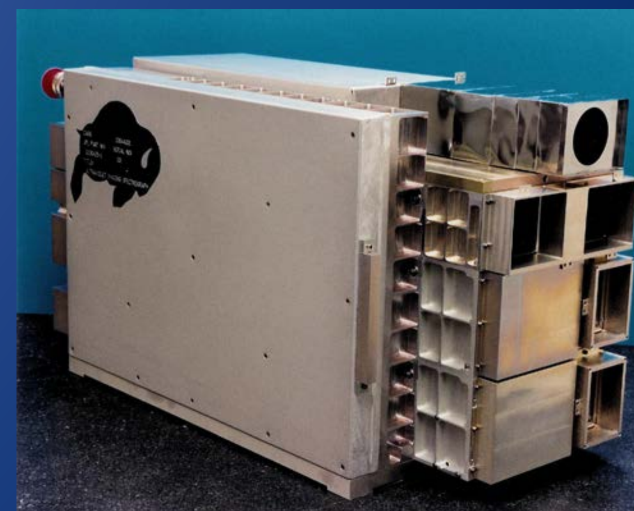
Saturn’s variable thermosphere. Part I. UV occultations

T. T. Koskinen[1,2], D. F. Strobel[3], I. C. F. Müller-Wodarg[4]

[1]Lunar and planetary laboratory, University of Arizona, Tucson, AZ, [2]Cassini participating scientist, [3]Johns Hopkins University, Baltimore, MD, [4]Space and Atmospheric Physics Group, Imperial College London, UK



Cassini UVIS: Esposito et al. (2004)

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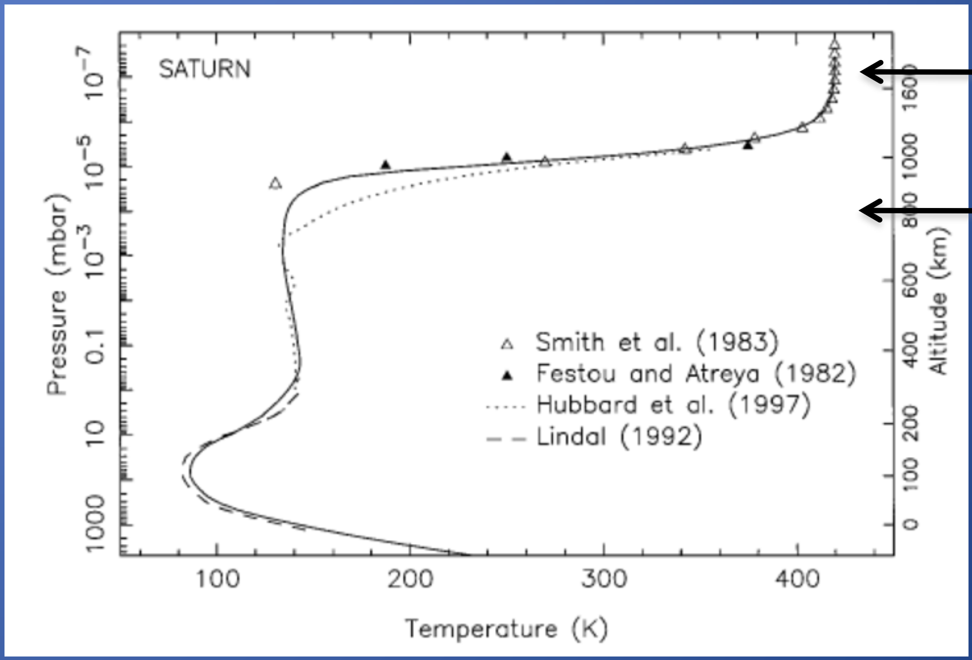
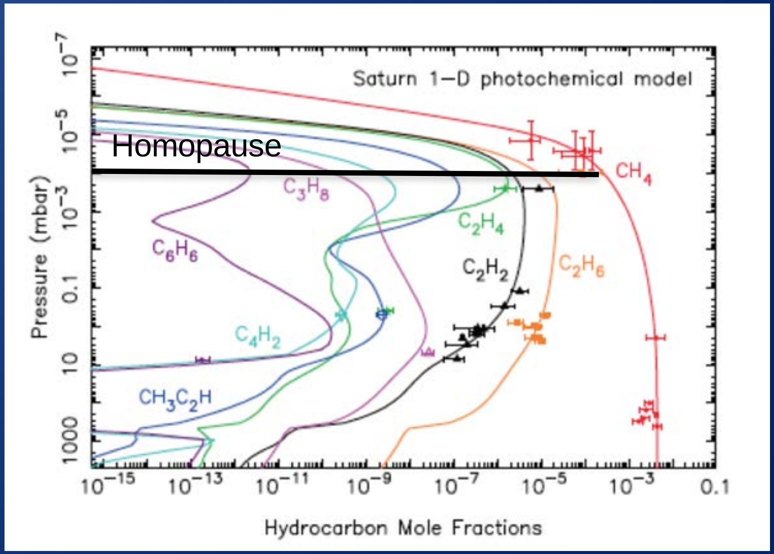
Thermosphere: Saturn



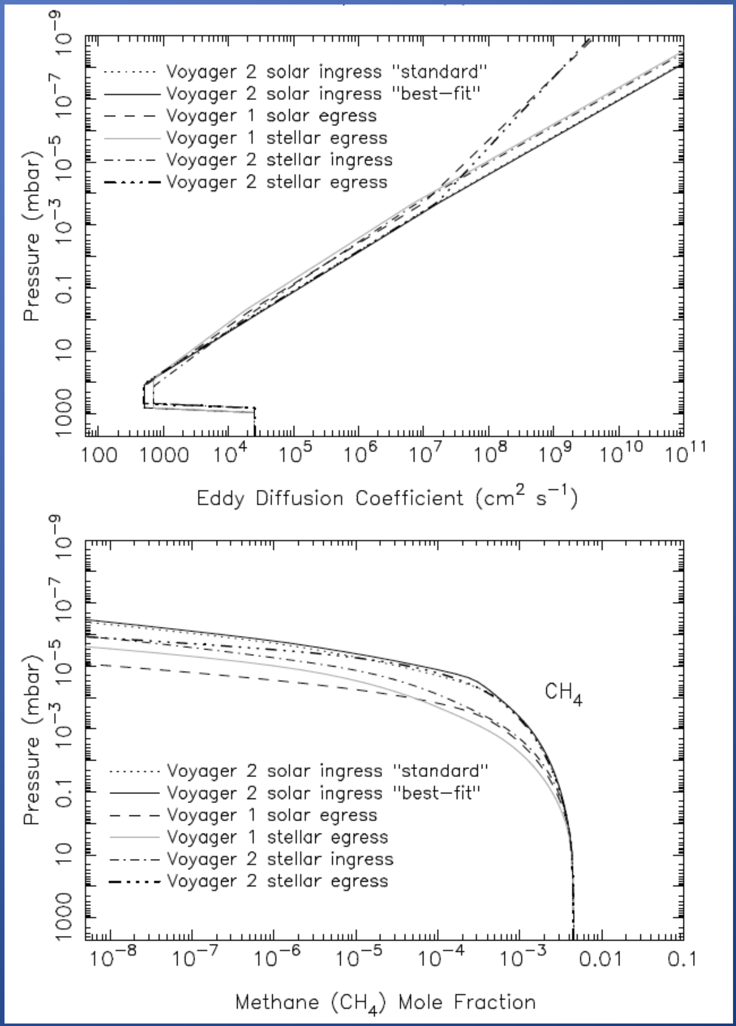
Thermosphere: Heating source unknown, solar EUV heating deposits less than 5 % of the required energy.

Upper stratosphere/mesosphere: Heating by solar near-IR in CH_4 bands, cooling by IR emissions from CH_4, C_2H_6 and C_2H_2.

Figures from Moses et al.(2000,2005). See e.g., Strobel and Smith (1973), Waite et al.(1983) and Yelle et al.(2001) for calculations of heating and cooling rates in giant planet thermospheres/mesospheres.



