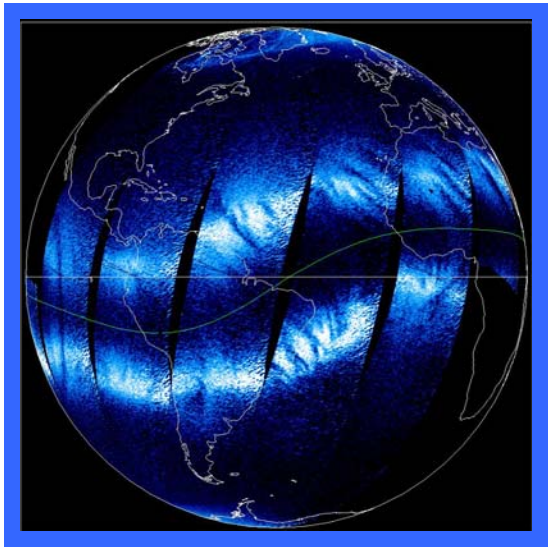
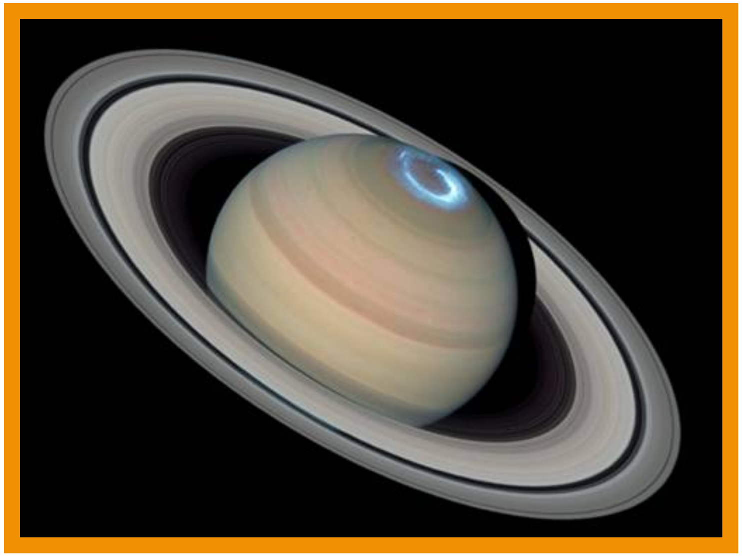
Comparative Aeronomy

Common Processes With
Common and Uncommon Results at
Earth and Saturn



TIMED (L. Paxton)

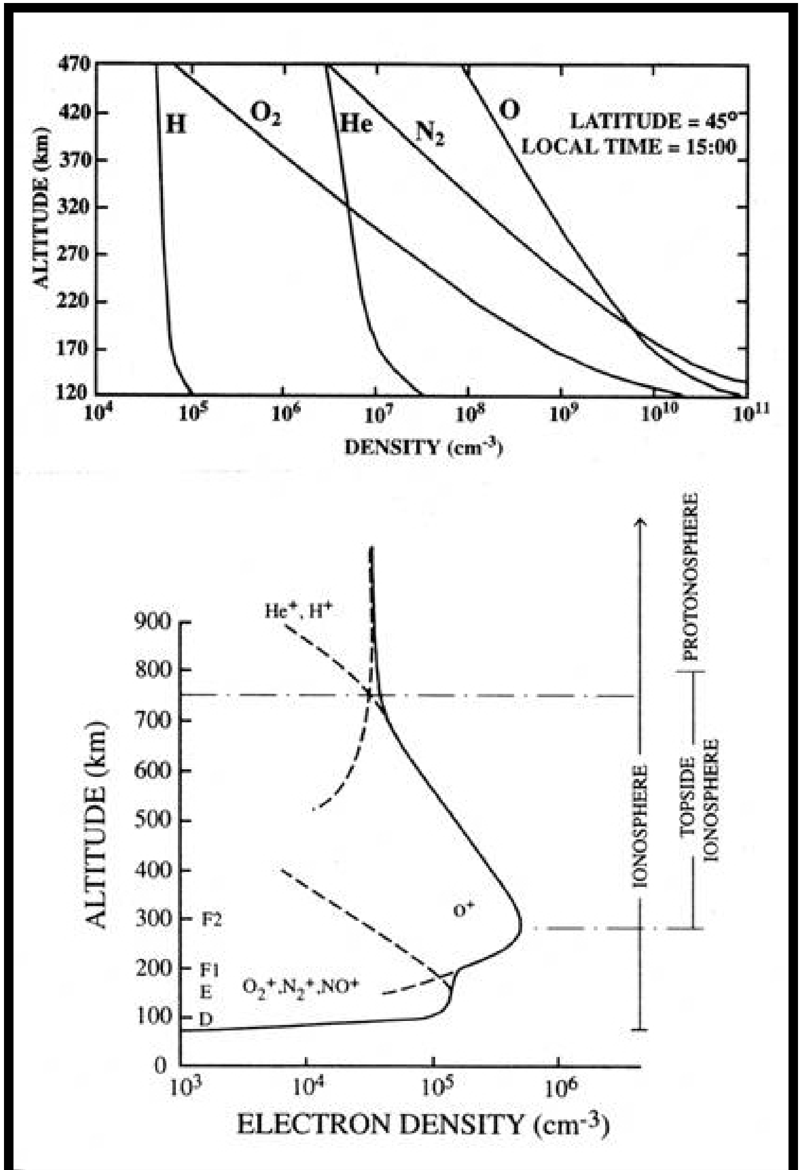
Michael Mendillo
and
Andrew Nagy



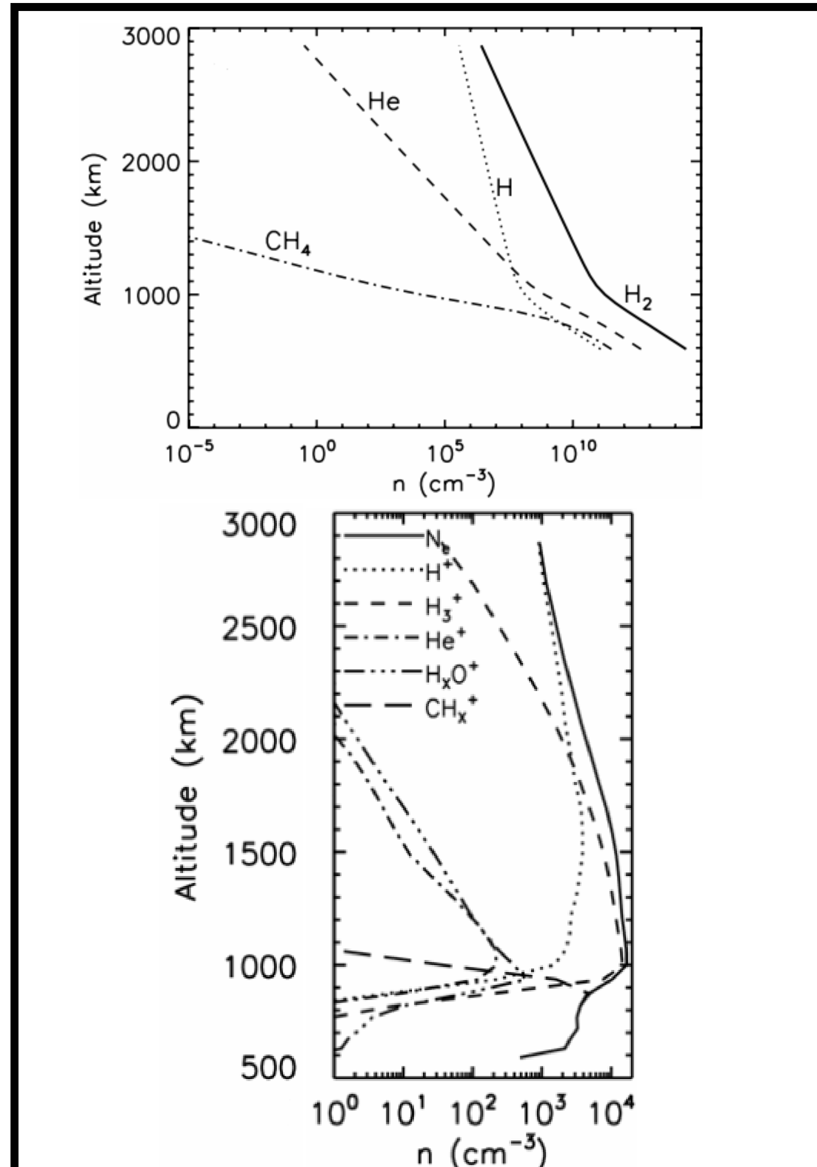
HST (J. Clarke)

Comparative Atmosphere/Ionospheres

EARTH



SATURN



Issues at Saturn

(A)Thermospheric "Energy Crisis"

- T_{exo} ~400° K (observed)
- T_{exo} ~150° K (from sunlight)
- **EARTH:** Solar EUV ~500 GW; Particle & Joule ~80 GW
- **SATURN**: Solar EUV ~270 GW; Particle & Joule ~1000 GW

(B) Type of Ionosphere

- Atomic Ion Dominated
  - Terrestrial F2-layer-like; long-lived
- Molecular Ion Dominated
  - Terrestrial E-layer-like; daytime

(C) Ionospheric Variability

- "No two N_e(h) alike!"

