

Exploring Giants

Understanding Gas and Ice Giants at
the Start of the 2020s



@LeighFletcher



UNIVERSITY OF
LEICESTER



Science & Technology
Facilities Council



European
Commission



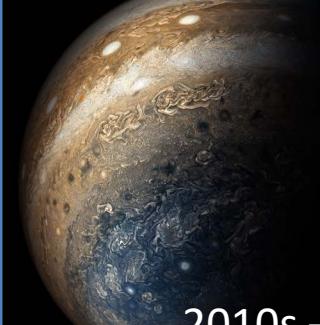
European Research Council
Established by the European Commission
Supporting top researchers
from anywhere in the world



**THE ROYAL
SOCIETY**

The Four Giants

1990s – Galileo

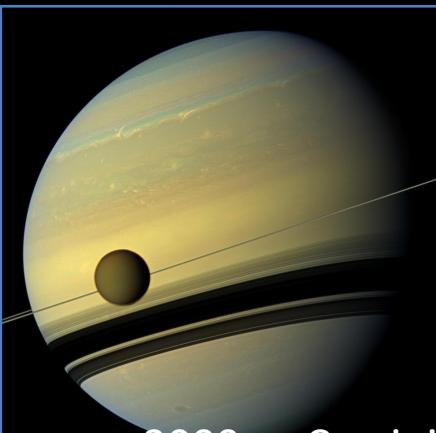


1980s – Voyager

- Time Capsules
- Dynamical Laboratory
- Potentially-habitable satellites
- Exoplanet/Brown Dwarf Archetypes

- 95-318x Earth Mass
- 9.5-11.2 Earth radii
- Mostly H₂ and He.
- NH₃ and NH₄SH clouds.
- Formed quickly.
- Metallic H₂ at great depth.

2010s – Juno
2020s – JUICE



2000s – Cassini



Jupiter Today - the Juno Mission

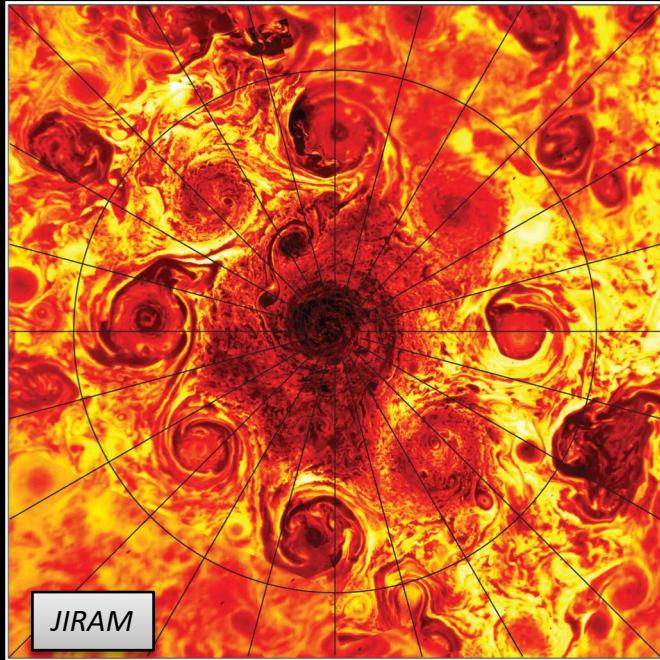
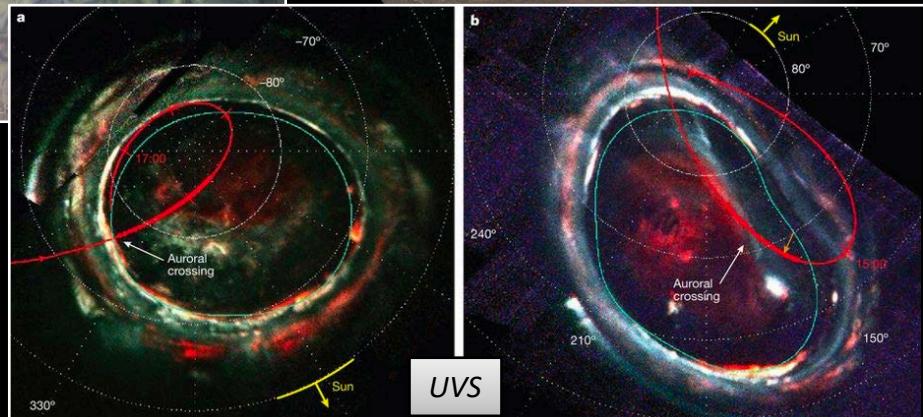