Homopause from Voyager UVS occultations



Model Parameters at Level Where CH_4 Mole Fraction is 5×10^{-5}

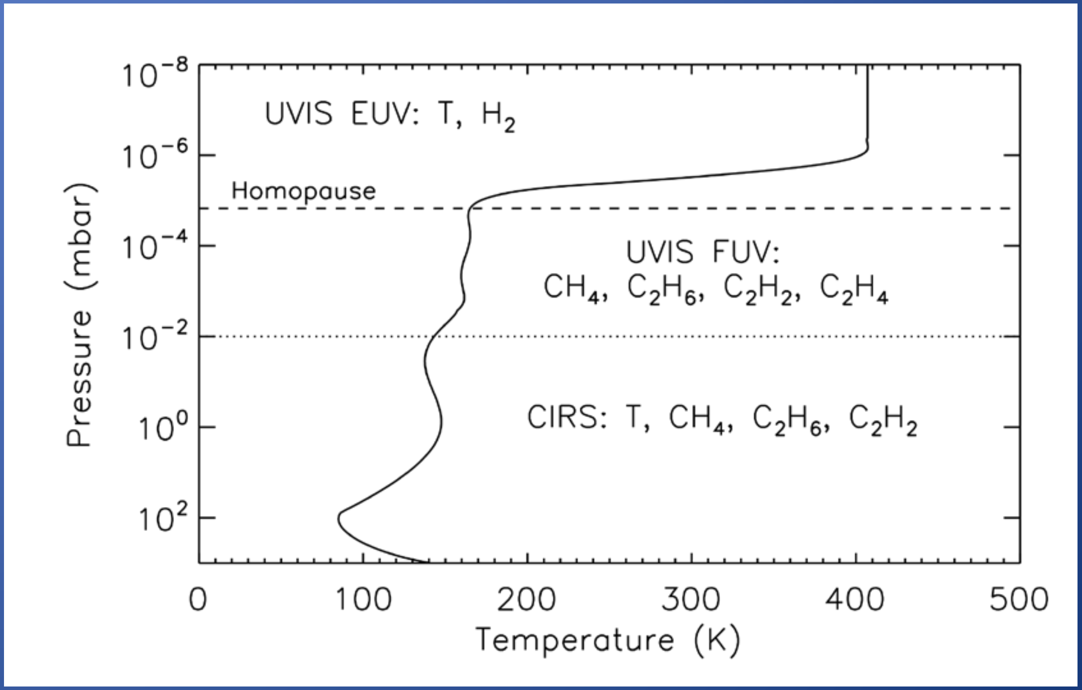
Occultation	Planetocentric Latitude	Pressure (mbar)	K_{zz} (cm^2 s^{-1})	Local Time[a] (average)
Voyager 2 solar ingress	29°			8.245
"standard model"		1.3×10^{-5}	1.6×10^{8}	
"best-fit hydrocarbon"		8.9×10^{-6}	2.4×10^{8}	
Voyager 2 stellar egress	3.8°	1.1×10^{-5}	6.0×10^{7}	9.63
Voyager 1 stellar egress	−4.8°	1.0×10^{-4}	1.3×10^{7}	10.56
Voyager 2 stellar ingress	−21.5°	4.1×10^{-5}	3.1×10^{7}	4.65
Voyager 1 solar egress	−27°	1.1×10^{-4}	1.4×10^{7}	2.77

[a] Local time is defined using a Saturn rotational period of 10.76 hours (i.e., "noon" is 5.38 and "midnight" is 10.76). These are averages of the values in Table 1.

CH_4 half light altitudes 680 – 1000 km above the 1 bar level. Note that Smith et al.(1983) determined $K_{zz} = 5 \times 10^{6}$ cm^2 s^{-1} and a homopause near 2.5×10^{-8} bar.

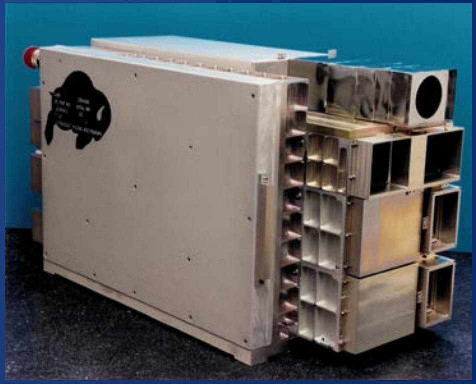
From Vervack and Moses (unpublished)

Scope of the occultations



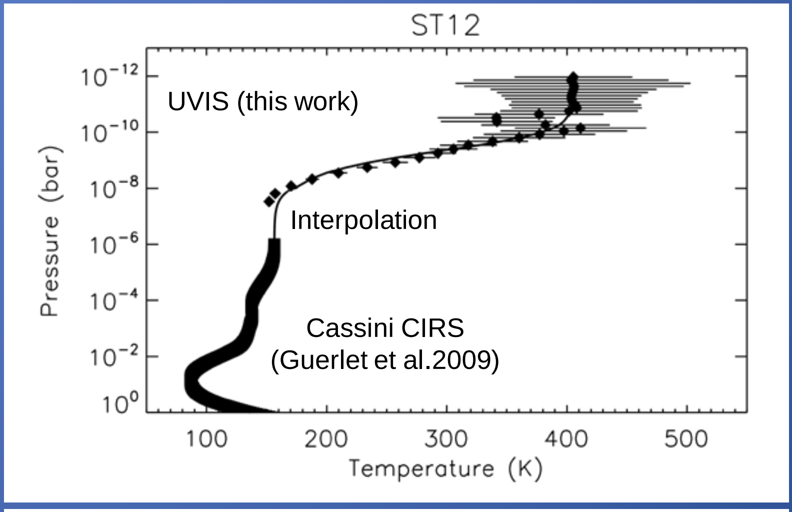
Solar occultations are observed in the EUV channel only, stellar occultations are observed simultaneously in the EUV and FUV channels. In the thermosphere we can retrieve density of H_2, upper limits on H and temperature.

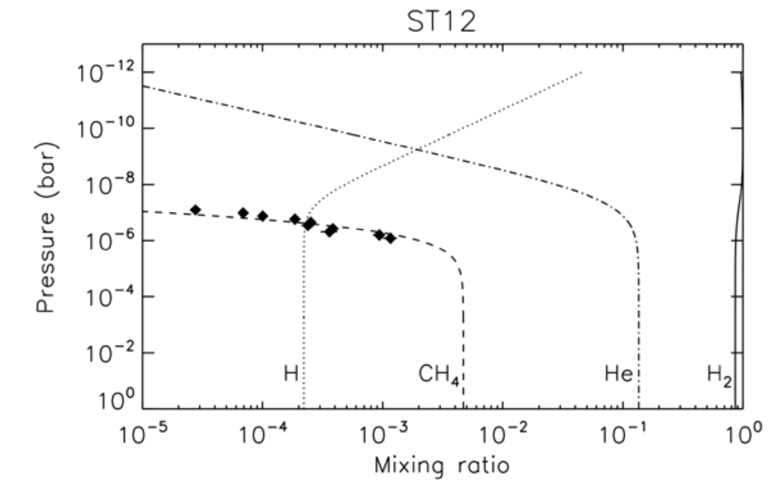
Esposito et al.(2004)



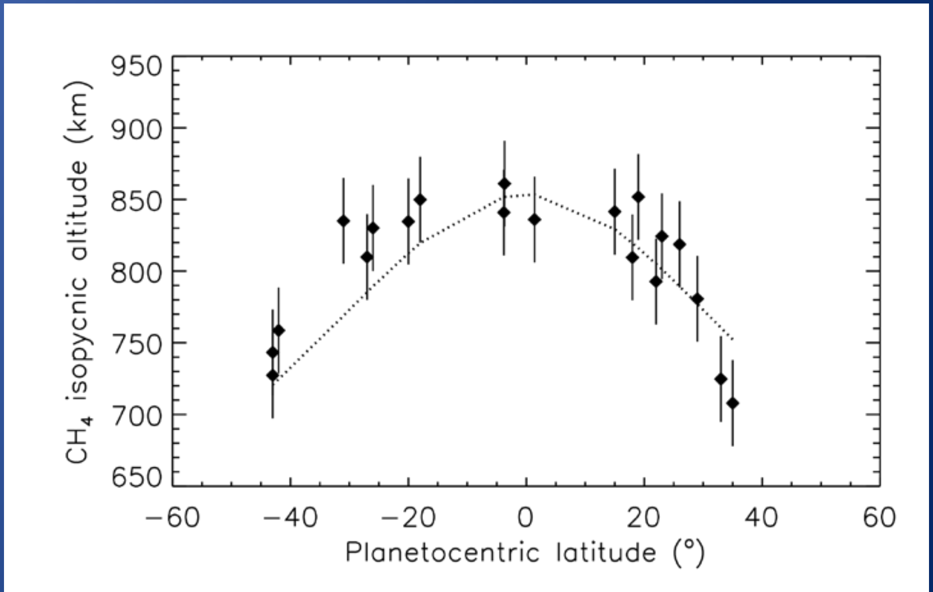
UVIS EUV channel:
563 – 1182 Å
UVIS FUV channel:
1115 – 1912 Å
Point source resolution:
2.8 Å