(A) Saturn's Energy Crisis

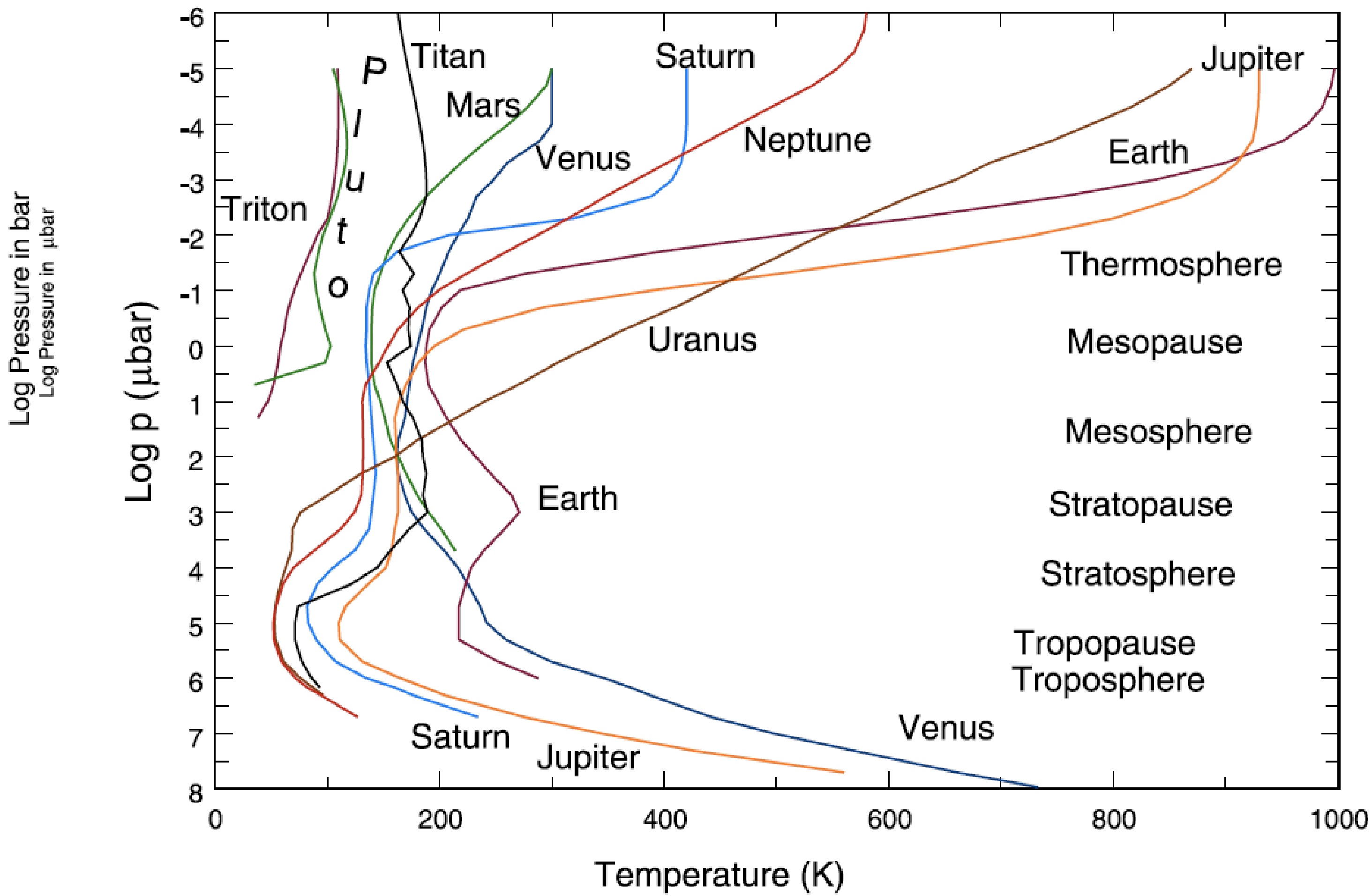
- Observed low latitude exospheric temperature reach 350-500 K

- Solar EUV heating at best will produce ~200 K

- Where does the missing energy come from?

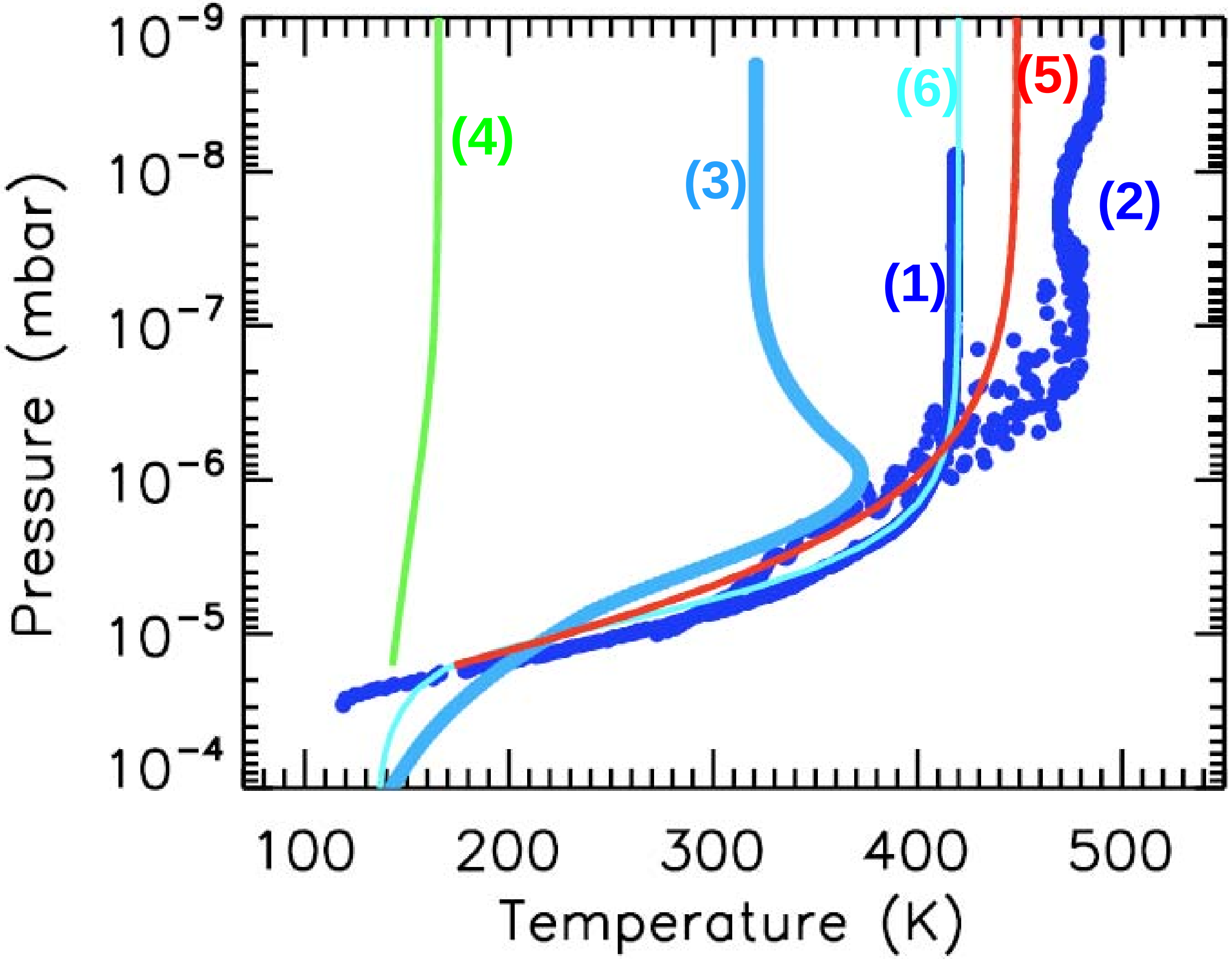
- Candidate processes:
  - Wave heating (Energy from interior)
  - Magnetospheric energy input (Joule & Particle)

