Giant Planets Atmospheric Sciences: Review and Future Vision
巨大惑星大気研究の現状と将来展望

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Hampton University

Symposium on Planetary Science 2018
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Scope of this talk

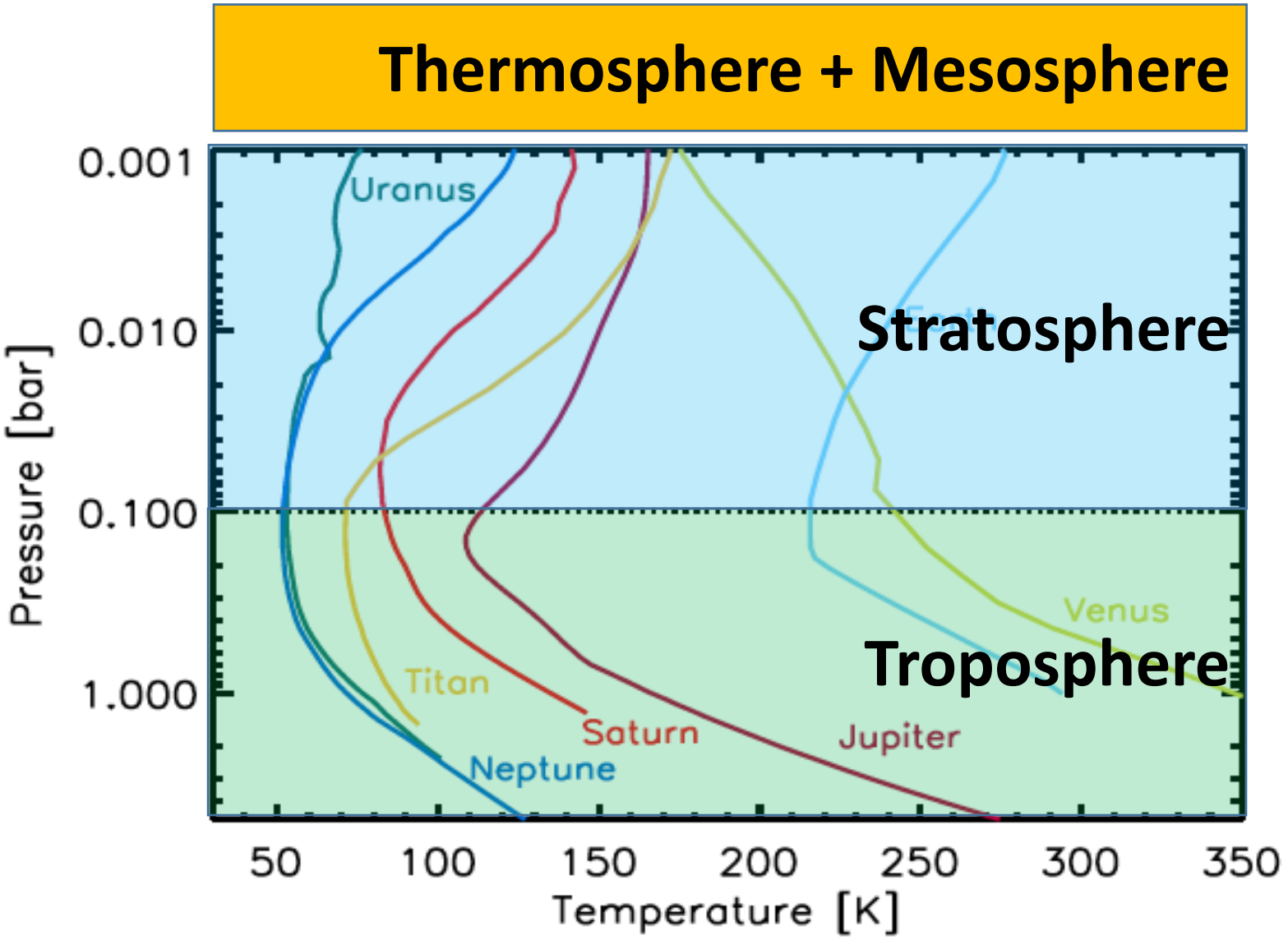
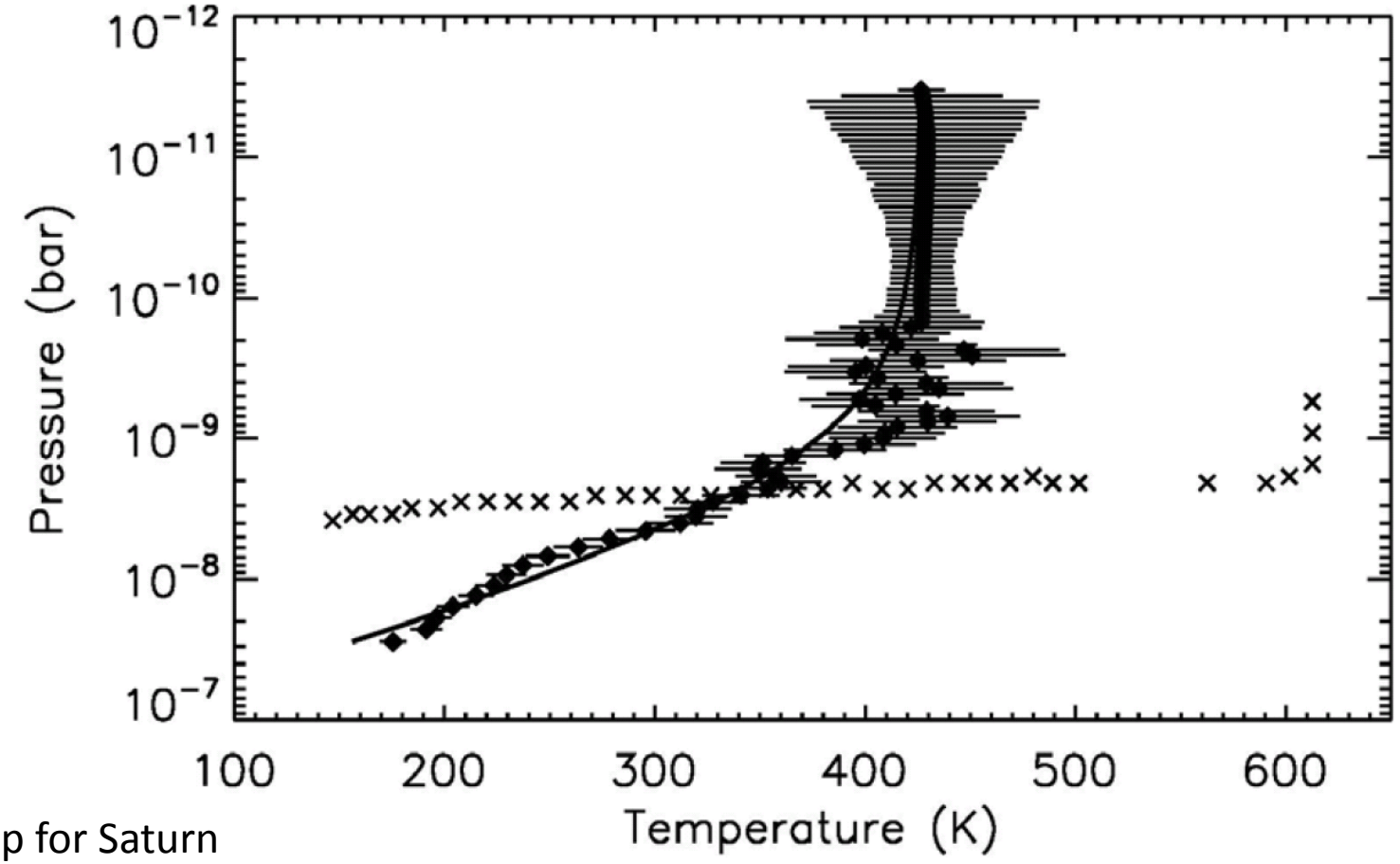


Figure from https://astrobites.org/2013/12/31/unifying-planetary-atmospheres/

Thermosphere

- Unexplained Hot Thermospheres of Giant Planets
  → “Energy Crisis”
- Thermospheric Heat Sources
  → Energy Crisis Solved by Aurora Heating?
- Uranus Case
  → Hot Thermosphere on Winter Hemisphere
- Venus
  → Night-time cooling

Thermosphere – "Energy Crisis"



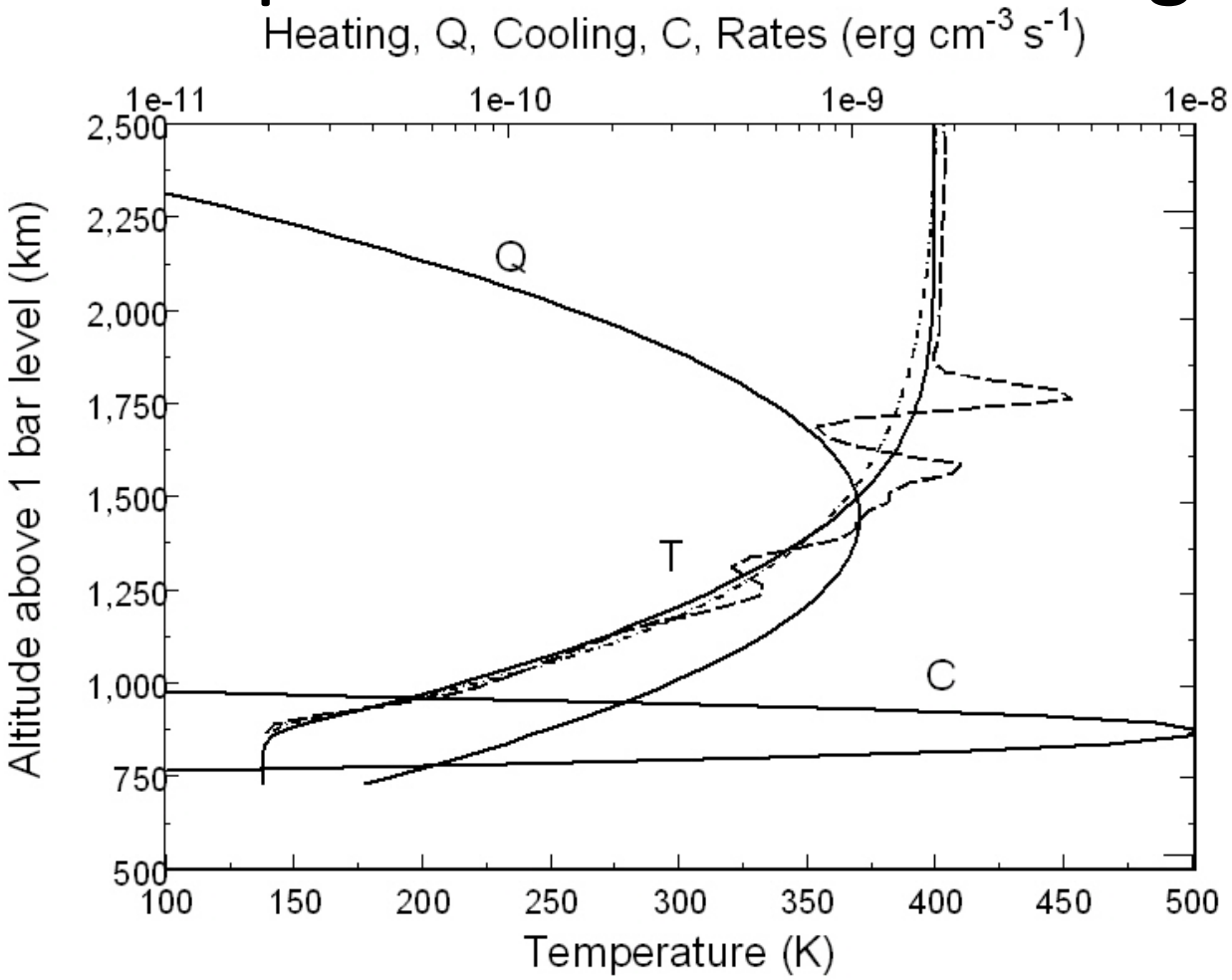
T vs p for Saturn

- Solid = Cassini Stellar Occultation Result
- Diamonds = Forward Modeling by Koskinen et al. (2015)
- Crosses = Shemansky and Liu (2012)

(Strobel et al. In Press, Chapter in upcoming Saturn book)

EUV Heating alone cannot explain the hot thermosphere (see next slide).

Thermosphere -- Inferred Heating Rate



Heating Rate for Saturn

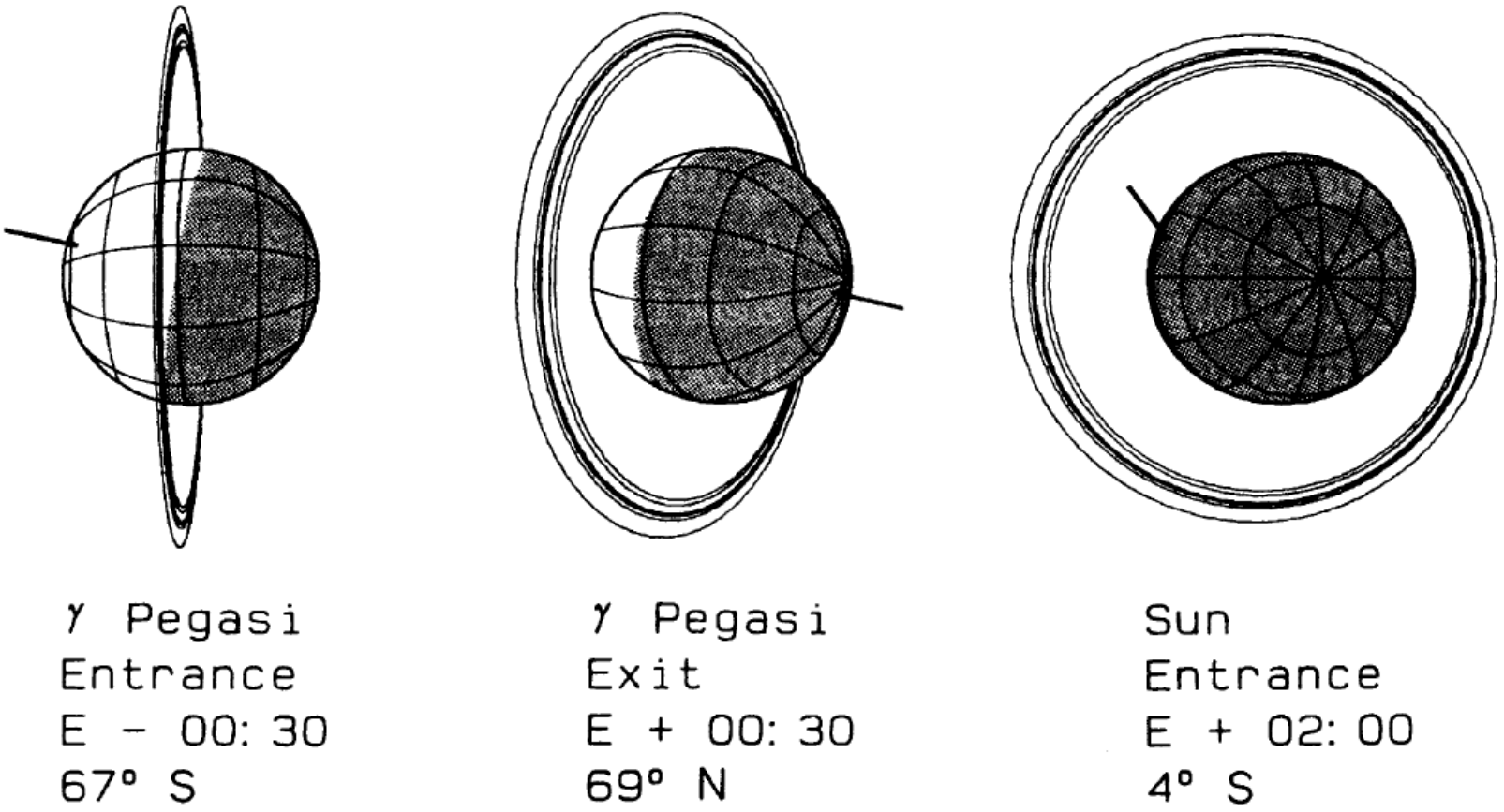
(Strobel et al. In Press, Chapter in upcoming Saturn book)