Homopause from Cassini UVIS





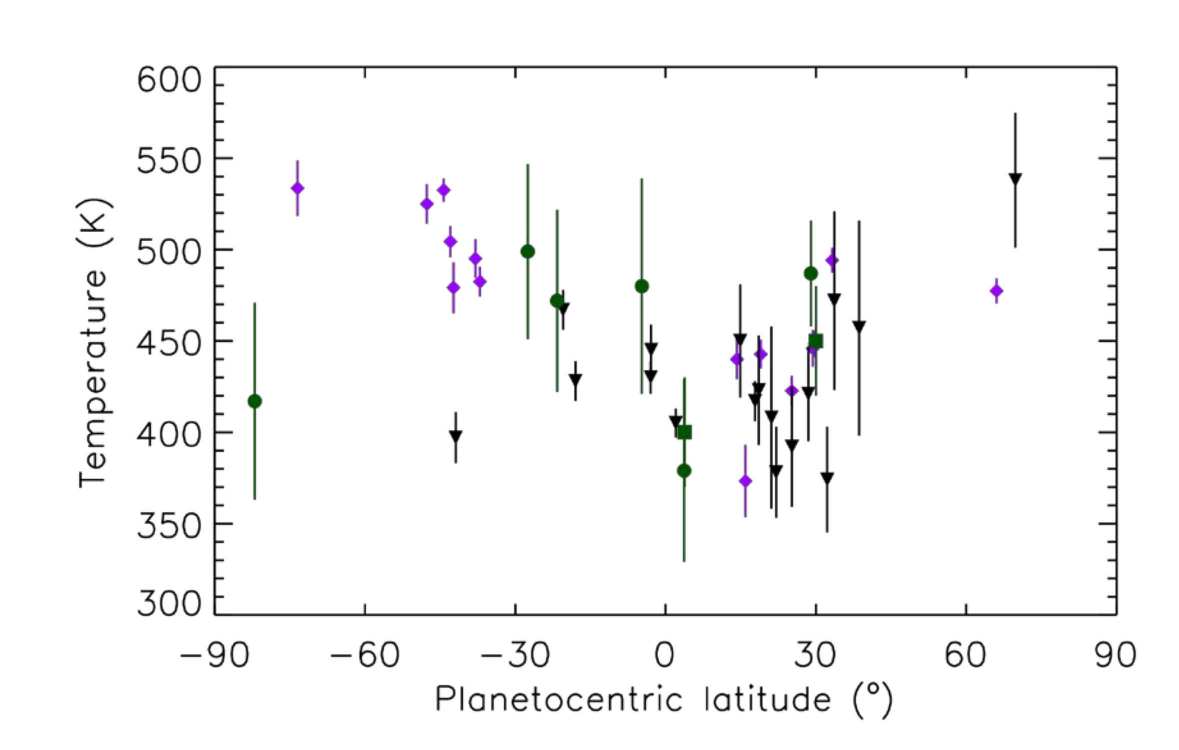
Saturn atmosphere model based on UVIS and CIRS at 26N, 2006. The homopause is at 10^{-7} bar (790 km) with $K_{zz} = 1.9 \times 10^{7}$ cm^2 s^{-1}.



Constant density (5.4×10^{14} m^{-3}) altitude for CH_4 (preliminary). The dotted line shows a constant pressure surface matching at the equator.

CH_4 data from Voyager (Vervack and Moses):
V1 solar egress (27S): 1.1×10^{-7} bar (K_{zz}= 1.4×10^{7} cm^2 s^{-1})
V2 solar ingress (29N): 1.3×10^{-8} bar (K_{zz}= 1.6×10^{8} cm^2 s^{-1})
V2 stellar ingress (21.5S): 4.1×10^{-8} bar (K_{zz}= 3.1×10^{7} cm^2 s^{-1})

Exospheric temperatures

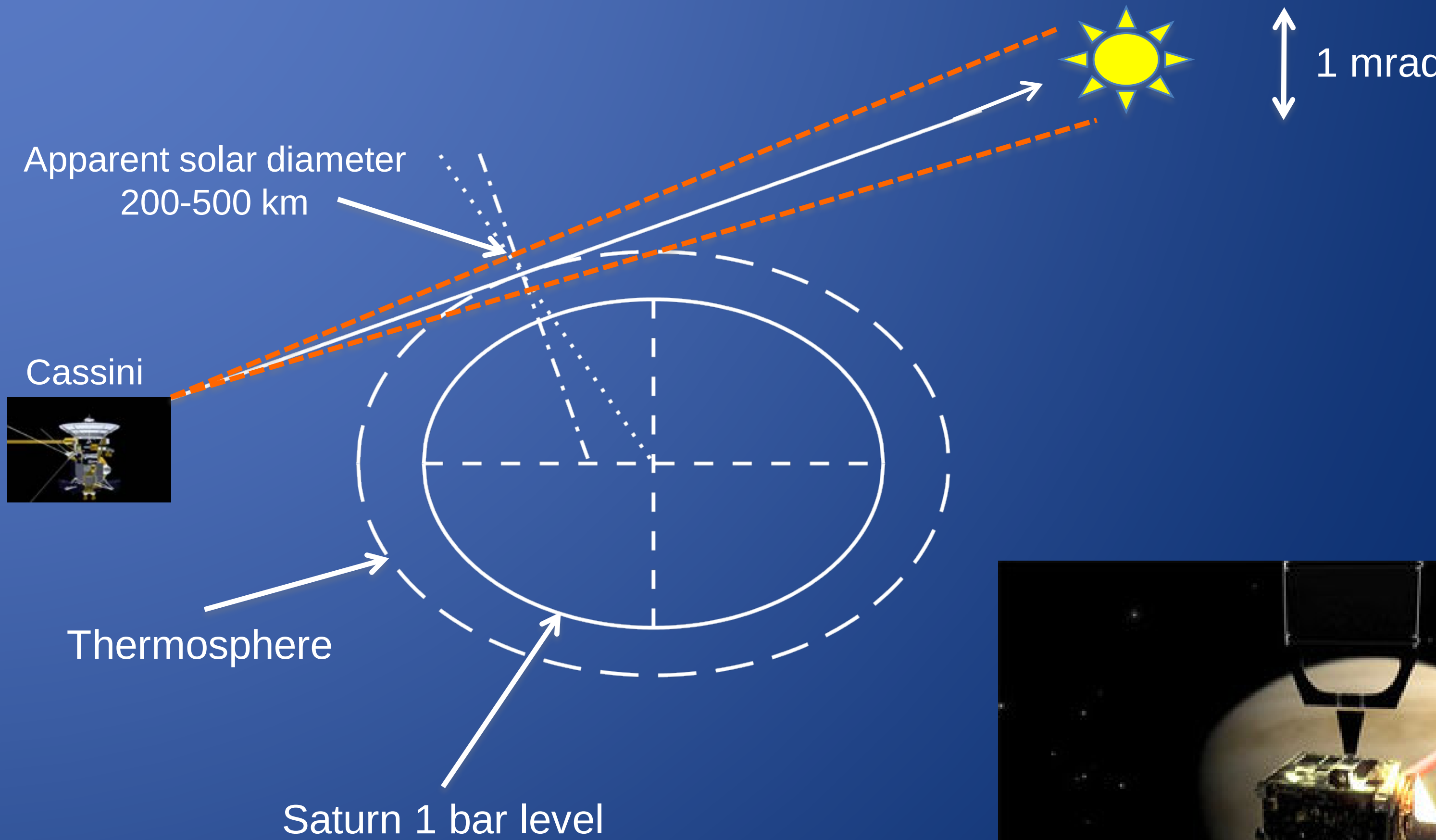


Exospheric temperatures from Cassini and Voyager range from 370 K to 550 K and appear to increase with latitude from the equator. Purple diamonds: 15 Cassini solar occultations (Koskinen et al.2013), black triangles: 16 Cassini stellar occultations (Koskinen et al., in preparation), green squares: Voyager UVS occultations (Smith et al.1983), green circles: Voyager UVS occultations (Vervack and Moses).

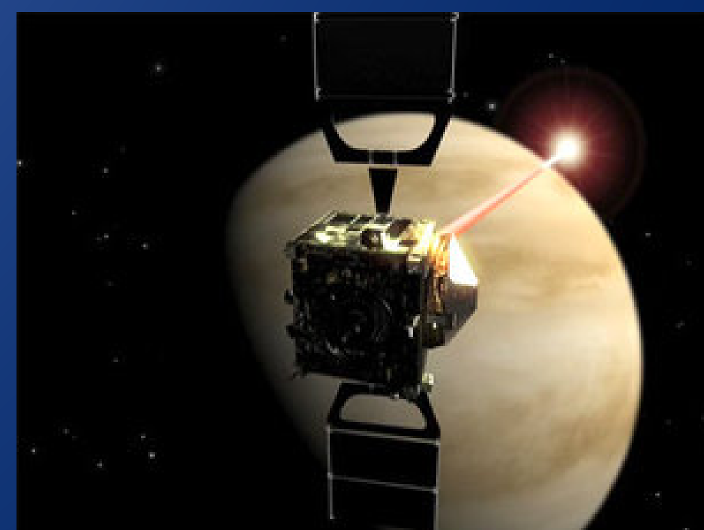
Past disagreements from Voyager data

Broadfoot et al.(1981): 850±100 K
Sandel et al.(1982): 400 K
Festou and Atreya (1982): 800±140 K

