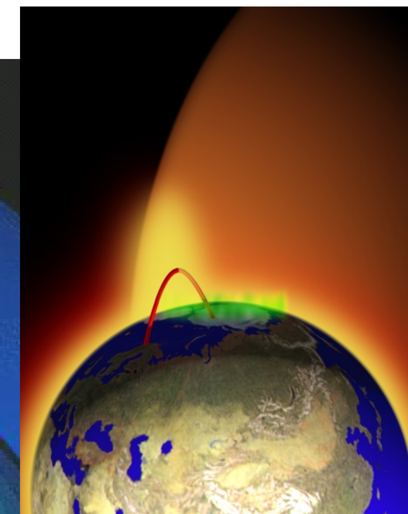


A simple demonstration of time spent refilling using Kp from the National Geophysical Data Center's Space Physics Interactive Data Center from 1974 through 2014 and Carpenter and Anderson's [1992] expression for the plasmapause L-shell: $Lpp_i = 5.6 - 0.46Kpmax$. The plasmasphere is assumed filled after 8-days of quiet at L=4 (Park, 1974) and in less (more) time inside (outside) that L-shell in proportion to $(L/4)^4$.

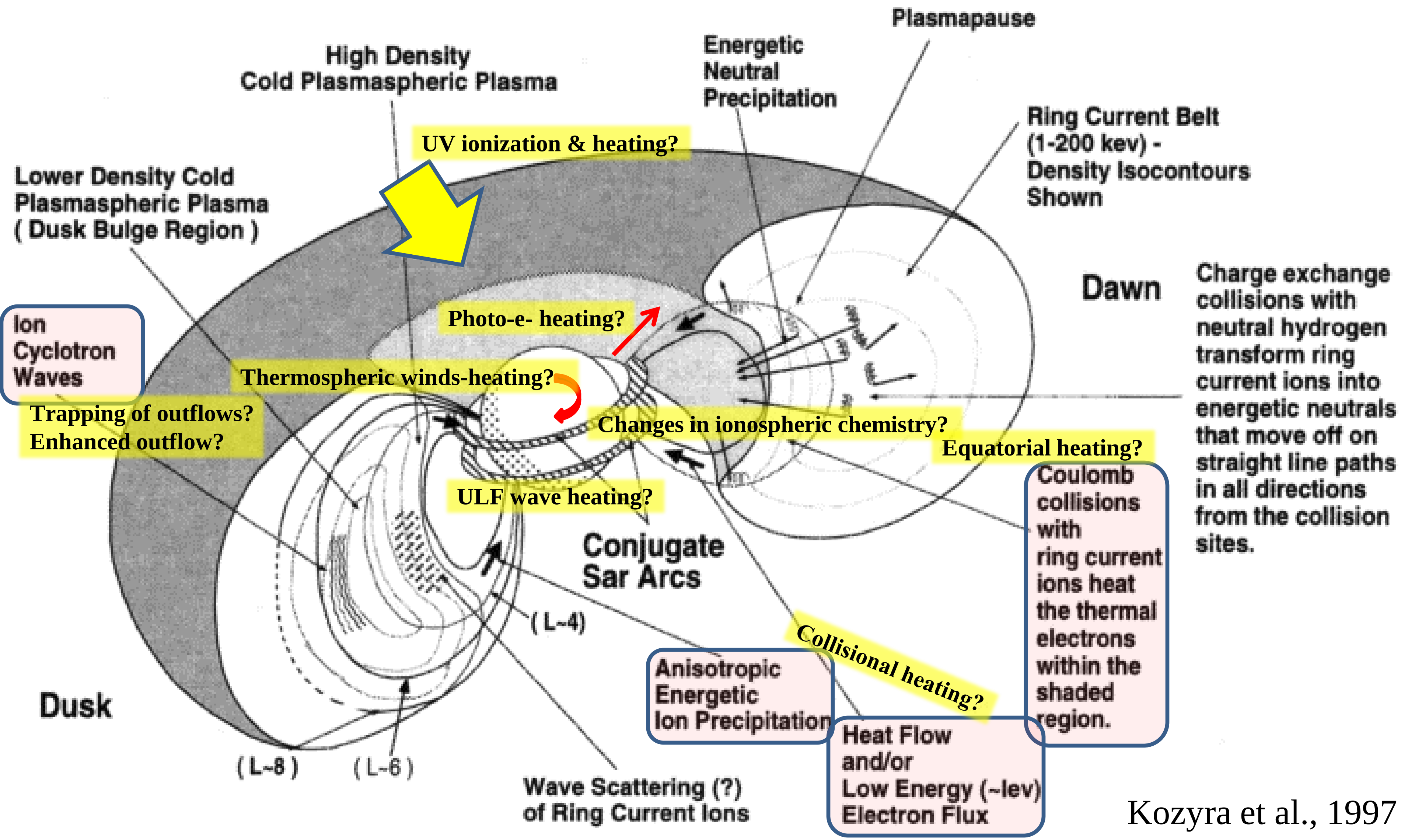
Matters of the Plasmasphere

- Why should anyone care about the plasmasphere?
  - Cold, dense plasma influences wave modes, wave propagation, wave-particle instability, particle-scattering effects, spacecraft charging