Q is greater than EUV Heating alone

Auroral Heating may be enough to supply the rest of the heat

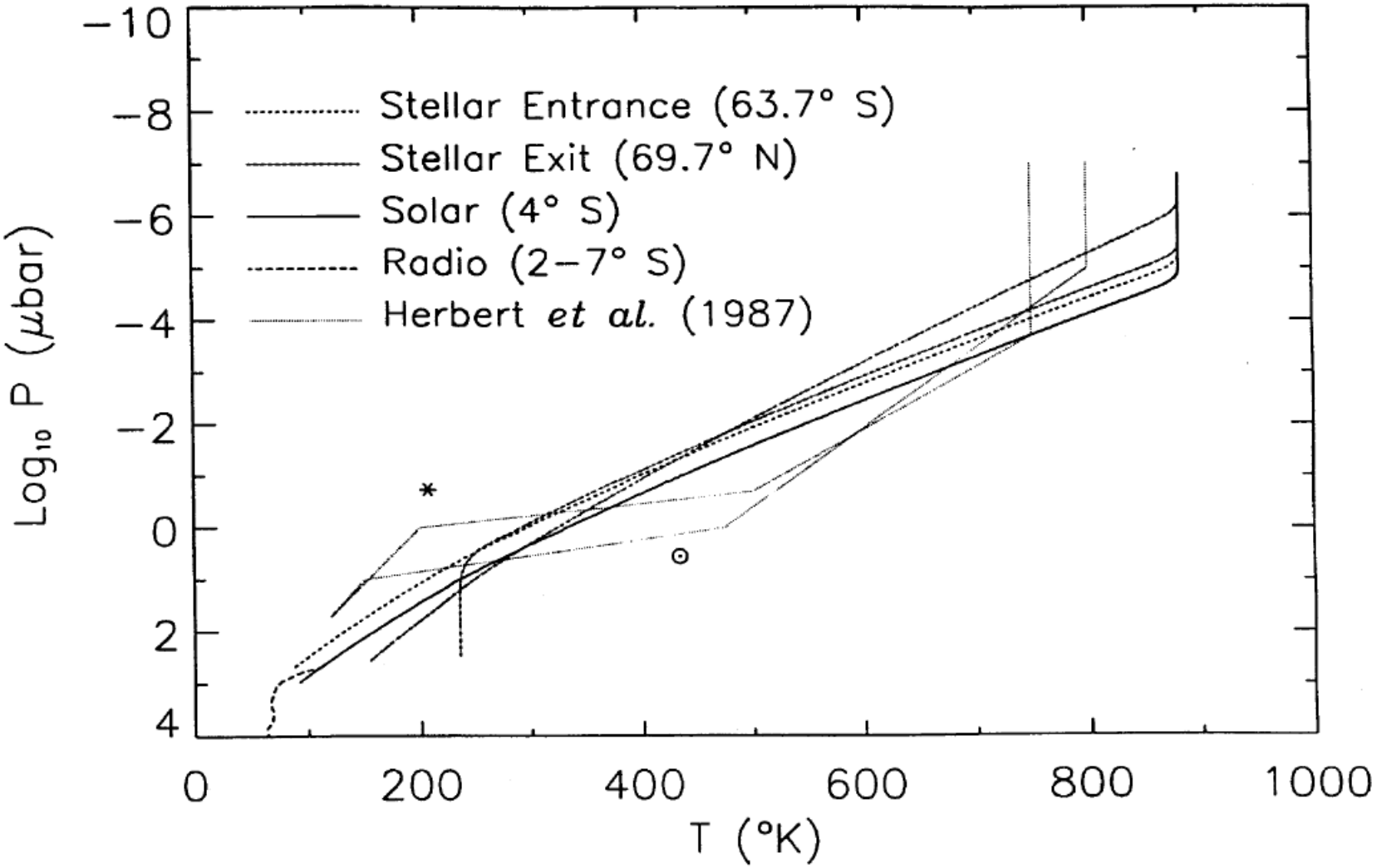
If Aurora is not sufficient, gravity waves are the next candidate

Thermosphere of Uranus -- interesting case study



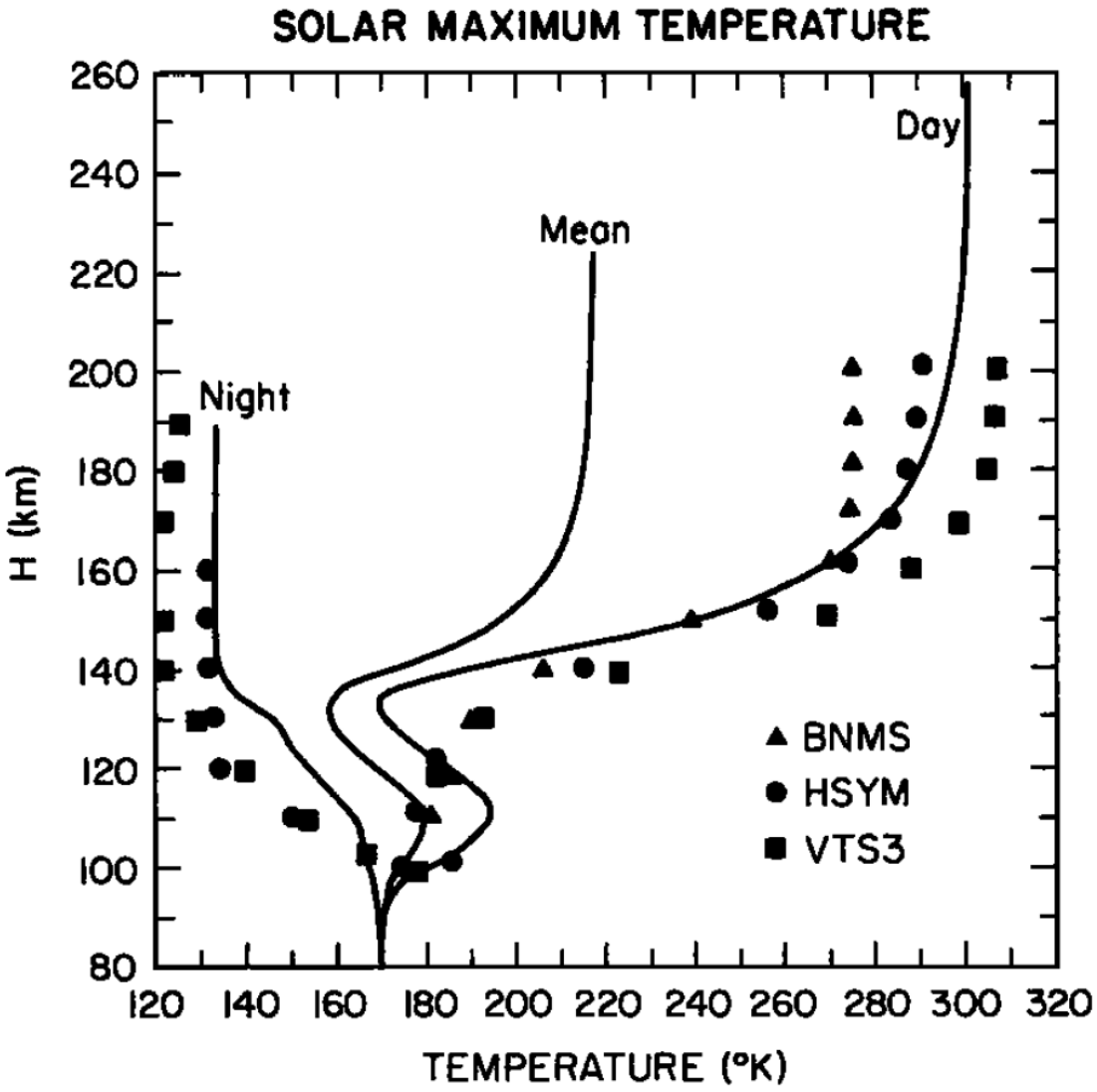
Voyager 2 Ultraviolet Occultation Measurement
(Herbert and Sandel, 1999)

Thermosphere of Uranus -- an interesting case study



No difference between the winter hemisphere and summer hemisphere (Herbert and Sandel, 1999)

Thermosphere of Venus -- another interesting case study



Venus Thermosphere Temperature vs. height (Dickinson & Bougher 1986)

→ The thermosphere of Venus can cool at night, in contrast to Uranus.

→ What process does Uranus have that Venus doesn't?

Thermosphere

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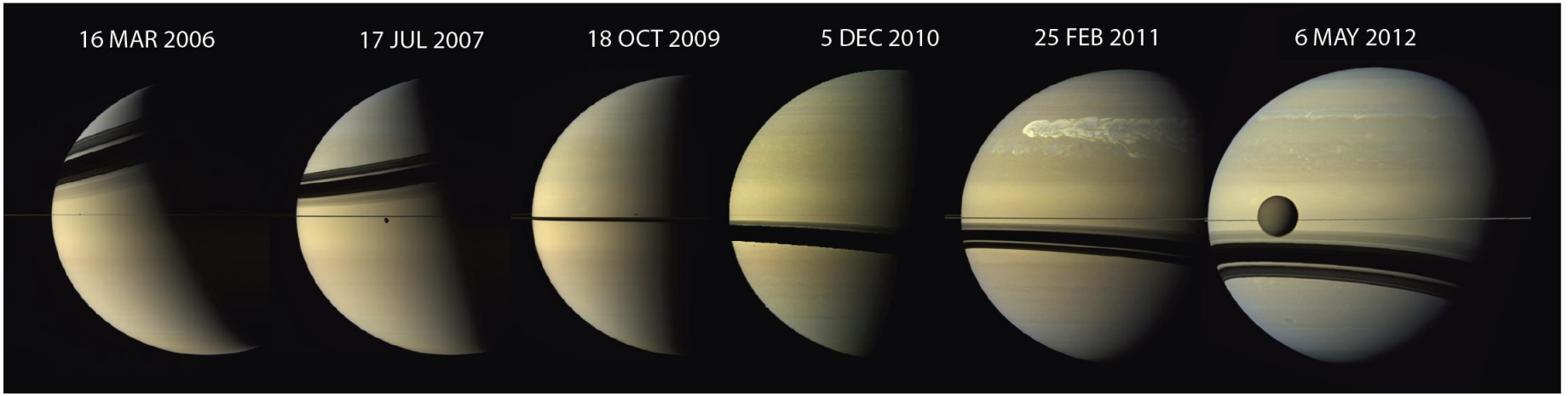
Stratosphere

- Seasonal Forcing
  - Temperature change
- Photochemistry
  - Affects composition distribution
- Disequilibrium species
  - indicators of vertical mixing
- Photochemical Haze production
  - Hexagon Color Change
- Stratospheric Oscillations
  - Analog of Earth's QBO

Stratosphere: Seasonal Forcing

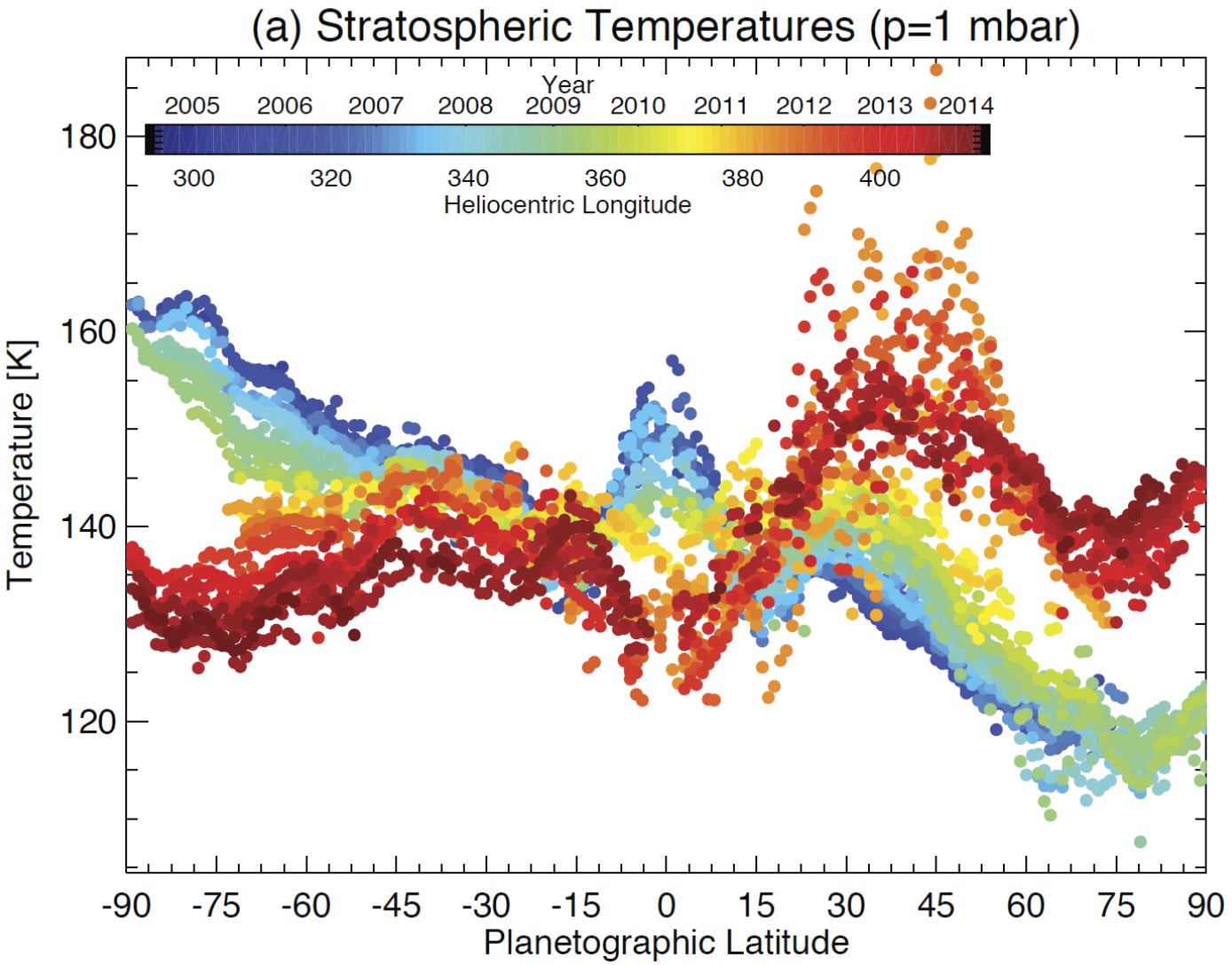


Seasons on Saturn

(See tilt of Terminator, and Ring Shadows)