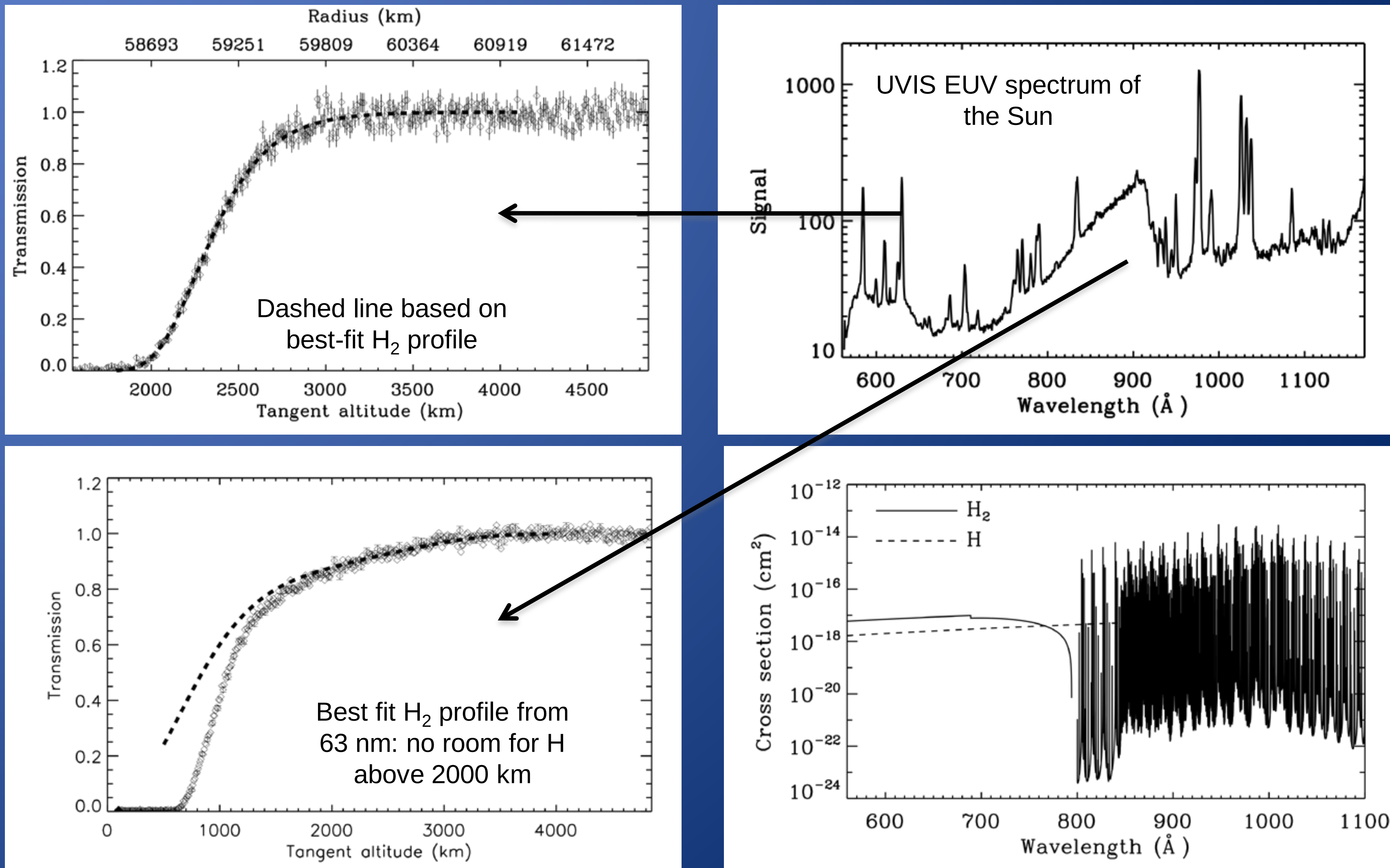
Occultation geometry



Stars are point sources: No need to worry about apparent diameter.

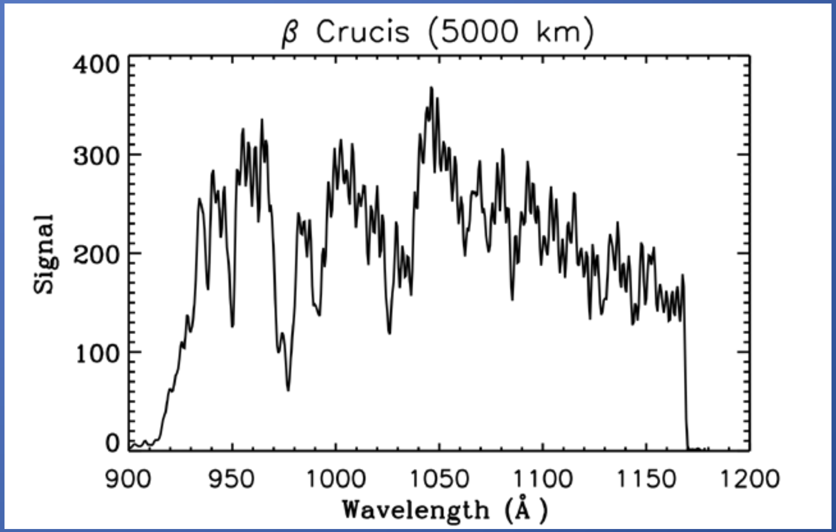


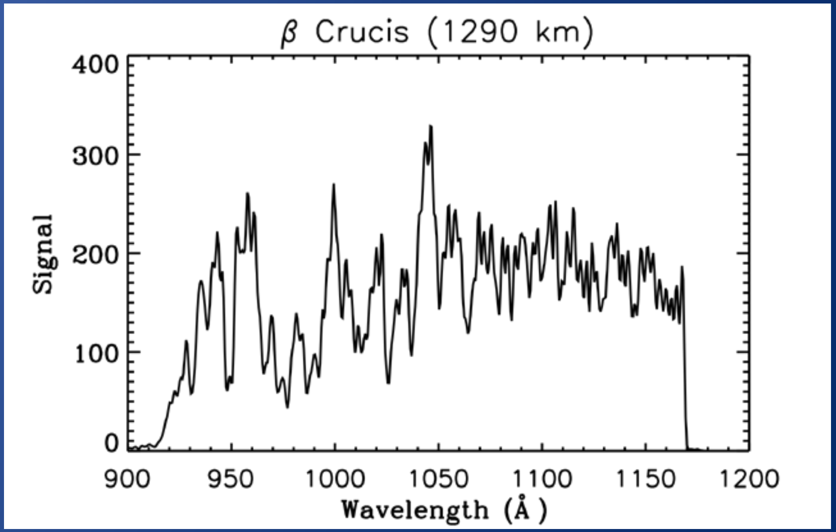
Solar occultations: H_2 and constraints on H

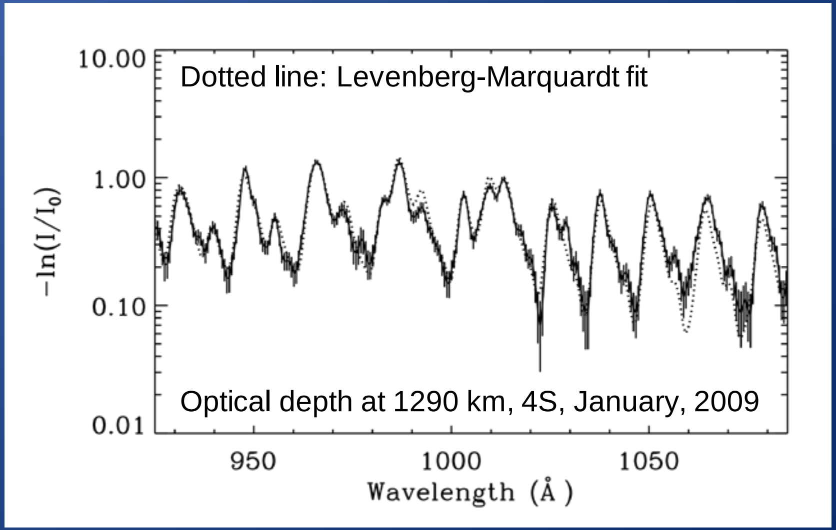


Fit a H_2 density profile to the data and get temperature from hydrostatic equilibrium. Monte Carlo error analysis (Koskinen et al.2013).

