Comparing the Earth’s ionosphere/thermosphere with the solar chromosphere

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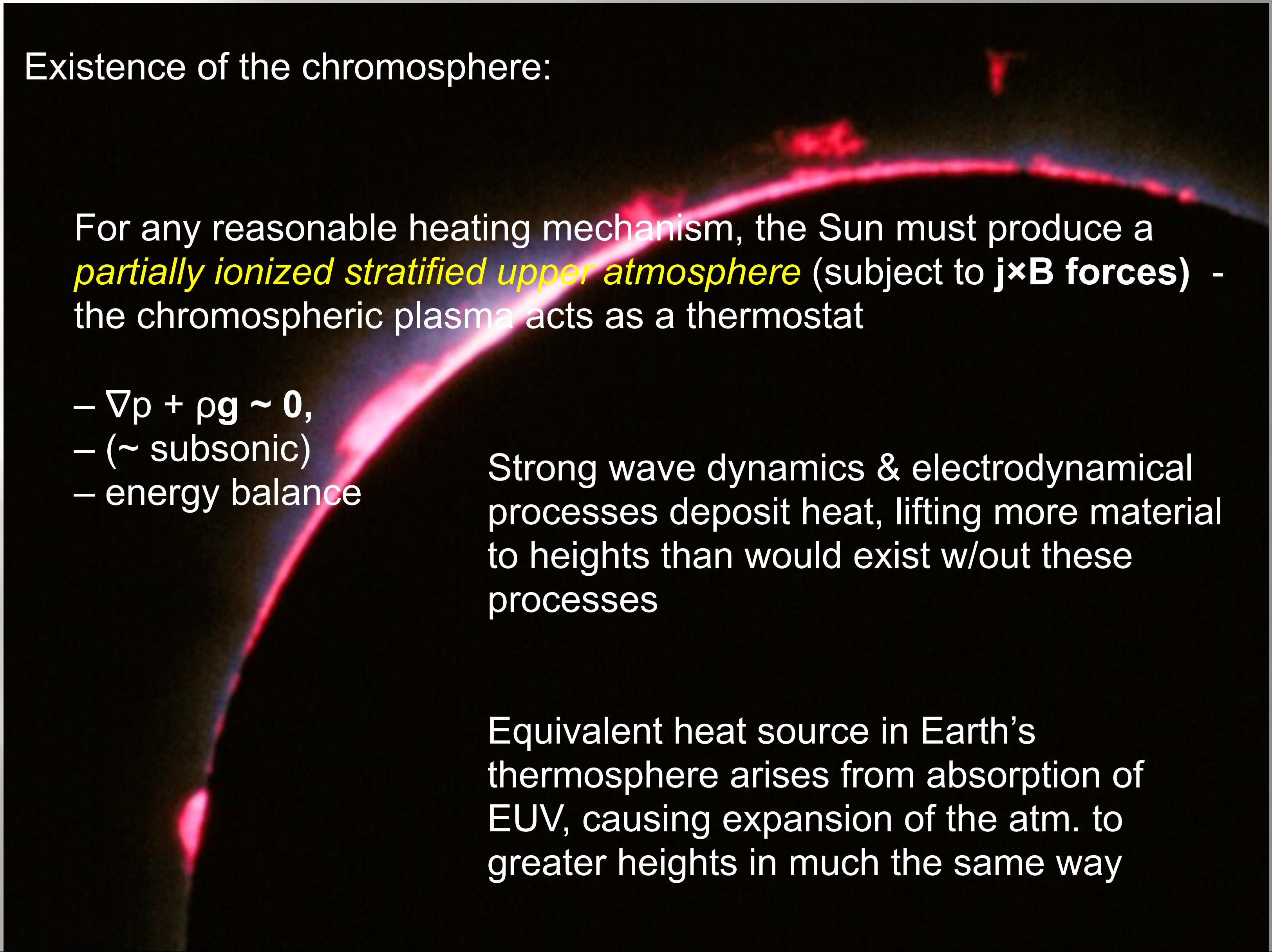
LWS TR&T Focused Science Team on Plasma Neutral Gas Coupling

- Chromosphere component;
  - My team: prominences
  - Phil Judge: Thermal & magnetic models for ion-neutral chromospheric studies
  - James Leake: Modeling effects of ion-neutral coupling on reconnection & flux ememergence in chromosphere

LWS TR&T Focused Science Team on Plasma Neutral Gas Coupling

- Ionosphere component;
  - Geoffrey Crowley: Thermosphere-ionosphere
  - Jiuhou Lei: Ion-neutral processes in the equatorial F-region
  - Wenbin Wang: Global ionospheric electric field variations

Thermosphere-Ionosphere vs. chromosphere



Existence of the chromosphere:

For any reasonable heating mechanism, the Sun must produce a *partially ionized stratified upper atmosphere* (subject to **j×B forces**) - the chromospheric plasma acts as a thermostat