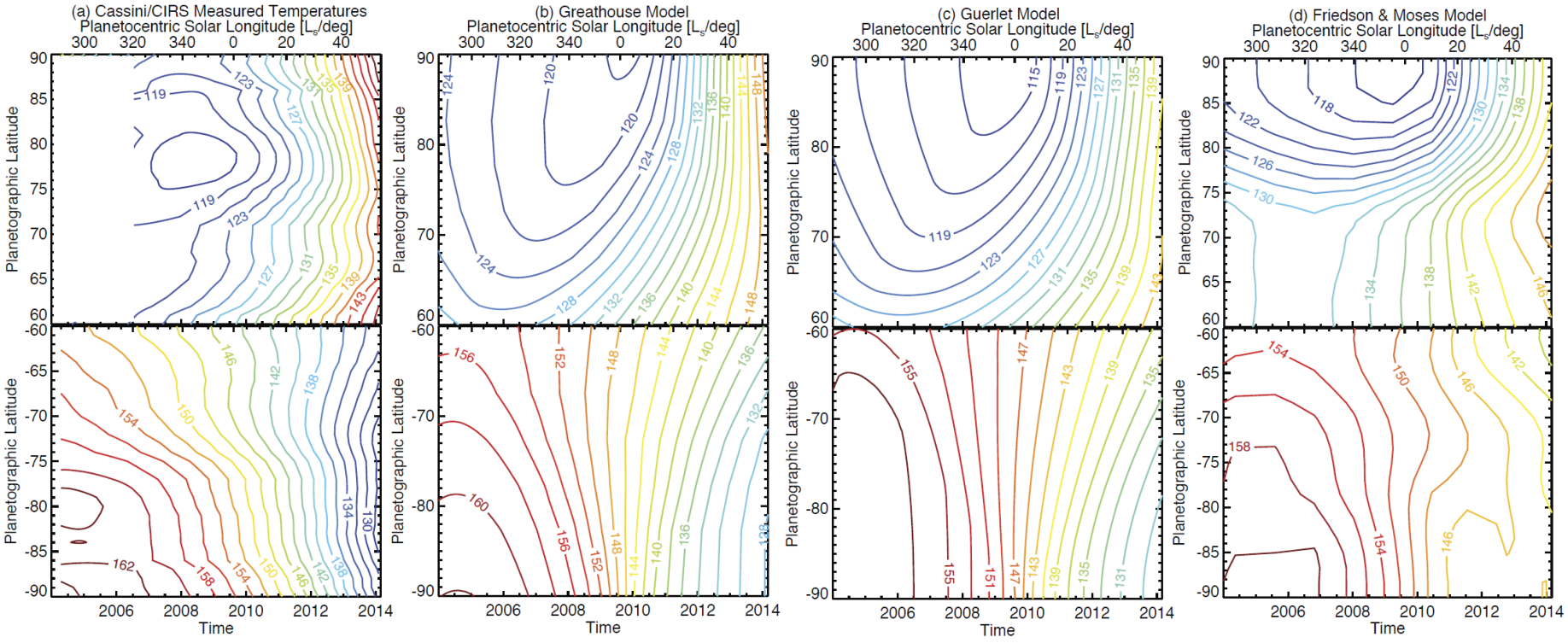
Rotation Axis Tilt = 26.73 degree

Saturn's Stratospheric Temperature - Observation



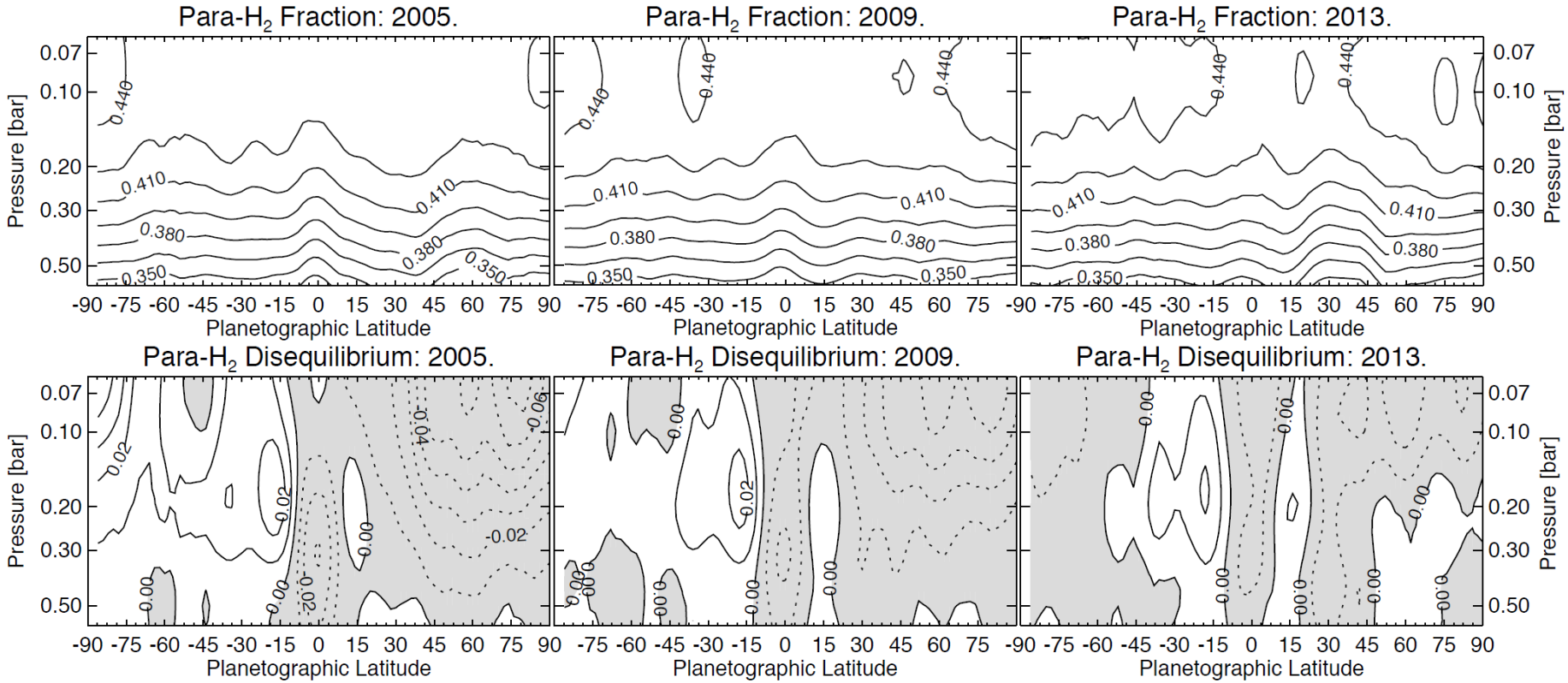
Cassini CIRS measurement of 1-mbar Tempearture between 2005-2015
From Fletcher et al (In Press, Book Chapter to be published)

Saturn's Stratospheric Temperature – GCM Modeling



Cassini measurements are compared to the model predictions of Greathouse et al. (2010), Guerlet et al. (2014) and Friedson and Moses (2012).
From Fletcher et al (In Press, Book Chapter to be published)

Saturn: Disequilibrium Species and Vertical Mixing

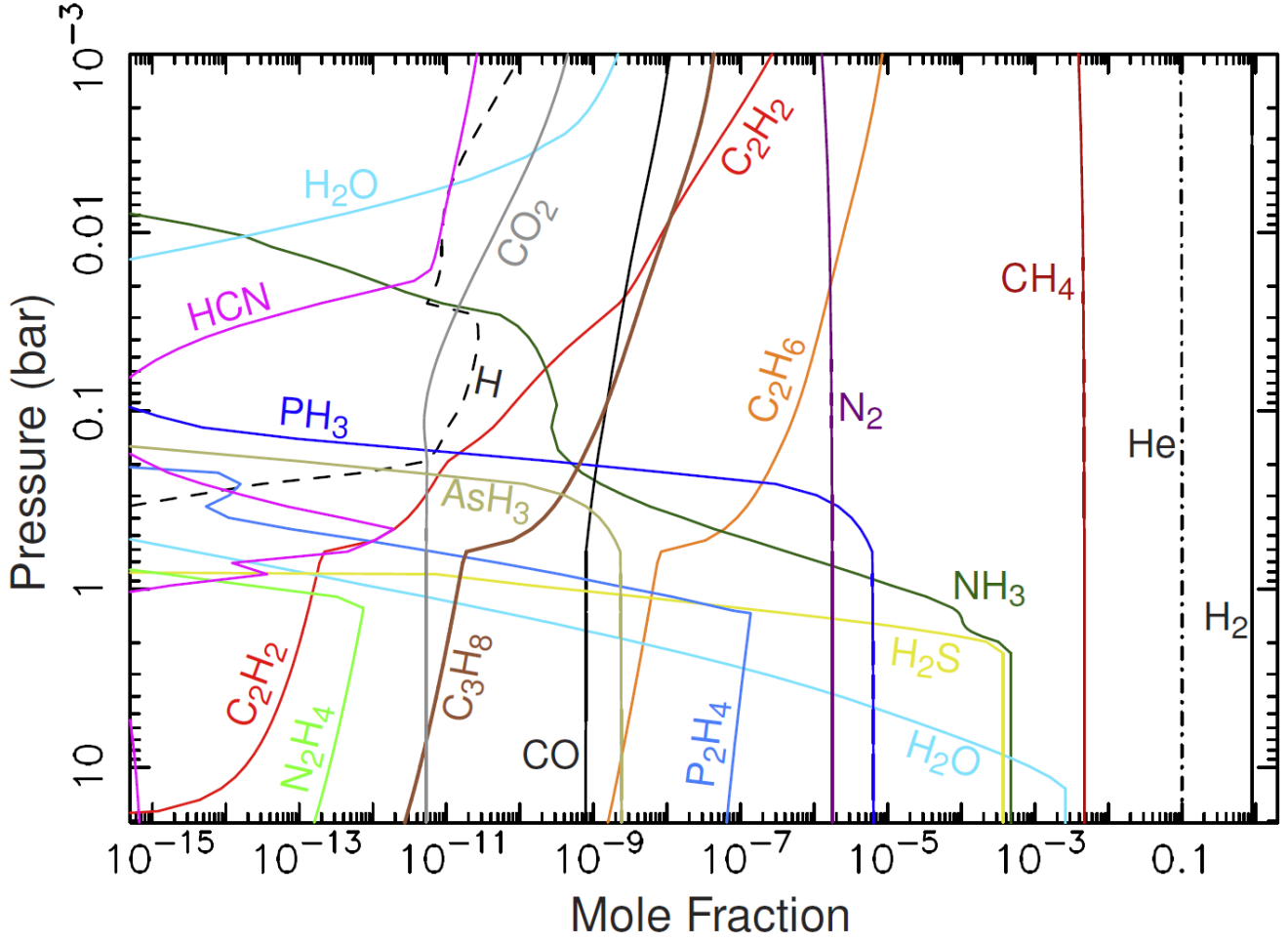


Para-Hydrogen Excess indicates Transport from warmer, lower atmosphere

Measured by Cassini/CIRS using the collision-induced H2-H2 continuum (Fletcher et al., 2007a, 2010, 2016)

From Fletcher et al (In Press, Book Chapter to be published)

Saturn's Stratospheric Chemistry



H2, He, CH4 and N2 are well-mixed

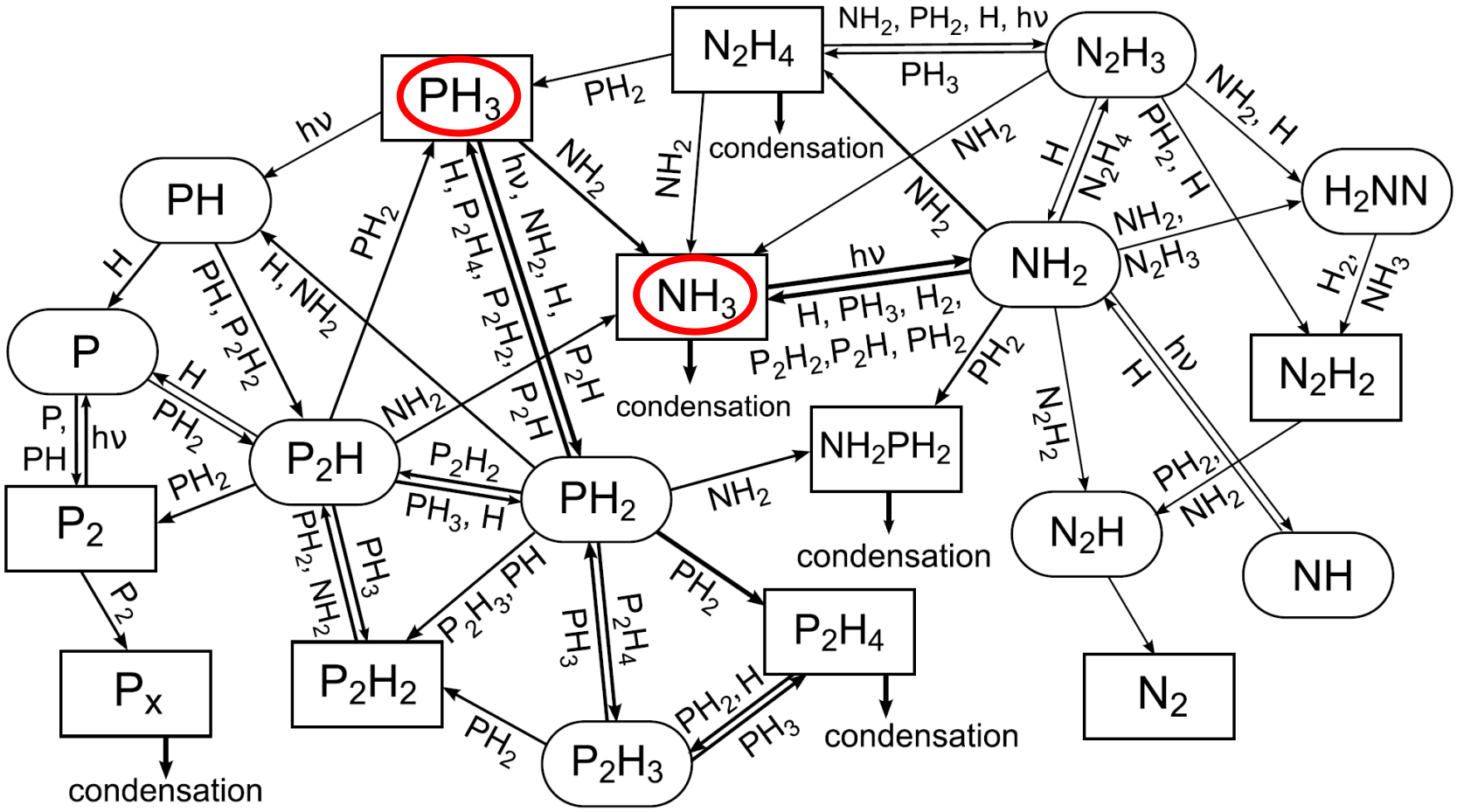
H2O, H2S, NH3, P2H2 and N2H4 decrease with altitude due to condensation