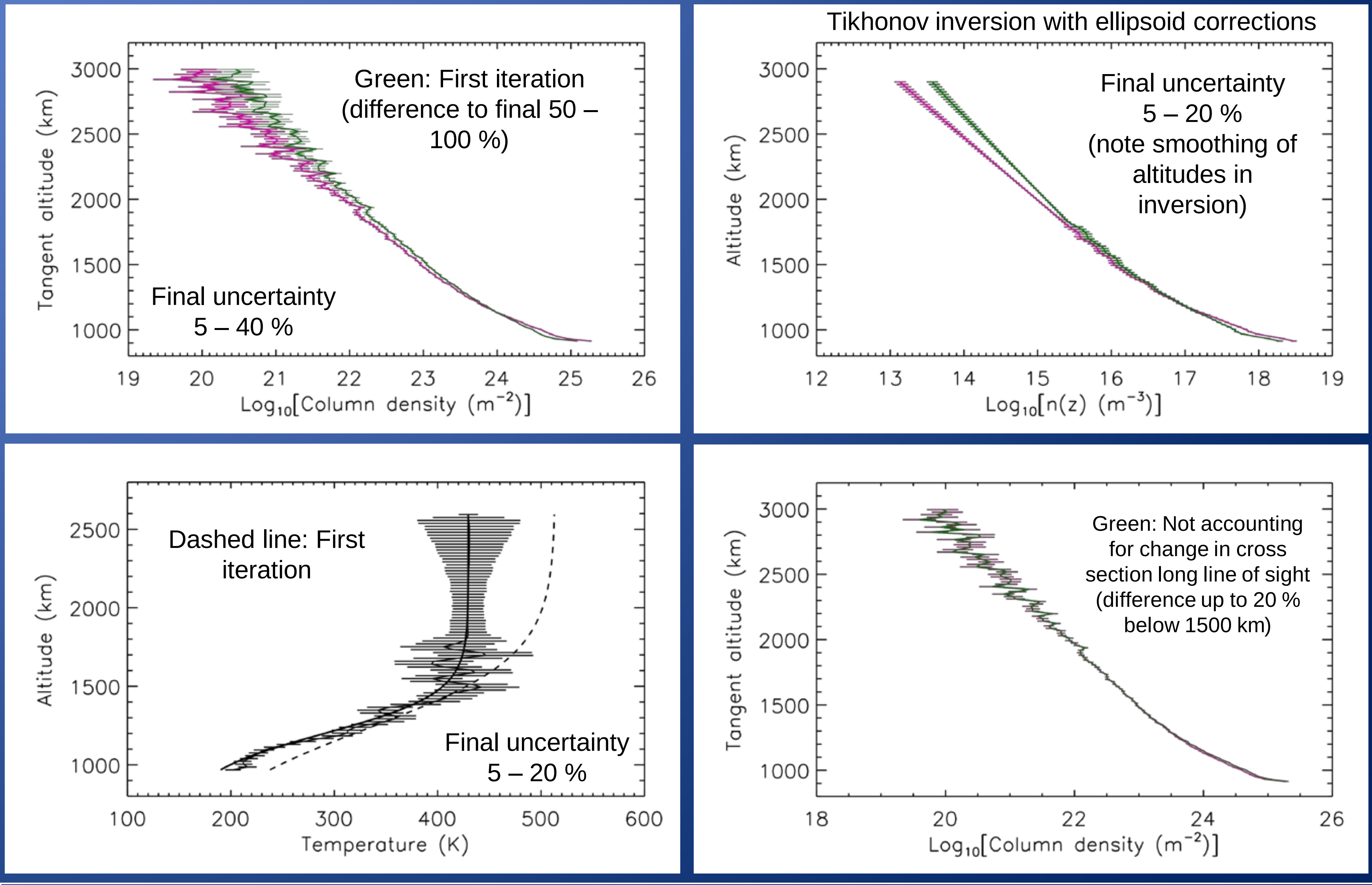
Stellar occultations: Full H_2 profiles





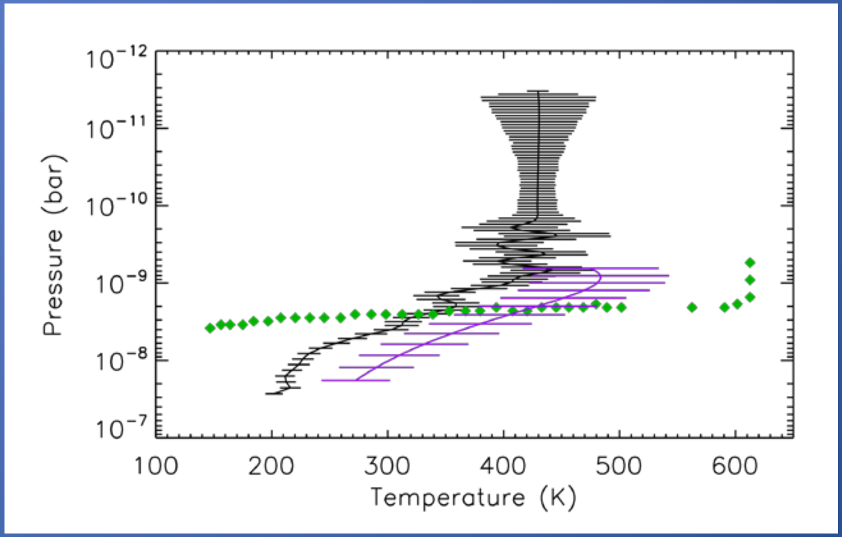


Iterative retrieval: ST24, 4S, 2009



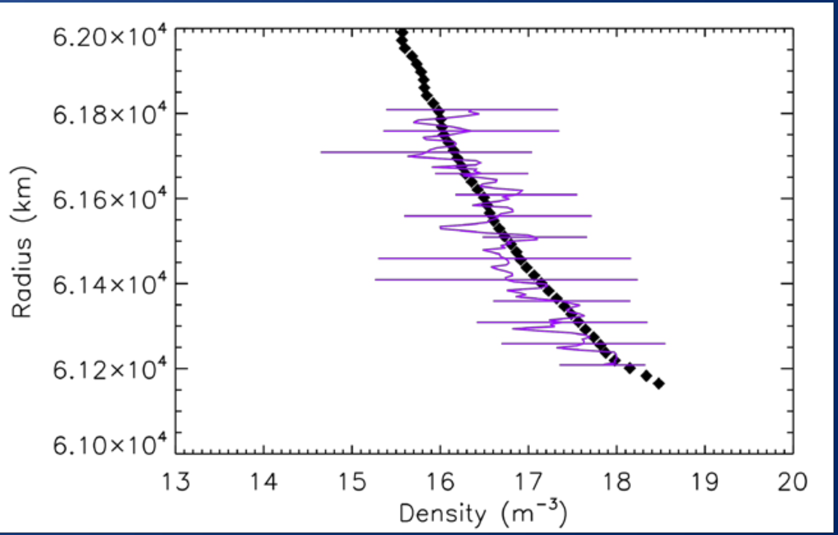
NOTE: Retrieval uses radial distance and not altitude that is only used for plotting here!!!

Comparison with previous retrievals

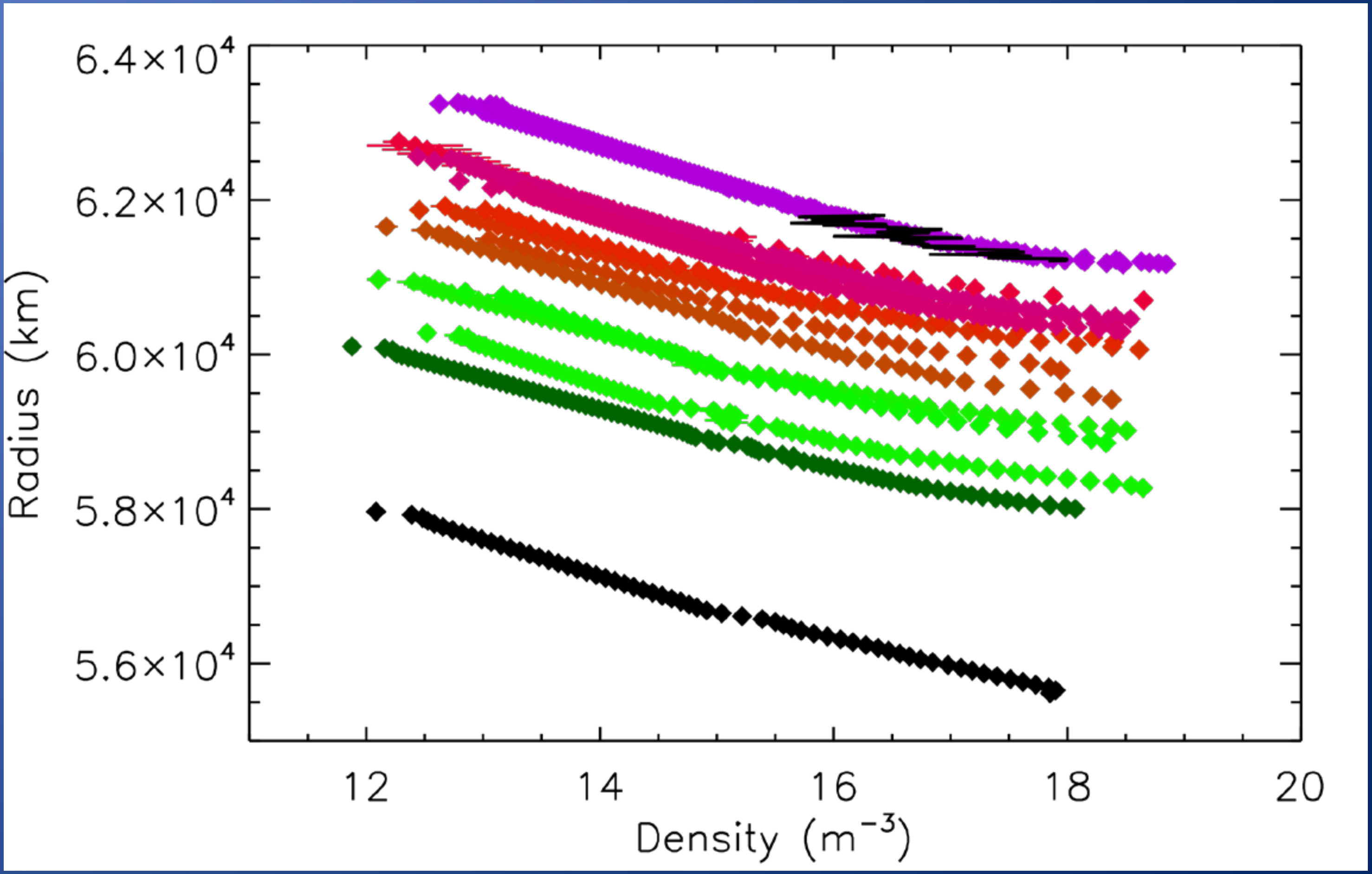


T-P profiles near latitude 4S. Black: Cassini UVIS ST24 (Jan, 2009) from our analysis, green: ST24 from Shemansky and Liu (2012), purple: Voyager 1 egress (Vervack and Moses)