Context: Solar System Temperatures



(from D.F. Strobel, 2008)

Saturn Temperatures



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

(2) Voyager UVS (Vervack and Moses, 2009)

(3) Cassini UVIS (Shemansky and Liu, 2009)

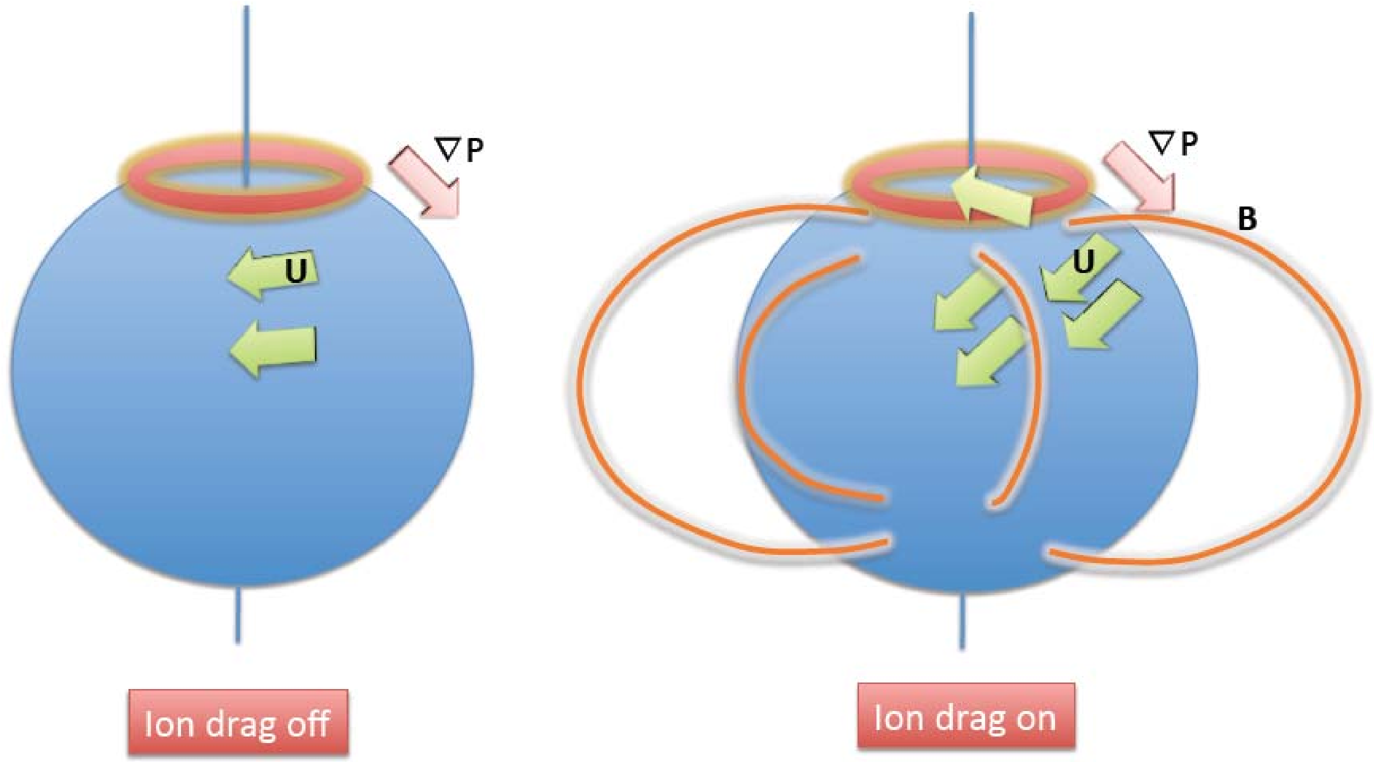
(4) STIM GCM, no ion drag (Mueller-Wodarg et al., 2006)

(5) STIM GCM, full M-I coupling

(6) Moses et al. (2004)

Mueller-Wodarg et al. (2009)

Effect of Ion Drag



- Without ion drag, flow primarily zonal due to fast rotation: auroral energy trapped in polar region
- Ion drag slows zonal flow via angular momentum transfer to magnetosphere. Equatorward winds enhanced, allowing meridional transport of energy

Mueller-Wodarg et al. (2009)

(B) Ionosphere: Photo-Chemical Equilibrium

--- Molecular Ions ---

	EARTH	SATURN
Production (P_o):	$N_2 + h\nu \rightarrow N_2^+ + e^-$	$H_2 + h\nu \rightarrow H_2^+ + e^-$
Transformation:	$N_2^+ + O \rightarrow NO^+ + N$	$H_2^+ + H_2 \rightarrow H_3^+ + H$
Loss (L):	$NO^+ + e^- \rightarrow N + O$	$H_3^+ + e^- \rightarrow H_2 + H$

For $P_o = L$ $\quad P_0 = \alpha N_e^2$

For $\quad P_0 \propto \Phi_{SUN} \propto \frac{1}{d^2}$

Giving $\quad N_e(d) \propto \frac{1}{d}$

Ionosphere

--- Atomic Ions ---

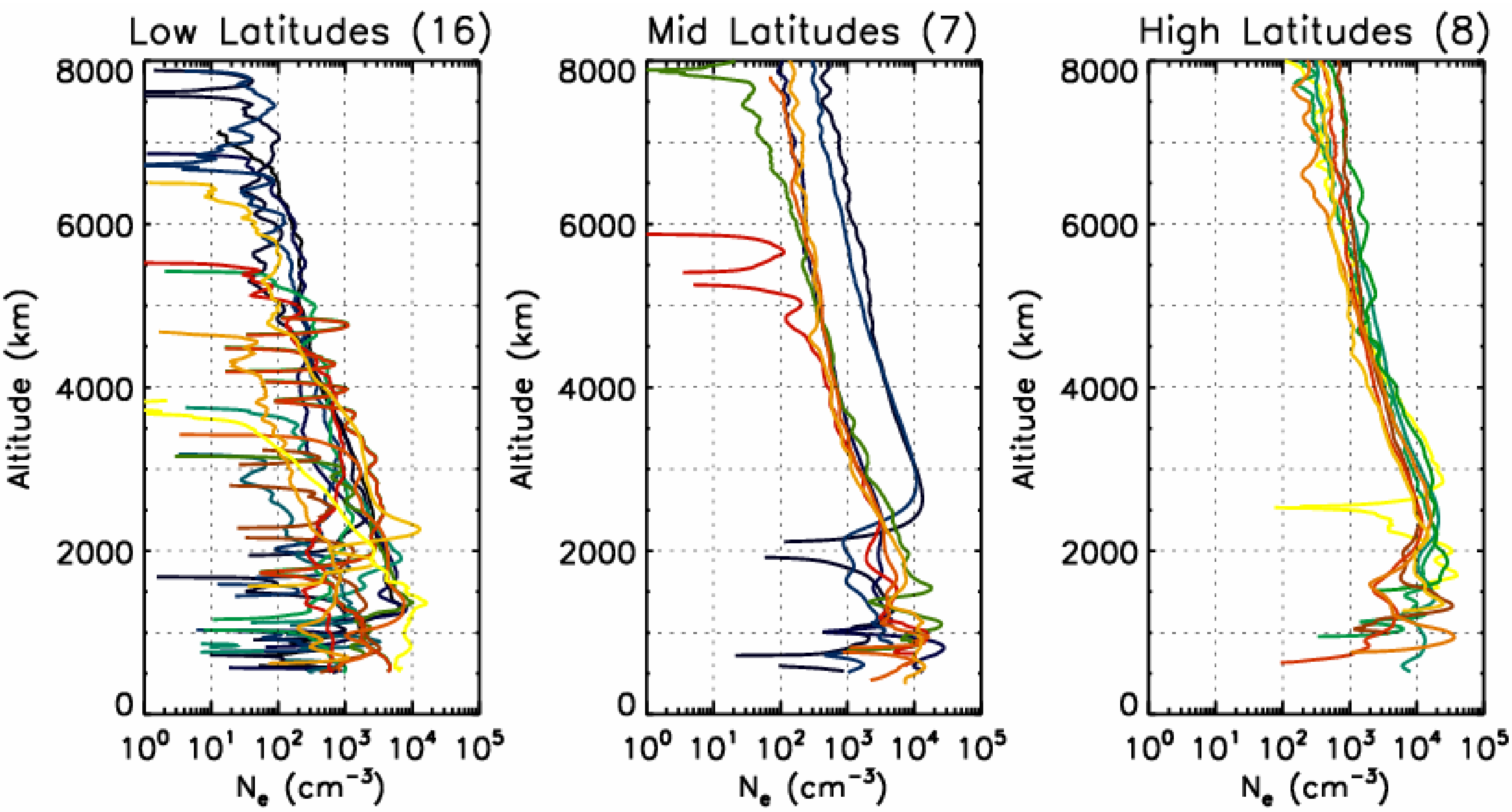
	EARTH	SATURN
Production (P_o):	**$O + h\nu \rightarrow O^+ + e^-$**	**$H + h\nu \rightarrow H^+ + e^-$**
Transformation:	**$O^+ + N_2 \rightarrow NO^+ + N$**	**$H^+ + H_2 \rightarrow H_2^+ + H$ (only if ν>3)** **$H^+ + H_2O \rightarrow H_2O^+ + O$ (water input)**
Loss (L):	**$NO^+ + e^- \rightarrow N + O$**	**$H_2O^+ + e^- \rightarrow H_2 + O$**