PH3 decrease due to photochemistry

(Based on the photochemical model described in Moses et al. (2010))

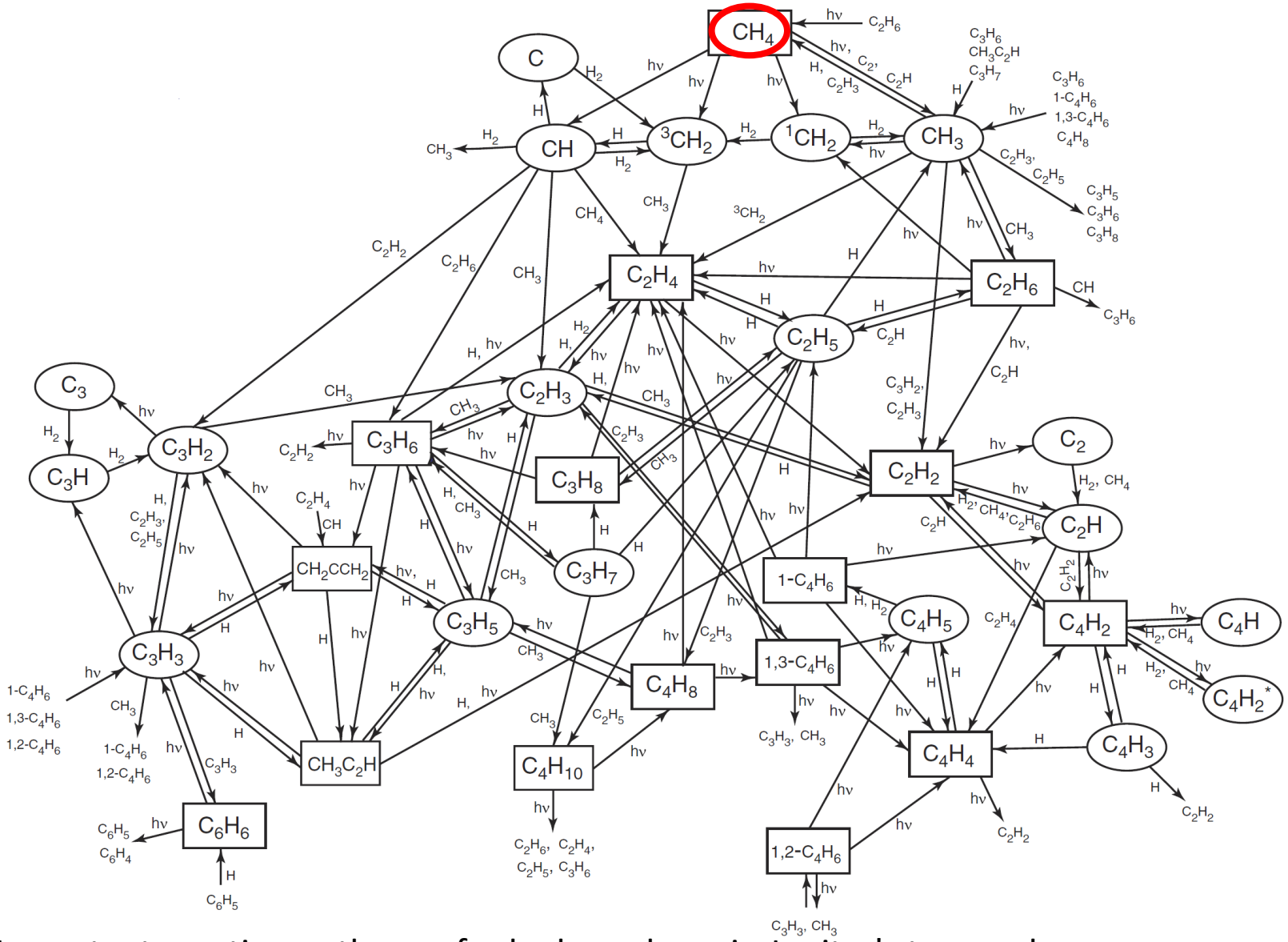
From Fletcher et al (In Press, Book Chapter to be published)

Photochemical Reaction Pathways – PH3 and NH3



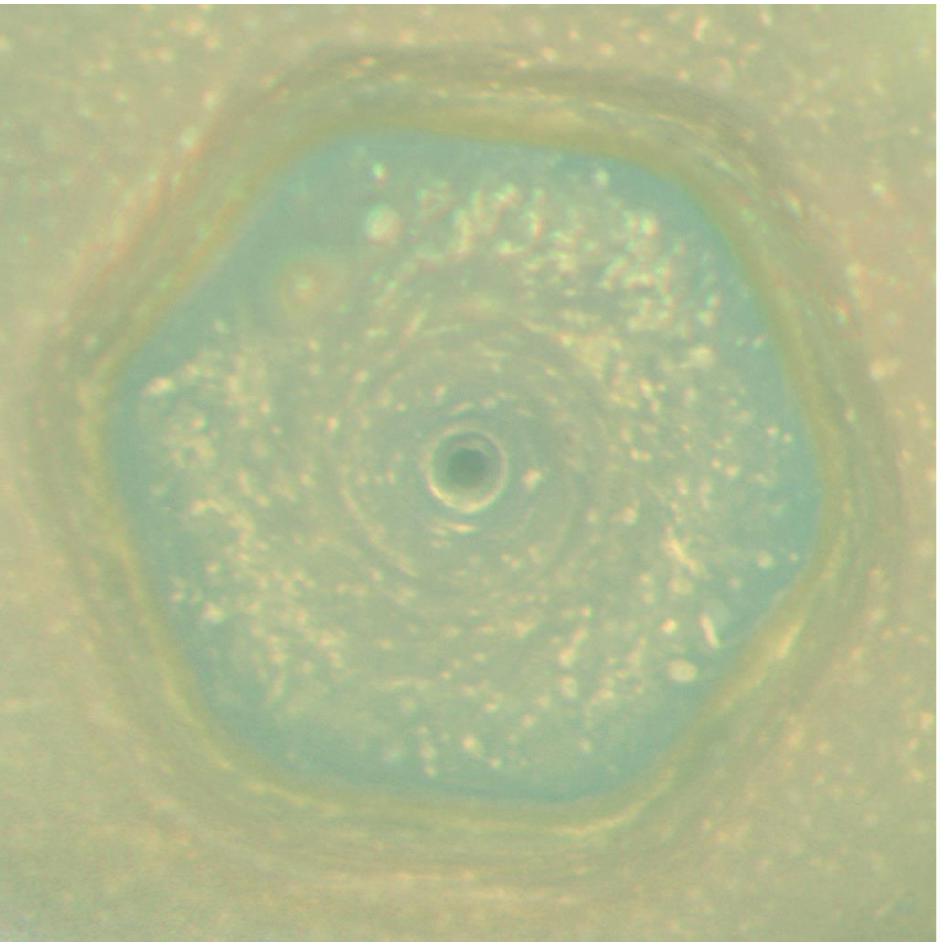
Important reaction pathways for involving PH3 and NH3 in Saturn's troposphere (based on Visscher et al., 2009; Kaye and Strobel, 1984)
From Fletcher et al (In Press, Book Chapter to be published)

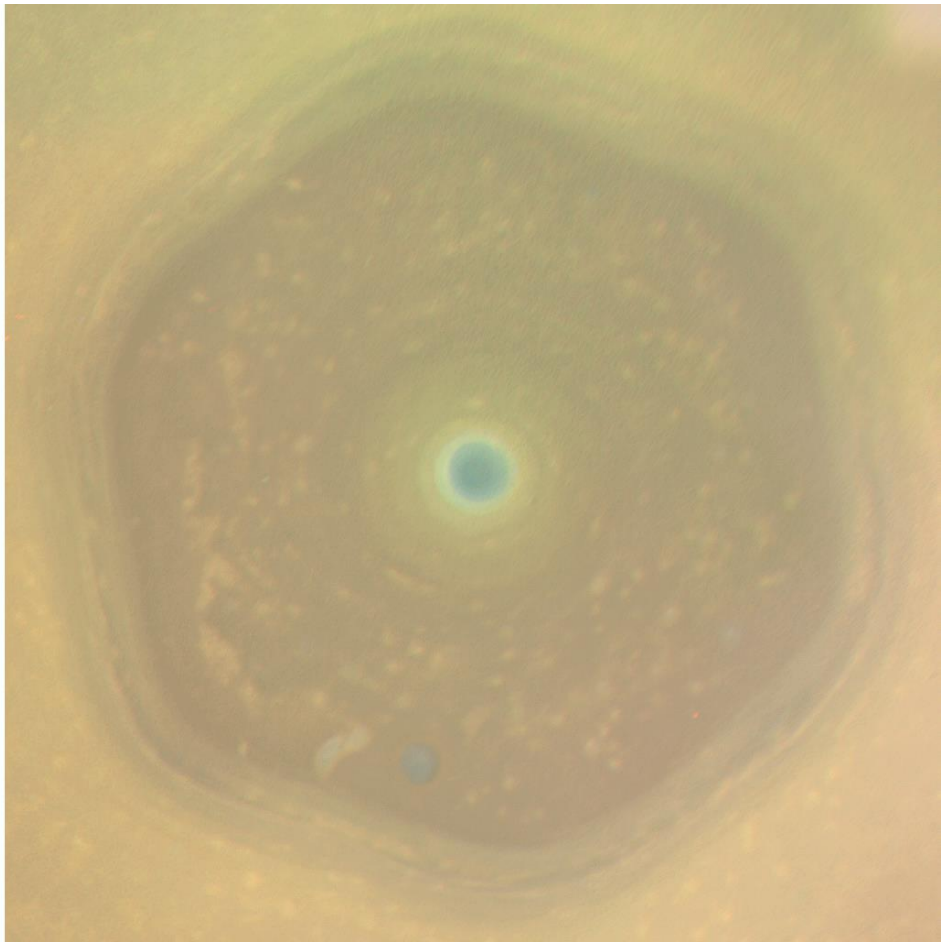
Photochemical Reaction Pathways – Hydrocarbons



Important reaction pathways for hydrocarbons in Jupiter's troposphere (based on Moses et al 2000, figure from Moses et al. 2004 in Jupiter Book)

Stratospheric Photochemical Haze Production

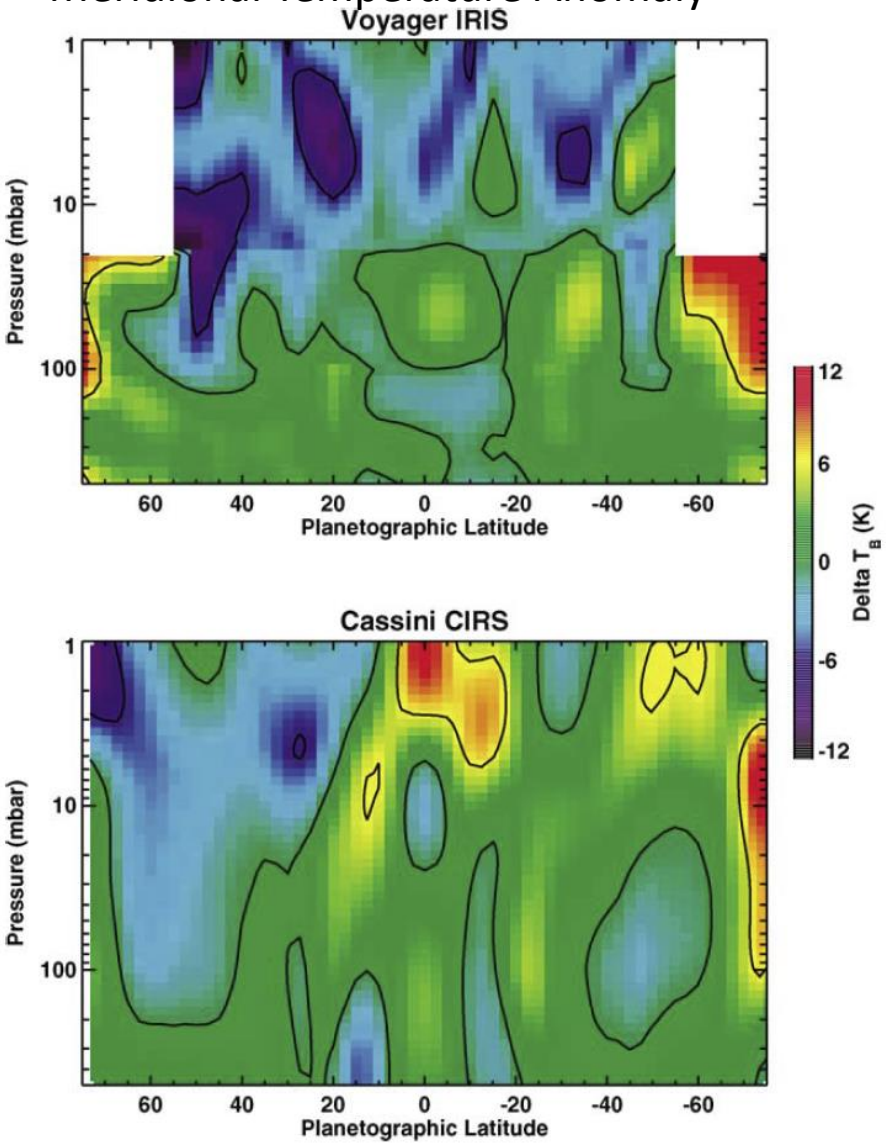




Cassini ISS Observation of Jupiter's North Pole
Left: December 2012
Right: April 2017