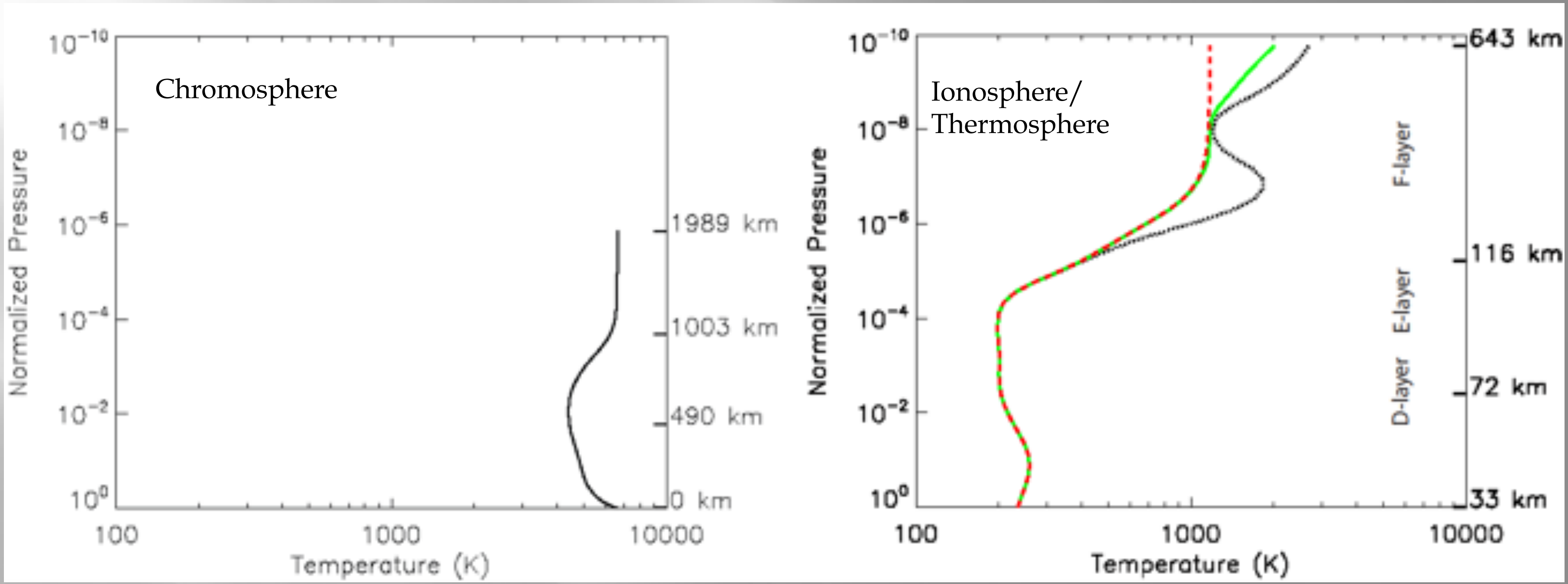
– $\nabla p + \rho \mathbf{g} \sim 0$,
– (~ subsonic)
– energy balance

Strong wave dynamics & electrodynamical processes deposit heat, lifting more material to heights than would exist w/out these processes

Equivalent heat source in Earth's thermosphere arises from absorption of EUV, causing expansion of the atm. to greater heights in much the same way

Ionosphere/Thermosphere (I/T) and chromosphere commonalities

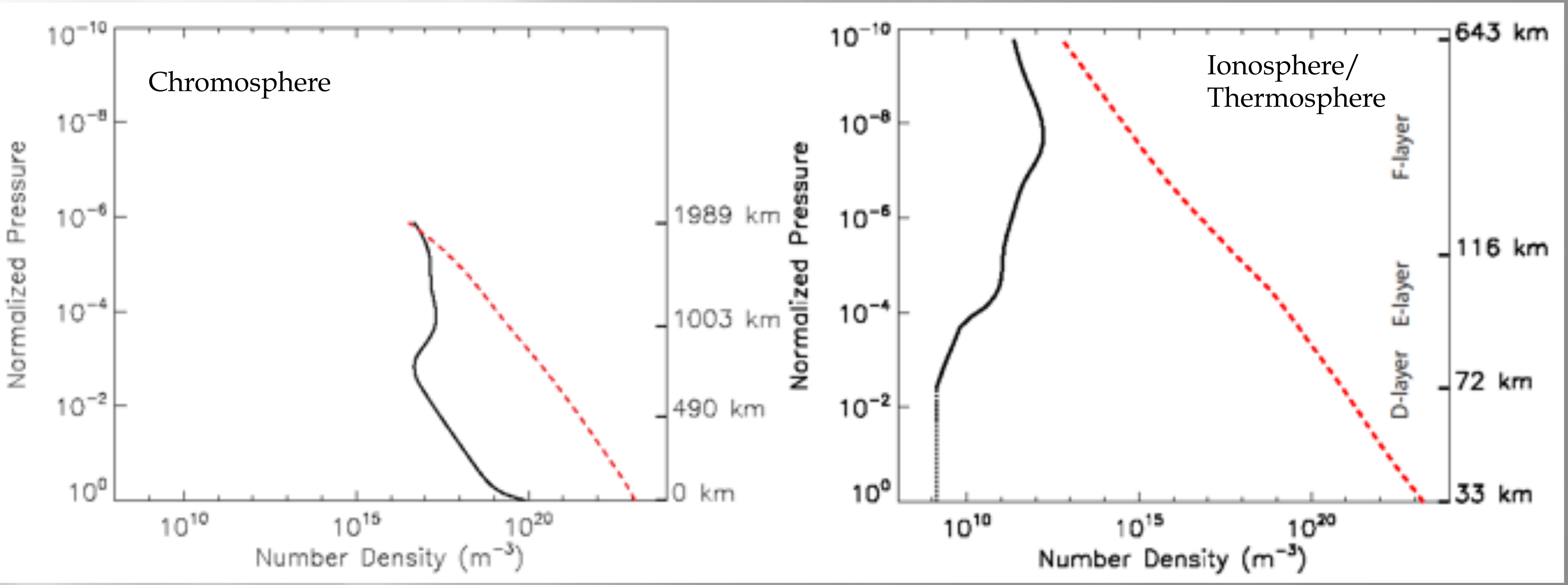
- Gravitationally bound partially ionized fluid
- Weakly ionized
- Temp. increases with height



Single-fluid temp (K) in the ALC7 chromosphere (left) and neutral (red dashed), ion (green solid), and electron (black dotted) temps in the TIMEGCM I/T (right).