- Without vibrational excitation (e.g., Huestis, 2009) and/or H_2O influx (Connerney and Waite, 1984), **$N_e \rightarrow 10^5$ e$^-$ cm^{-3}**

- Observed **N_{MAX} ~10^4 e$^-$ cm^{-3}**

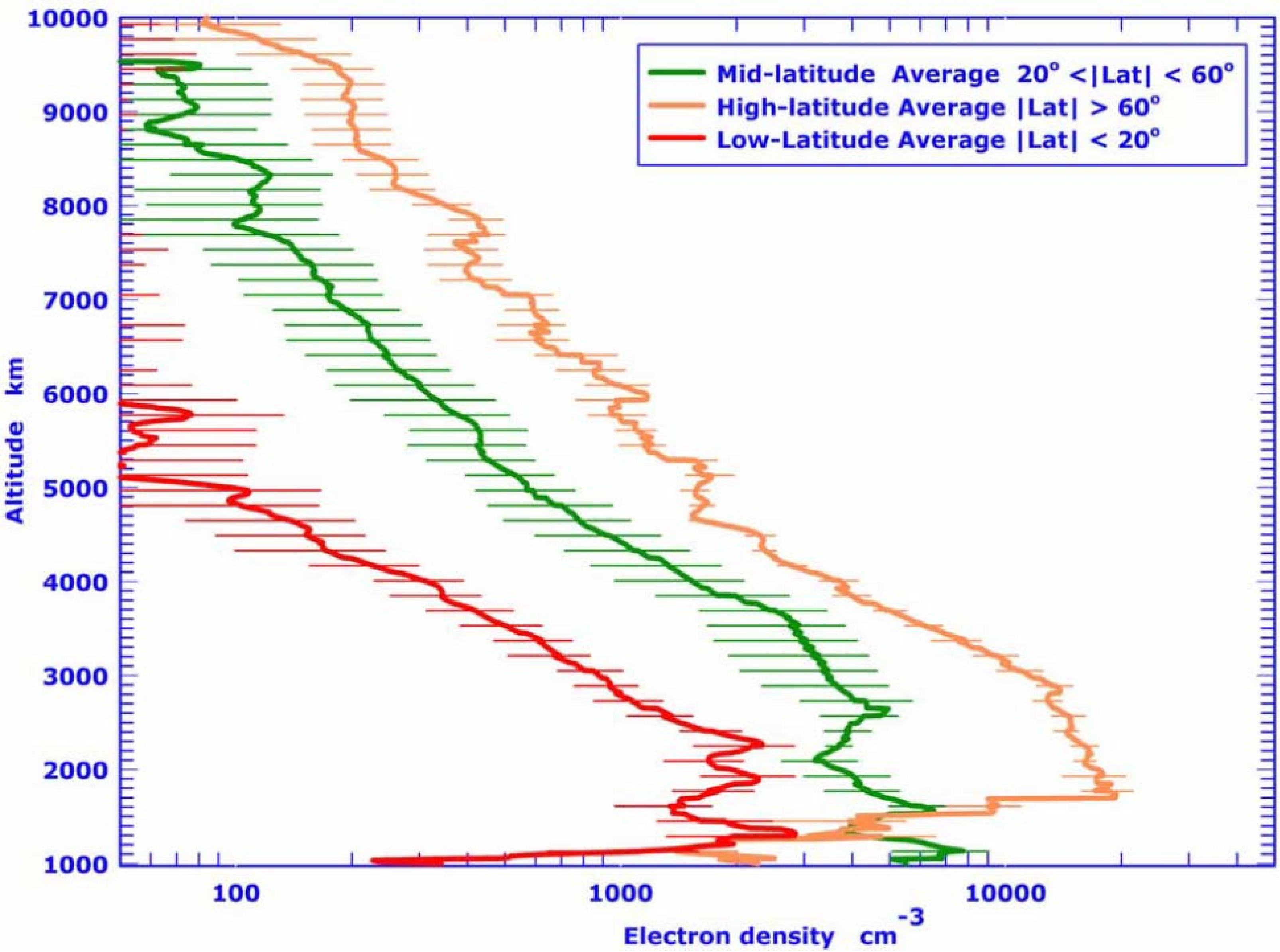
(C) Ionospheric $N_e(h)$ Variability

- Pioneer 11 and two Voyager fly-bys (1979-1981) = **6 $N_e(h)$**
- Cassini in orbit around Saturn (2004-present) = **31 $N_e(h)$**

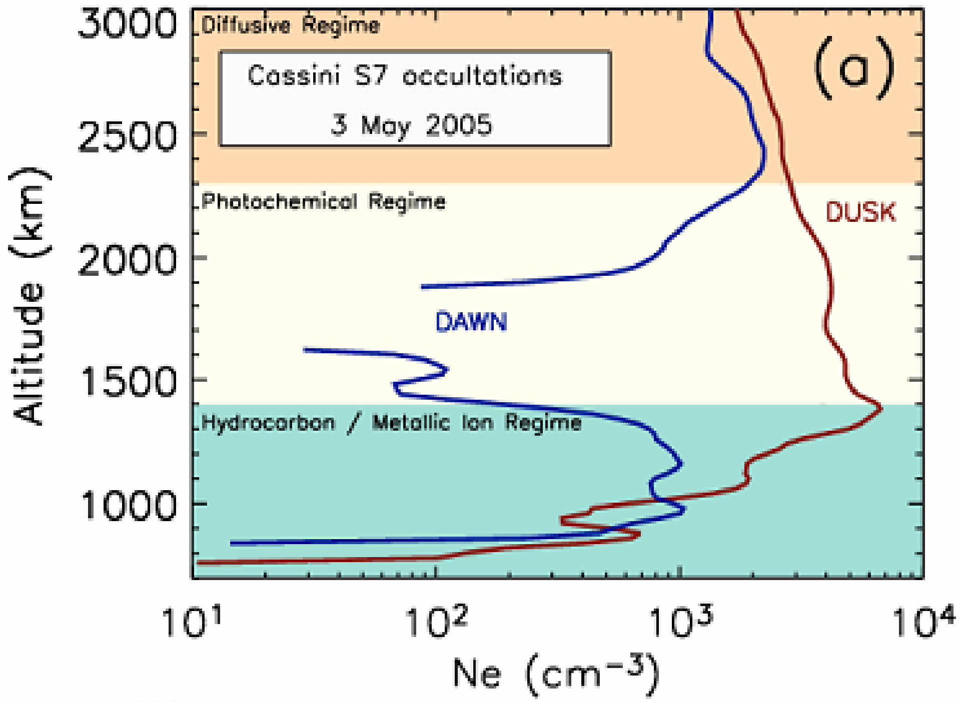


Nagy et al. (2006); Kliore et al. (2009)

Average Latitude Pattern



Kliore et al. (2009)



“Ionospheric Holes”