- There may be ionospheric outflow at all latitudes and local times.





“On the Table” for Influencing Plasmaspheric Outflow (an incomplete treatment)



Kozyra et al., 1997

Extra Heating Needed

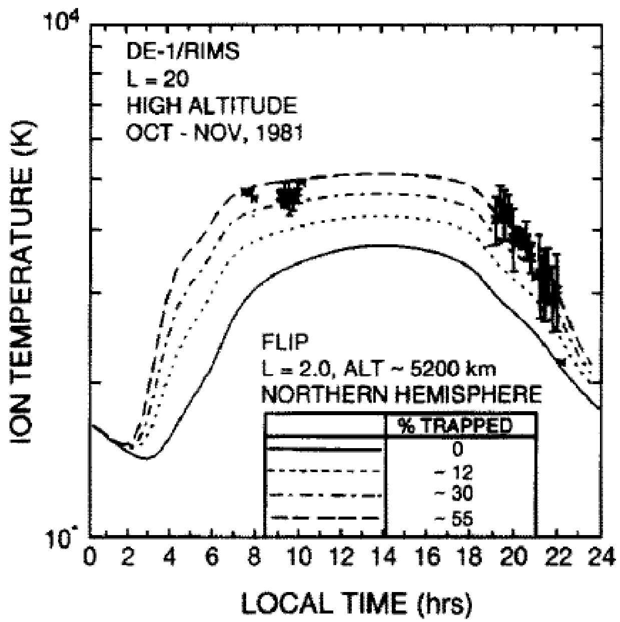


Fig. 10. Observed ion temperatures (x) together with calculated temperatures for different percentages of photoelectron trapping plotted versus local time. (After /6/.)

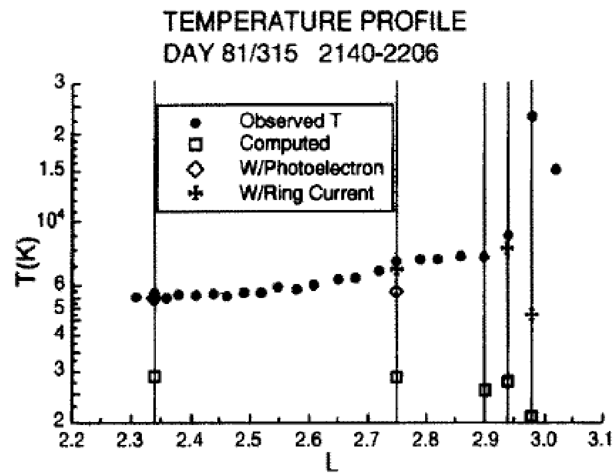


Fig. 11. H+ temperature profile observed by DE1/RIMS together with calculated temperatures calculated by FLIP for selected locations with indicated additional heat sources.