Commonalities, con't….

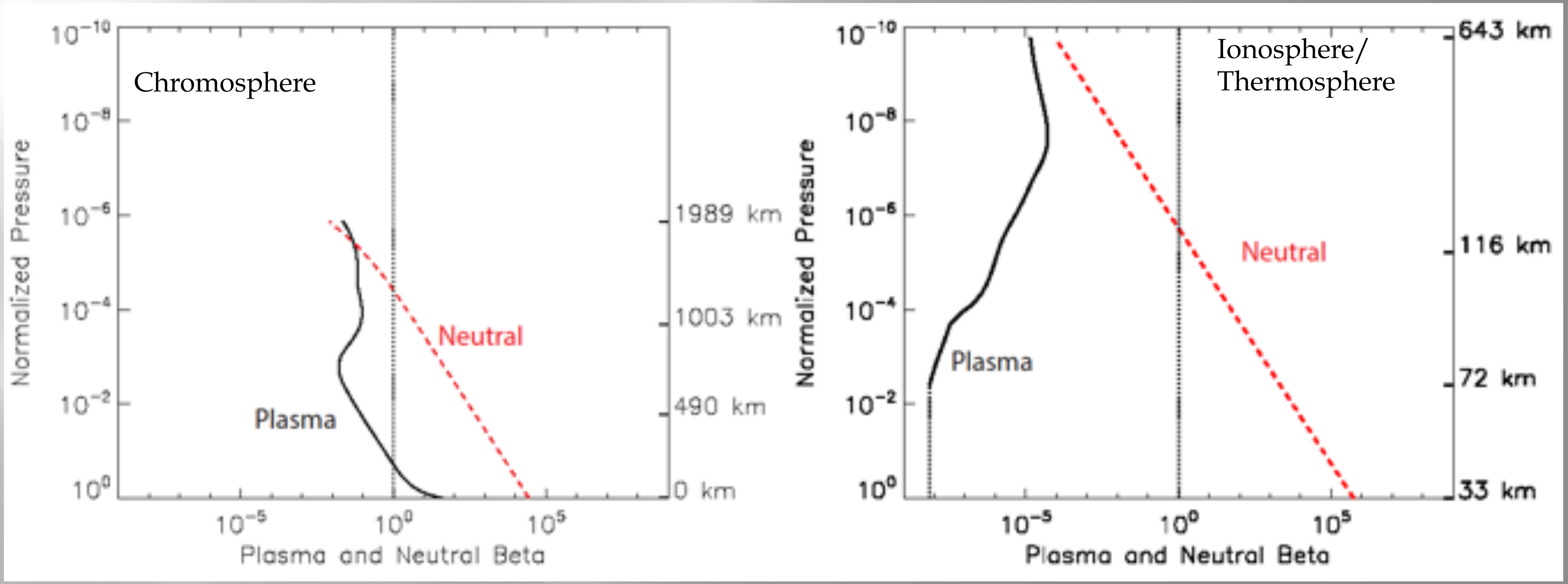
- **Increasing ionization fraction with height**



Neutral (red dashed) and plasma (black solid) number densities vs. normalized pressure in the ALC7 chromosphere (left) and the TIMEGCM I/T (right).

Commonalities, con't….

- Typical plasma beta < 1
- Neutral beta (or total) transitions from greater than to less than 1



Commonalities, con't….

