Thermosphere - Ionosphere - Magnetosphere Coupling

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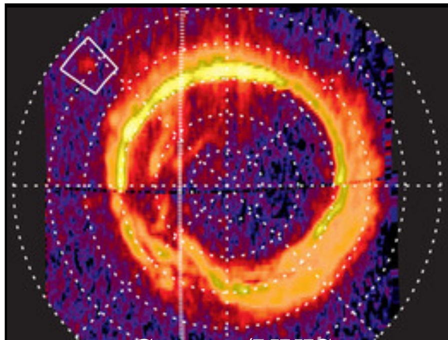
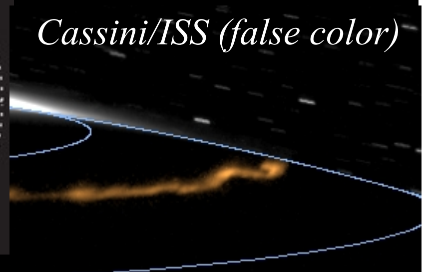
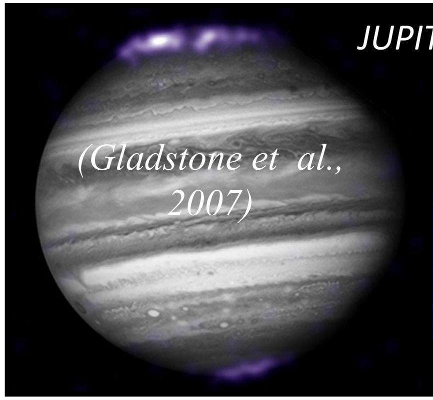
1. Energy crisis at giant planets
2. TIM coupling
3. Modeling of IT system
4. Comparison with observations
5. Outstanding questions