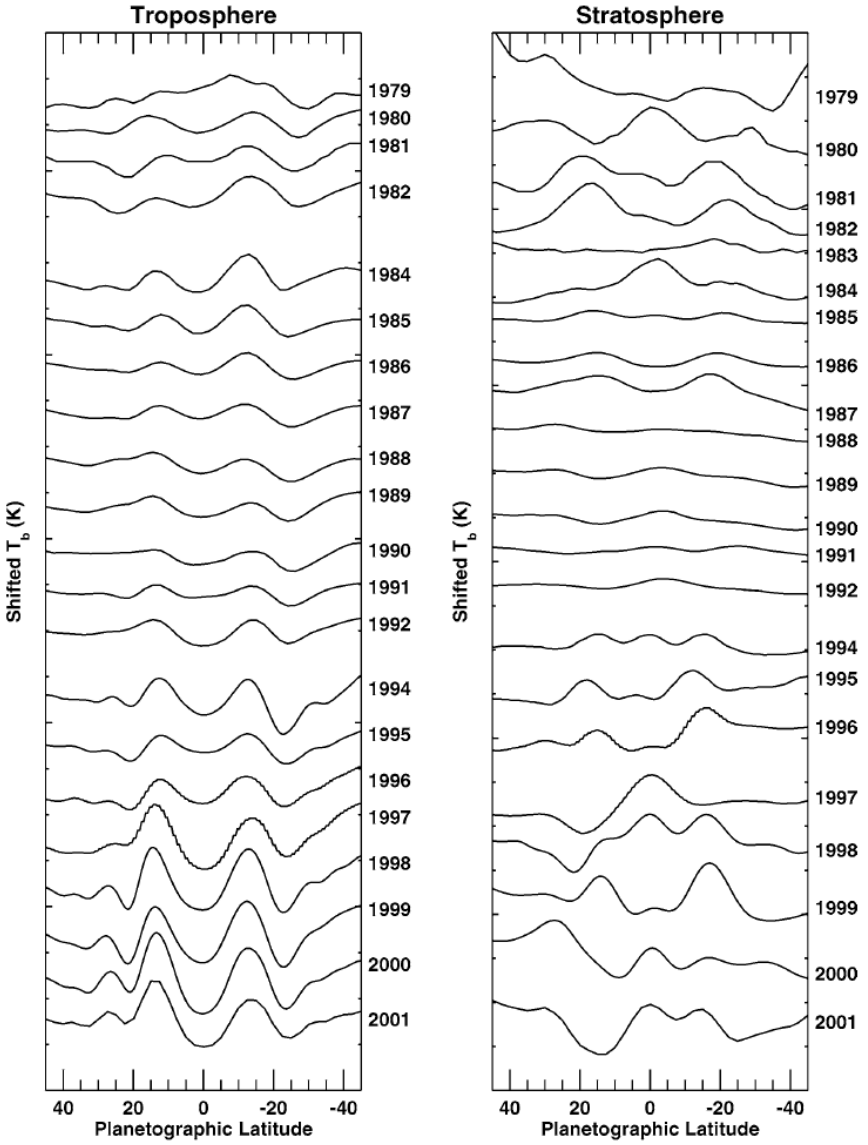
Jupiter's Stratospheric Oscillation – 4-year Period

Meridional Temperature Anomaly



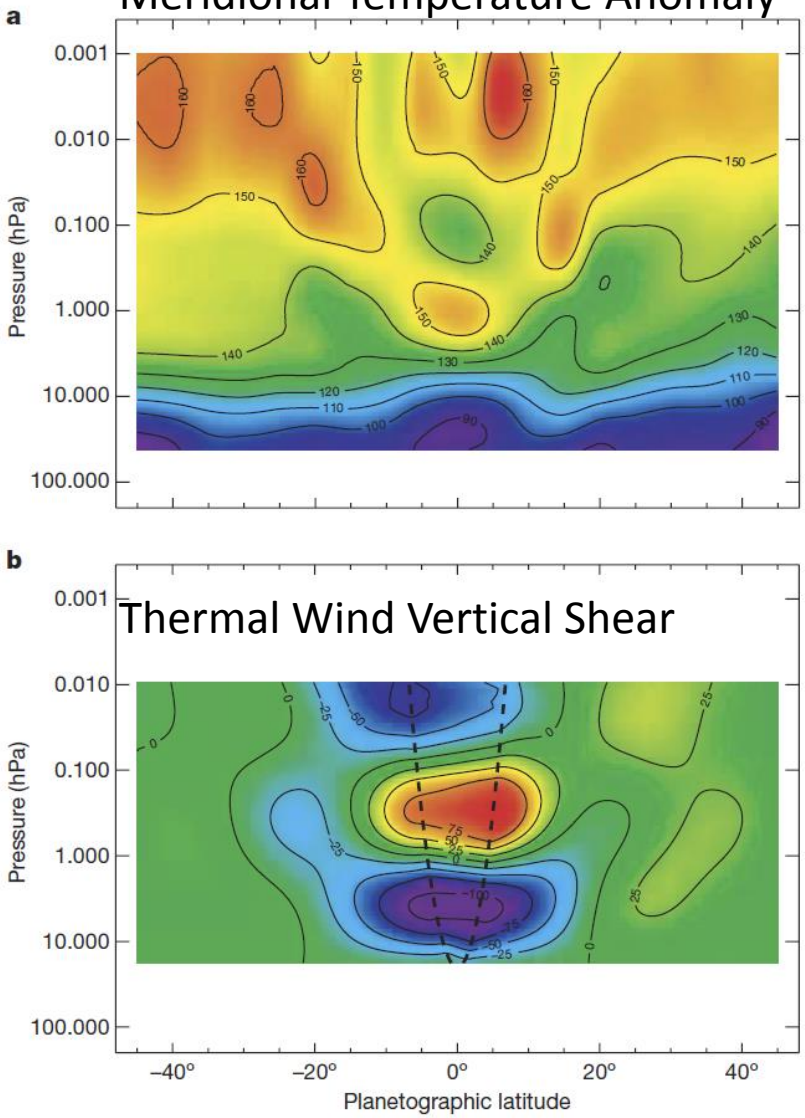
Simon-Miller et al. (2006)

Meridional Temperature Anomaly



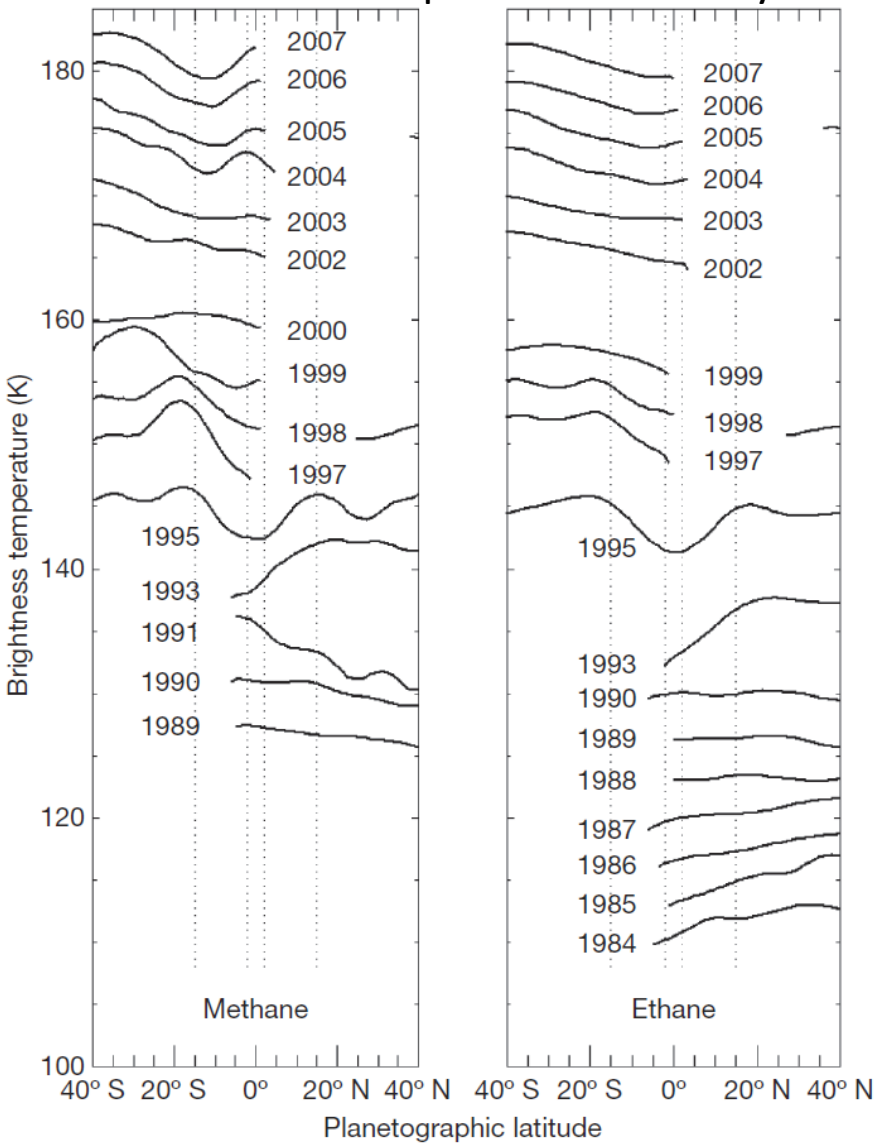
Saturn Stratospheric Oscillation ("SSO")

Meridional Temperature Anomaly



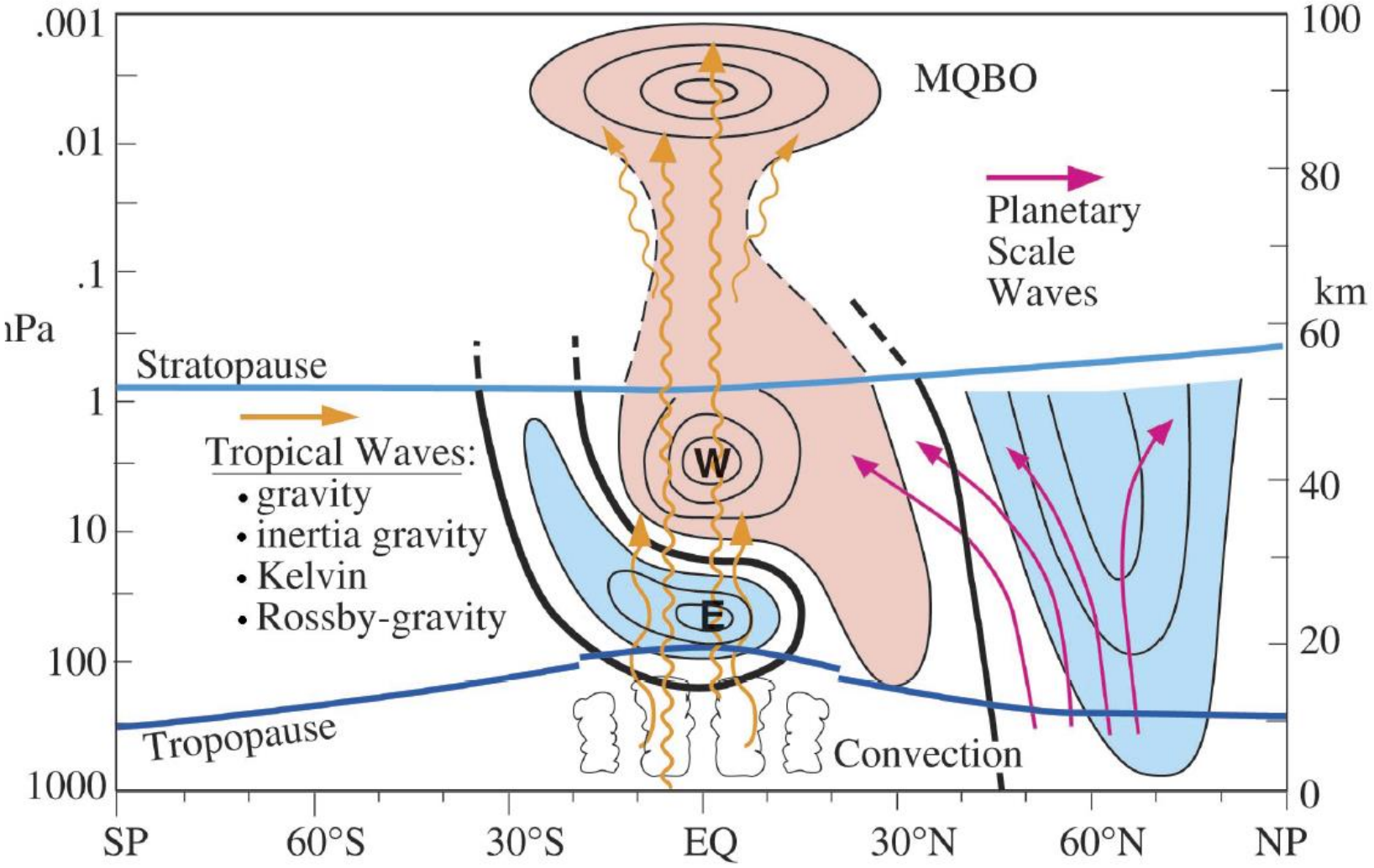
Fouchet et al. (2008)

Meridional Temperature Anomaly



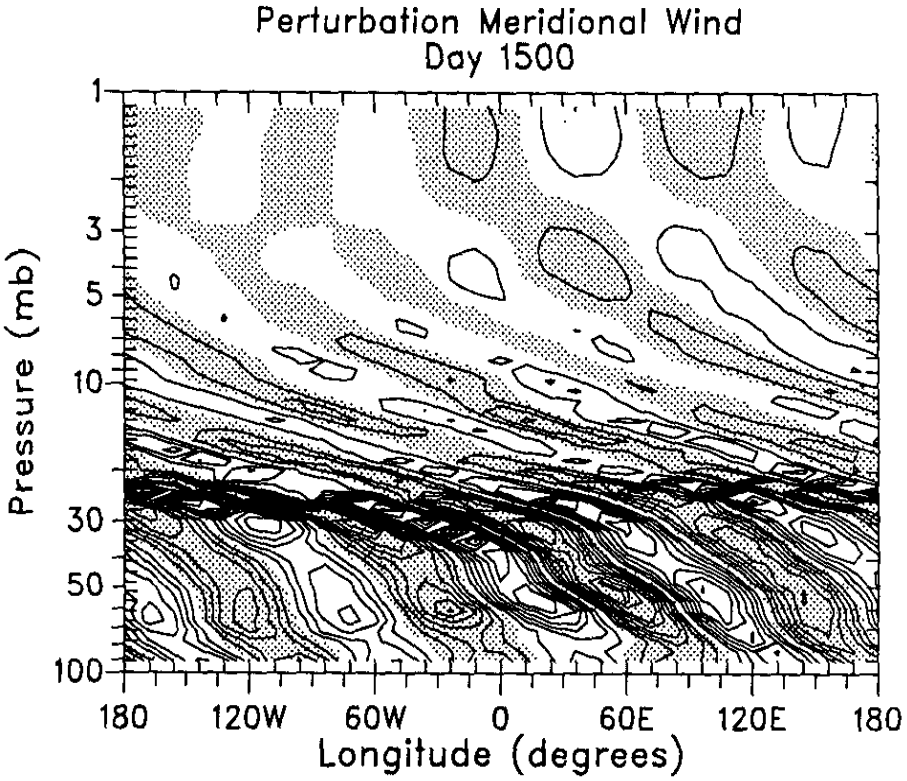
Orton et al. (2008)