Jupiter Today – the Juno Mission

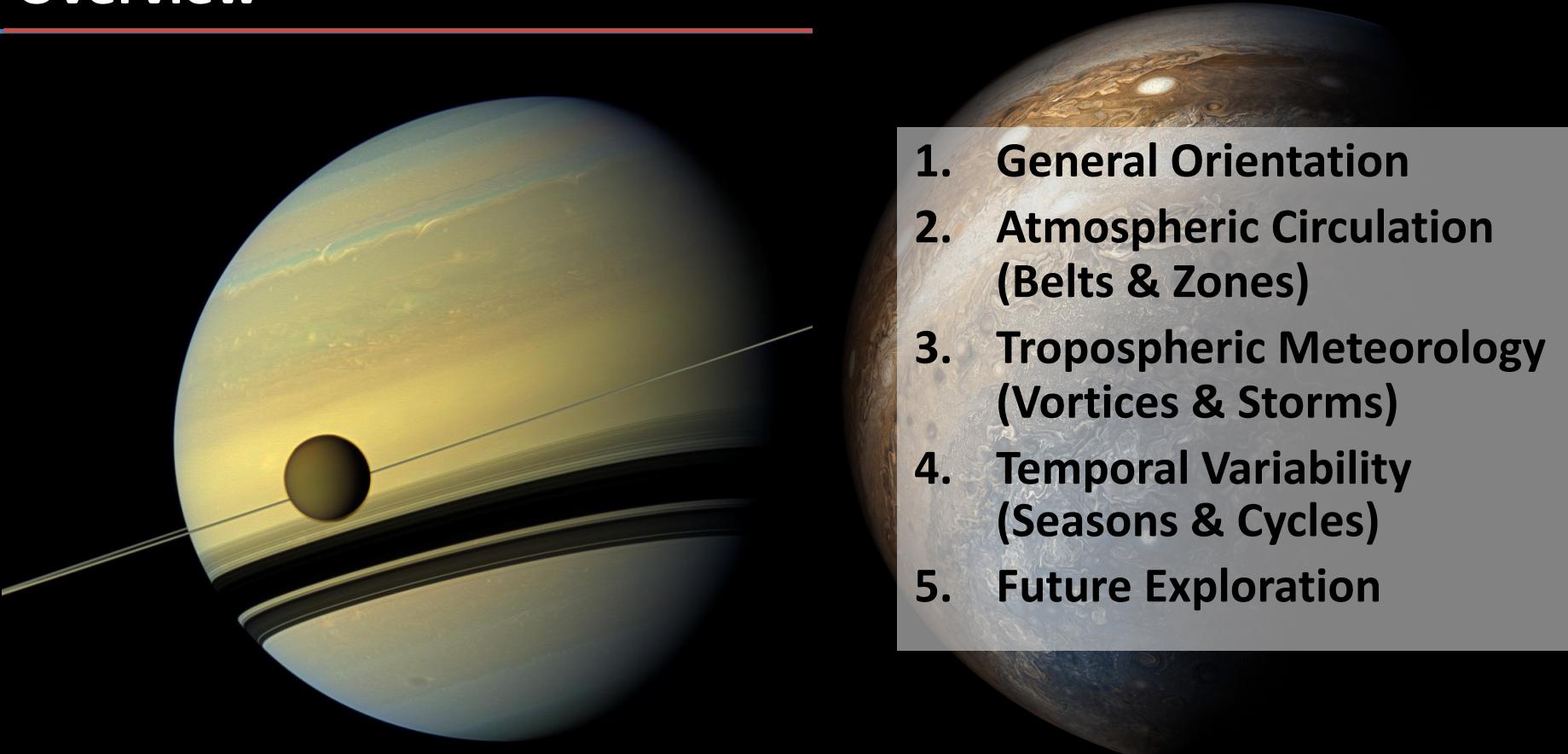


Sean Doran

Kevin M. Gill

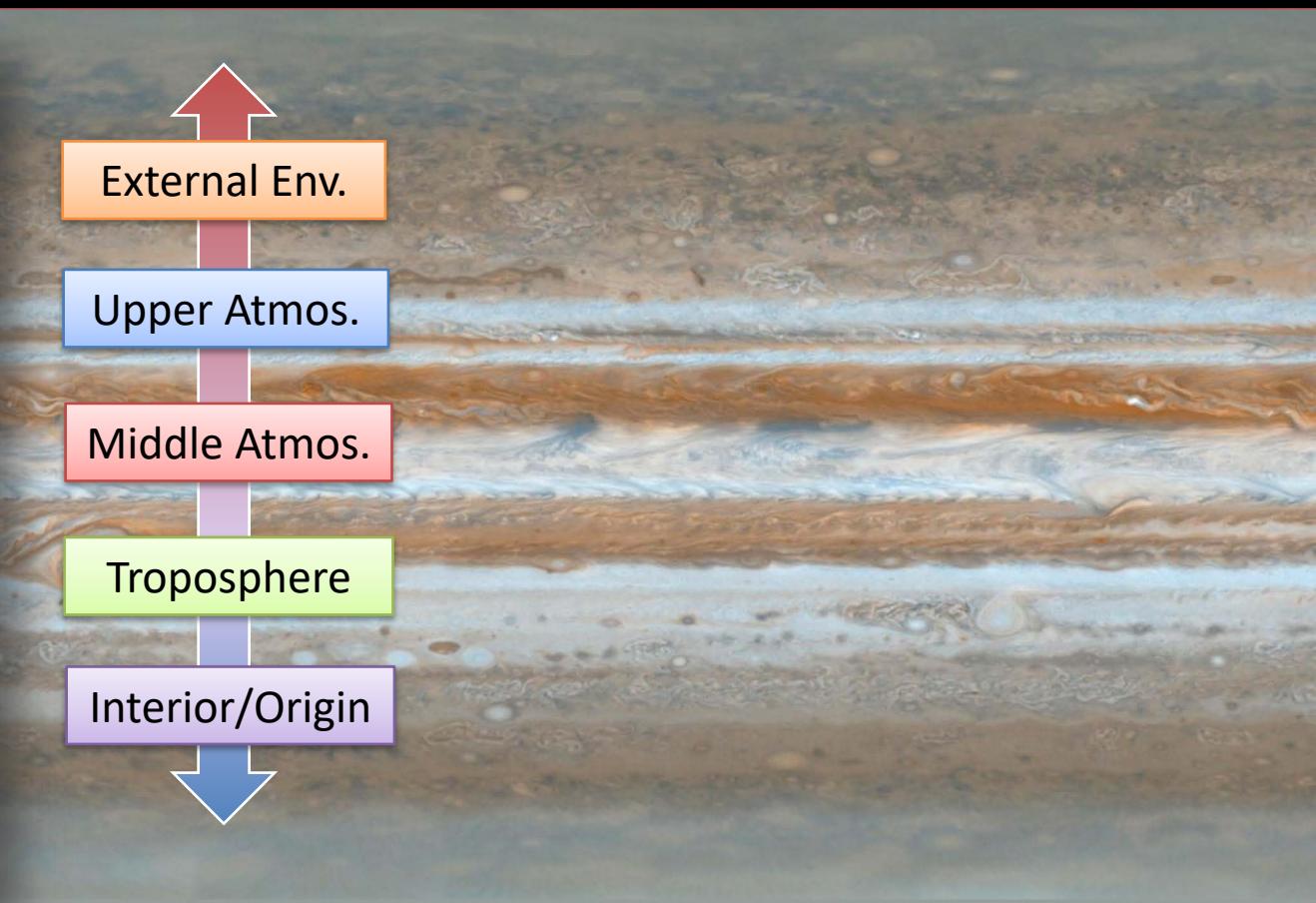
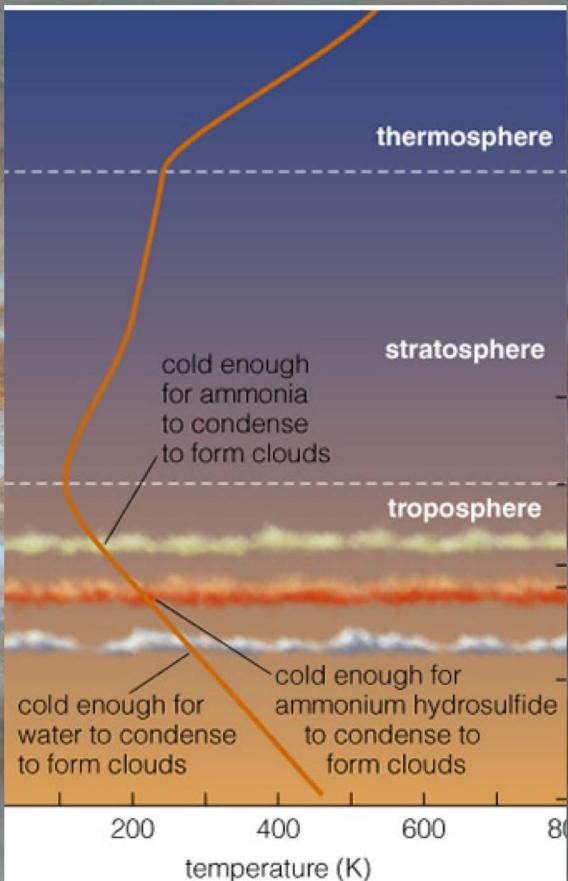


Overview



- 1. General Orientation**
- 2. Atmospheric Circulation
(Belts & Zones)**
- 3. Tropospheric Meteorology
(Vortices & Storms)**
- 4. Temporal Variability
(Seasons & Cycles)**
- 5. Future Exploration**

[1] Orientation: Structure of a Giant



[1] Orientation: Composition of a Giant

Photochemicals:
 C_2H_2
 C_2H_6
 $\text{C}_3\text{H}_x, \text{C}_4\text{H}_x\dots$

Exogenic:
 H_2O
 CO_2
 CO

H, He, C, O, N, S, P

Volatiles:

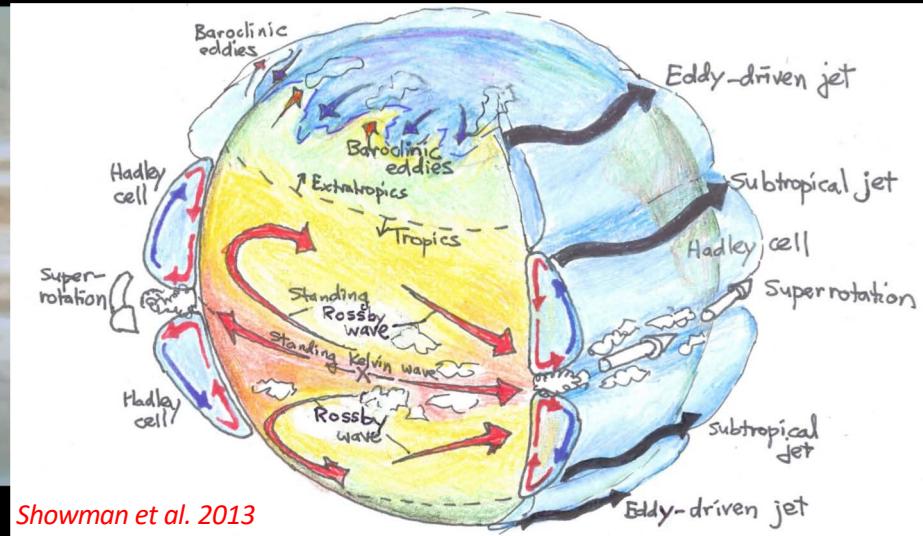
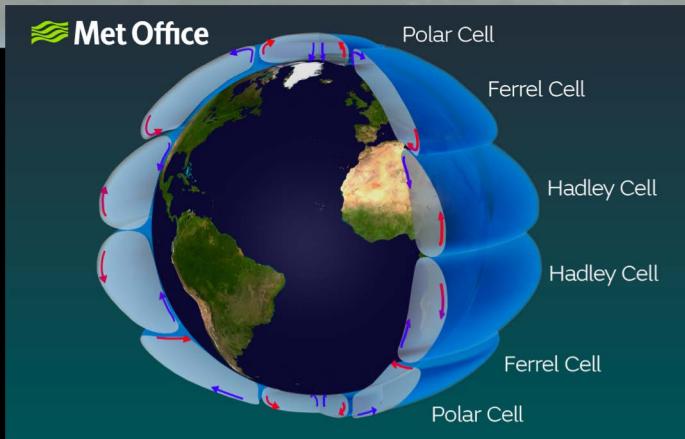
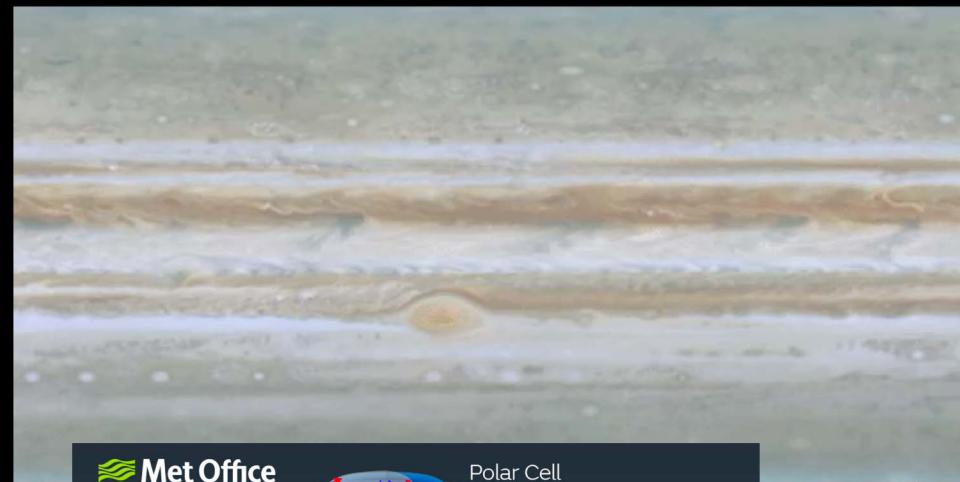
CH_4
 $\text{NH}_3, \text{H}_2\text{S}, \text{H}_2\text{O}$

Disequilibrium:

PH_3
CO
Para- H_2



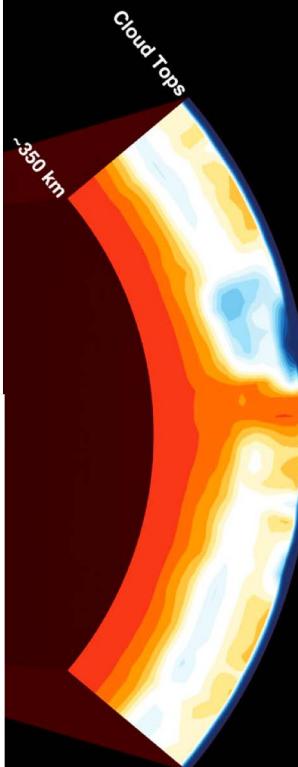
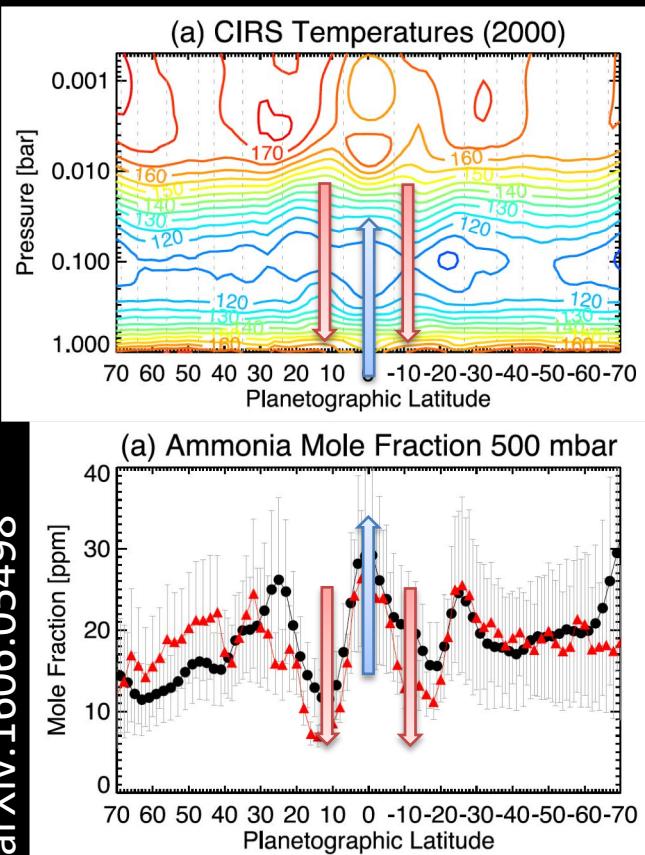
[2] Atmospheric Circulation