Magnetization = gyrofrequency/collision frequency

$k_{in} = (eB)/(.5m_i\, v_{in})$

$k_{en} = (eB)/(m_e\, v_{en})$

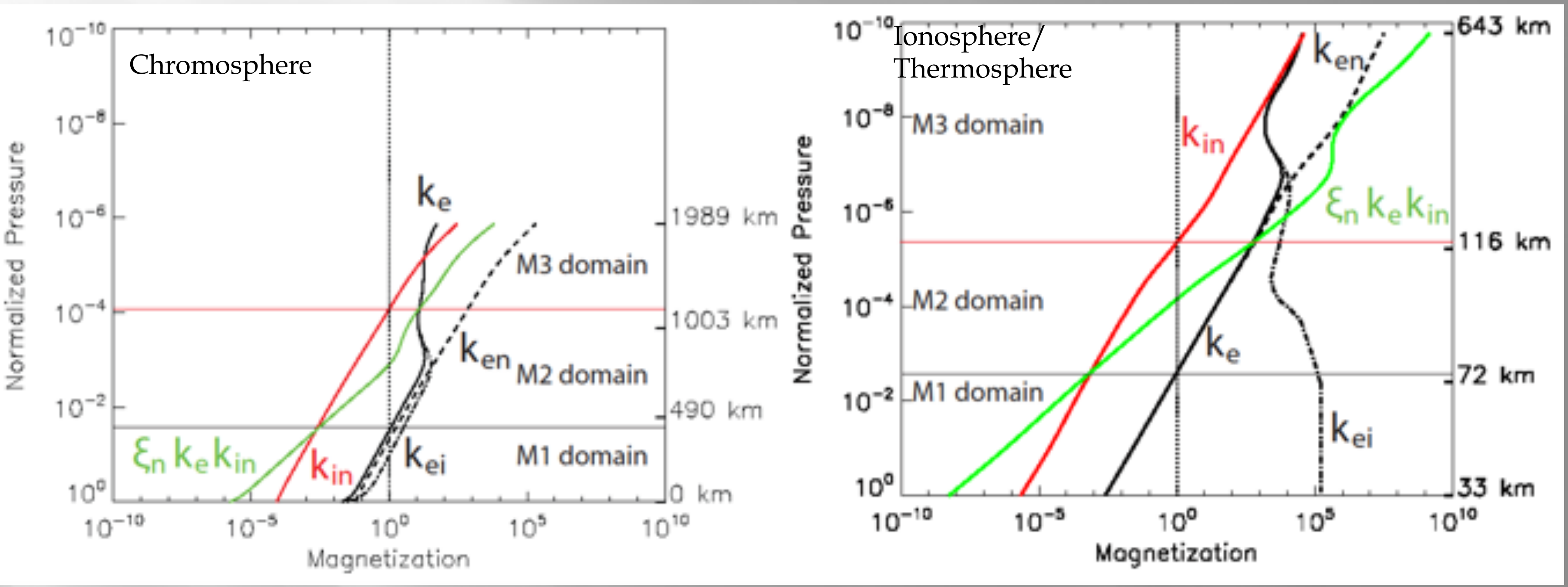
$k_{ei} = (eB)/(m_e\, v_{ei})$

$1/k_e \equiv 1/k_{en} + 1/k_{ei}$

Commonalities, con't….

- **Magnetized ions: transition from unmagnetized to magentized w/ increasing height**

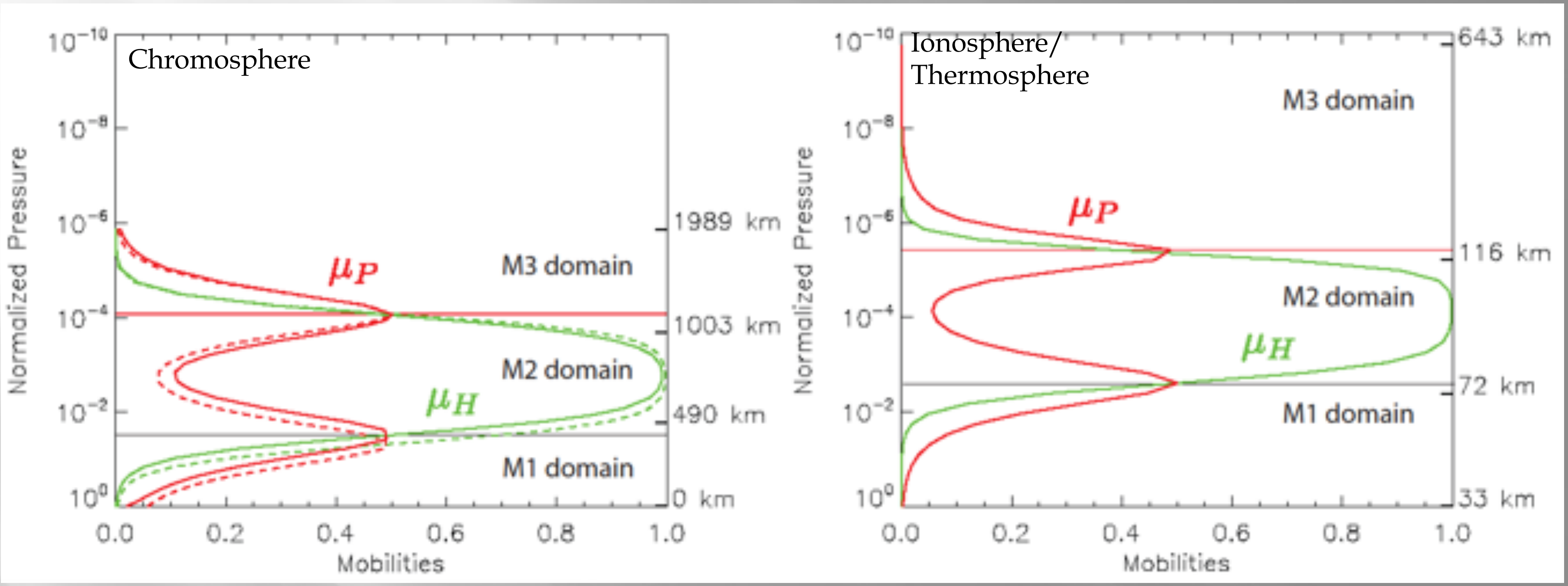
- **Contain a region where only electrons are magentized**



Chromosphere (left) and I/T (right).
M1, M2, M3 domains highlight commonalities in the charged-particle dynamics w/in the chromo and I/T. In both atmospheres the charged particles undergo a transition from completely unmagnetized (lower M1) to completely magnetized (upper M3), with a central region (M2) in which ions are unmagnetized and electrons are magnetized. The height at which the function represented by the green line = 1 is approx the location where a transition occurs from isotropic transport processes to anisotropic.

Commonalities, con't….