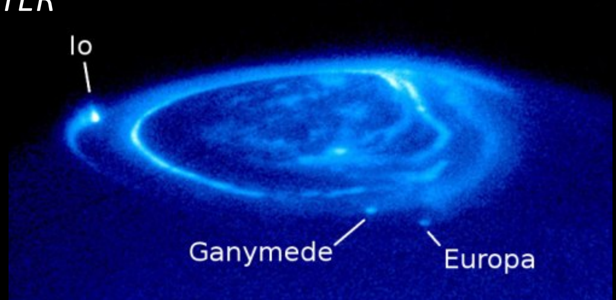




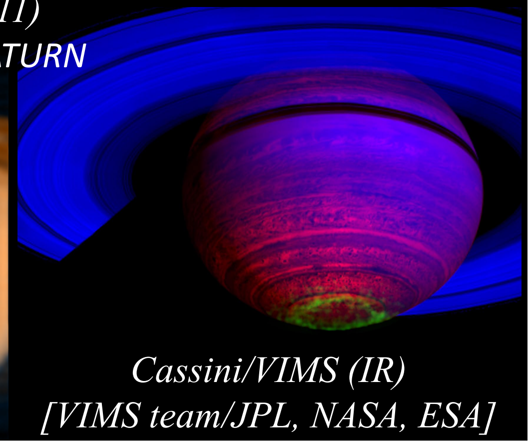
SATURN

JUPITER





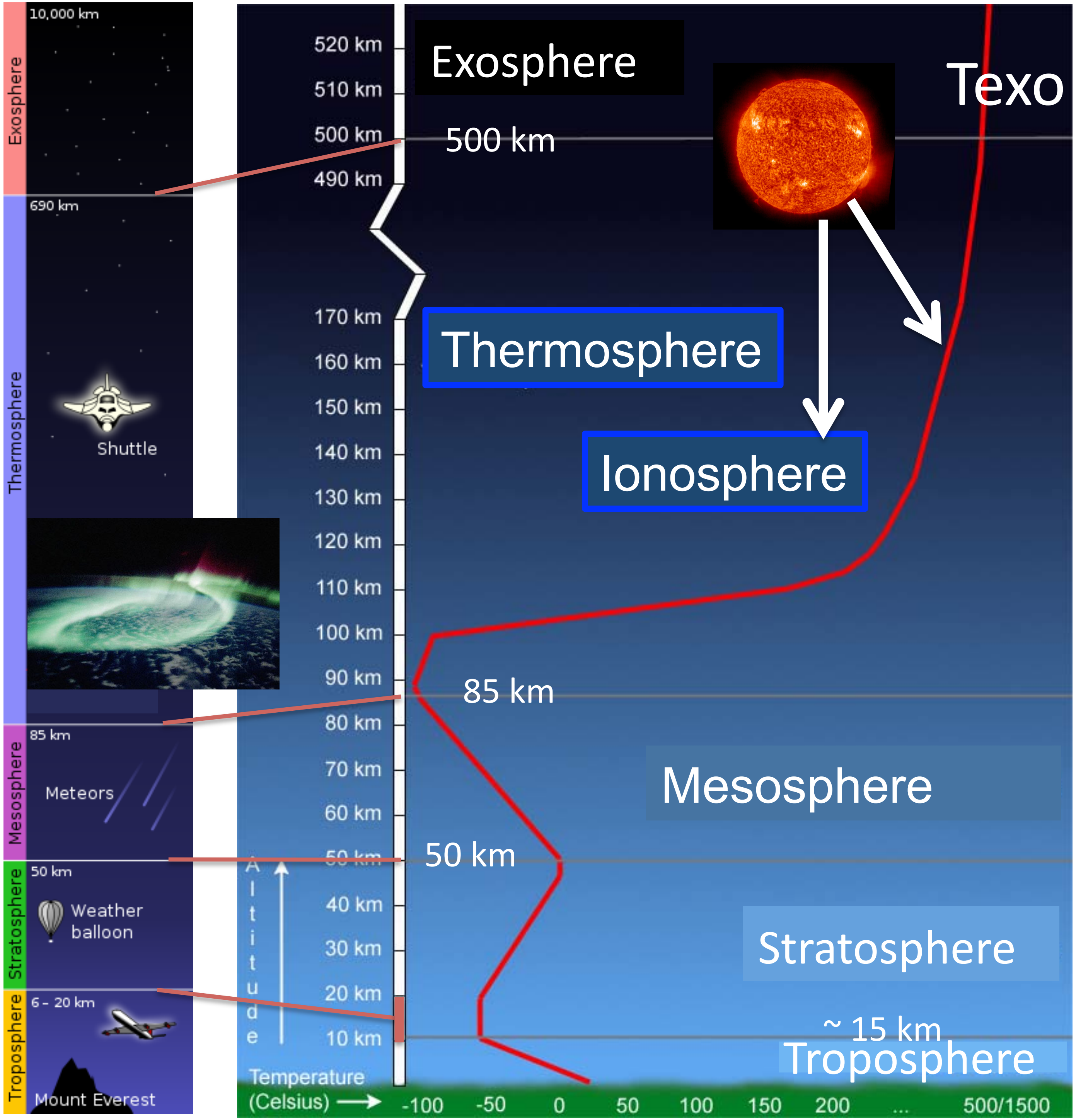
Credit: J. Clarke (BU), NASA



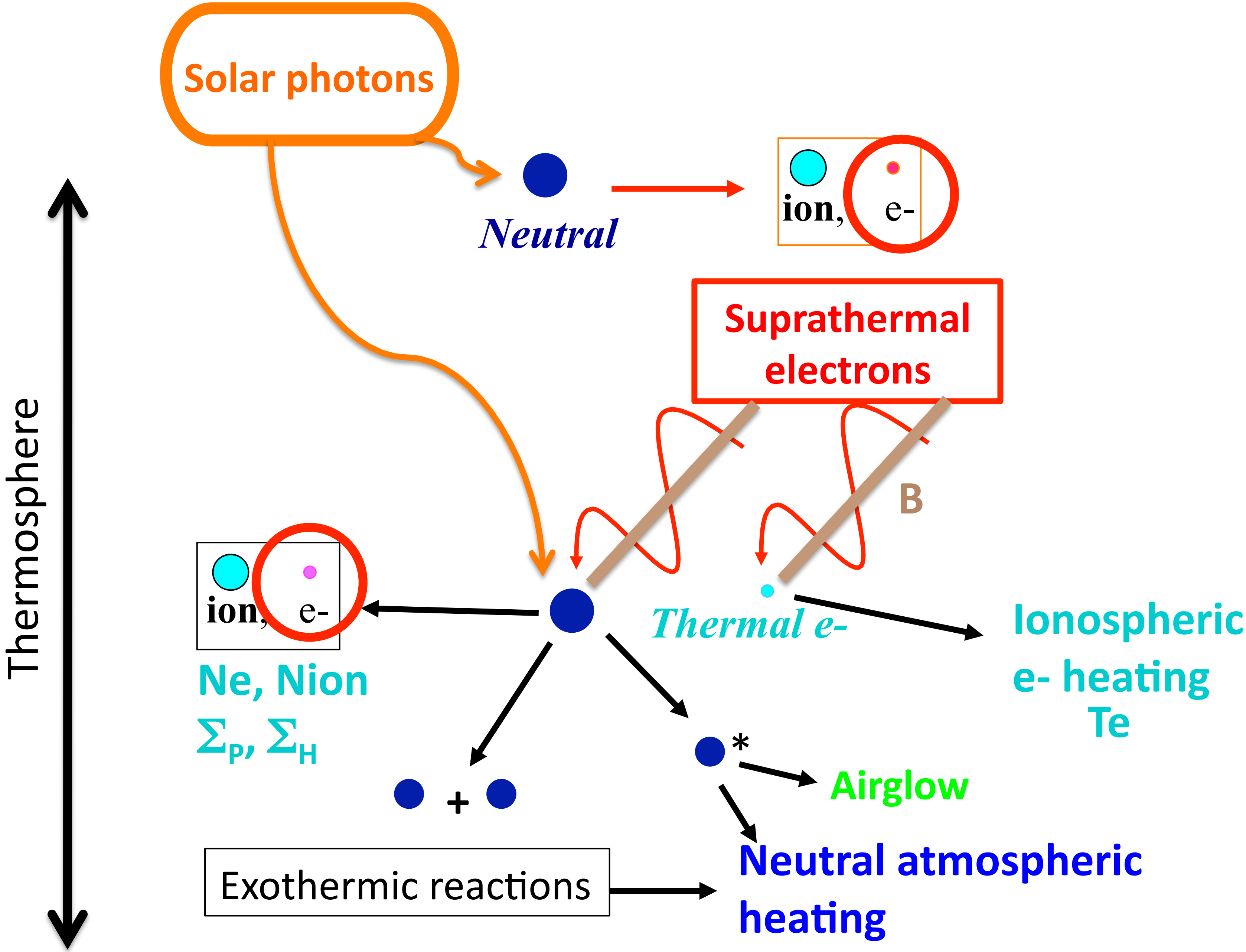
1. SETTING THE SCENE:
THE ENERGY CRISIS AT THE GIANT PLANETS

THERMAL PROFILE (EARTH)

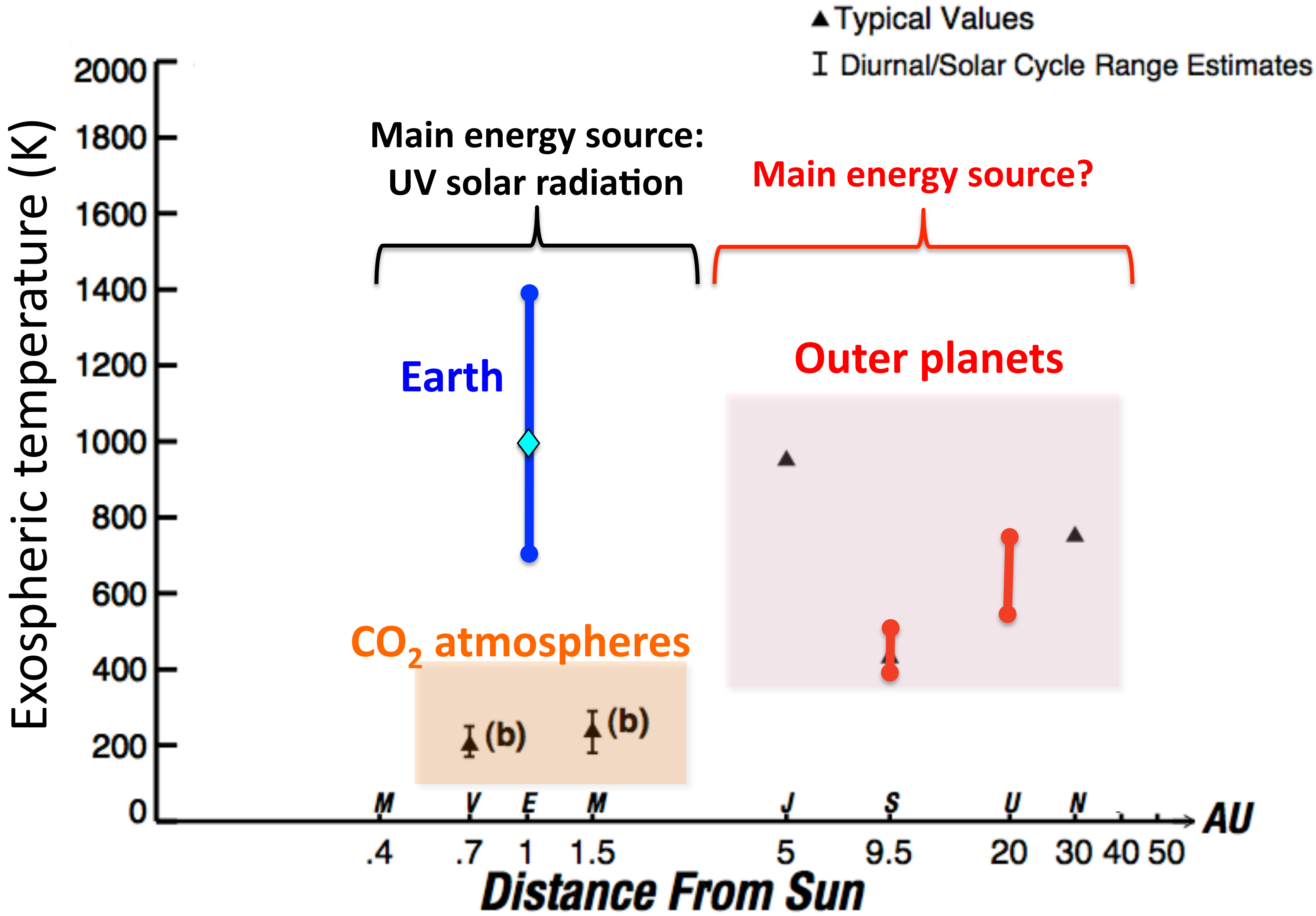
Key transition region between the space environment and the lower atmosphere