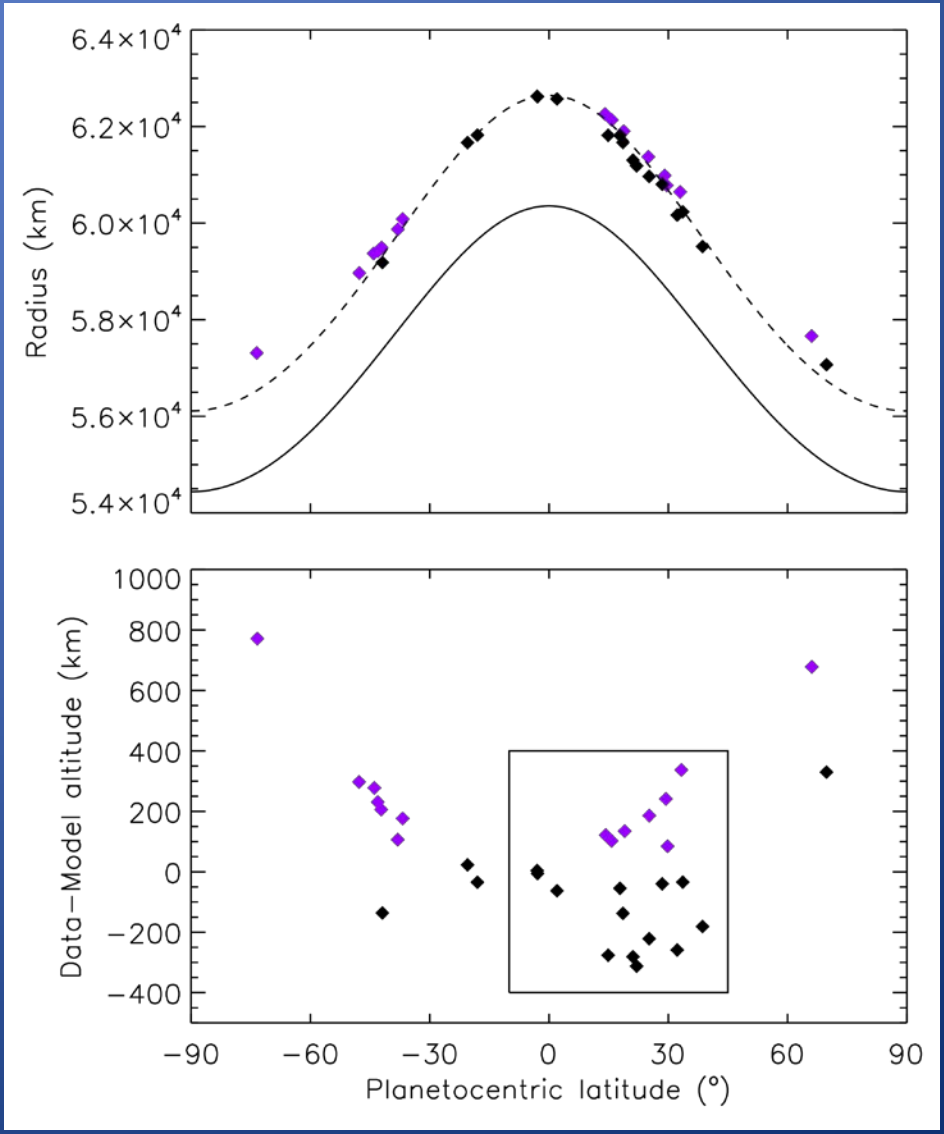
Below: A comparison of the Cassini ST24 density profile (this work) with the V1 egress occultation.



Densities from all stellar occultations

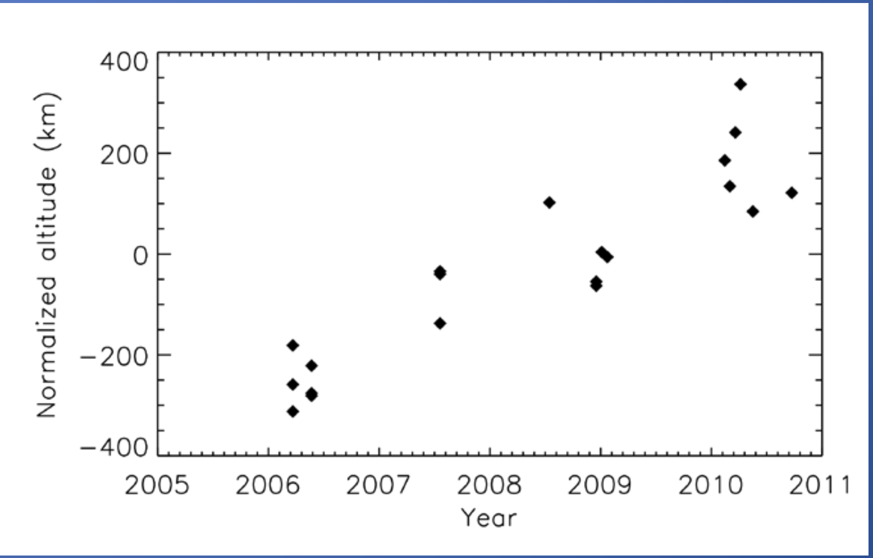


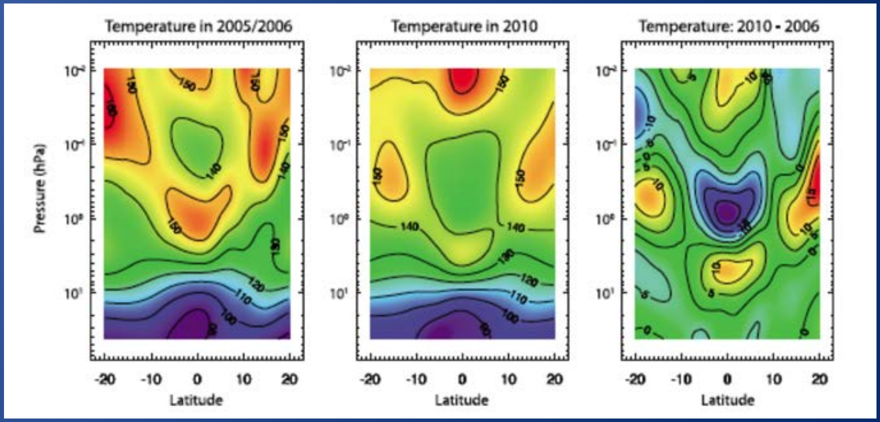
Pressure levels from UVIS occultations



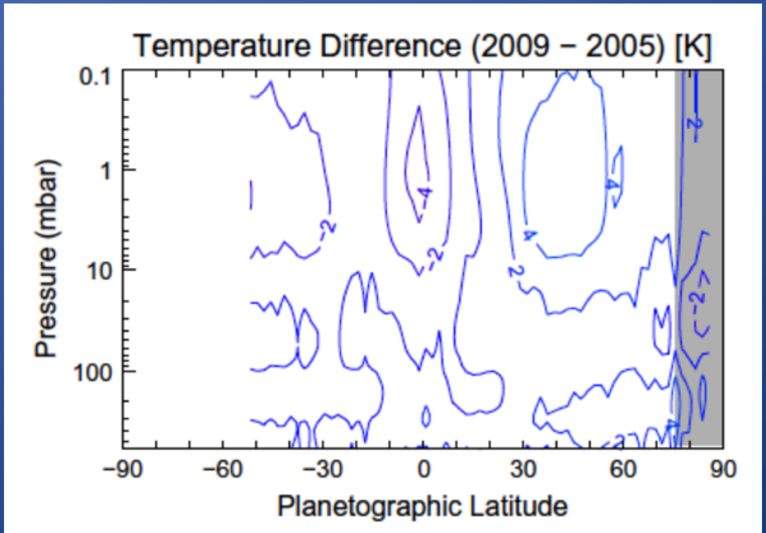
Upper panel: Radii of the 0.01 nbar pressure level from Cassini solar occultations (purple diamonds, Koskinen et al. 2013) and stellar occultations (black diamonds, this work). The solid line is the 1 bar level based on Anderson and Schubert (2007) and the dashed line is an extrapolation of the 1 bar level to 0.01 nbar. Lower panel: Altitude of the data points above and below the dashed line in the upper panel.

Expanding thermosphere?

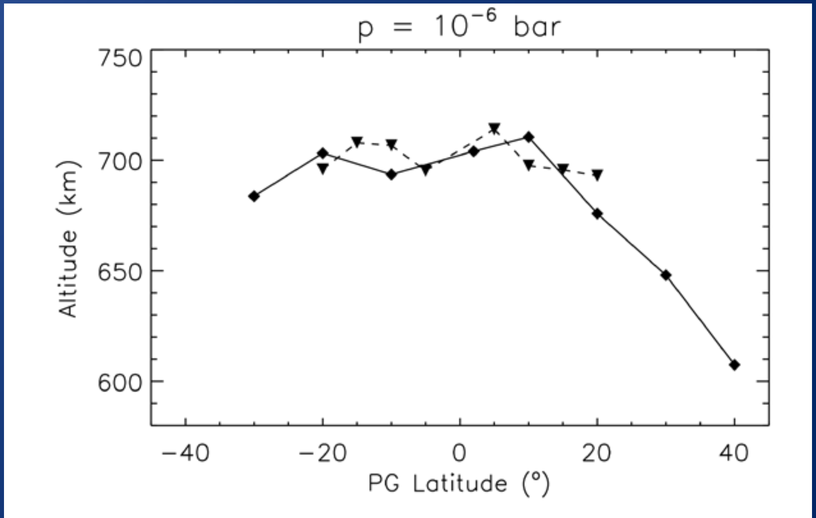




Guerlet et al.(2011)