Stratospheric Oscillations on Jupiter+Saturn: QBO Analog

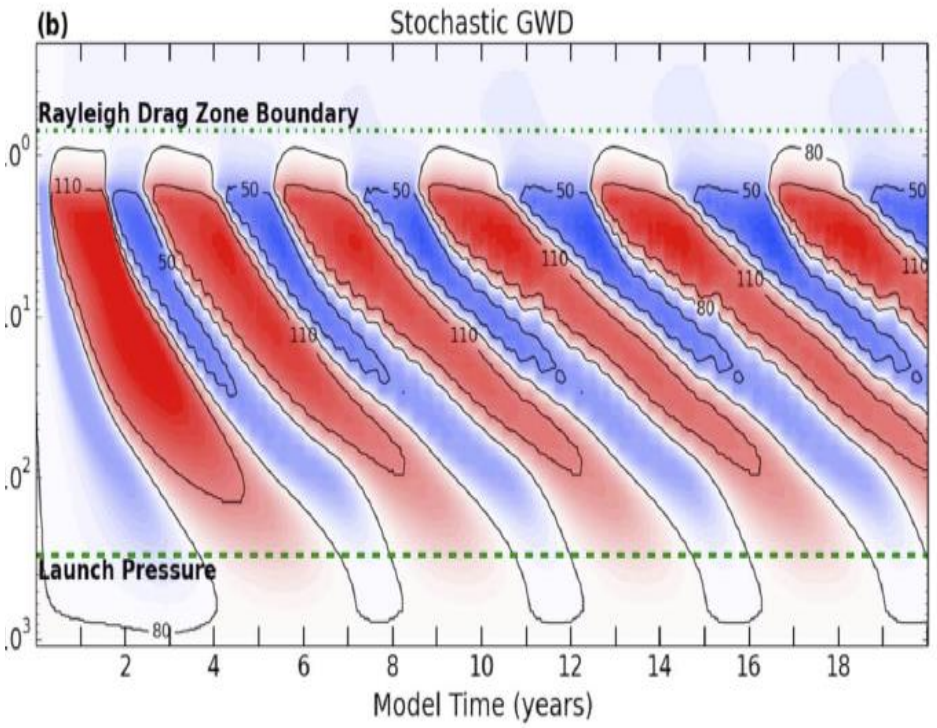


Review Article by Baldwin et al. (2001)

Jupiter – Quasi-Quadrenniel Oscillation (“QQO”)



Earth QBO Model
by Takahashi & Boville (1992)



Jupiter QQO Model
by Cosentino et al. (2017)

Stratosphere

- Seasonal Forcing
  - Temperature change
- Photochemistry
  - Affects composition distribution
- Disequilibrium species
  - indicators of vertical mixing
- Photochemical Haze production
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- Stratospheric Oscillations
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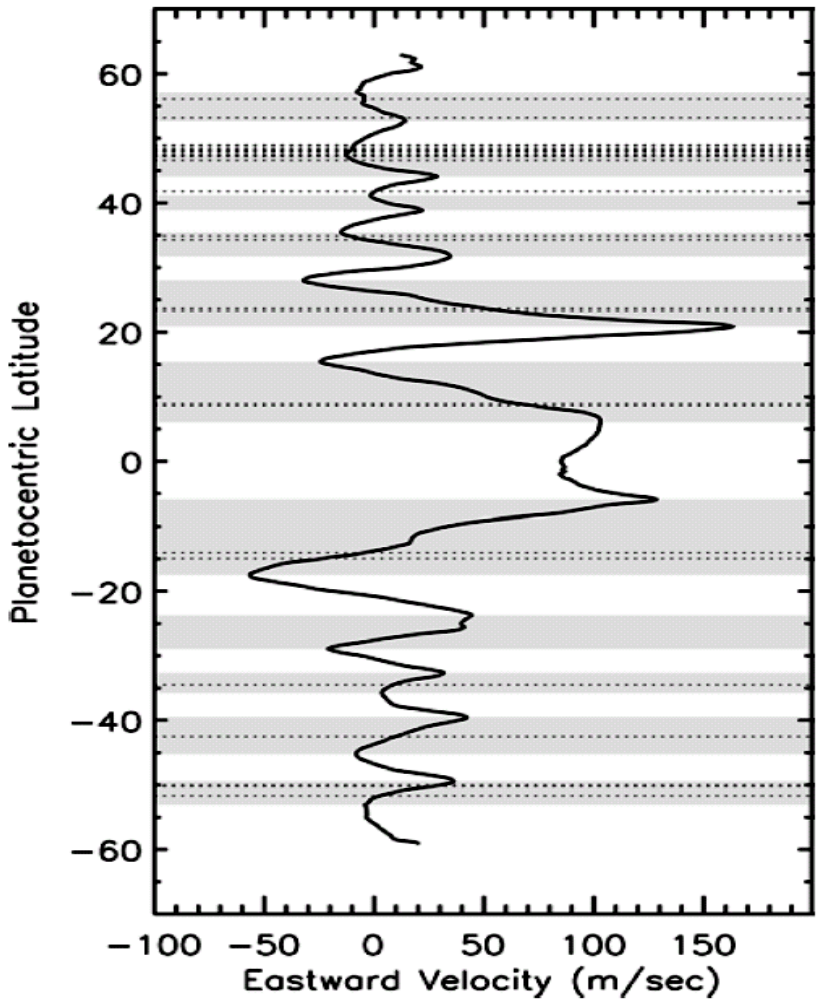
Troposphere

- Zonal Jets
  -- Vertical structure: Deep or Shallow?
- Vertical Stratification
  -- Deep static stability is uncertain
- Vertical Cloud Layers
  -- Existing predictions are based on equilibrium
- Non-Linear Models with Clouds
  -- Sugiyama et al. (2014) show much promise

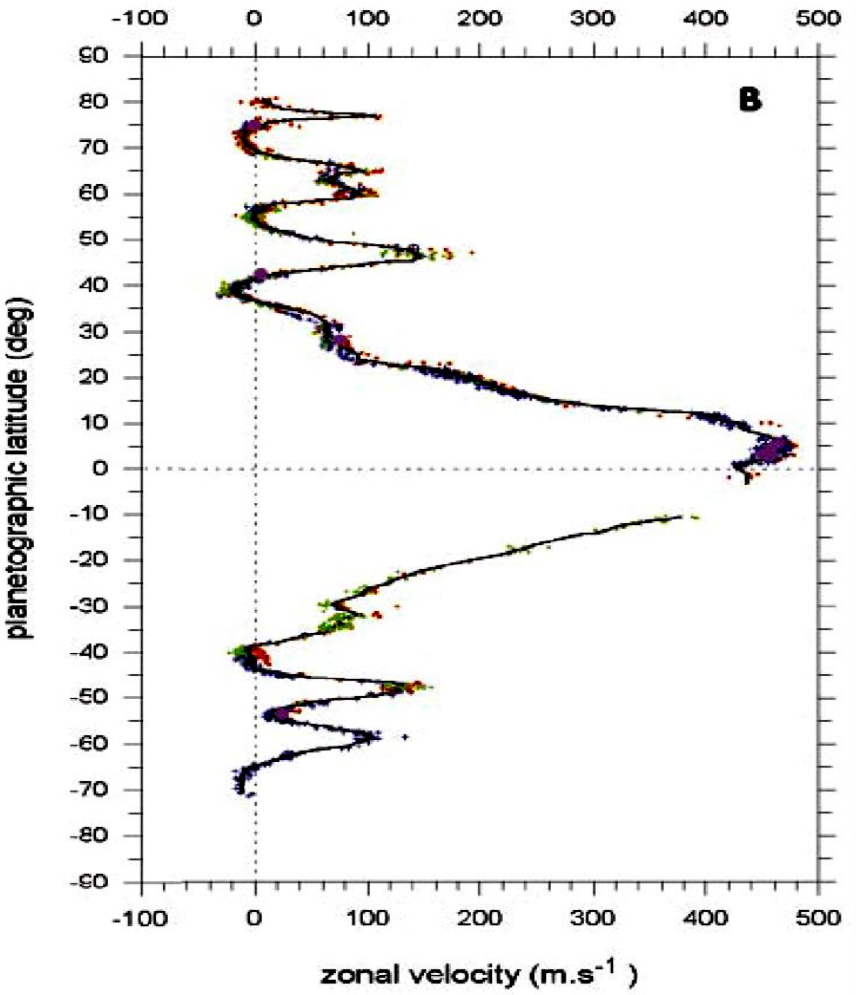
Atmospheric Jets

- **<u>Zonal Jets</u> between the bands**

Zonal wind speed on Jupiter
(Ingersoll et al 2004)
Shaded/Light = Cyclonic Zone/Anticyclonic

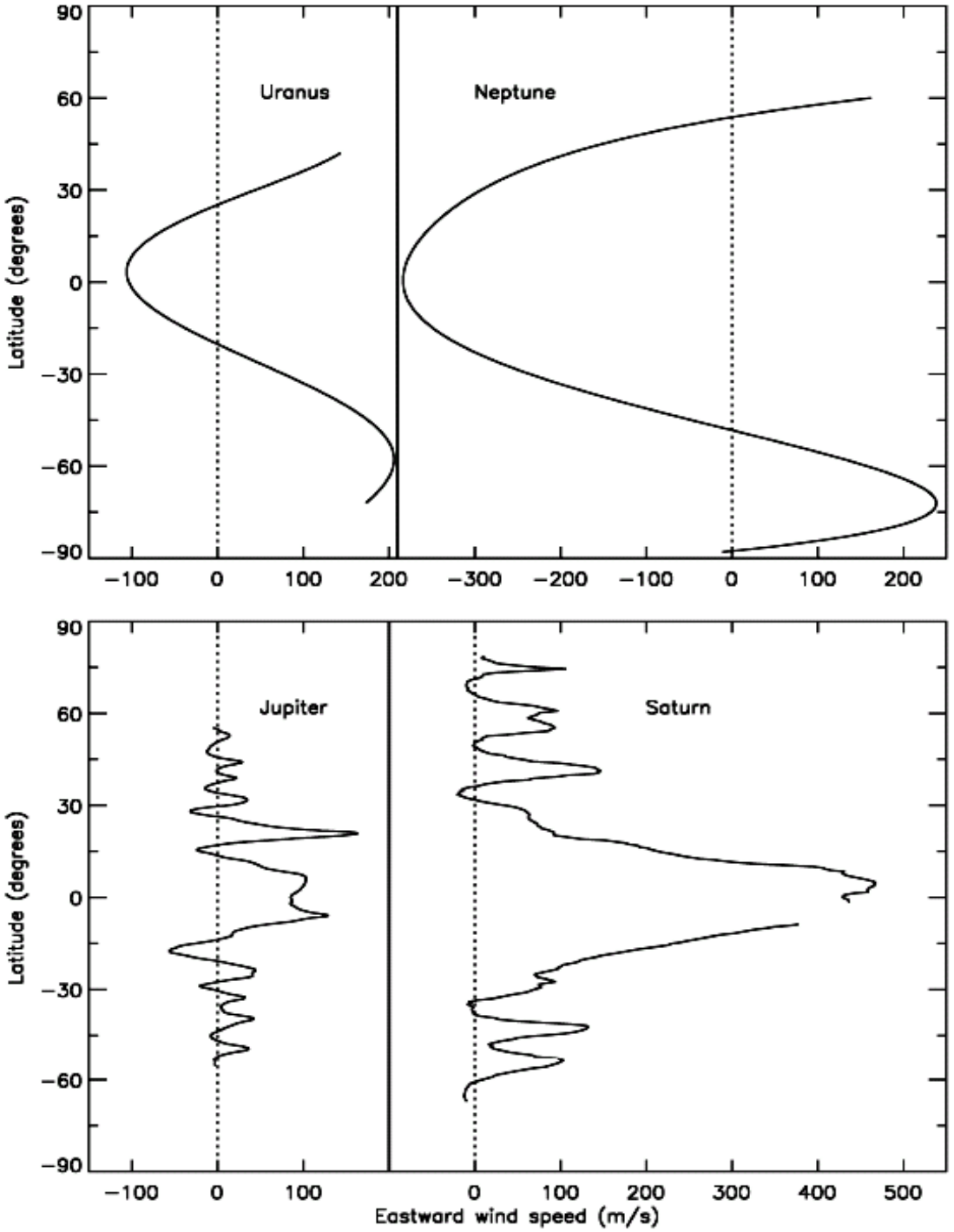


Zonal wind speed on Saturn
(Sanchez-Lavega et al 2000)