SOLAR ENERGY DEPOSITION IN THE UPPER ATMOSPHERE

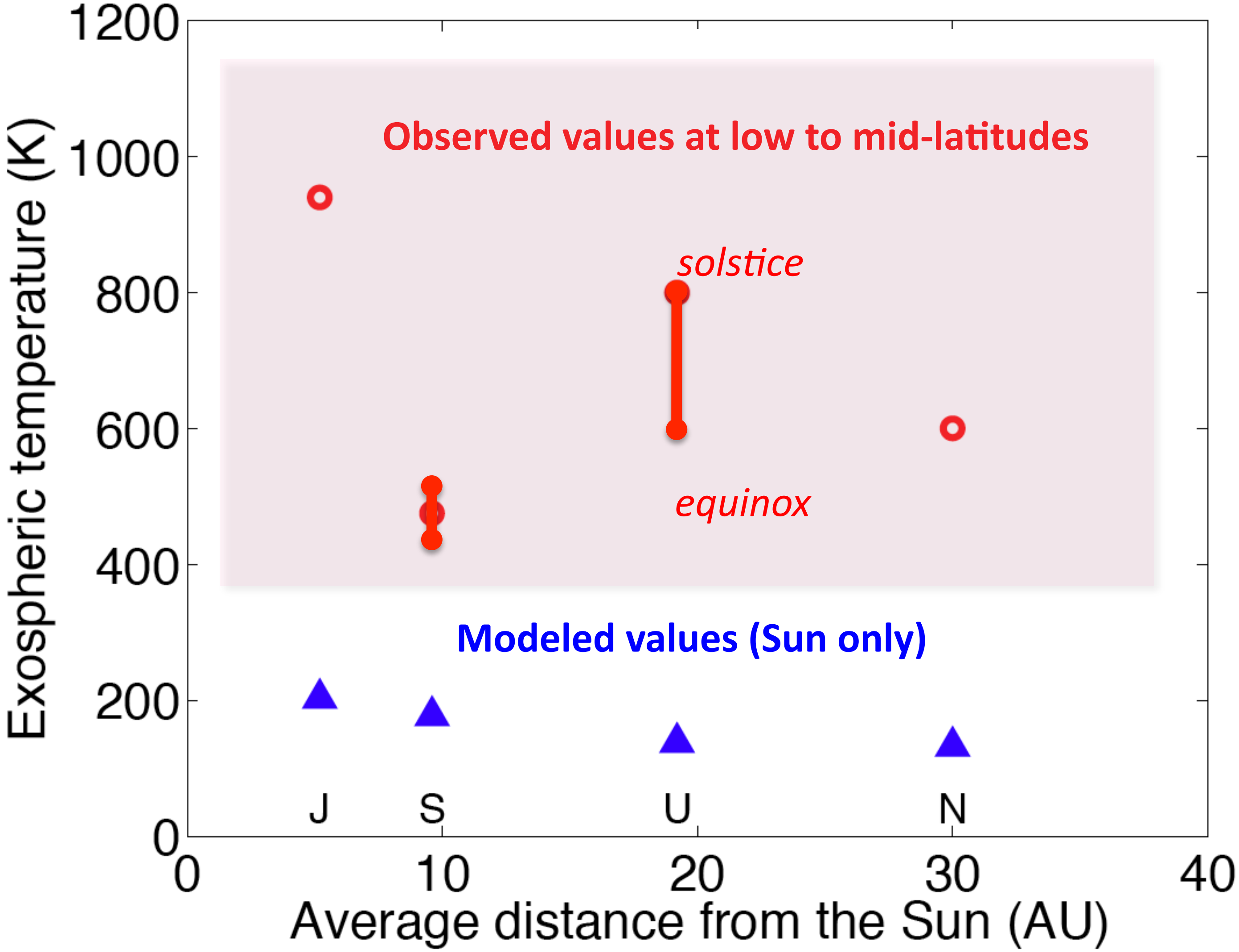


IS THE SUN THE MAIN ENERGY SOURCE OF PLANERATY THERMOSPHERES?



[after *Mendillo et al., 2002*]

ENERGY CRISIS AT THE GIANT PLANETS



[After *Yelle and Miller*, 2004; *Melin et al., 2011 (+poster)*]

ENERGY BUDGET OF THE THERMOSPHERE

◆ HEATING SOURCES

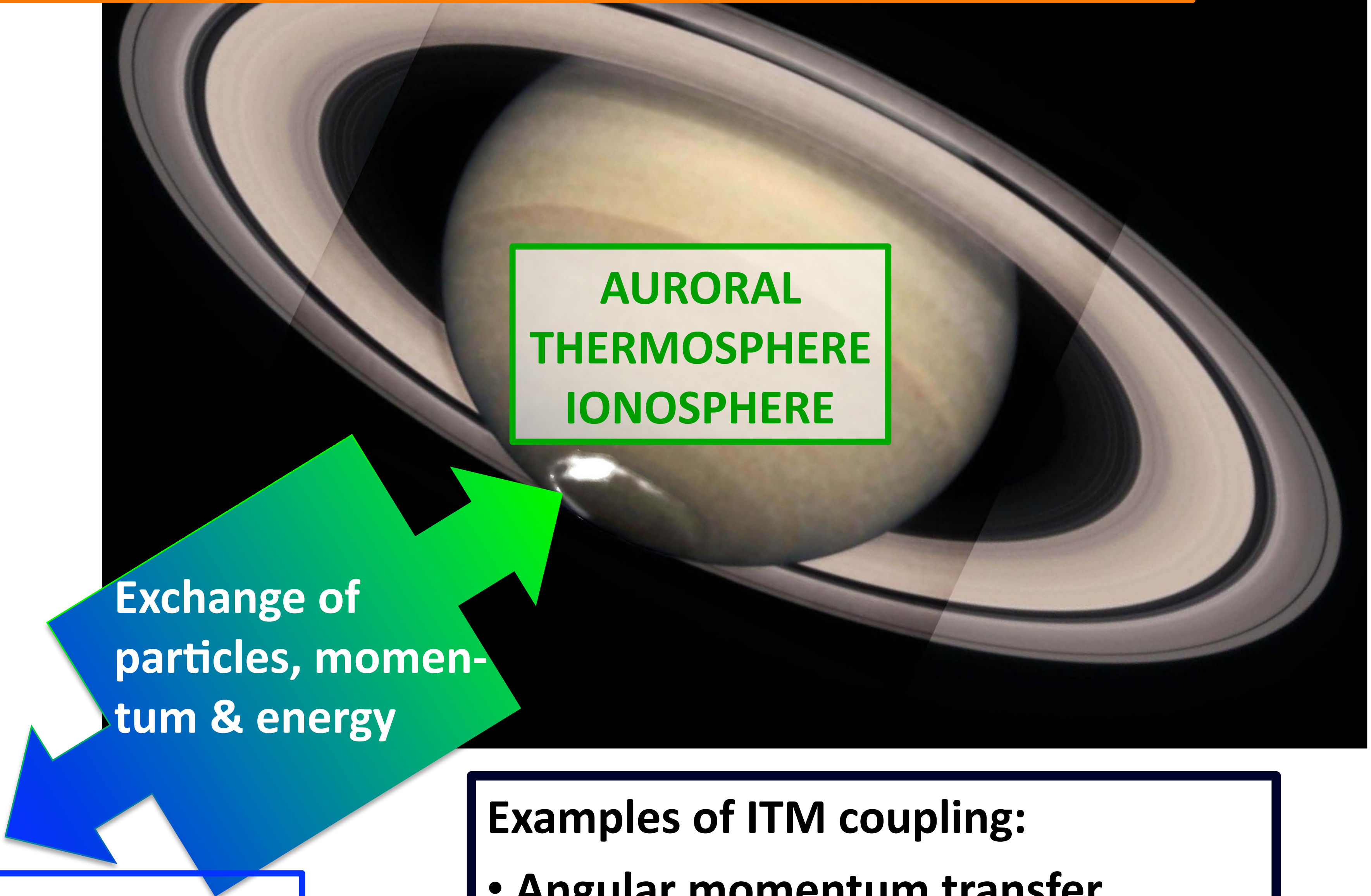
- ➢ ***Solar heating*** through excitation/dissociation/ionization + exothermic chemical reactions
- ➢ ***Auroral particle heating*** via collisions + chemistry [*Grodent et al.*, 2001]
- ➢ ***"Ionospheric Joule heating"*** via auroral electrical currents and ion-drag heating [*Vasyliũnas and Song*, 2005]
- ➢ *Dissipation of upward, propagating* ***waves*** (such as gravity waves, …)

- **Solar EUV/FUV heating***: 0.5 TW (Earth), 0.8 TW (Jupiter), 0.2 TW (Saturn)
- **Auroral part./Joule heating***: 0.08 TW (Earth), 100 TW (Jupiter), 5-10 TW (Saturn)

[*: *Strobel*, 2002]

2. THERMOSPHERE-IONOSPHERE-MAGNETOSPHERE COUPLING

MAGNETOSPHERE-IONOSPHERE-THERMOSPHERE COUPLING



Examples of ITM coupling:

- **Angular momentum transfer**
- **Ion outflow, particle precipitation**

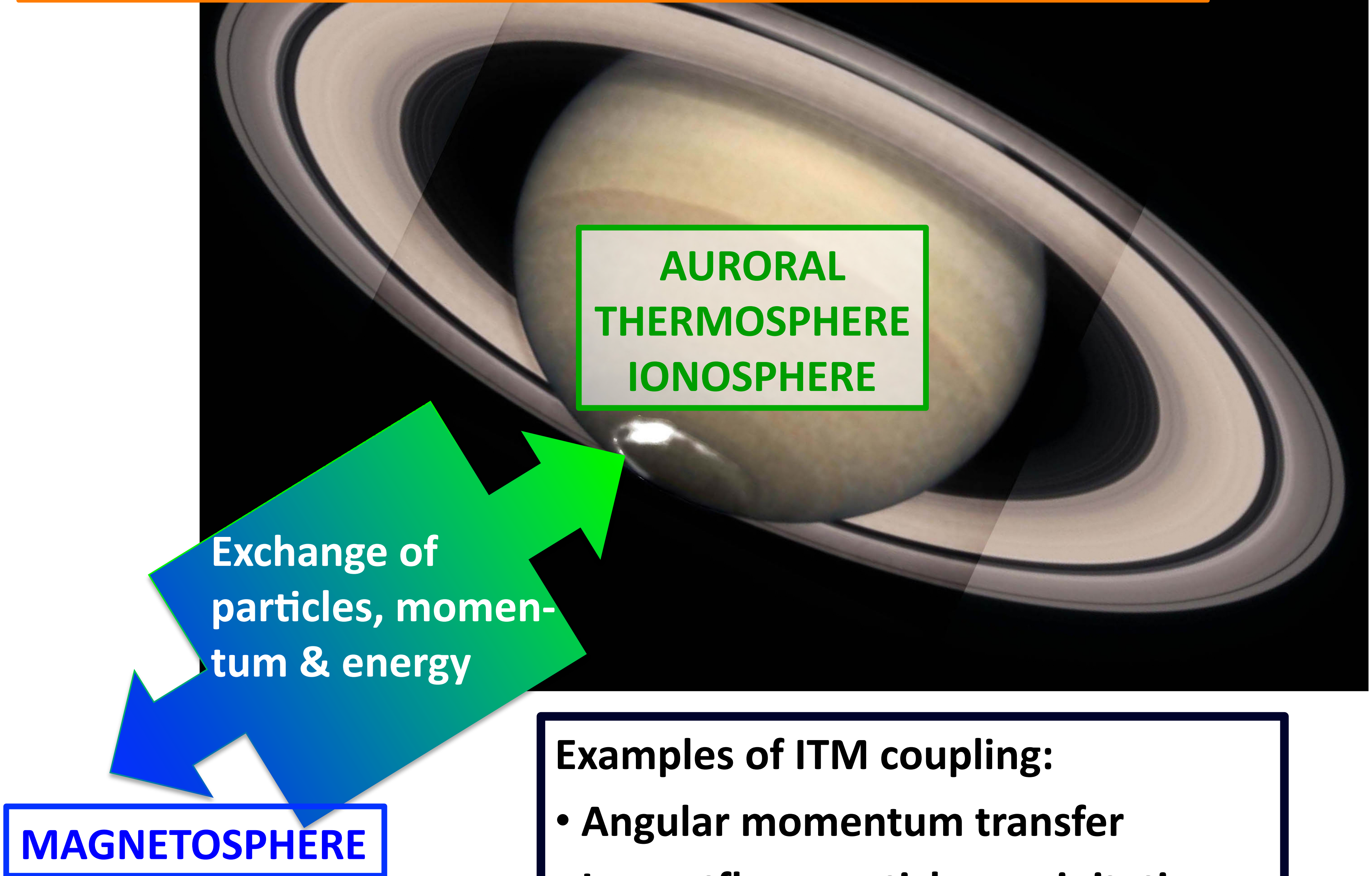
MAGNETOSPHERE-IONOSPHERE-THERMOSPHERE COUPLING

- Overall, at high latitudes:

  the magnetosphere extracts angular momentum from the upper atmosphere through the magnetic field-aligned currents [e.g., *Hill*, 1979]

→The magnetosphere "swims" on the ionosphere.

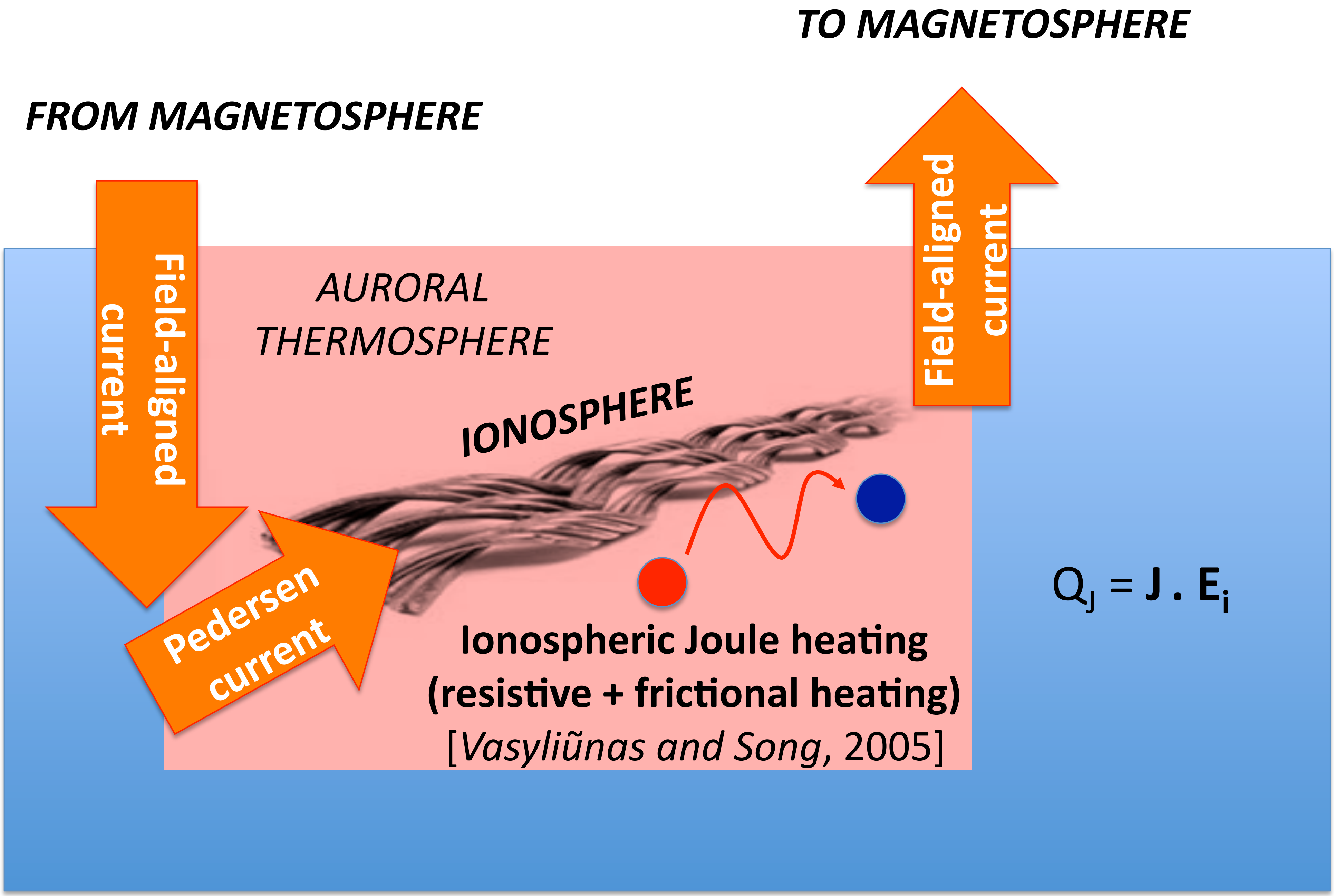
MAGNETOSPHERE-IONOSPHERE-THERMOSPHERE COUPLING