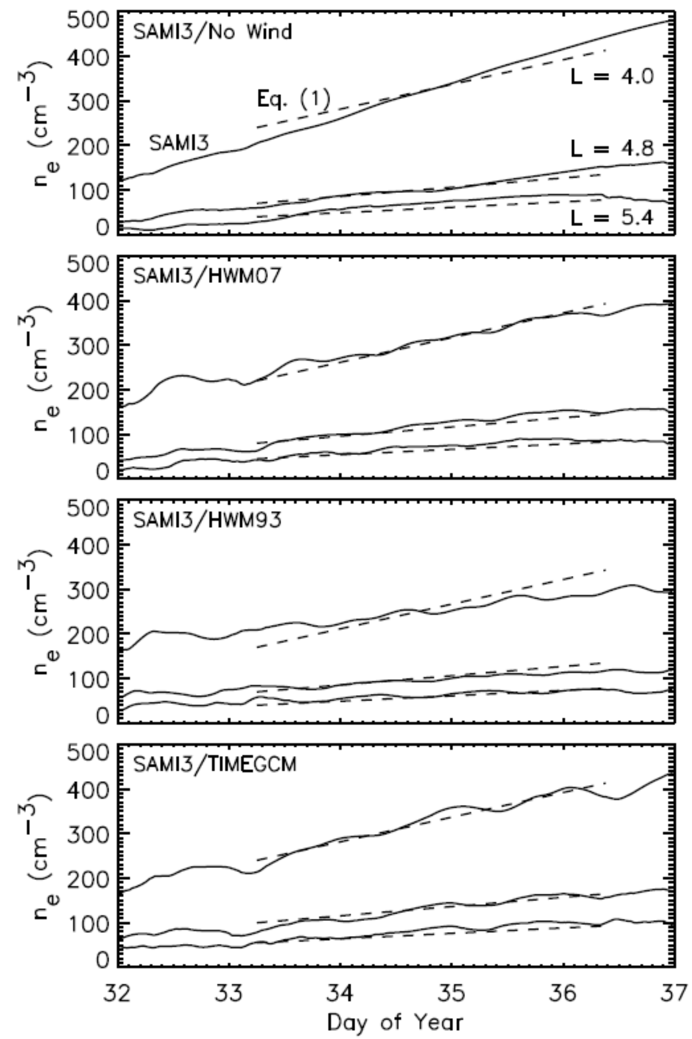
Comfort et al [1997] found extra heating was required to explain observed temperatures in both the inner plasmasphere and outer plasmasphere during refilling. Could come from greater photoelectron heating efficiency, ring current collisional heating, and wave-particle heating

One Recent Modeling Effort Focused on Effects of the Thermosphere during Quiet Times

- SAMI3 (Krall et al., 2014) solves the continuity and momentum fluid equations for 7 ions and includes the thermospheric wind-driven dynamo electric field.
- The temperature equation is solved for 3 atomic ions and electrons, with a higher photoelectron heating rate than used previously.
- The Weimer global electric field is used, but not designed for subauroral latitudes and the parallel interchange mode is not included in the simulation, which may be significant during quiet conditions.
- Krall et al., (2014) find thermospheric winds must be included to represent observed asymmetric plasmaspheric structure in the equatorial plane, yet this also results in lower refilling rates than without winds.
- Rough agreement with IMAGE/RPI observations are found, but measurements are limited in MLT and time.
- SAMI3 refilling rates are similar to RPI derived rates, though the trend tends to be smaller than observed at low L-value and higher at higher L.