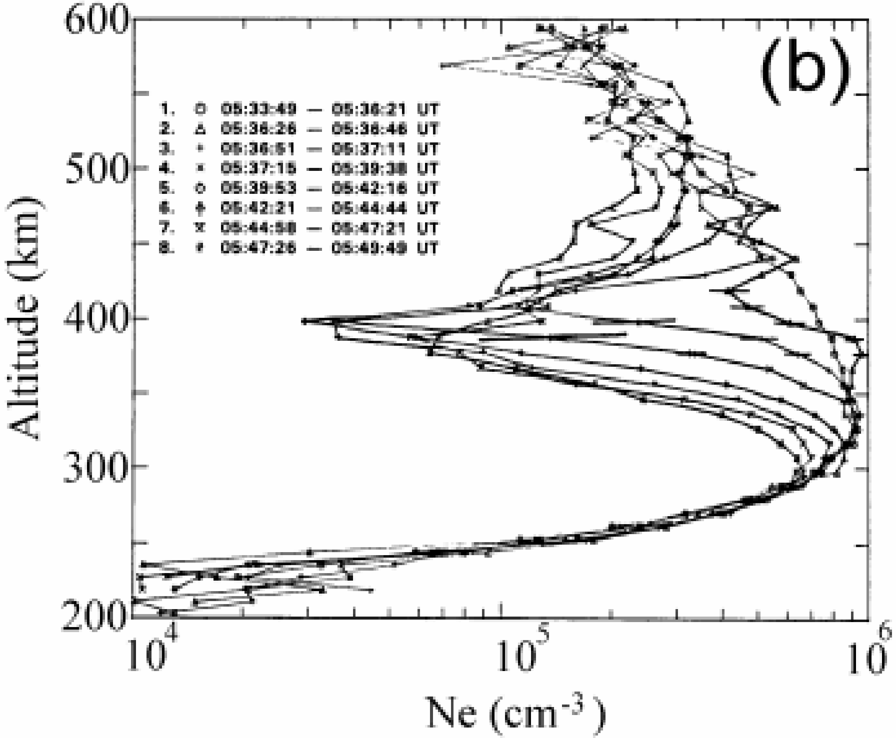
at

Saturn

by

$H_2$0 Influx?

Moore and Mendillo (2007)



Rocket Exhaust-Induced

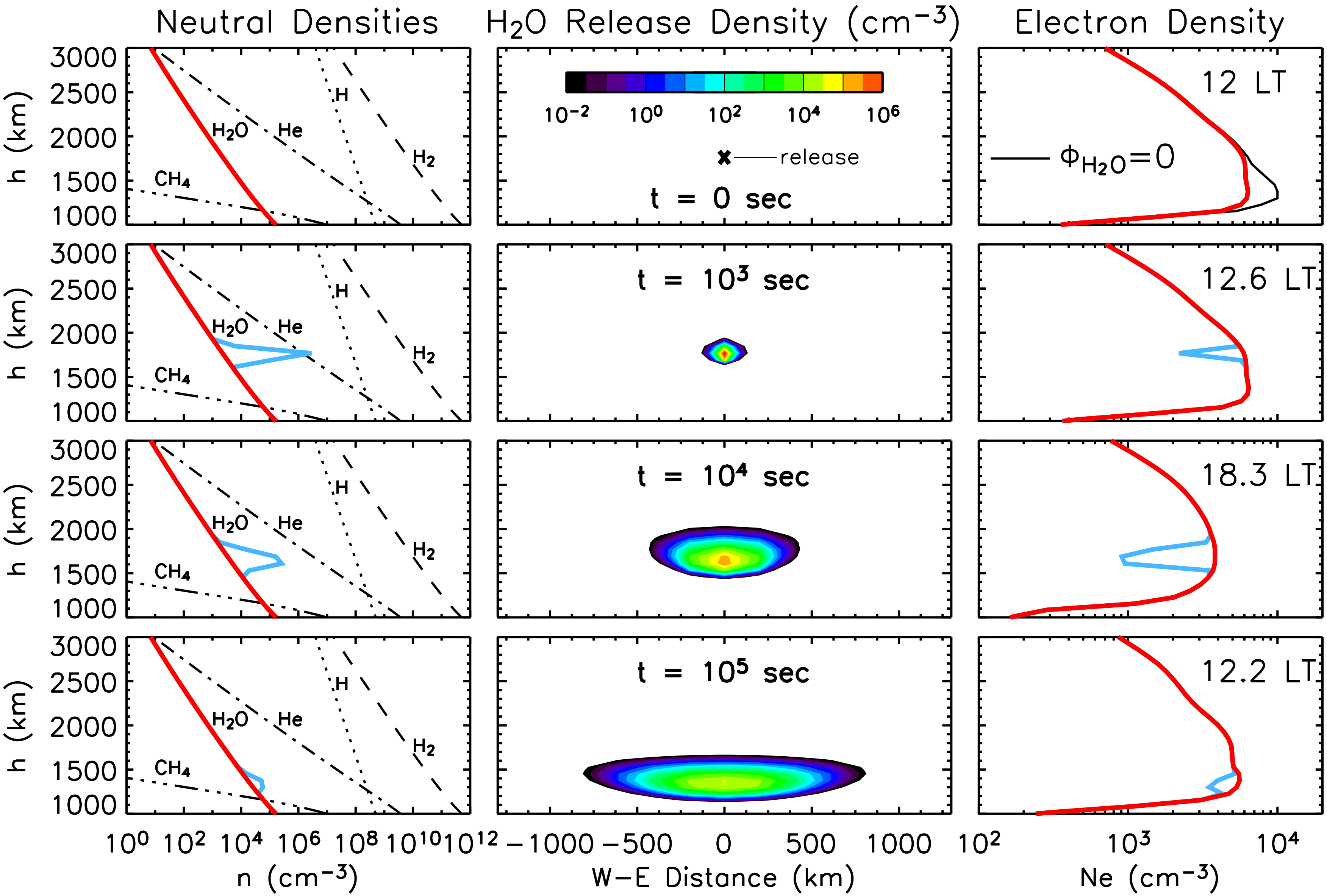
“Ionospheric Holes”

at

Earth

Wand and Mendillo (1984)

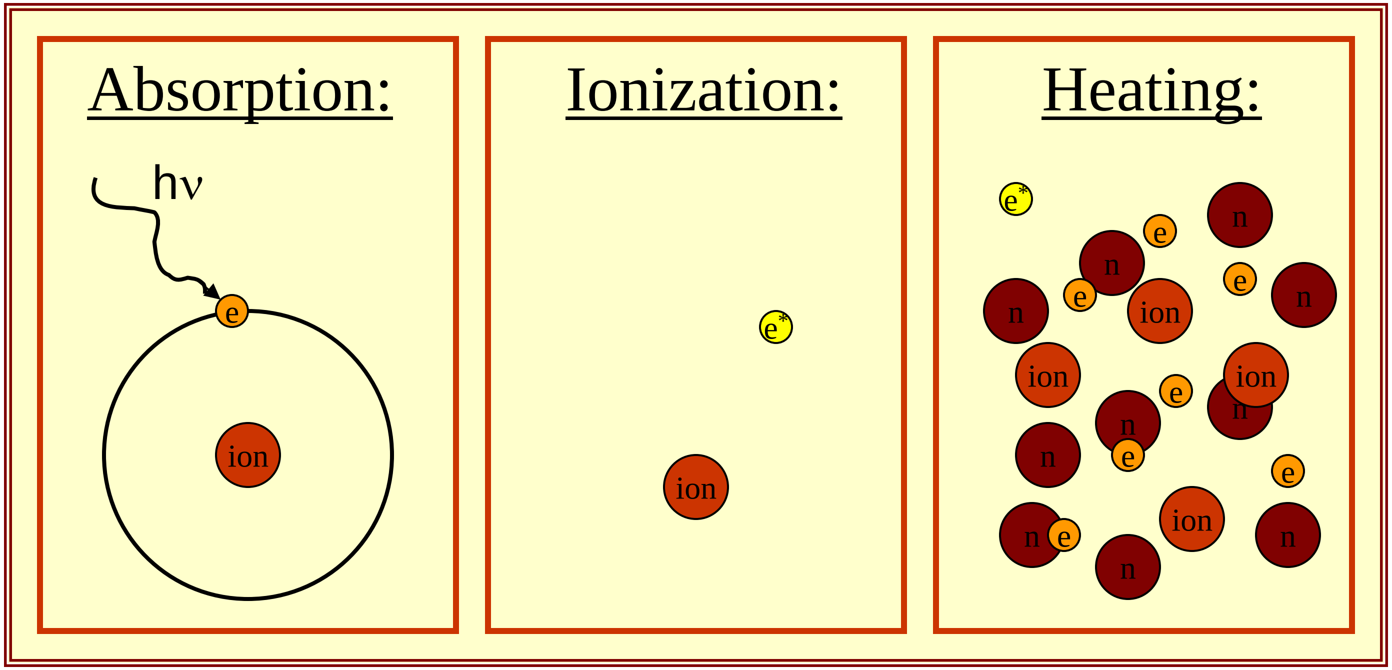
Active Experiments at Saturn?