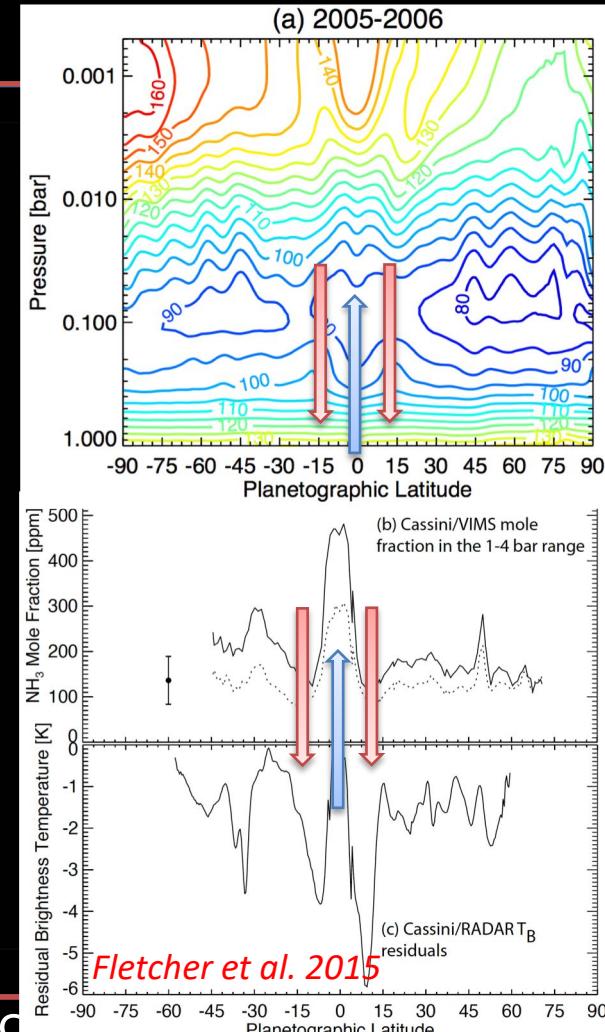
- Flavours of Jets:
 - Tropics: thermally driven (Hadley sub-tropical jets, return-flow trades).
 - Extra-tropics: eddy driven (Ferrel Cell, Rossby wave propagation).