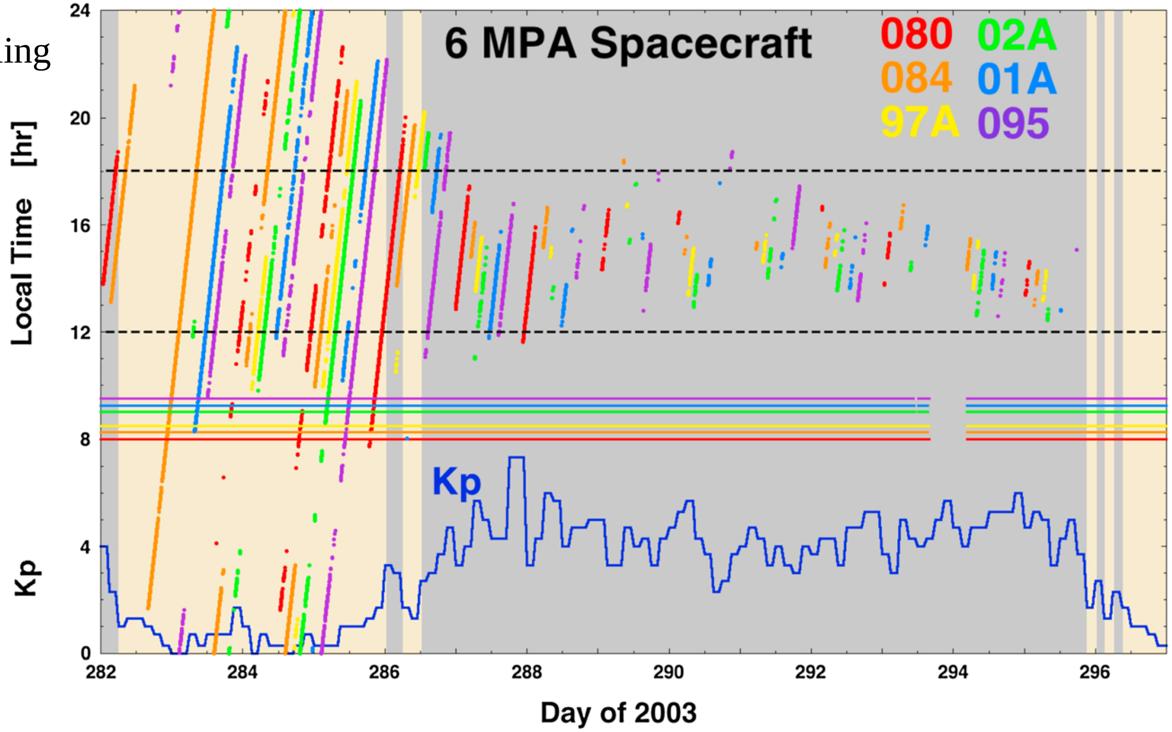
$$dn_e/dt = 3.81(6.8/L)^{4.94}\ cm^{-3}day^{-1}$$

$$= 4.4\ cm^{-3}day^{-1} @\ L = 6.6$$



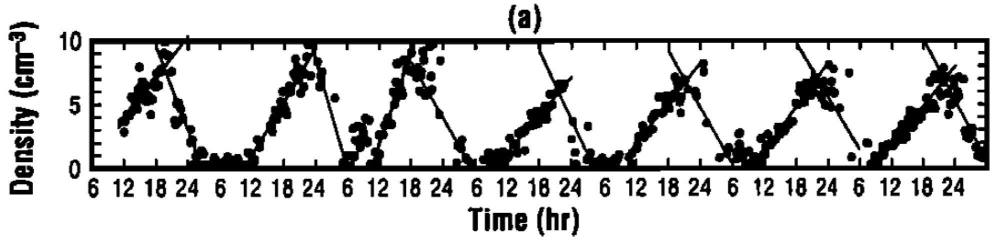
Persistent Plumes May Require 10x the Refilling Rate to Explain

- Borovsky et al. (2014) find what appears to be drainage plumes persisting for many days with elevated Kp.
- Initial drainage (1.5-2 days) of the outer plasmasphere is sometimes followed by sustained, narrow-MLT plume-like high densities for as long as 11 or more days.
- Refilling rates of 100-500 cm-3 day-1 may be necessary without any other source. Refilling rates at geosynchronous orbit have previously been found to be 0.6-50 cm-3 day-1 (Denton et al., 2012 and references therein) and **possibly include early to late variation in the refilling rate**.
- Other possible sources include substorm disruption, velocity-shear instability, and ionospheric, high-latitude tongue of ionization.
- Notably, Krall and Huba (2013) find refilling within a factor of 2 from their modeling with SAMI3 at L=2,3, but diverges at L=5 where SAMI3 is low by a factor of 5. **Is the problem with models reaching observed refilling rates greater at larger L?**