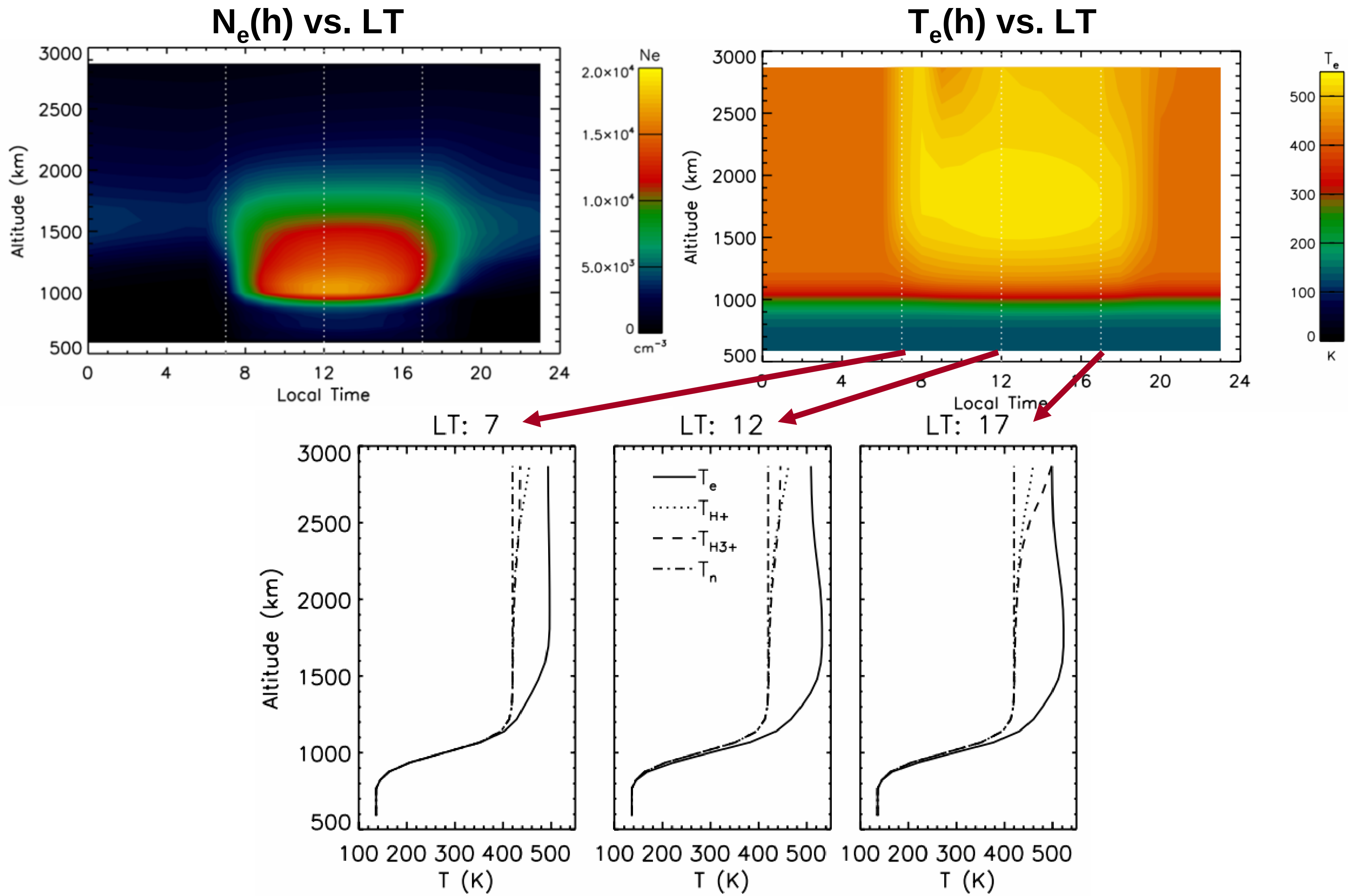
Moore and Mendillo (2007)

Current Topics:

Plasma Temperatures
Secondary Ionization
Conductivity



Saturn Plasma Temperatures

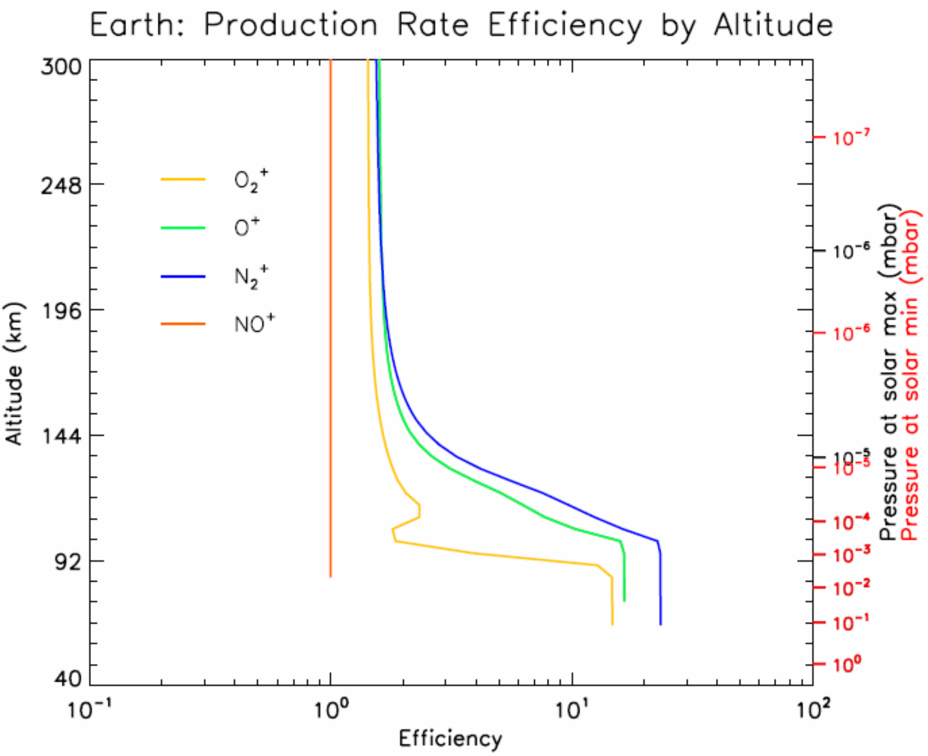


Moore et al. (2008)