Jupiter

arXiv:1606.05498



Li et al. 2017

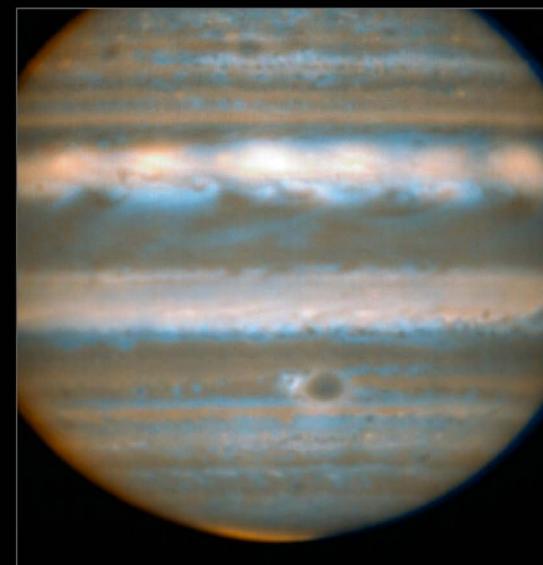
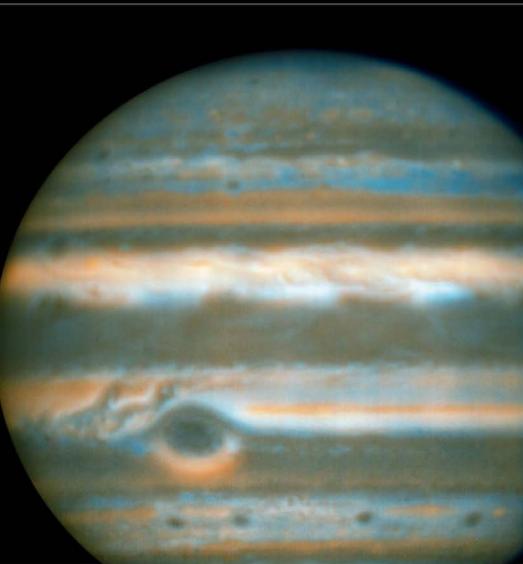
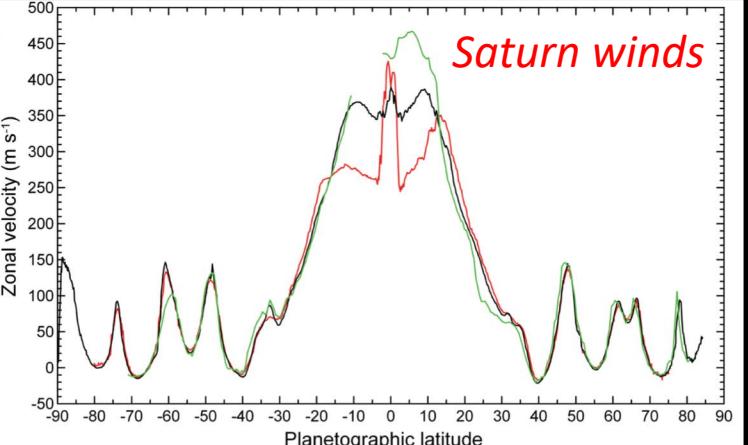
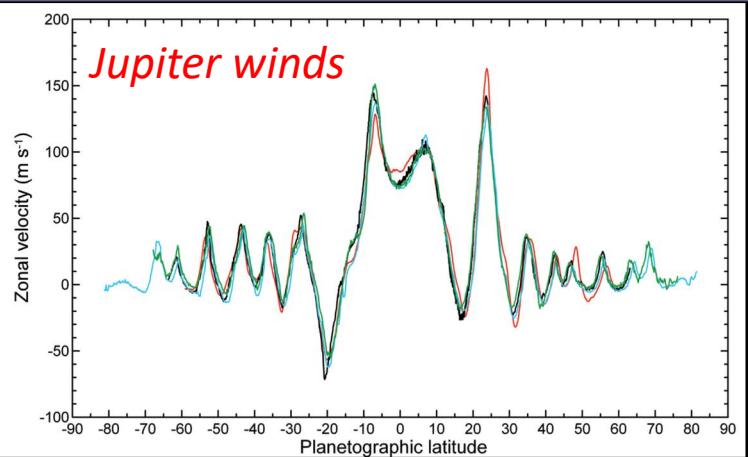