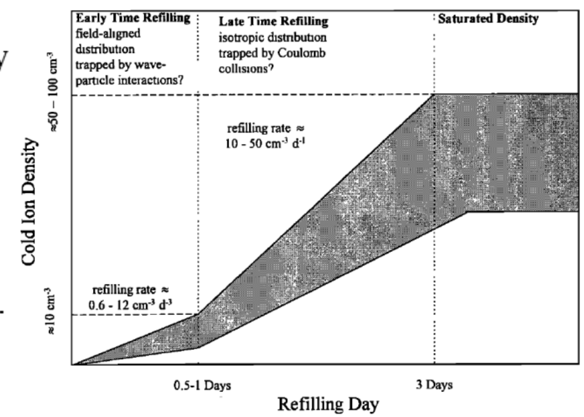


Is Refilling a Two-Stage Process?

- Geosynchronous orbit affords a view of flux-tube refilling both at low densities characteristic of the trough and at higher densities associated with the plasmasphere. Refilling is refilling isn't it?

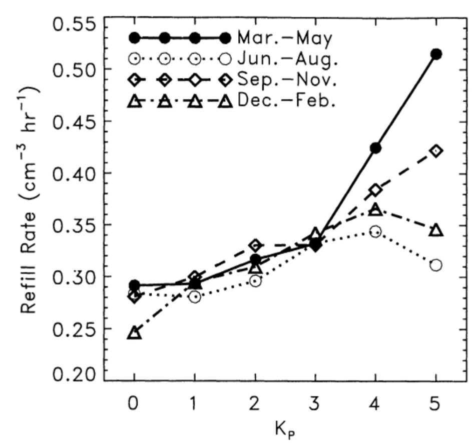


- Gallagher et al., 1998 used Higel & Wu, 1984 GEOS 2 measurements over 7 consecutive days to obtain the $Refilling\ rate = 13.4 \pm 1.9\ \ [cm^{-3}day^{-1}]$. In this case the rate is based on the gradient of each linearly-fitted rising-density profile.