Secondary Ionization

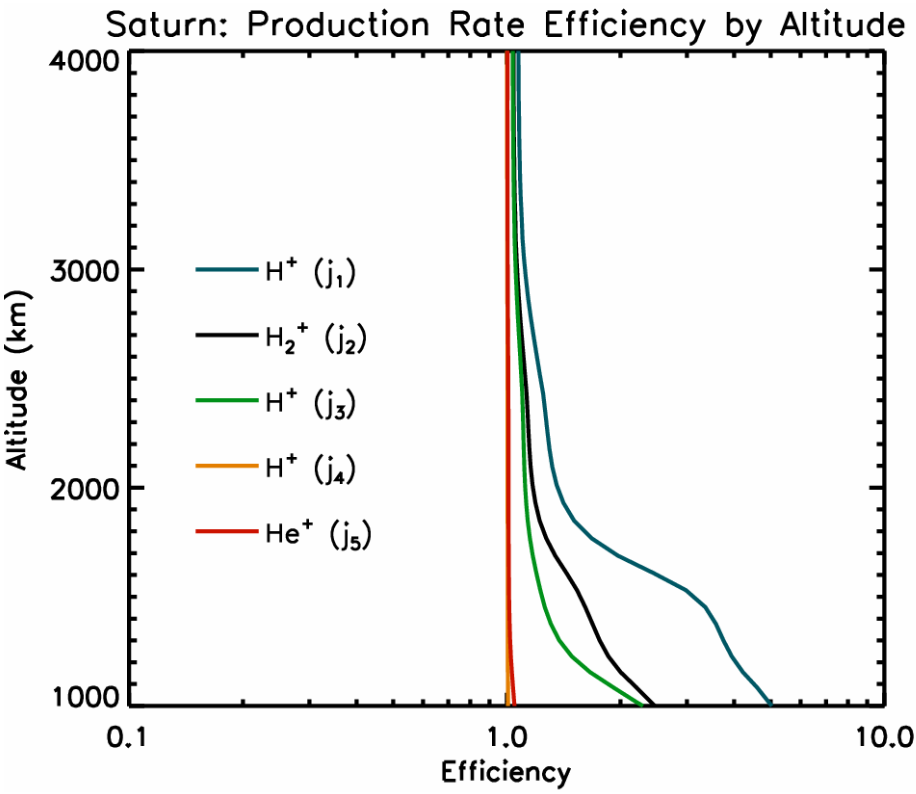
$$P_{TOT} = \eta_{TOT} P_{h\nu}$$

EARTH



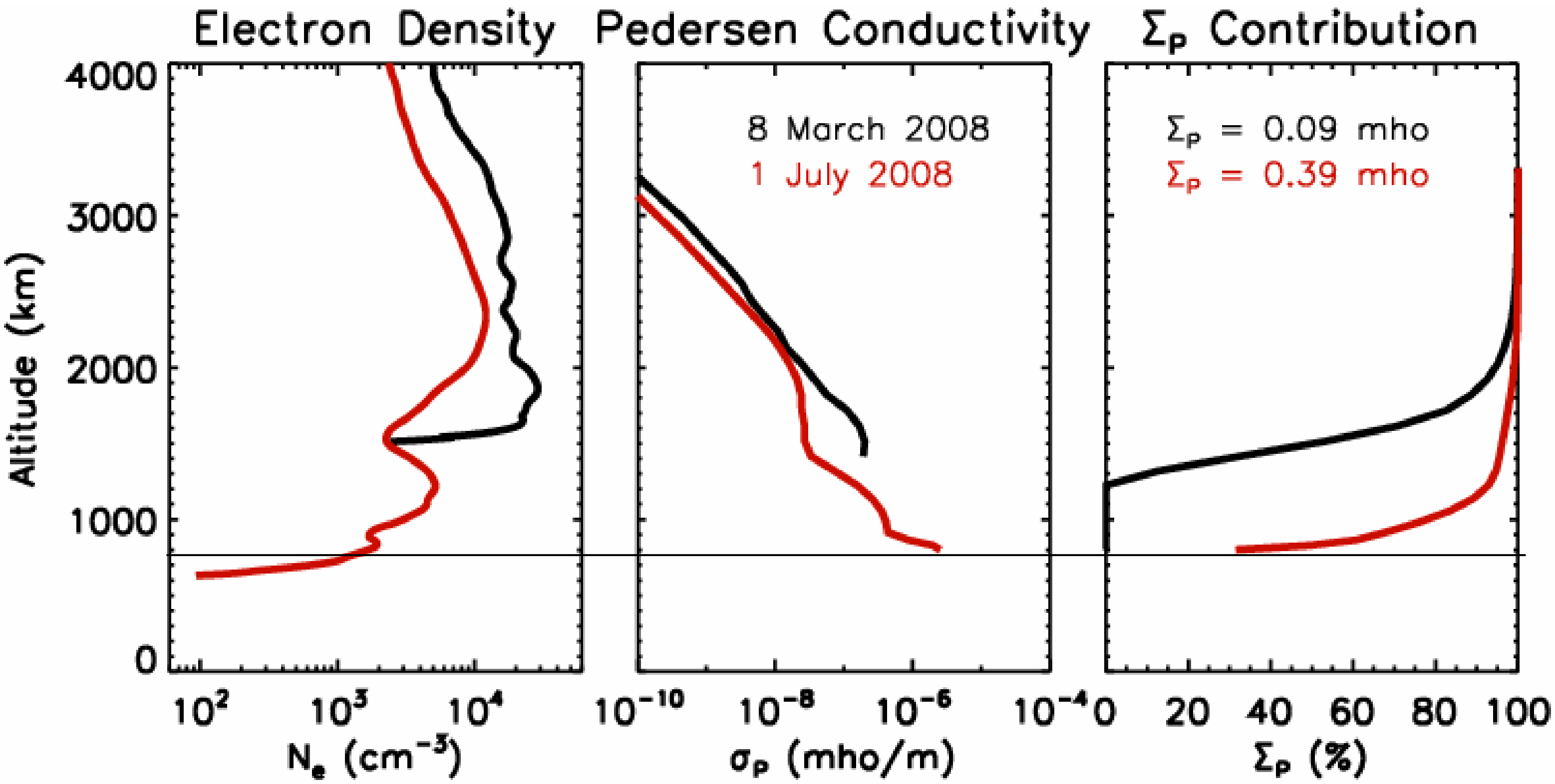
Titheridge (1996)

SATURN



Galand et al. (2009)

Pedersen Conductance



- Saturn $N_e(h)$ variability combined with unreliability of occultation technique at low altitude makes determining accurate conductance difficult for some RSS profiles.

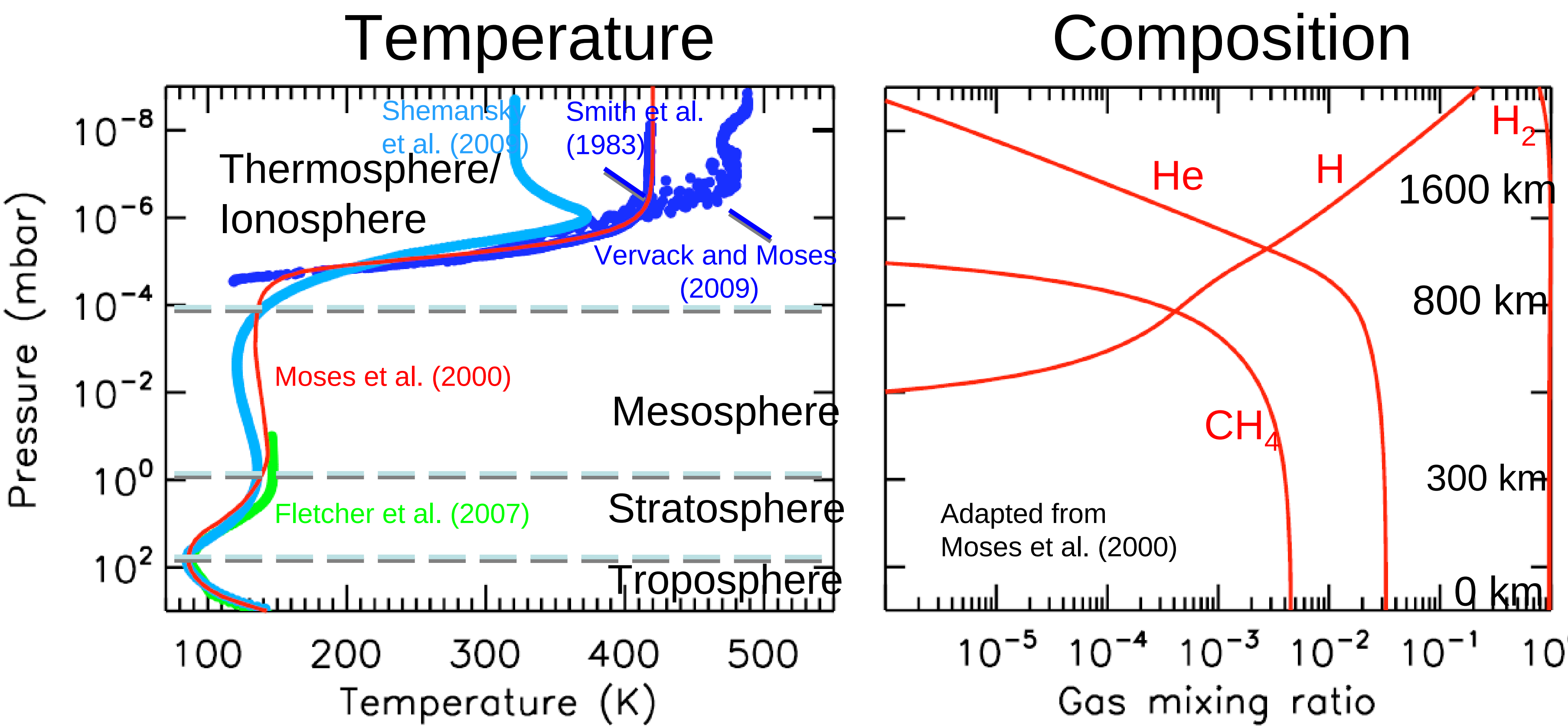
-Models need to give full treatment to bottom side ionosphere.