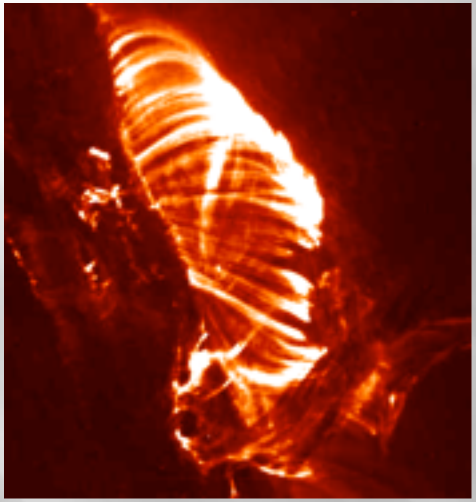
- **Similar profile of mobility** (mobility = measure of ability of ionized plasma to be accelerated by electric fields while being retarded by collisions w/neutral gas)

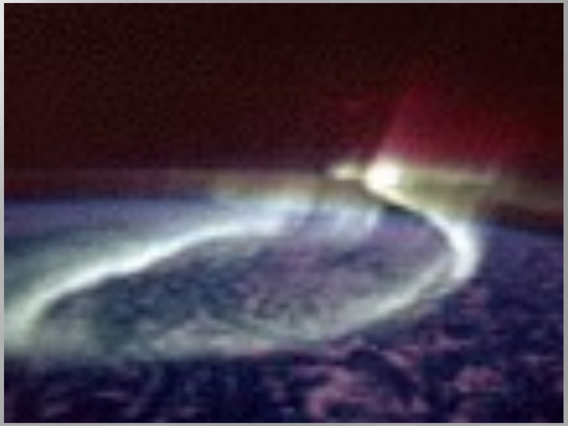


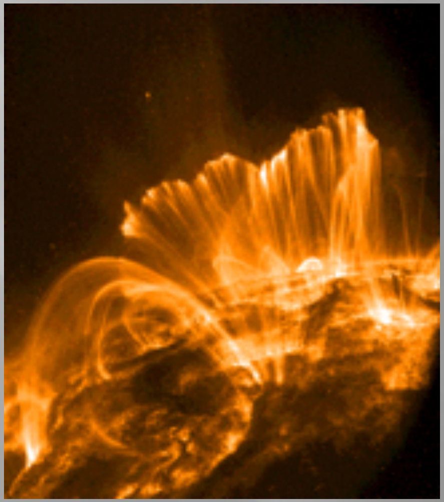
Pedersen (μ_P; red) and Hall (μ_H; green) mobilities in the chromo (left) and I/T (right). Dashed lines show the corresponding values when electron-ion collisions are ignored. The mobilities are explicit functions of the magnetizations that show the relative contributions of electrons and ions to the electric current.

Commonalities, con't….

- Ionization by energetic particle precipitation is important (flares, geomagnetic activity, nighttime ionosphere)







Ionosphere/Thermosphere (I/T) and chromosphere differences

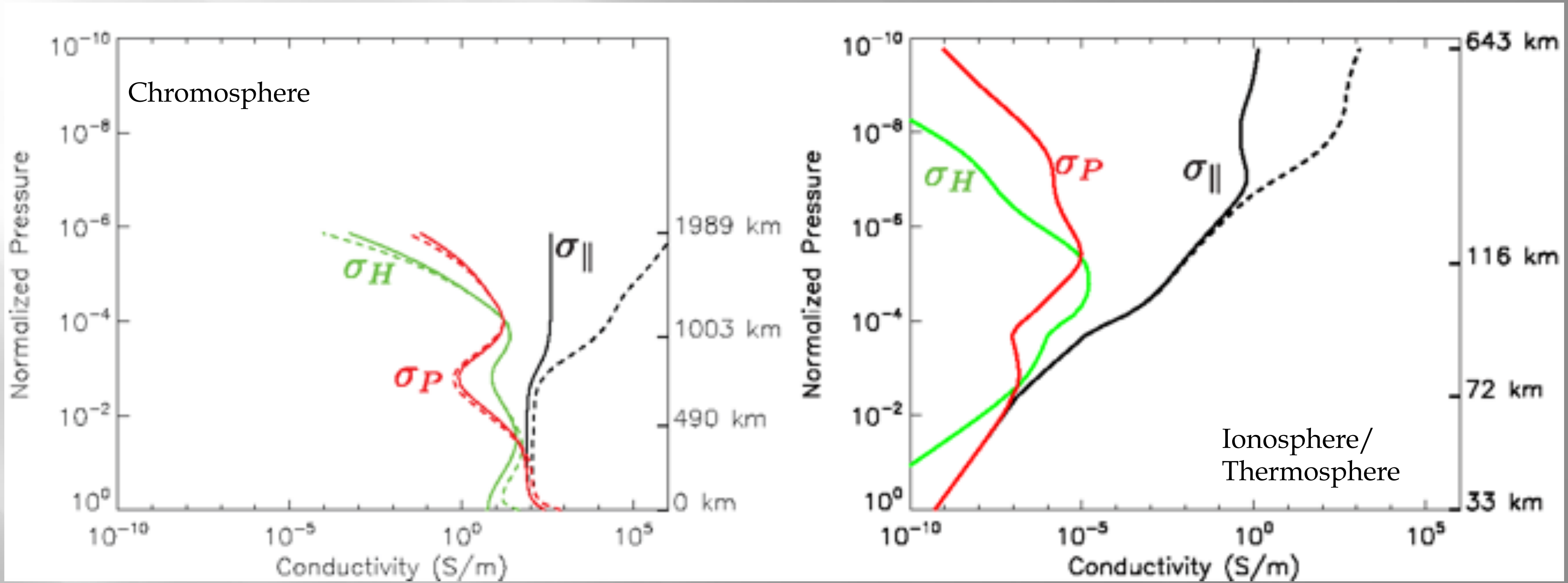
- Physical descriptions of, and paradigms used to discuss the 2 environments
  - I/T: E and J are primary variables (B and flows secondary)
  - Chromo: opposite is true (E are mainly transient and quickly destroyed by electric currents)

- Drivers: magnetic field vs. neutral winds

- Plasma heating mechanism
  - I/T: daytime ionosphere (in quiescence) heated primarily by UV and EUV radiation from Sun
  - Chromo: heated by non-radiative energy coming from *within* the Sun (e.g., collisional (Joule) heating)

Differences, con't….