Fletcher et al. 2015

Saturn

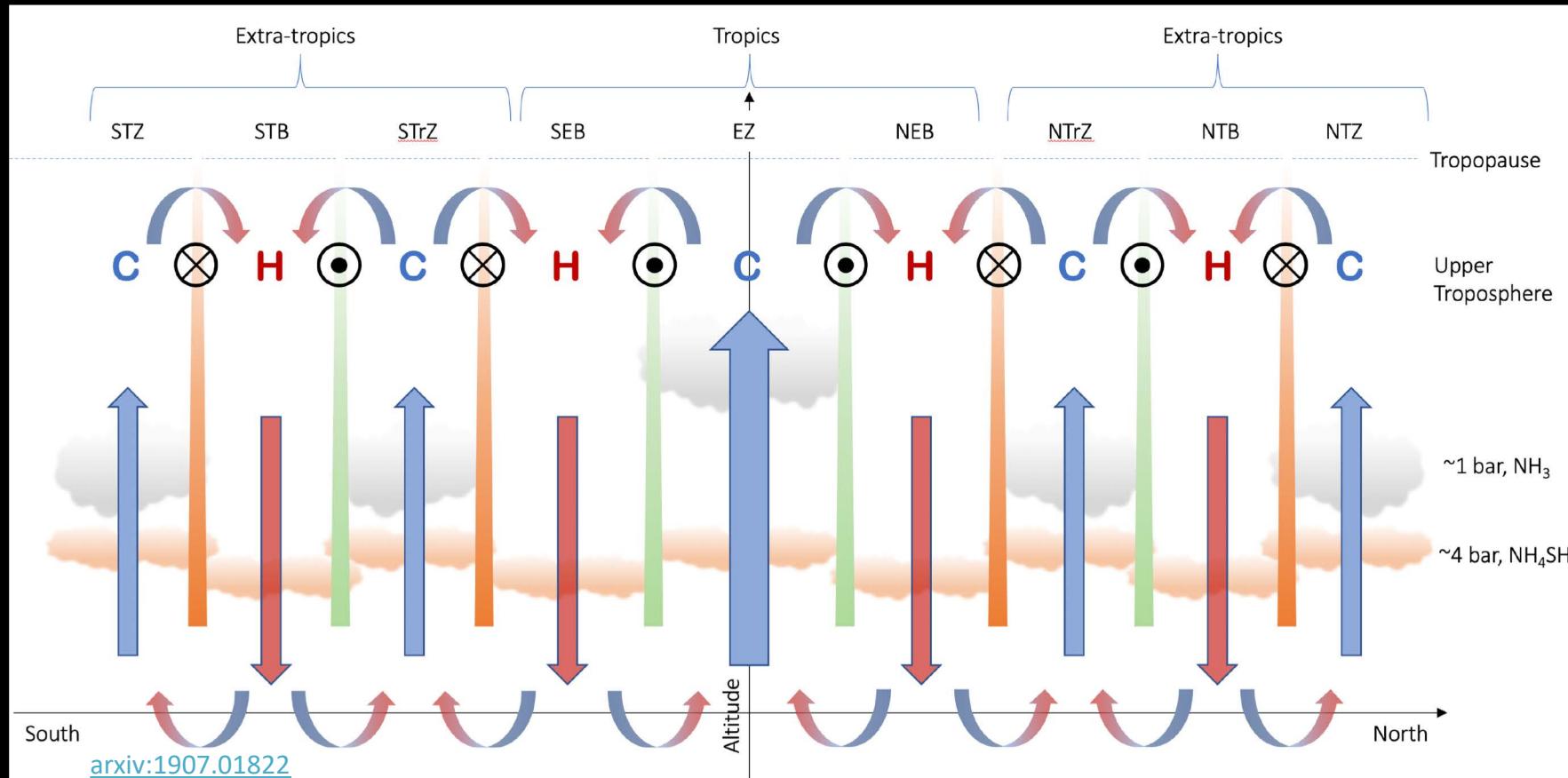
arXiv:1510.05690

[2] Extratropical Ferrel Cells?



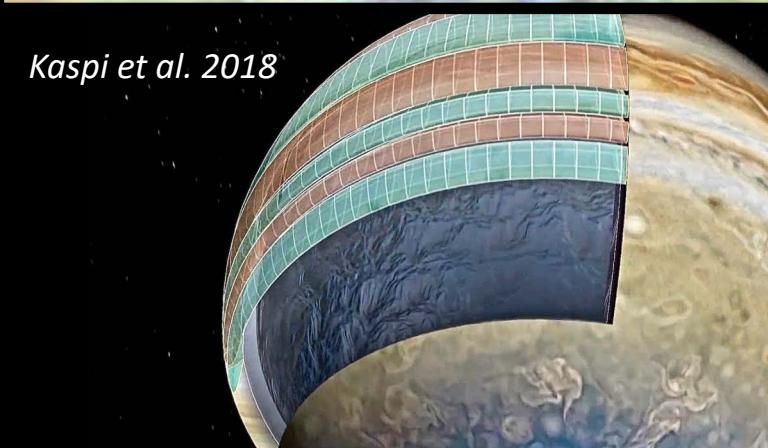
Jupiter from VLT VISIR at 8.6 and 10.7 μm , Fletcher et al., arXiv:1708.05179

[2] Atmospheric Circulation (Classical View)