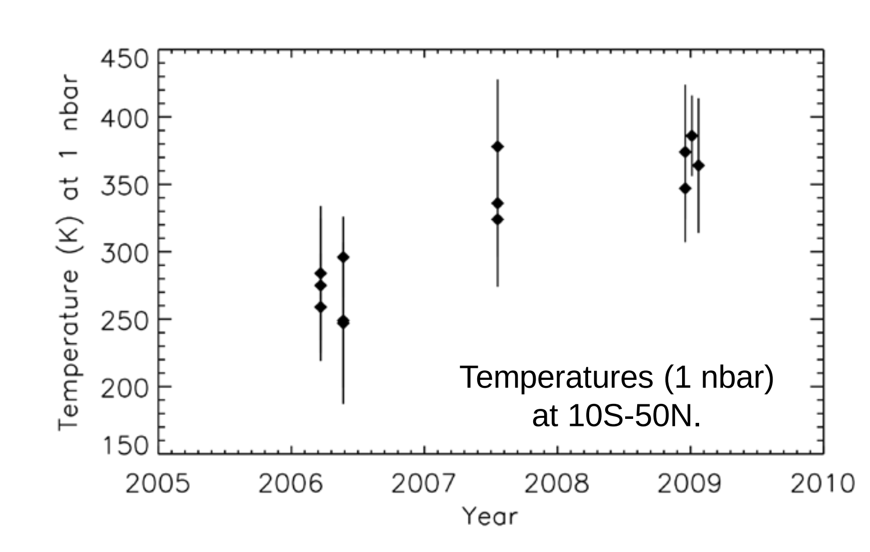


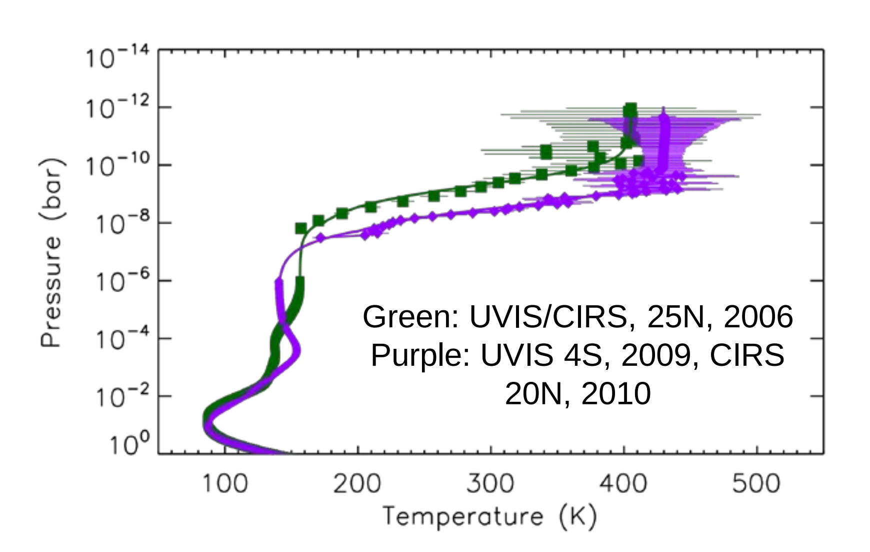
Sinclair et al.(2013)

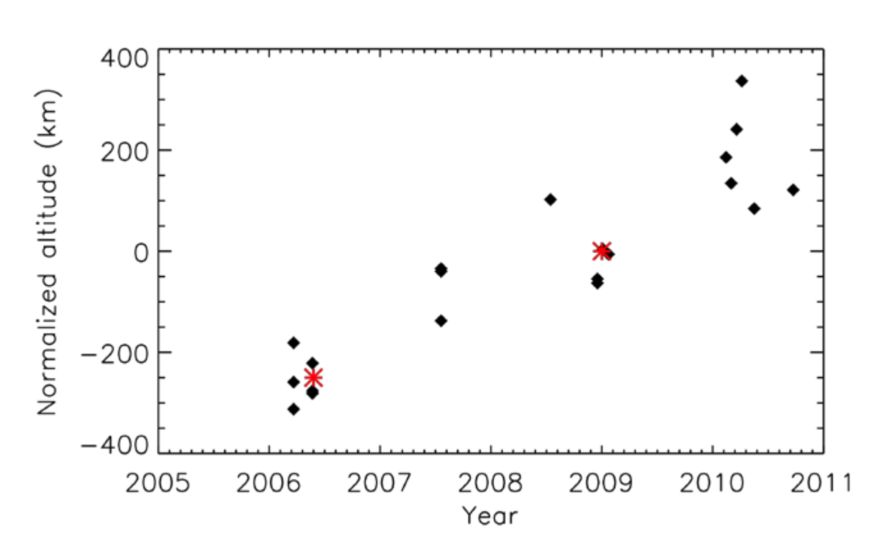


Limb altitudes based on the temperature profiles from Guerlet et al.(2011)

Thermospheric heating?



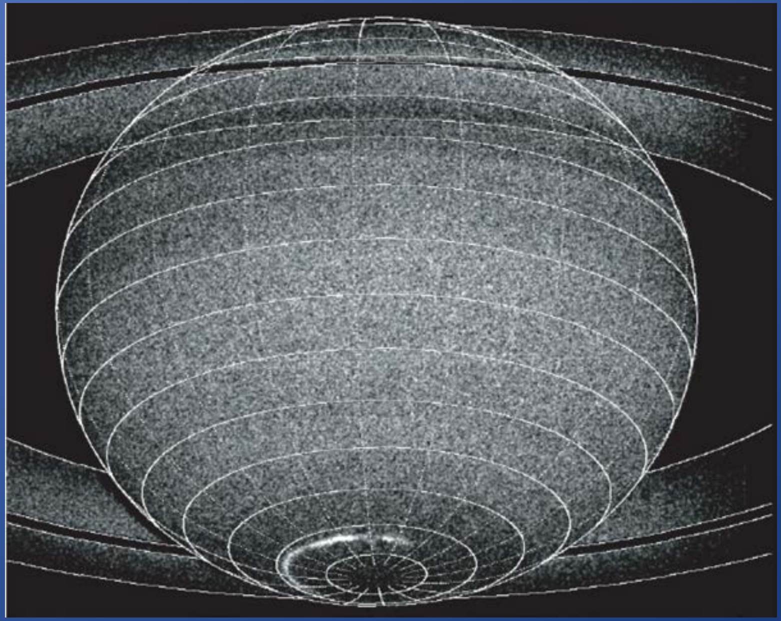


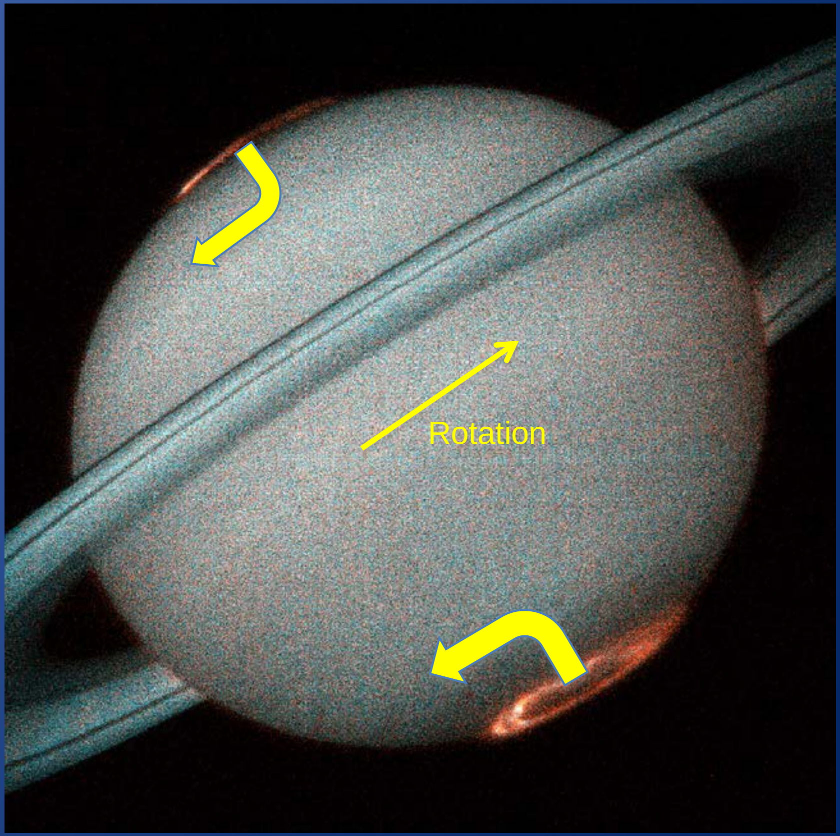


The red crosses on the left show model normalized altitudes at 0.01 nbar based on the T-P profiles above.