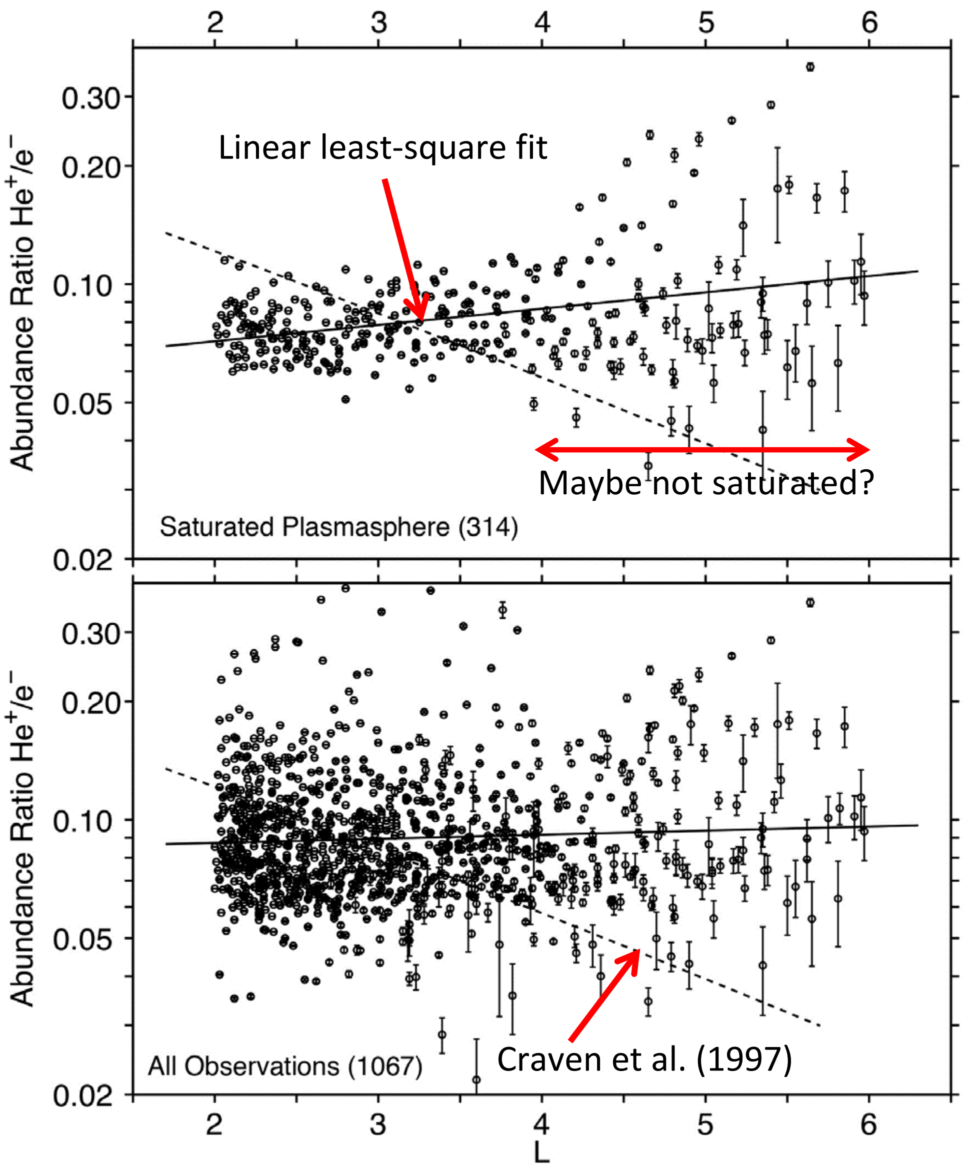
- Lawrence et al., 1999, using 7-years of LANL MPA measurements found refilling at low densities (first 24-h) much less than during later refilling (2-4 days). Rates are based on the density change since start of refilling in days.
  $Early\ rate = 0.6 - 12\ \ [cm^{-3}day^{-1}]$
  $Late\ rate = 10 - 50\ [cm^{-3}day^{-1}]$

- Su et al., 2001 further extended MPA studies to include 11-years of data and characterization of refilling as a function of activity, local time, season, and solar cycle phase. Here however rates were quantified as the time a flux tube is exposed to refilling, dependent on convection, finding
  $Early\ rate = 2.5 - 6.5\ \ [cm^{-3}day^{-1}]$
  $Late\ rate = 10 - 25\ [cm^{-3}day^{-1}]$



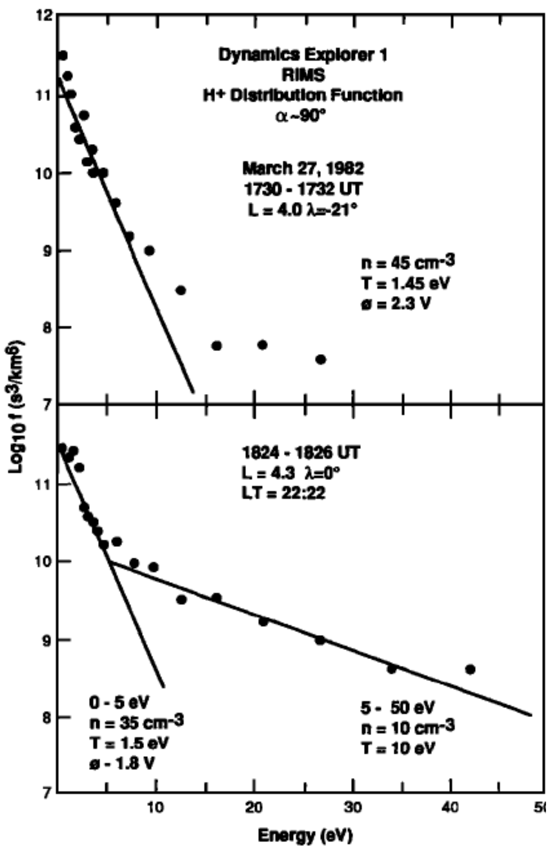
Mass-Dependent Outflow

- Sandel (2011) found He+ abundance changed during refilling, suggestive of mass dependent refilling rates.