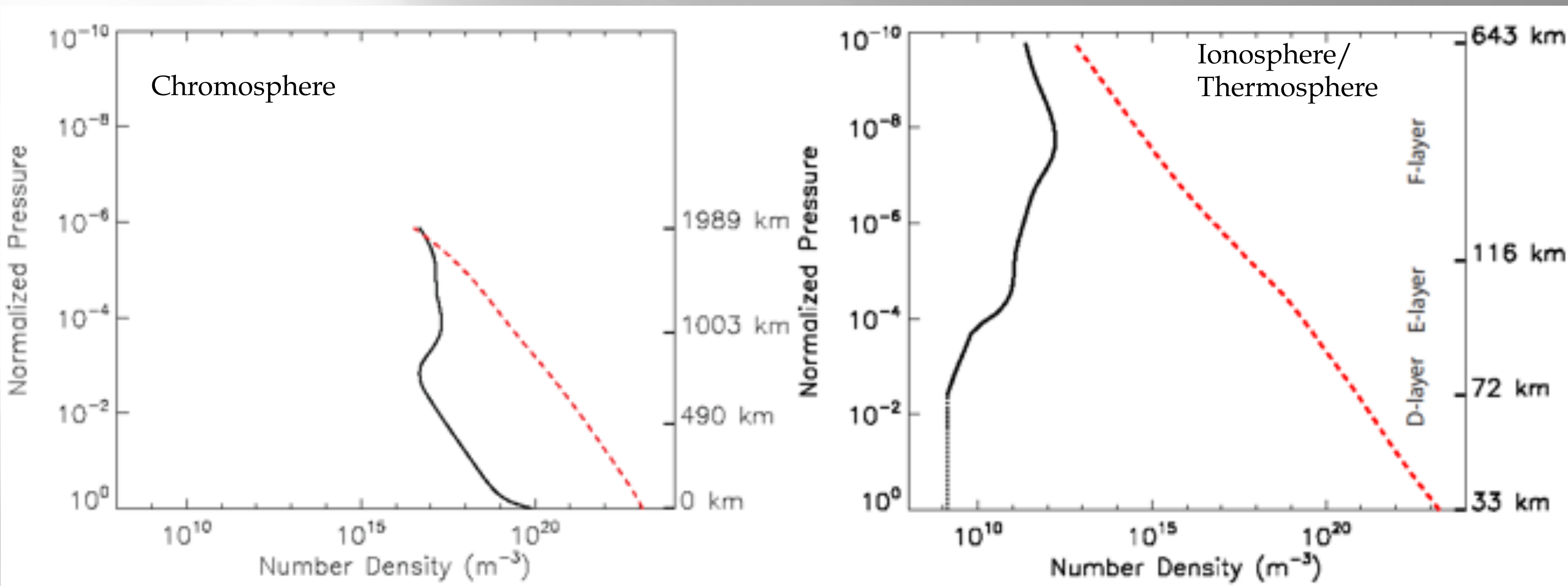
- **I/T, mag. field largely static and conductivity is low**
- **Chromo, mag. field highly dynamic, high conductivity**



Parallel ($\sigma_\parallel$; black) Pedersen (σ_P; red) and Hall (σ_H; green) conductivities (in Siemens/m) in the chromo (left) and I/T (right). Dashed lines show the corresponding values when electron-ion collisions are ignored

Differences, con't….