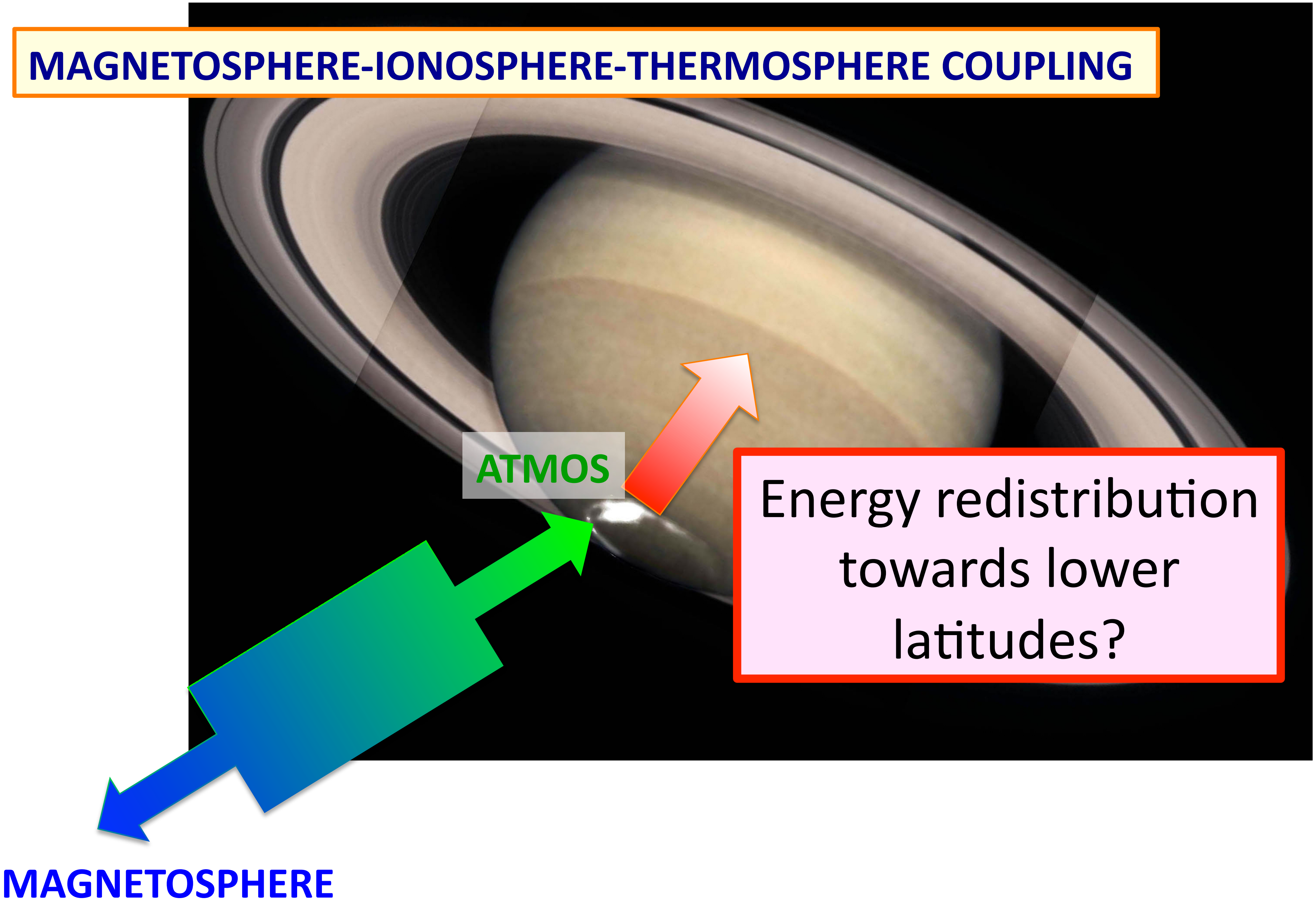


Examples of ITM coupling:

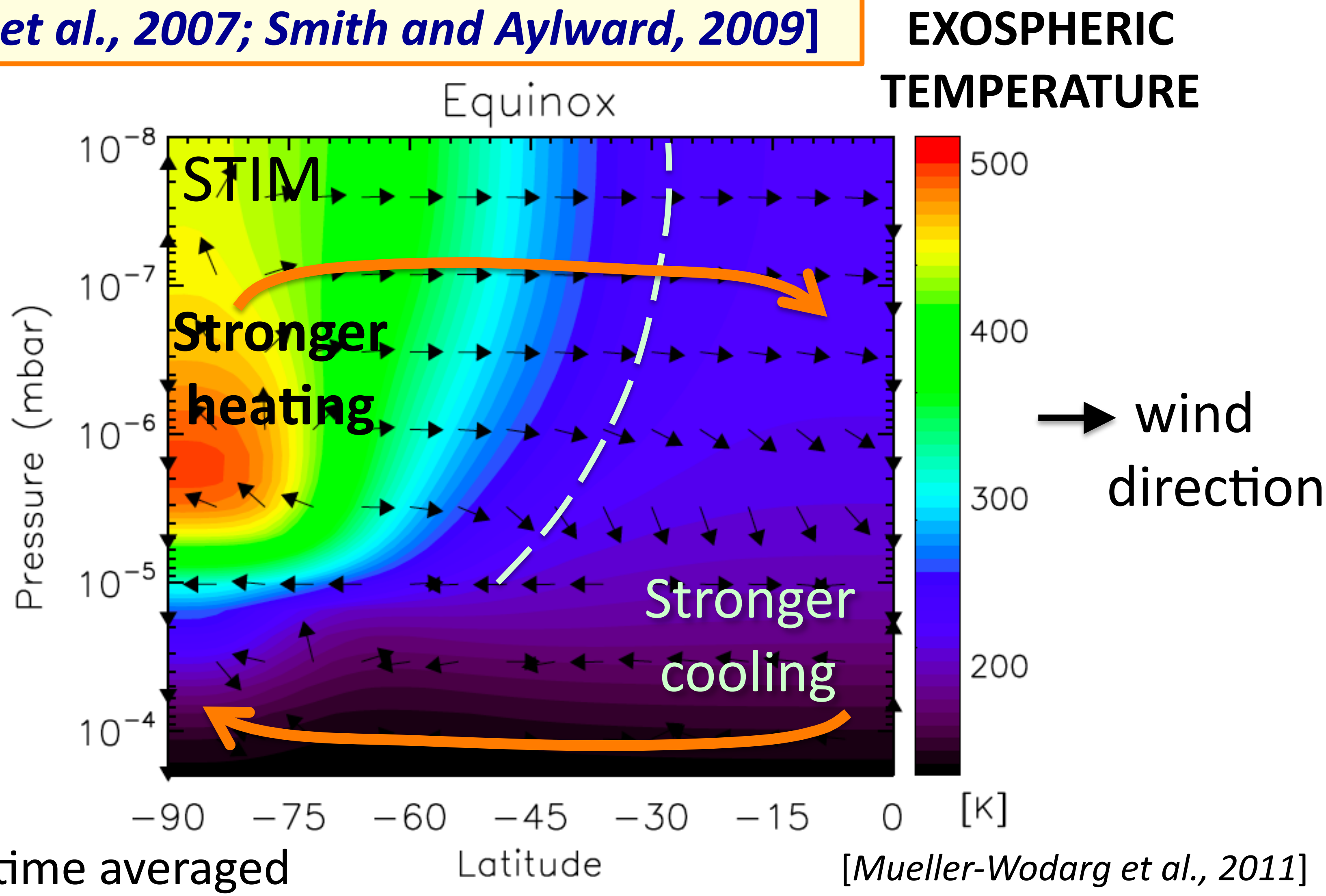
- Angular momentum transfer
- Ion outflow, particle precipitation

TIM coupling through current system




MAGNETOSPHERE-IONOSPHERE-THERMOSPHERE COUPLING
ATMOS
Energy redistribution towards lower latitudes?
MAGNETOSPHERE

Ion drag fridge mechanism
[*Smith et al., 2007; Smith and Aylward, 2009*]