LOW-latitude	$<\Sigma_P>$	~ 0.89 mho
MID-latitude	$<\Sigma_P>$	~ 3.2 mho
HIGH-latitude	$<\Sigma_P>$	~ 1.3 mho

Moore et al. (2009)

Backup Slides

Saturn: A Brief Introduction



Missions to Saturn:

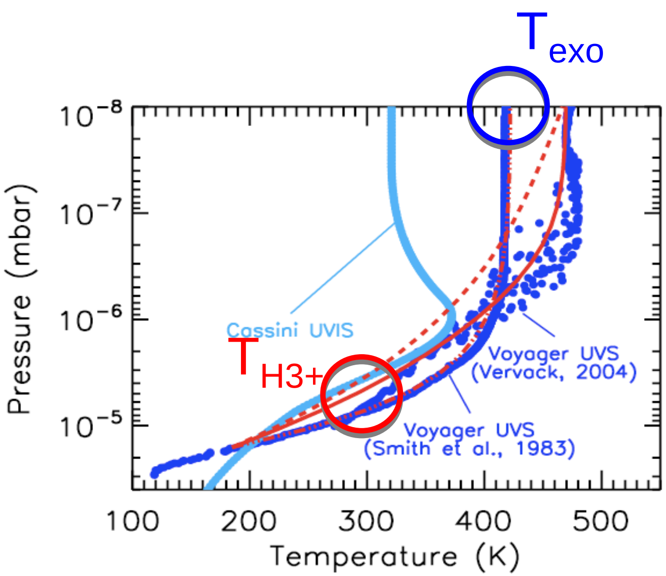
Pioneer 11 (flyby Sept 1979)

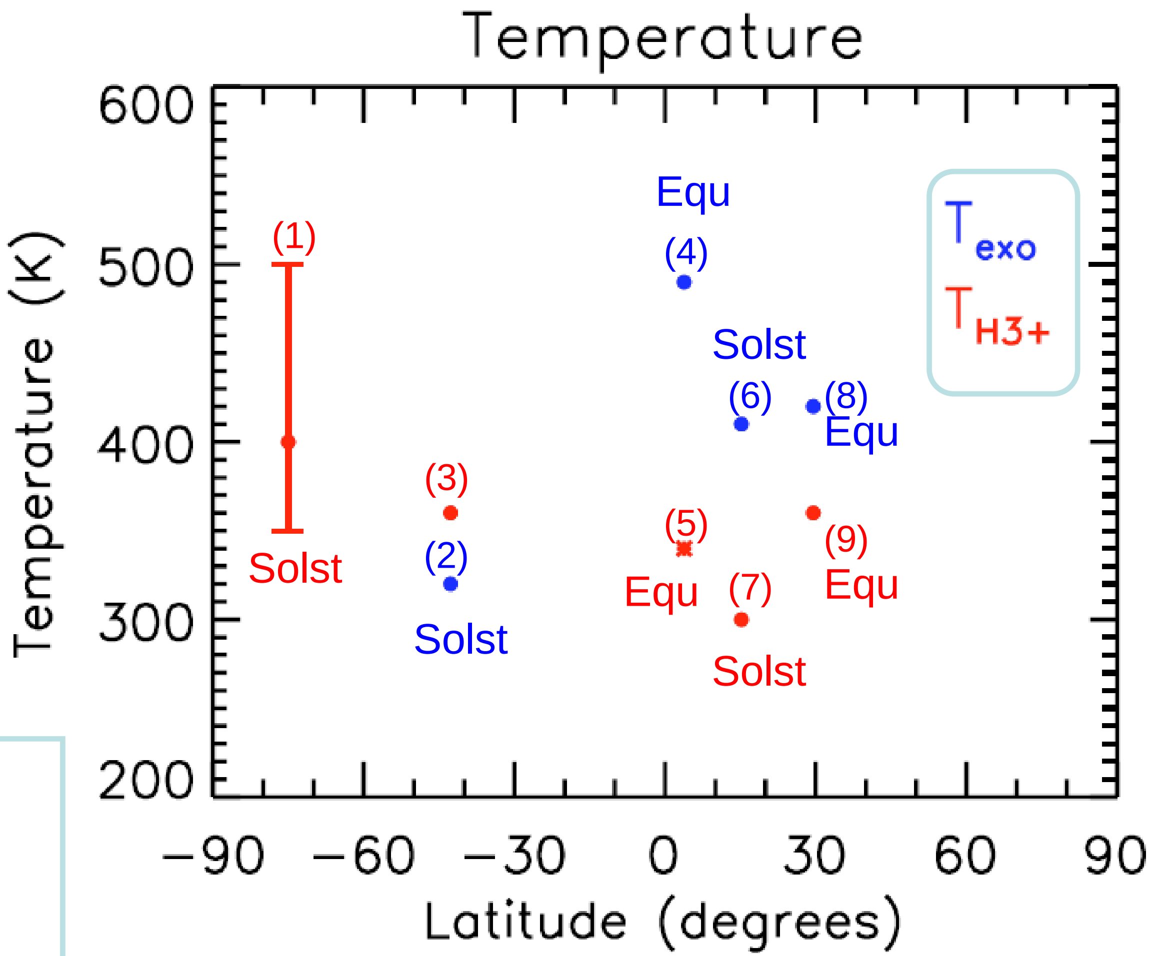
Voyager 2 (flyby Aug 1981)

Voyager I (flyby Nov 1980)

Cassini/Huygens (in orbit, 2004-2017?)

Temperature observations





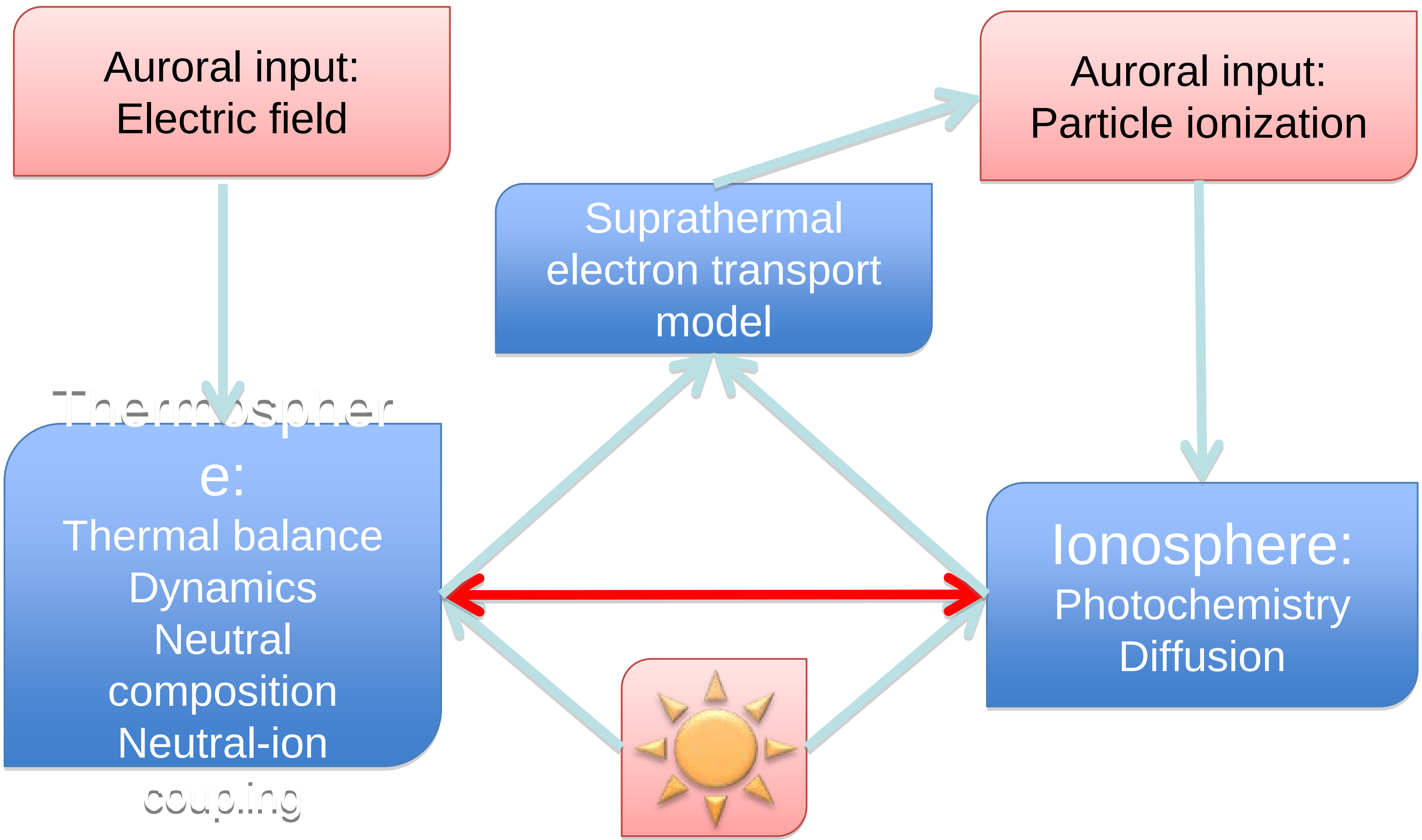
(1): Melin et al. (2007)

(2), (3), (6), (7) : Shemansky et al. (2009)

(4), (5): Vervack and Moses (2009)

(8), (9): Smith et al. (1981)

The Saturn Thermosphere Ionosphere Models (STIM)



Exospheric Temperature