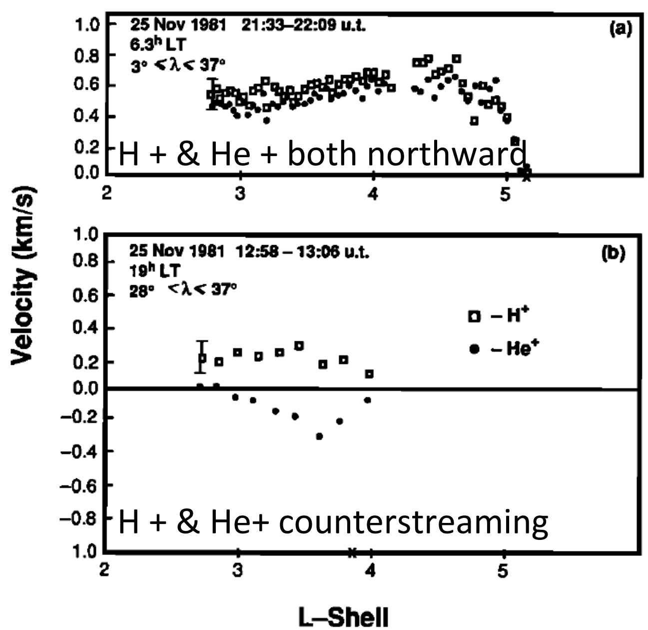
There is More to Refilling Than Might be Expected?

Suprathermal ions were found at the magnetic equator during refilling.

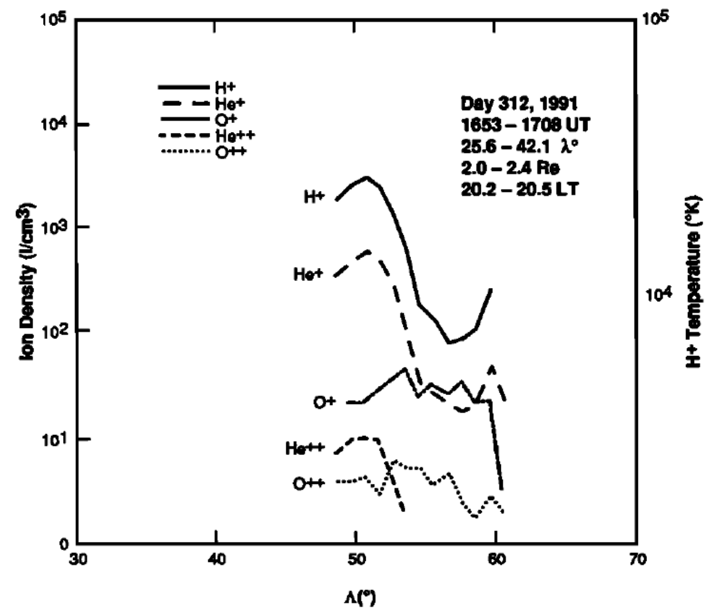


Singh and Horwitz (1992)

Counter streaming H+ and He+ from the summer and winter hemispheres, respectively.