Local time averaged

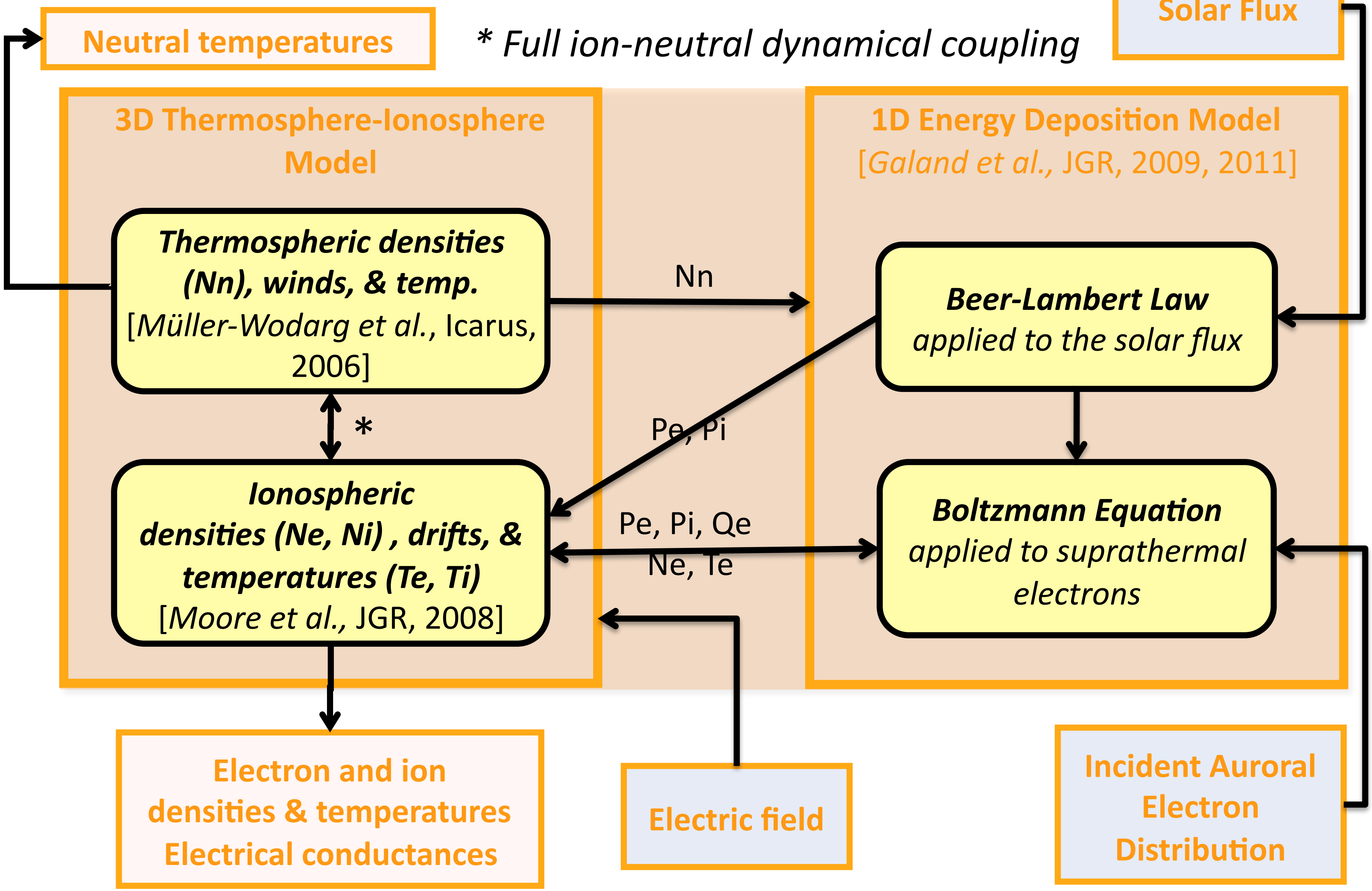
[*Mueller-Wodarg et al., 2011*]

Polar sub-corotation due to auroral forcing (westward ion velocities due to ambient E fields) drives equator-to-pole circulation

Does the ion drag fridge mechanism rule out auroral energy in solving the global energy crisis at Giant Planets?

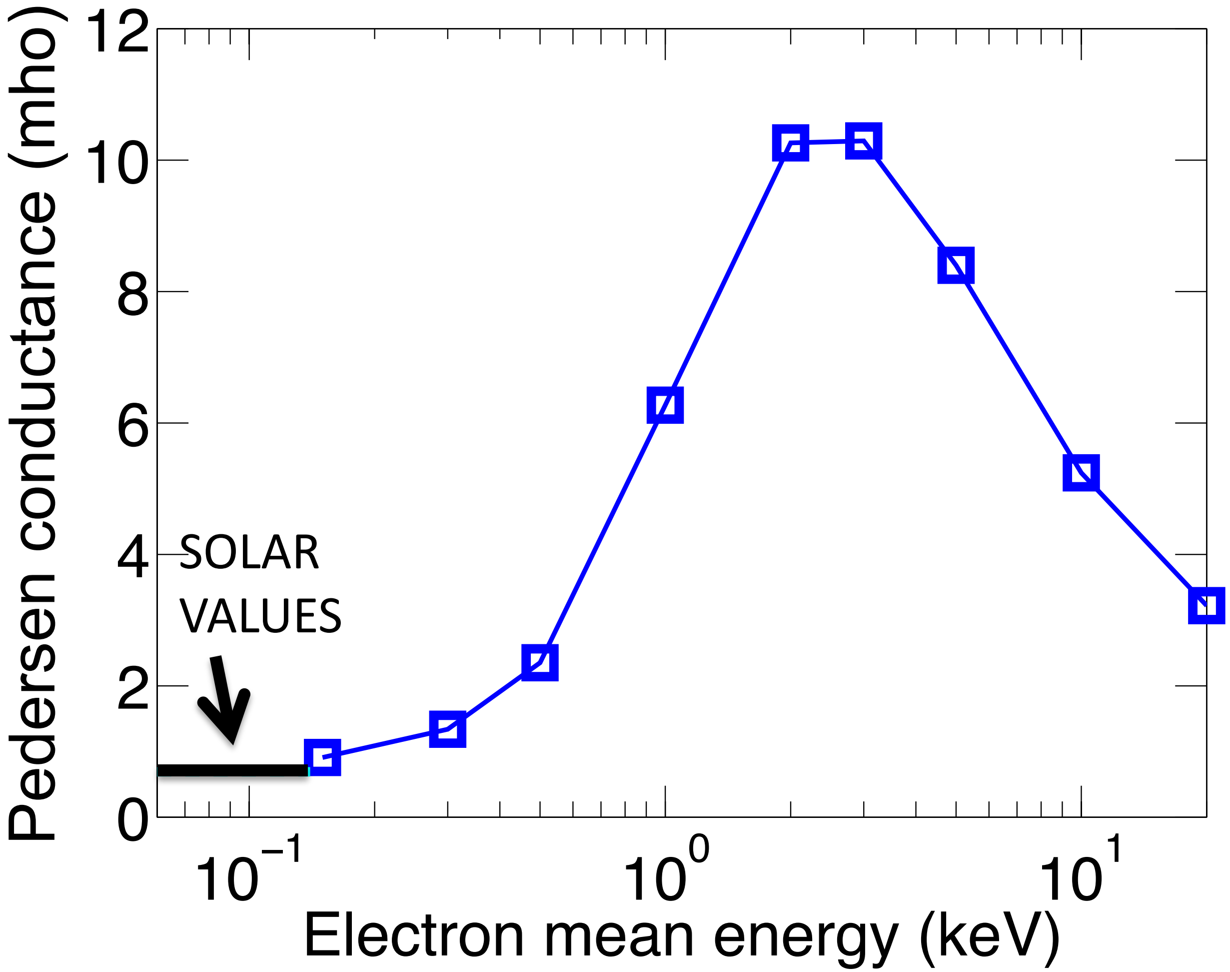
3. MODELING THE THERMOSPHERE/IONOSPHERE SYSTEM

COUPLED FLUID/KINETIC STIM MODEL



Flexible model which allows us **to explore the parameter space** and assess the effect of it on ionospheric/thermospheric quantities, such as Ne, Σ, Tn.

STIM RESULT 1: Ionospheric conductances in auroral regions



$Q_0 = 0.2\ mW\ m^{-2}$

12 LT

$$\Sigma_P \propto \sqrt{Q_0(t - \Delta t)}$$

with Δt = 25 min

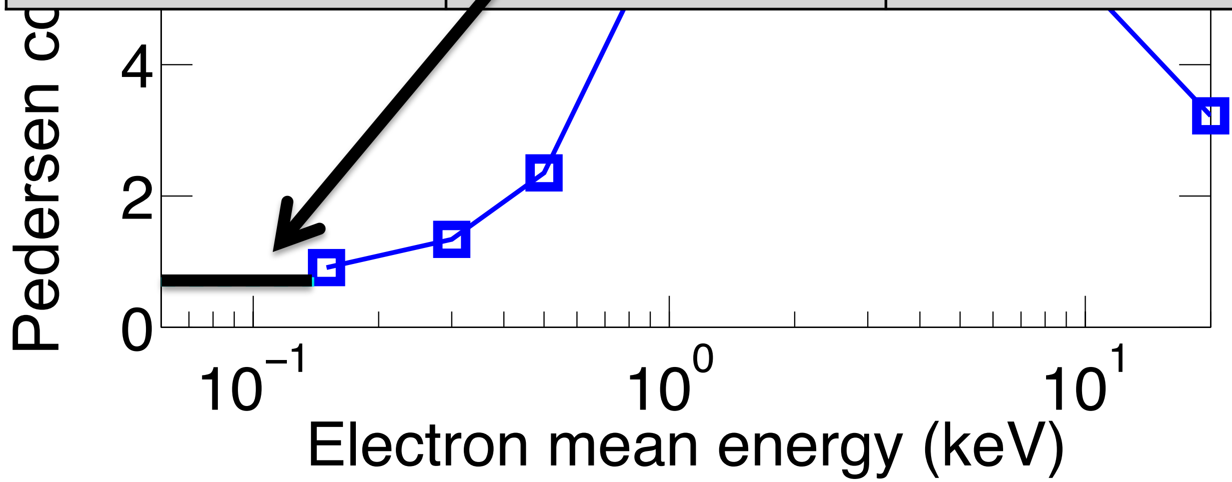
-Pedersen conductivities peak at the homopause → conductances peak near 2.5 keV