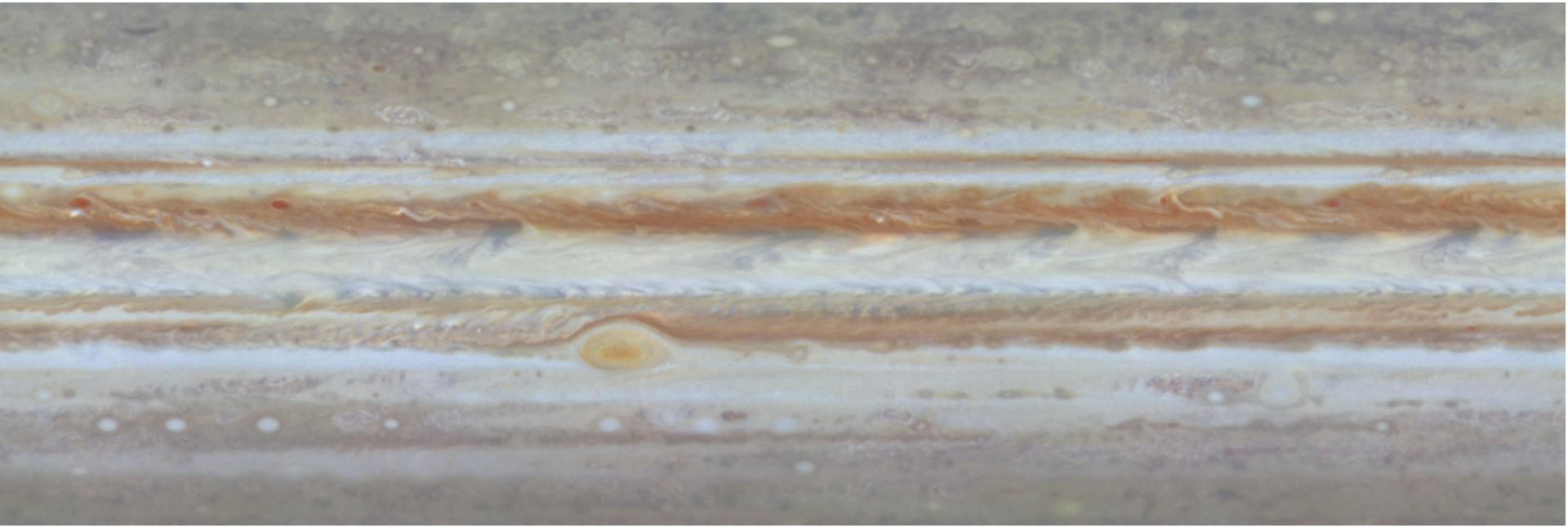
The “Jets” Problem

- **How Deep?**
- **Why Stable?**
- **Why Superrotate?**
- **What Drives Them?**

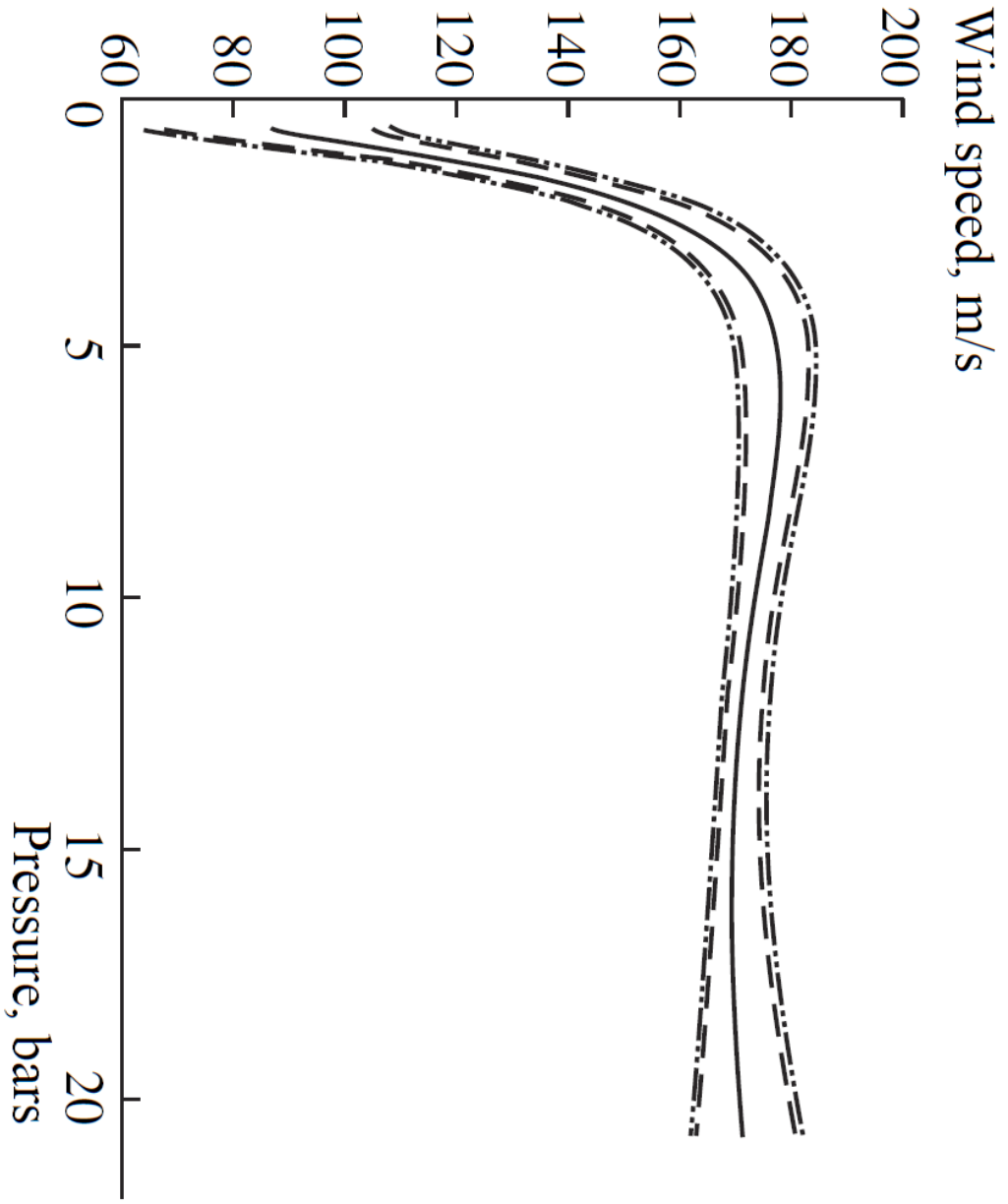


Beebe. (2005) Fig. 1

Cloud Motion on Jupiter



Vertical Jet Structure



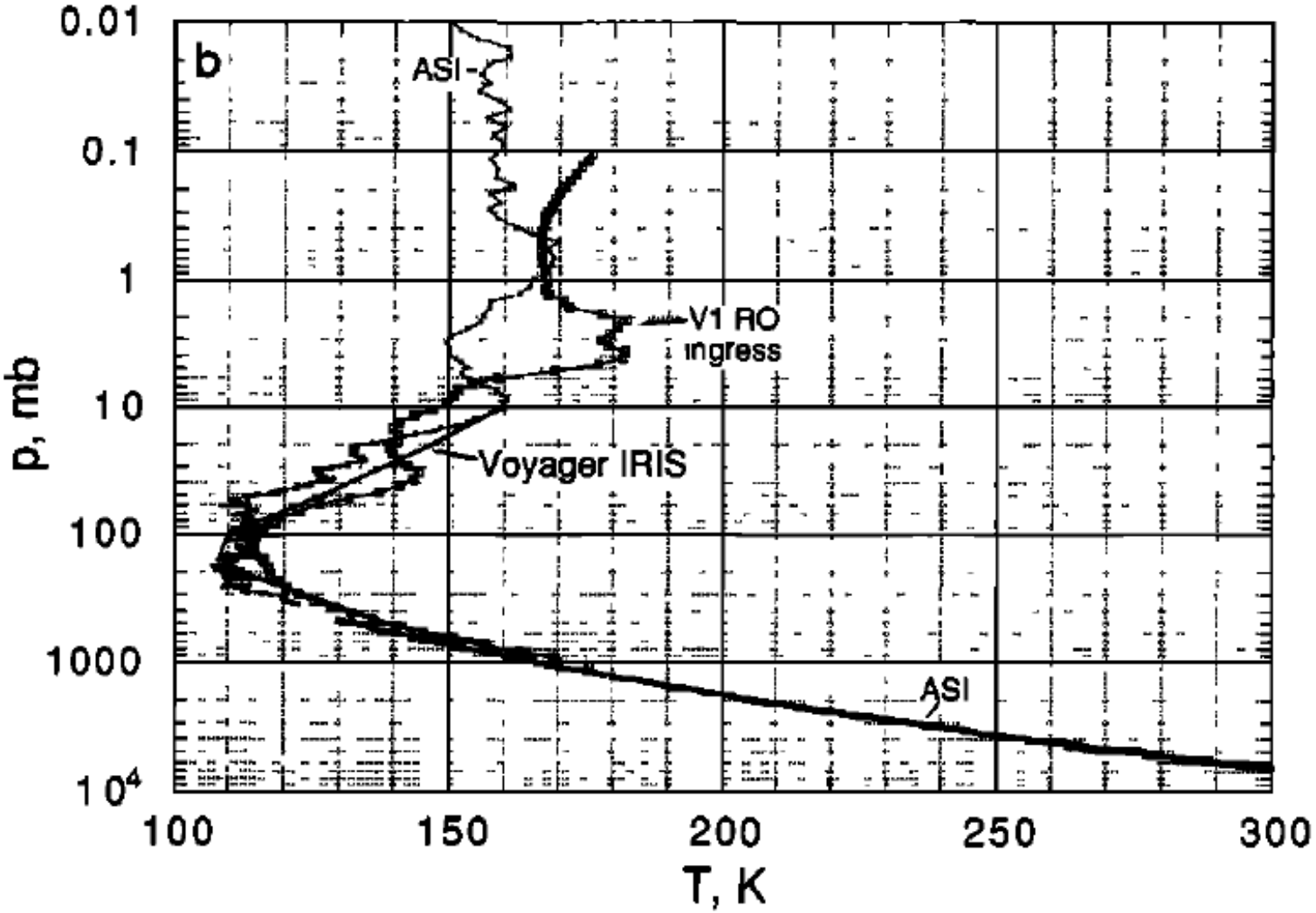
Galileo Entry Probe Wind Measurement (Atkinson, 2001)

Only In-situ measurement of Giant Planet atmosphere

Structure at depth – to be determined

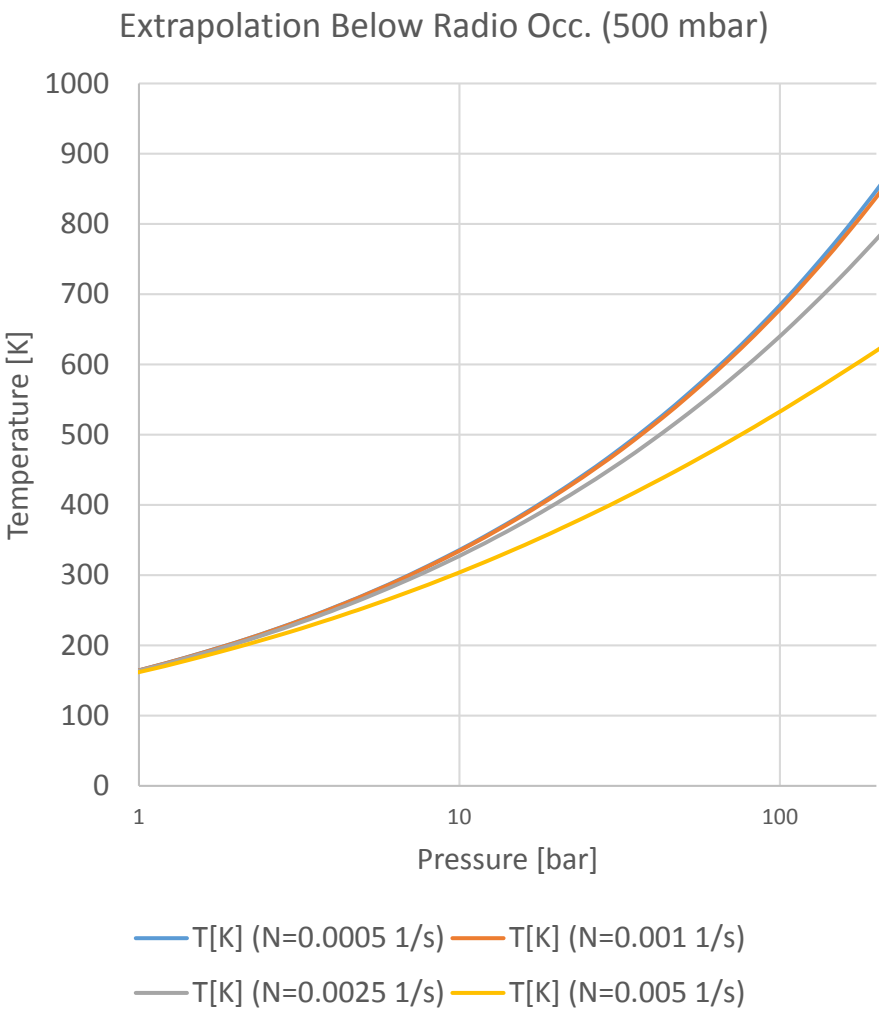
Juno's gravity measurements should place constraints.

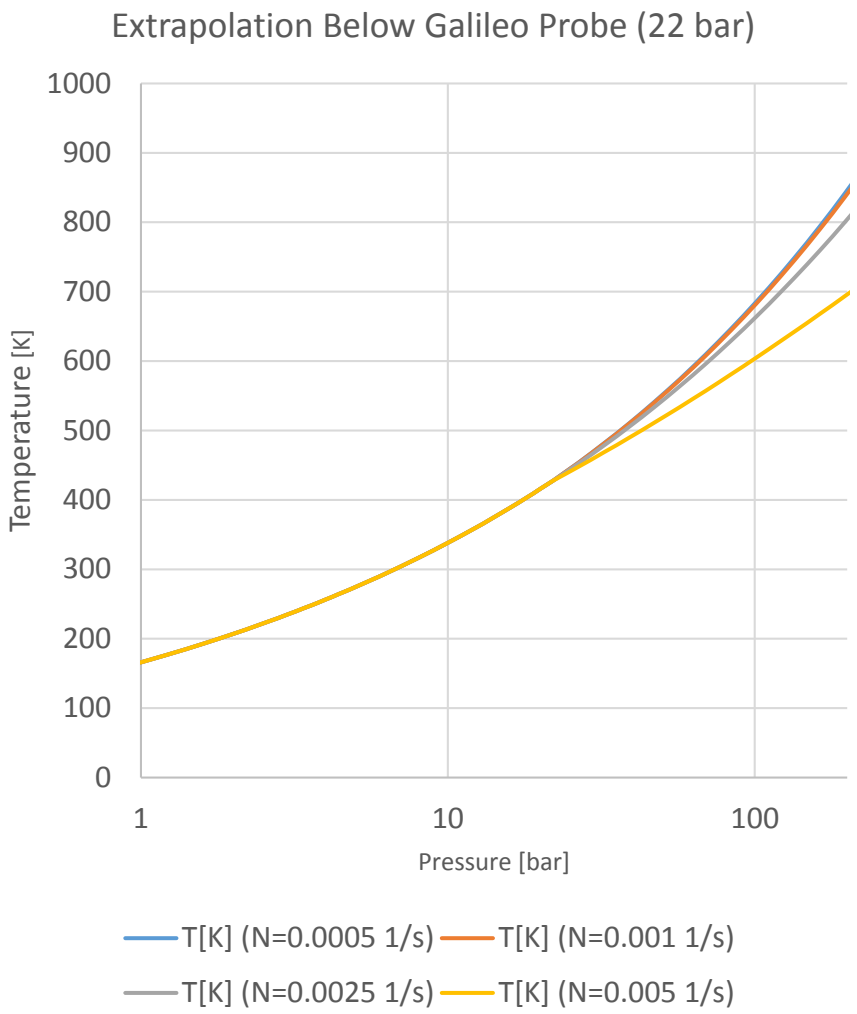
Vertical Thermal Structure



Galileo Entry Probe Temperature Measurement (Seiff et al, 1998)