- **Ionization**

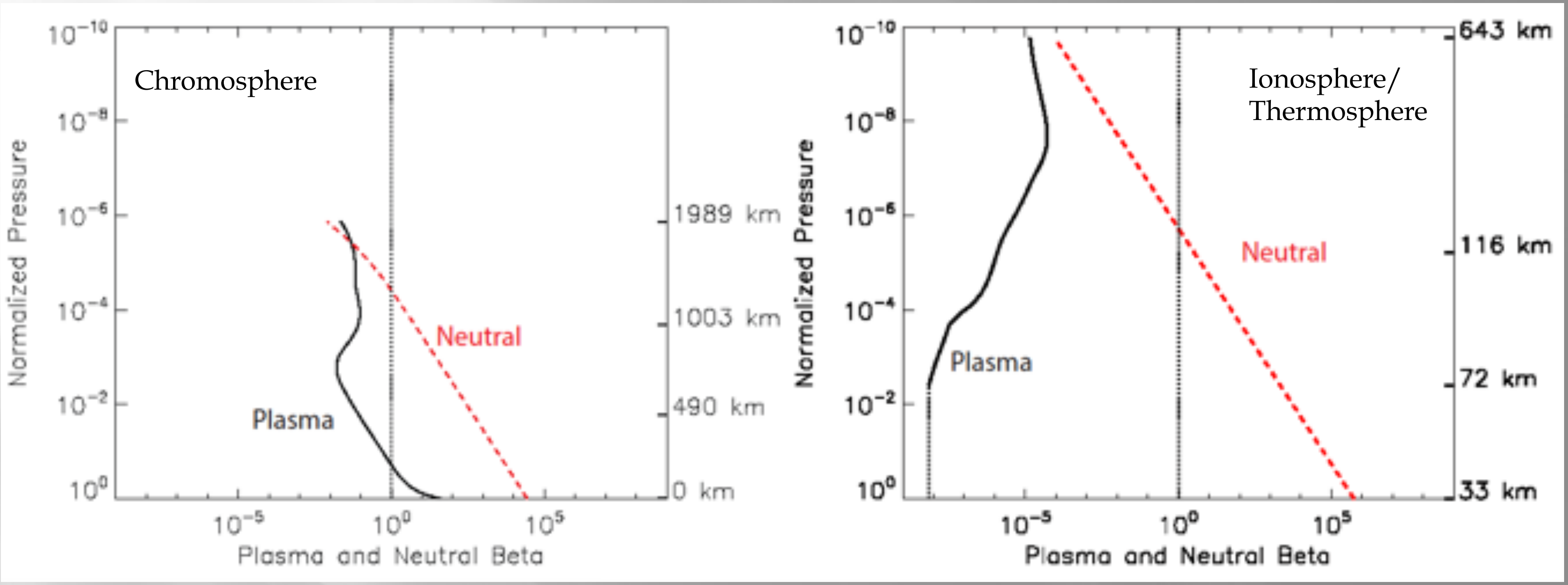


Neutral (red dashed) and plasma (black solid) number densities vs. normalized pressure in the ALC7 chromosphere (left) and the TIMEGCM I/T (right).

The plasma densities differ by several orders of magnitude between the chromo and the I/T, due to the combination of their order-of-magnitude temp difference and to the disparate ionization processes that dominate in the two atmospheres.

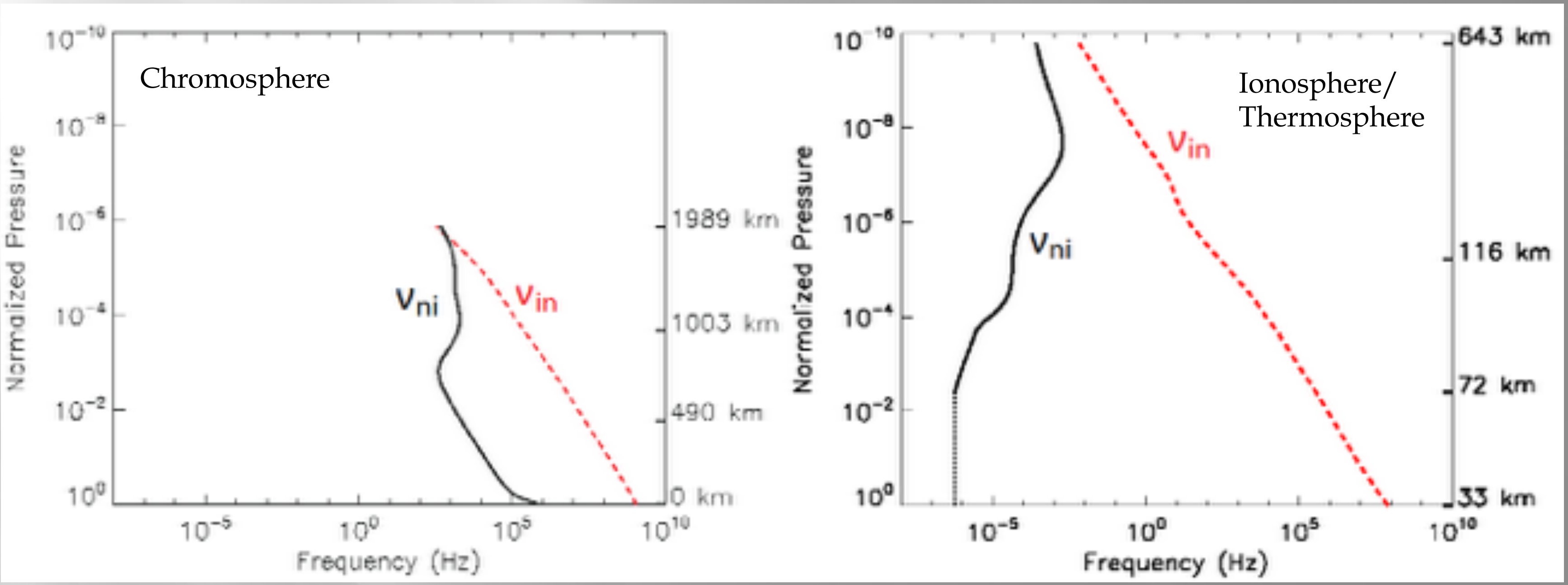
Differences, con't….

- Plasma β



Differences, con't….

- **Collisional coupling: (ion densities in ionosphere at least 1000 times lower for any given neutral density, resulting in a much weaker ion-neutral coupling)**



Note: the response of the neutrals to the ions is strong in the chromosphere but extremely weak in the I/T.

Differences, con't….