- At low energies, conductances are driven by the solar source

[*Galand et al., 2011*]

STIM RESULT 1: Ionospheric conductances in auroral regions

Sun only 12 LT 78°S LAT	Equinox Solar min	Equinox Solar max	Summer Solar min
Pedersen conductances	0.7 mho	1.6 mho	2.6 mho



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[*Galand et al., 2011*]

STIM RESULT 1: Ionospheric Conductances in auroral regions

Auroral electron mean energy & energy flux	**Earth** *[Fuller-Rowell and Evans, 1987]*	**Saturn** *[Galand et al., 2011]*	**Jupiter** *[Millward et al., 2002]*
10 keV 1 mW m^{-2}	Σ_P = **4-6 mho**	Σ_P = **11-12 mho**	Σ_P = **0.1-0.2 mho**

Composition
Altitude range
Σ_P=max(Σ_P)/10 over 70 km (E) and 500 km (S)

Strength of B field
B field 20 times stronger at J cp w/ S

Slippage parameter[1] for Jupiter[2] & Saturn[3]: $k = \dfrac{\Omega - \omega_n}{\Omega - \omega_i} = \sim 0.5$

(1) *Bunce et al.* [2003]; (2) *Cowley et al.* [2004]; (3) *Galand et al.* [2011]

STIM RESULT 2: sensitivity to vibrationally excited H_2 rate

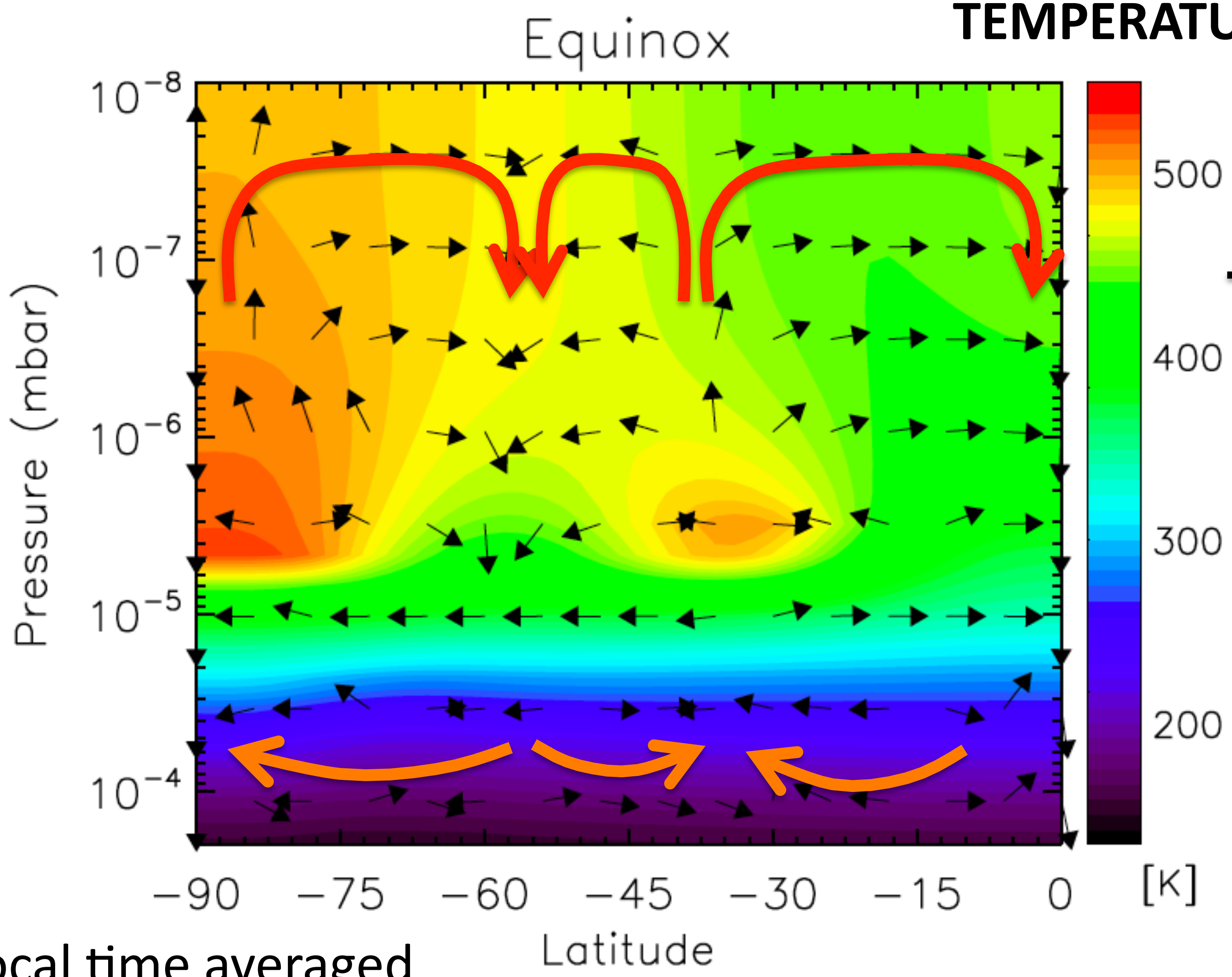
- Charge exchange reaction **$H^+ + H_2(v \geq 4) \rightarrow H_2^+ + H$** **(1)**

  controls the abundance of H_3^+ as it is quickly followed by:

  $$H_2^+ + H_2 \rightarrow H_3^+ + H$$

- Reaction rate **$k_1^* = k_1 [H_2(v \geq 4)]/[H_2]$**
  - Low k_1^* means less charge exchange reaction and increase in ionospheric densities
  - $k_1 = 10^{-9}$ cm^3 s^{-1} [*Huestis*, 2008]
  - **At low- and mid-latitudes**: *Moore et al.* (2010) found best match between model and Cassini RSS data for **a reduction of** ($[H_2(v \geq 4)]/[H_2]$) from *Moses and Bass* [2000]
  - **In the auroral regions**, expected **to be larger**: *Galand et al. (2011)* assumed 2 x ($[H_2(v \geq 4)]/[H_2]$) from *Moses and Bass* [2000]
- **How does this affect thermospheric circulation?**