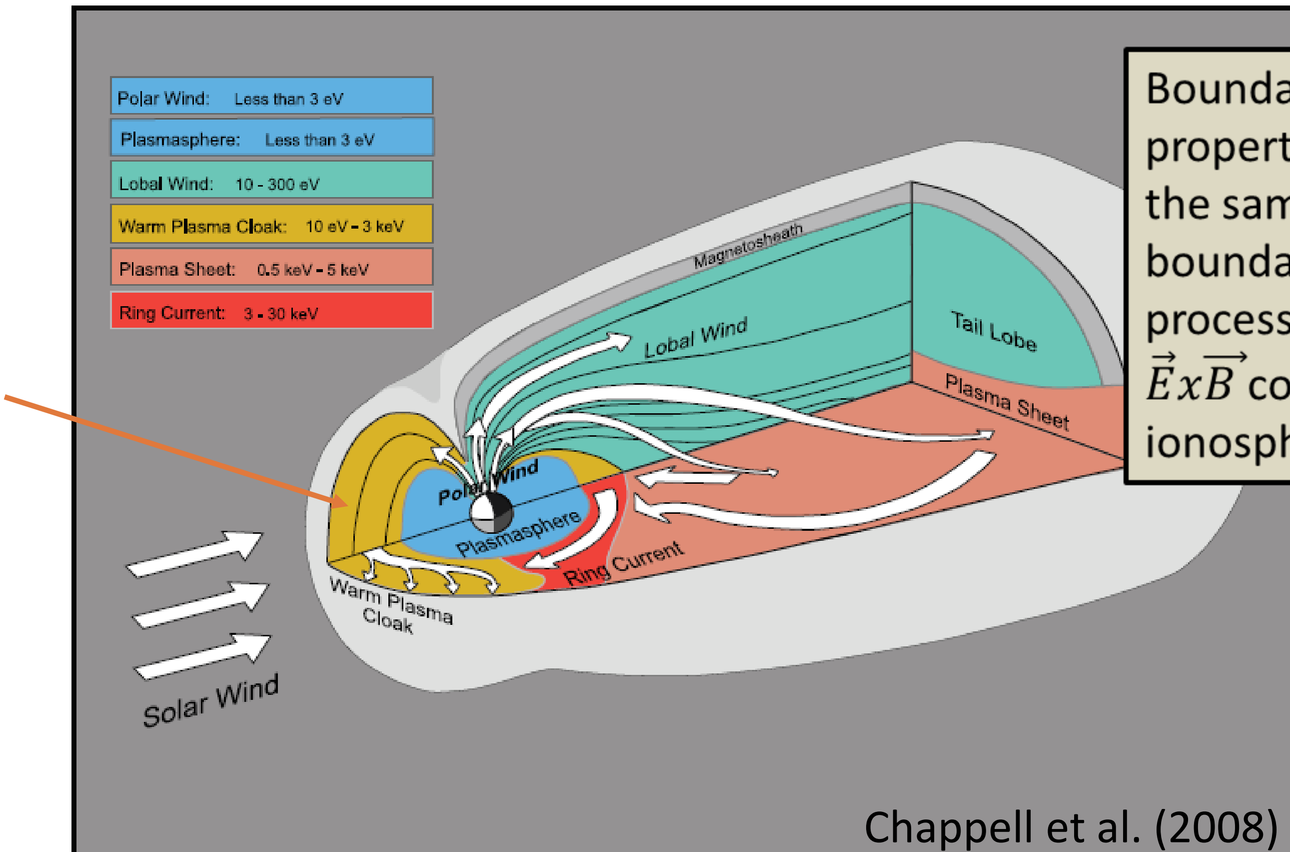


Heavy ions become prominent in early-stage refilling or is a storm effect?



Then There’s the Warm-Plasma Cloak

- The plasma cloak is a bidirectional field-aligned distribution with energies from a few eV to <400 eV, found just outside the ~1 eV plasmasphere.
- Thought to be ionospheric plasma energized through a stepwise process at high latitudes.
- Does this or other high latitude sources contribute to or confuse interpretations of plasmasphere refilling and dynamics?



Chappell et al. (2008)

Boundaries in plasma properties may not be the same as boundaries in plasma processes, such as $\vec{E} x \overrightarrow{B}$ convection or ionospheric outflow.

“The experimenter who does not know what he is looking for will not understand what he finds.”
Claude Bernard

“The more you explain it, the more I don't understand it.”
Mark Twain

“Anyone who isn't confused really doesn't understand the situation.” Edward R. Murrow

“It is difficult to get a man to understand something when his salary depends upon his not understanding it.”
Upton Sinclair

What is the significance of thermospheric properties and dynamics upon refilling?
What changes in ionospheric chemistry influence refilling?
How effectively does photoelectron heating influence refilling?
Do the physical processes operating during refilling change as refilling progresses?
What is the role of mass and how that changes during refilling?
What high altitude processes influence refilling?
Does plasma of different origin and process confuse our picture of plasmaspheric refilling?

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