High latitude electrodynamics

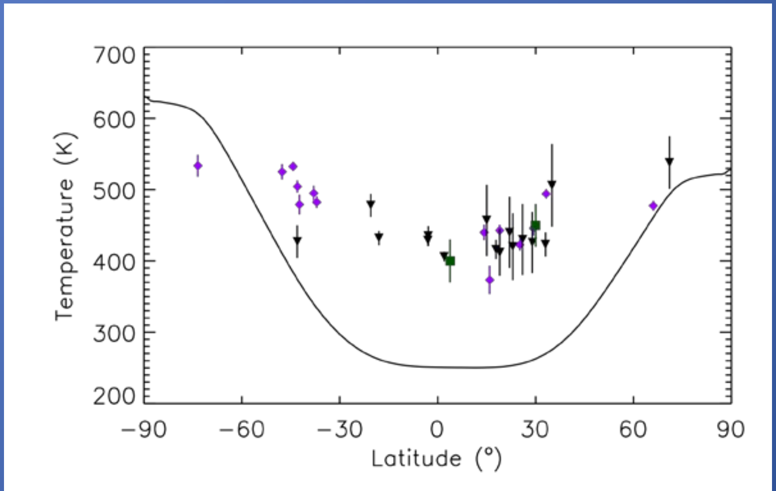
Auroral Joule heating provides ~10 TW of energy at the poles that can solve the temperature problem (Cowley et al. 2004a,b).

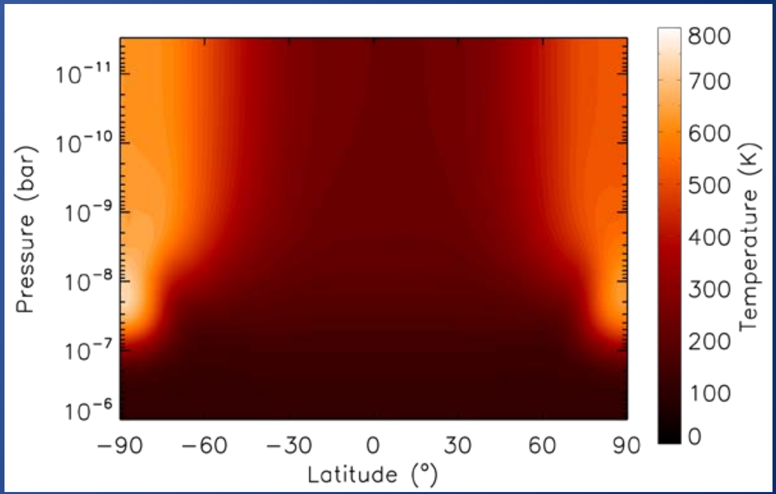




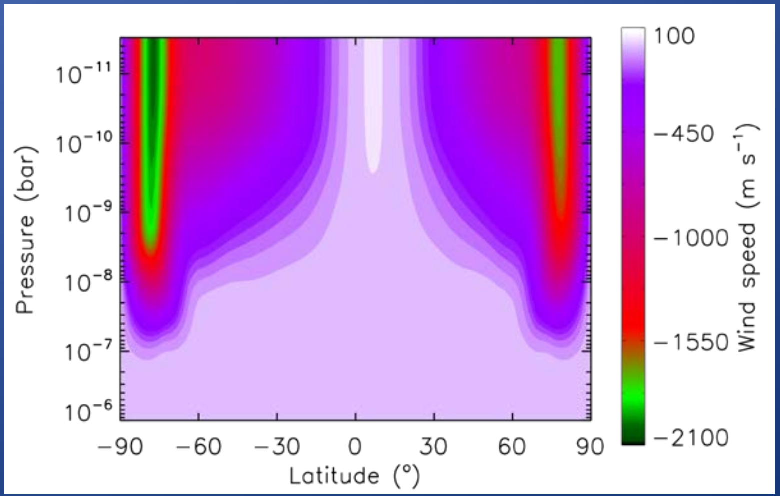
Westward Coriolis force (-2Ω x u), aided by ion drag (j x B), turns meridional flow from the poles into zonal flow and traps the energy at the poles (e.g., Smith et al. 2007).

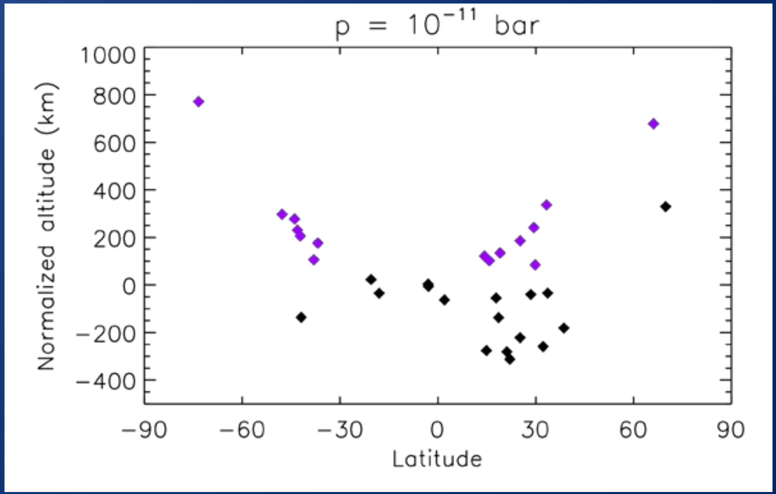
The word from circulation models





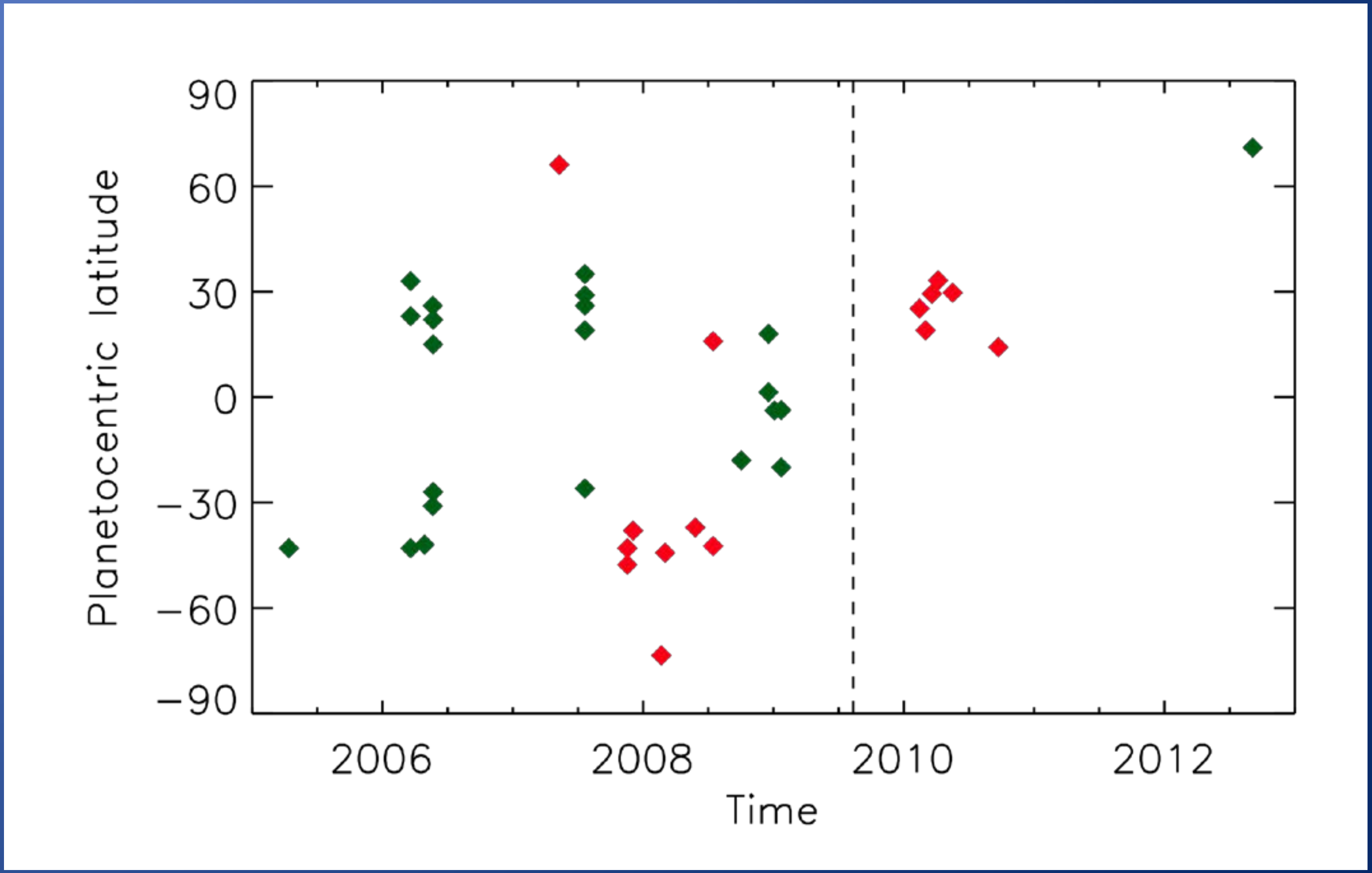
Above left: Observed/model temperatures (GCM of Müller-Wodarg et al. 2012). Above right: Zonal mean temperatures from the model. Below left: Zonal winds from the model. Below right: Normalized altitudes at 0.01 nbar from Cassini show some evidence for a deeper thermosphere at high latitudes.





BACKUP

Cassini UVIS occultations



UVIS stellar (green) and solar (red) occultations. The vertical dashed line shows the Equinox of August 11, 2009 (DOY 223).

Anti-correlation with solar activity (2005-2009)