STIM RESULT 2: sensitivity to vibrationally excited H_2 rate



EXOSPHERIC TEMPERATURE

→wind direction

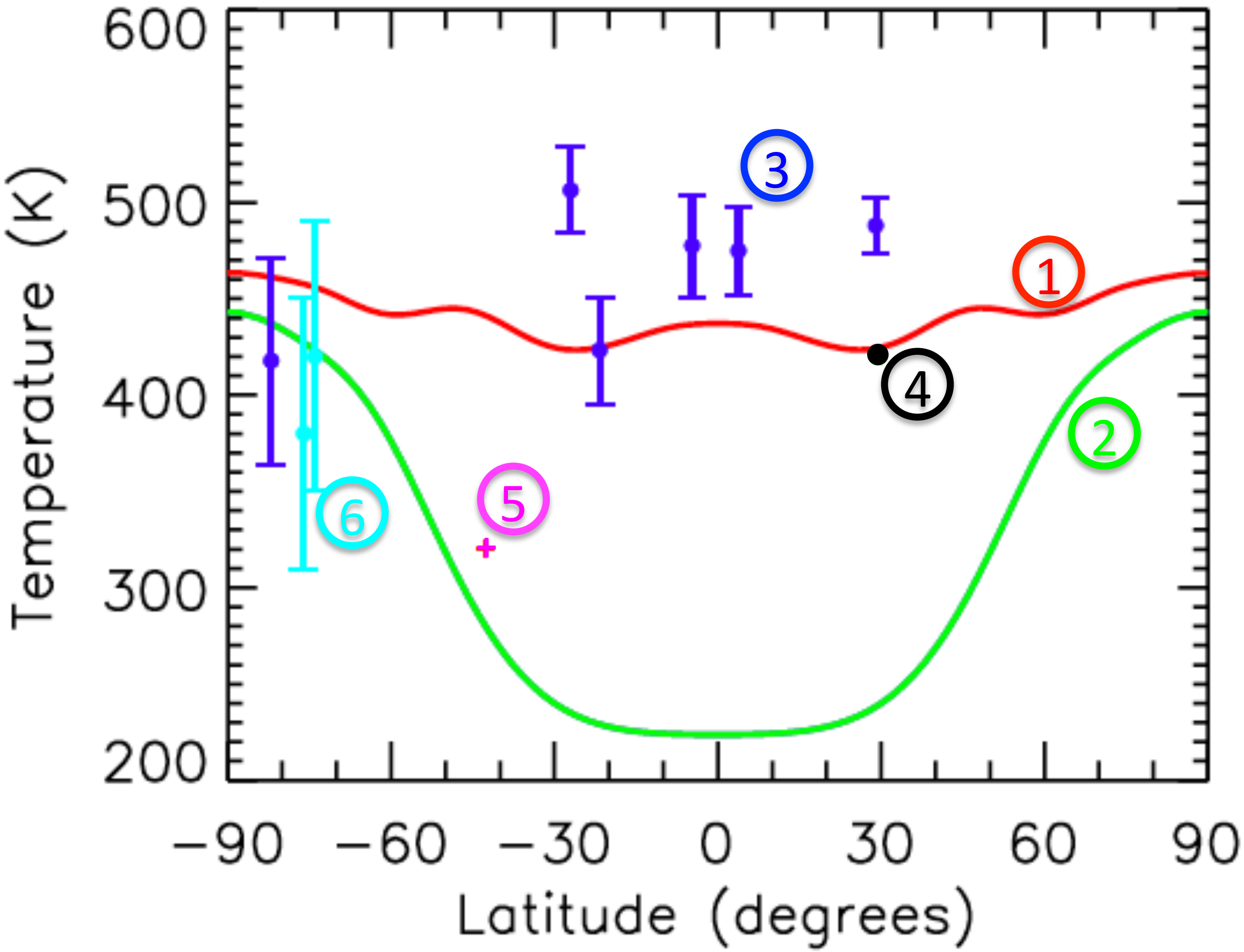
3 cells

Local time averaged

[*Mueller-Wodarg et al.,* 2011]

4. OBSERVATIONS OF THE THERMOSPHERE/IONOSPHERE SYSTEM

Implication for exospheric temperatures



(1) STIM, 3 cells

(2) STIM, 1 cell

(3) Voyager UVS (Vervack and Moses, 2011)

(4) Voyager UVS (Smith et al., 1983)

(5) Cassini UVIS (Nagy et al., 2009)

(6) UKIRT (Melin et al., 2007)

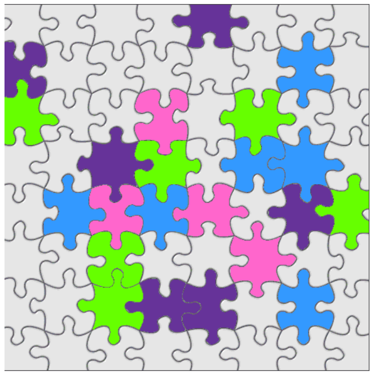
[*Mueller-Wodarg et al.*, 2011]

Sample of relevant observations: Earth-based + space missions

Which observations can help constrained the problem?

Type of observat.	Radio occultations	H_3^+ IR emissions	UV emissions	Radio emissions
Physical quantities	Electron density	Effective H_3^+ column density, temp, and velocity vector	Auroral e- energy flux & energy (generating aurora)	Auroral e- energy flux and energy (within accele region)

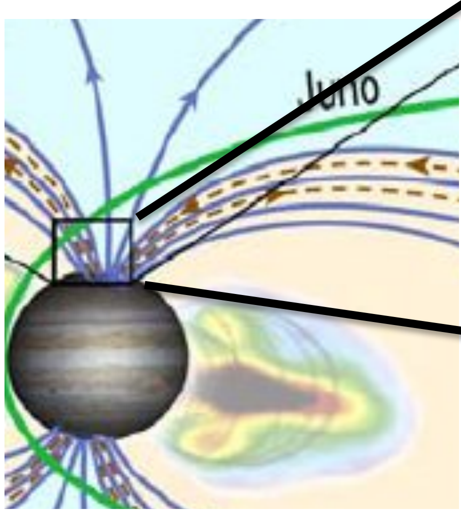
UV occultations	In situ measurements (particle, fields)
Atmosph. densities, Texospheric	Down/upgoing auroral particles (if conditions allows), Magnetic field strength/ direction, Electric currents



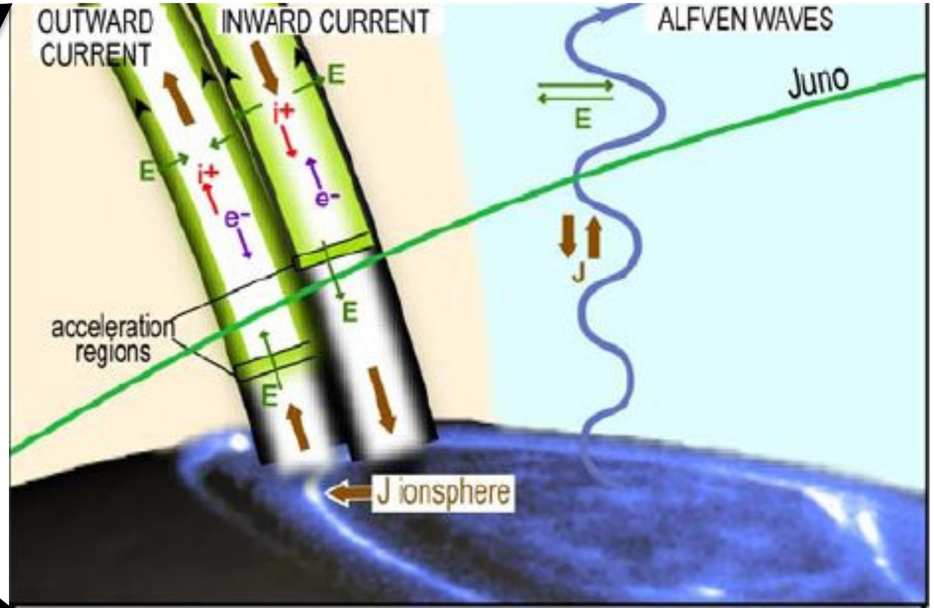
✓ **Combine as many as possible to better constrain the problem**

[*e.g., Melin*, talk]

JUNO
over the polar regions



Credit: *Juno Team*



Credit: *Juno Team*

JUNO observations through the magnetic field lines connected to the auroral ionosphere, close/within the acceleration region (expected to be 2-3 RJ from center [*Ray et al., 2009*]):

- Electric currents along magnetic field lines
- Plasma/radio waves revealing processing responsible for particle acceleration [*see Hess, tutorial*]
- Energetic particles precipitating into atmosphere creating aurora
- Ultraviolet/IR auroral emissions regarding the morphology of the aurora

Outstanding questions

- ***Can the energy crisis be solved via auroral forcing alone as proposed here?***
  - **Is the mechanism proposed efficient at Jupiter, Uranus** (seasonal asymmetry [*Melin et al.*, 2011 + poster]), **and Neptune?**
  - At Saturn, beside the solar contribution which is dominant [*Moore et al.*, 2010], are they **additional energy sources at low- and mid-latitudes?** [e.g., break-down in co-rotation of the ions in the ionosphere [*Stallard et al.*, 2010; *Tao*, poster; *Ray*, talk], molecular neutral torus of Saturn through charge-exchange (ENA) [e.g., *Jurak* & *Johnson, 2001*], **wave heating** (super-rotat≠IR)]

  → Further **constraints on ionospheric densities** at different LT [dawn/dusk RSS, Max Ne SEDs, ground-based IR in H_3^+ (noon!)]

- ***What drive the hemispheric differences observed at Saturn in the magnetosphere and auroral, ionospheric regions?***
  - Asymmetry in B field? Hemispheric (seasonal) differences in the atmosphere? If the latter, should reverse now as going out of equinox?

- ***Is the variable rotation rate observed in the magnetosphere linked to atmospheric dynamics?*** *[e.g., Jia/Kivelson talk]* (two-way MI coupling)