- **Lundquist number**

$$S \equiv \frac{\mu_0^{\frac{1}{2}} B_0 l}{\rho_0^{\frac{1}{2}} (eta)} = \frac{\mu_0 V_{A0} l}{eta}$$

$$S' \equiv \frac{\mu_0 V_{At0}^2}{(eta)_P \mathrm{v}_{ni}}$$

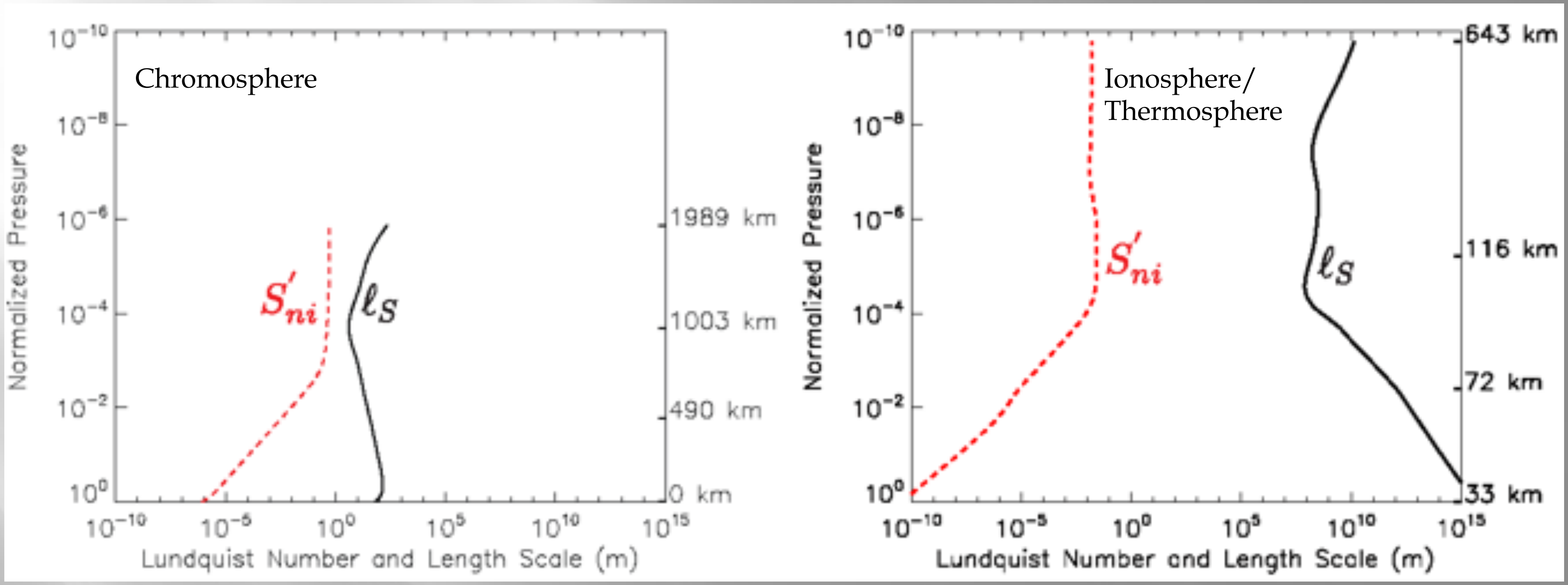
$$l = \frac{B_0}{\mu_0^{\frac{1}{2}} \rho_0^{\frac{1}{2}} \omega} = \frac{V_{A0}}{\omega}$$

$$l_S \equiv \frac{V_{At0}}{\mathrm{v}_{ni}} \frac{1}{S'_{ni}}$$

l = characteristic length of variations in the B and velocity fields

Differences, con't….

- **Lundquist scale**



Values of the Lundquist number (red, dashed) for Alfven waves at the neutral/ion collision frequency and of the Lundquist scale (black solid) in m, using the Pedersen resistivities in the ALC7 chromo (left) and the TIMEGCM I/T (right).

Gross differences

Thermosphere-Ionosphere	Chromosphere
Potential B *E = (delta)φ*	*Non-potential B, fields tied to subphotosphere* *E(parallel) = 0*
E, σ "electrodynamics", *B "fixed"* *j determined by E, σ*	*v, B, σ full MHD (coupled fluid and induction equations), "frozen field"* *j determined by j×B-∇p+..*
Heating mechanisms largely known	*Electrodynamic heating: unknown*
Horizontal scales » vertical *∂f/∂x, ∂f/∂y « ∂f/∂z*	*Vertical scales ≳ horizontal* *Photospheric flux concentrations* *∂f/∂x, ∂f/∂y ≳ ∂f/∂z*

Summary of properties

Property	Chromosphere	Ionosphere/Thermosphere	Discussion
Ionization	*0.1% — 100%*	*1e-8% — 1%*	*I/T strongly neutral dominated*
Collisional Coupling	*Strong mutual coupling*	*Ions couple strongly to neutrals Neutrals couple weakly to ions*	*Single-fluid Chromo Multi-fluid I/T*
Beta	*High ~ 100%*	*Low ~ .01%*	*δB/B0 large in Chromo, small in I/T*
Lundquist Scale	*Very small* L_S	*Very large* L_S	*Chromo: Ideal at large scales I/T: Resistive at all scales*
Drivers	*Magnetic field*	*Neutral winds*	*V,B (MHD) vs E,J (ED)*

Why is I/T system better understood?

- Easier to make wide range of measurements in the I/T domain
- The main, unresolved issues for the chromo are more general in nature:
  - Heating of chromo
  - Driving of solar wind
  - Transport of energy and mass across the chromo into the corona
  - Nature of transient phenomena (e.g., spicules, jets)
  - Precise role of the magnetic field in heating and energy transfer

Common issues to investigate

- Are Alfvén waves important to the transfer and dissipation of electromagnetic energy in ***both*** the I/T and chromosphere?

- How do the I/T and chromosphere change the energy transfer from the magnetosphere and photosphere respectively?