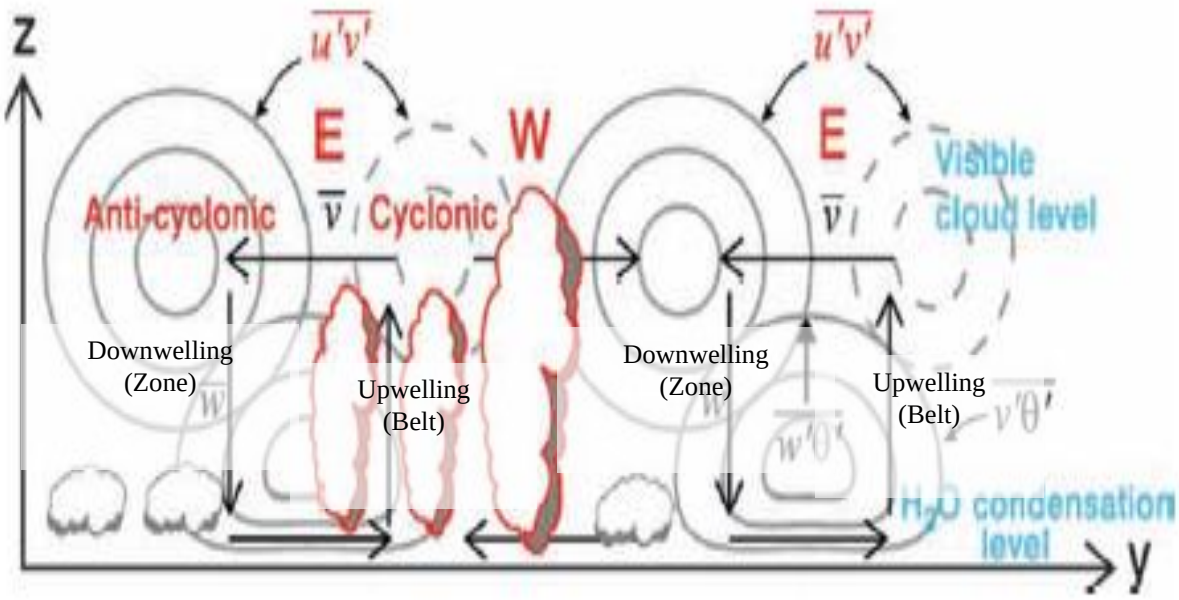
Vertical Thermal – Uncertainties at Depth

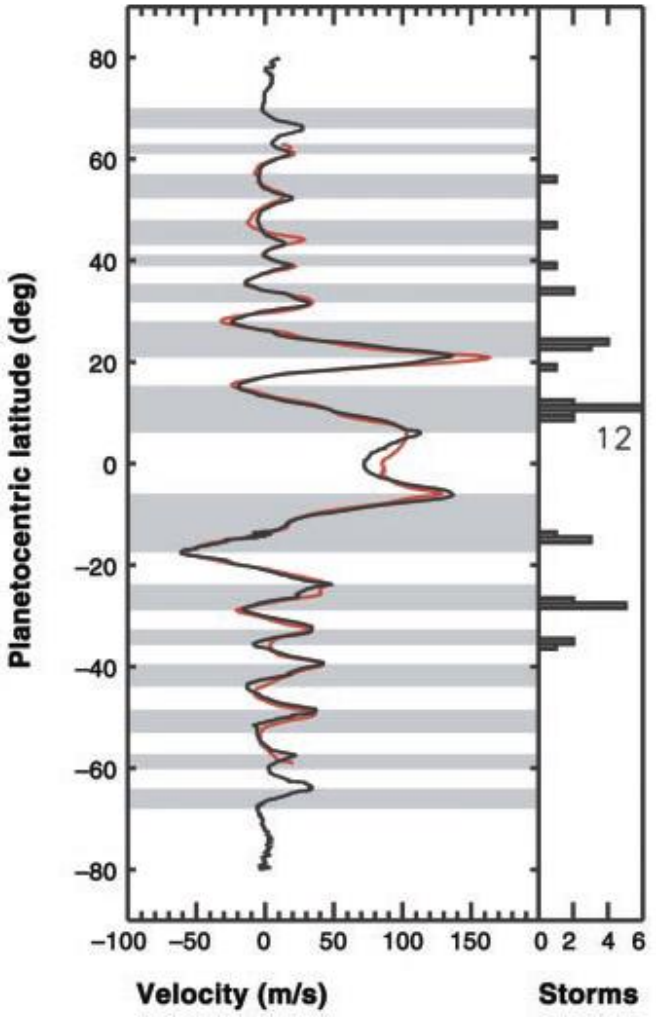




200-bar temperature can diverge by 200K depending on the assumed static stability

Meridional Circulation

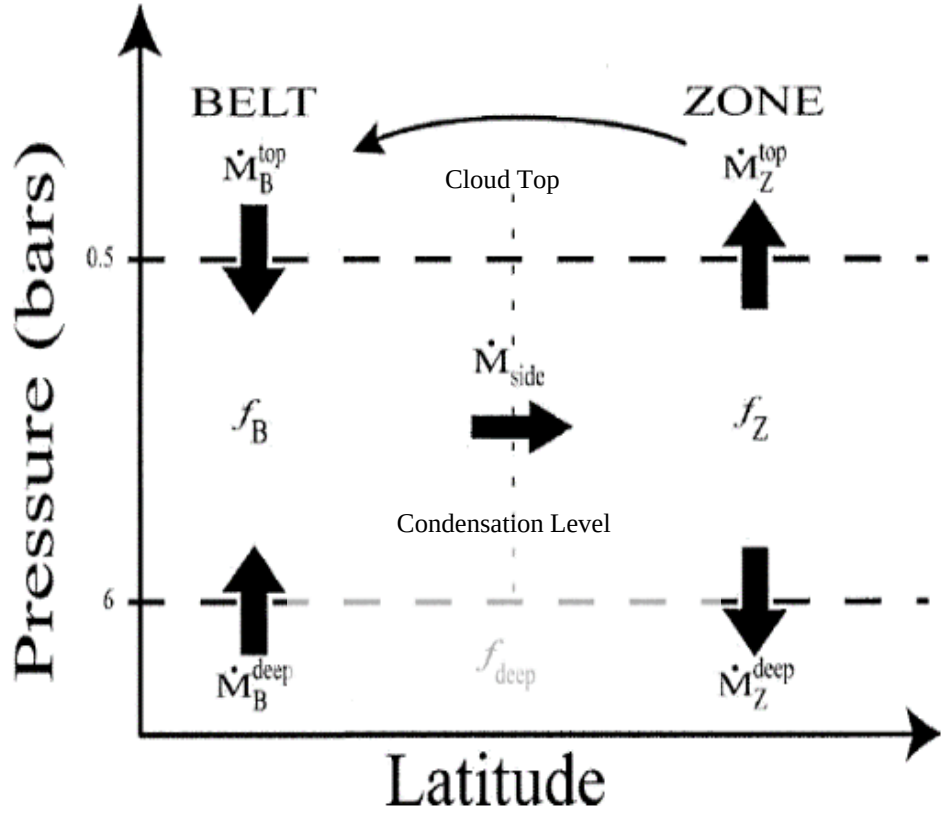




Cloud-top circulation reach the cloud condensation level [figure from *Del Genio et al.*, 2009].

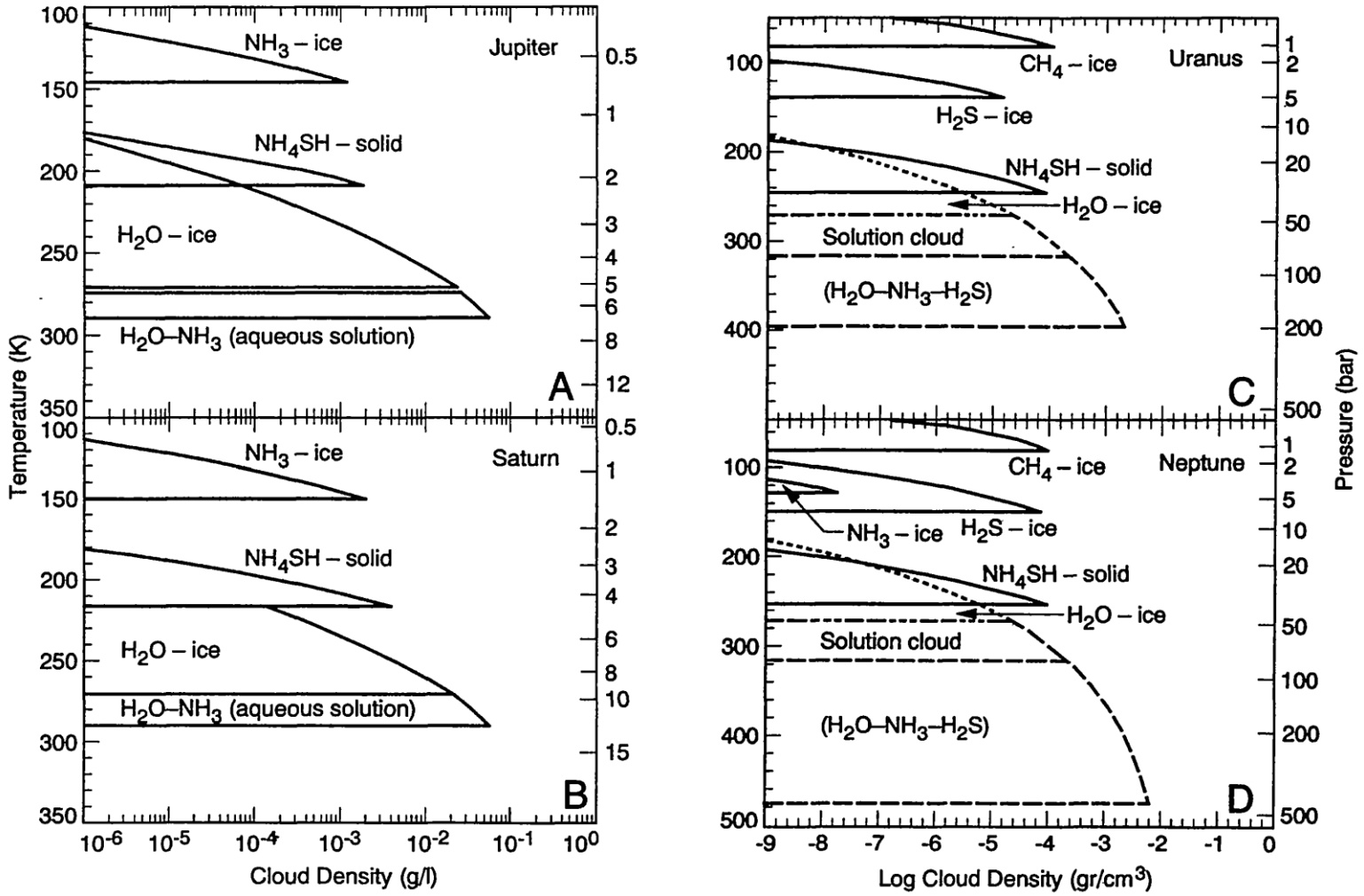
The Cloud-top Temperature Profile is not consistent with above picture, i.e., Belts are warmer than the Zones

Meridional Circulation – Alternative Hypothesis



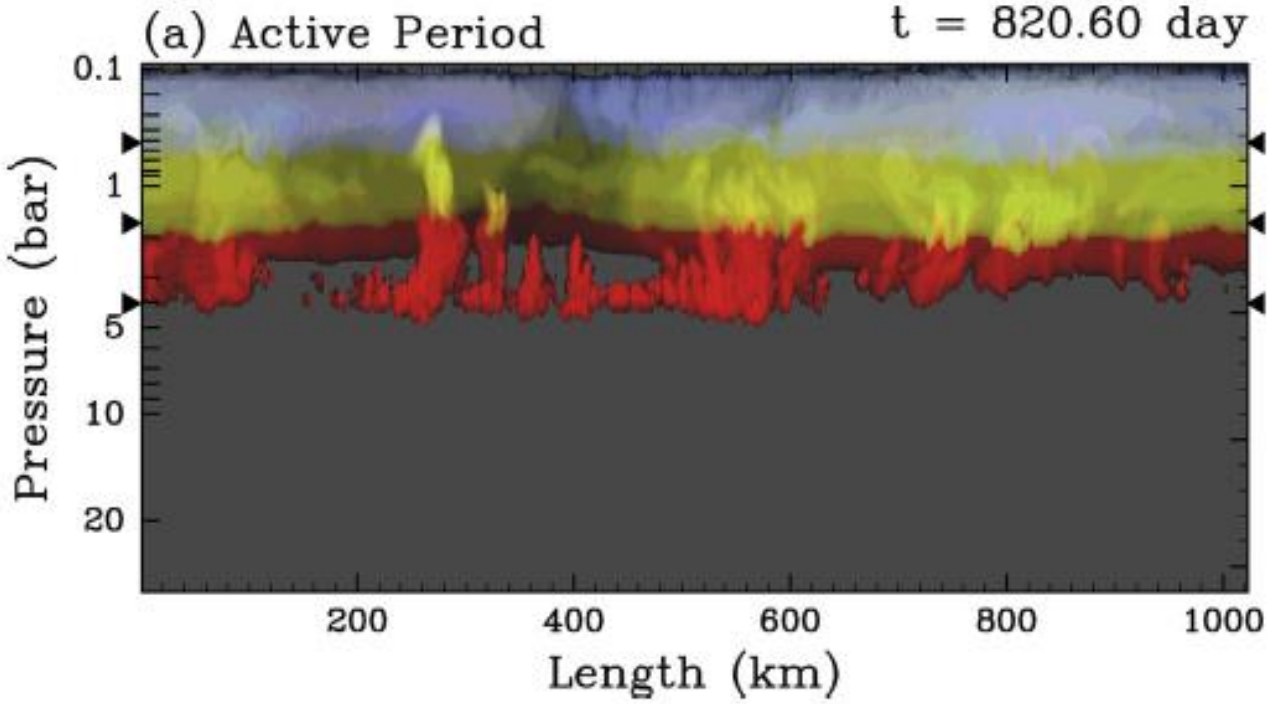
Vertical flow component reverses direction between the cloud top and the condensation level
Hypothesis by Ingersoll et al. 2000
Figure from *Showman and de Pater*, 2005].

Vertical Cloud Structure



Jupiter and Saturn: S. K. Atreya and M. Wong, based on S. K. Atreya & P. N. Romani (1985).
Uranus and Neptune were first published by de Pater, Romani & Atreya (1991).
These are Thermo-Chemical Equilibrium Model, Does not take account of Dynamics.
Figure from West (2000).

Convection Modeling



Sugiyama et al. (2014)

Does not include radiation, but three-dimensional Moist Convection Capability

Probably the closest to modeling the three-dimensional cloud structure of Jupiter

Troposphere

- Zonal Jets
  -- Vertical structure: Deep or Shallow?
- Vertical Stratification
  -- Deep static stability is uncertain
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Summary

- Energy Balance:
  - Thermosphere:
    Unknown Energy Input (Aurora Heating?)
  - Stratosphere:
    Wave Transport, Radiation and Chemistry
  - Troposphere:
    Moist Convection