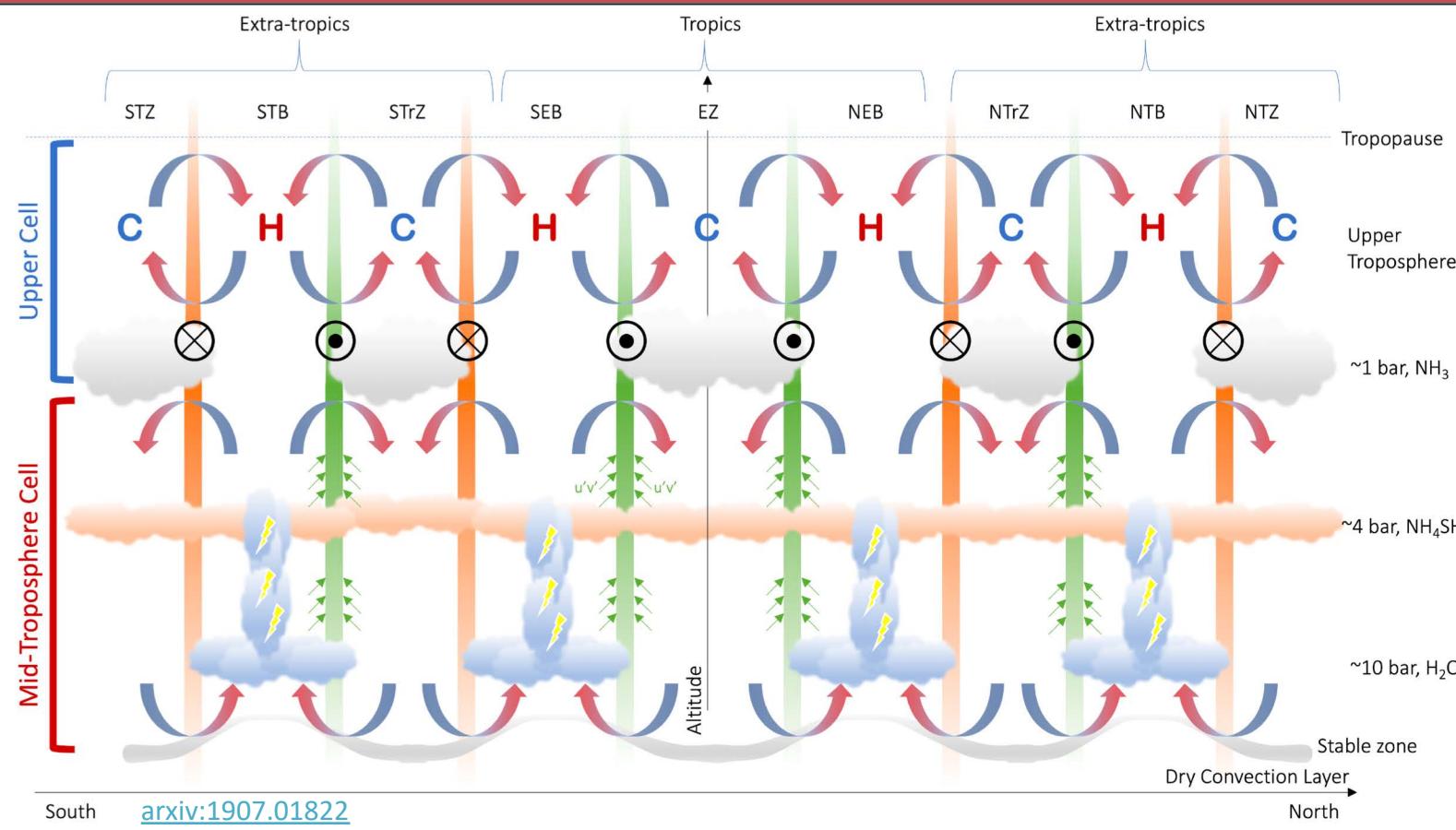


...what's happening below the clouds?

- **Lightning:**
 - Preferentially located in belts, should be associated with moist-convective uplift...
- **Chemical tracers:**
 - Some (PH_3 , AsH_3) display opposite trends to that expected from upwelling in zones.
- **Eddy-momentum flux (EMF):**
 - EMF converging & supplying energy to eastward jets, mass balance implies *upwelling* in belts, *downwelling* in zones....
- **Winds:**
 - Juno Grav shows jets go deep, but decay away by ~3000 km depth to uniform rotation...
 - NB deep winds ≠ deep forcing



Atmospheric Circulation (Stacked Cells)



Wave-driven,
radiative, wind
damping in upper
troposphere.
[Numerical models
rarely capture
this.]

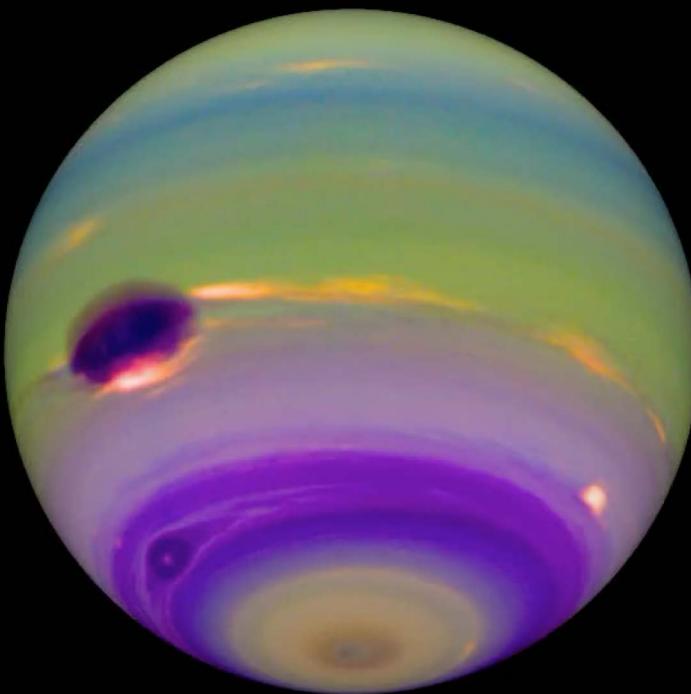
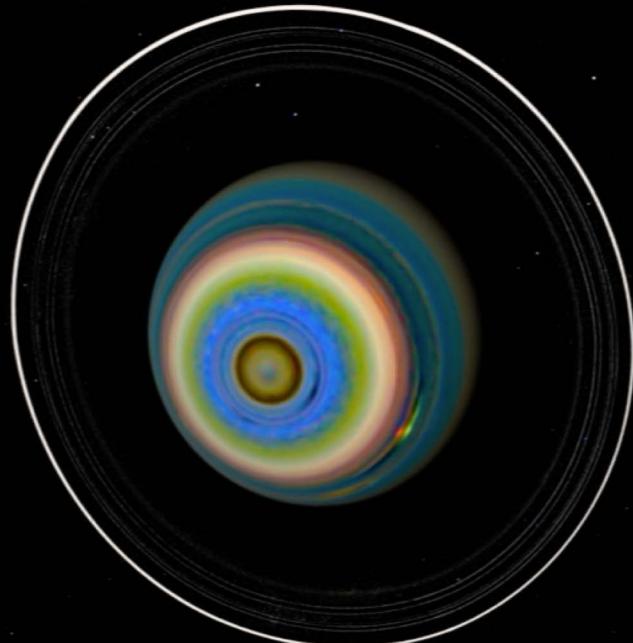
Unknown
transition
pressure...

Eddy forcing &
moist convection in
mid troposphere.
[Numerical models
see this]

Dry convection in
lower troposphere,
slow jet decay?

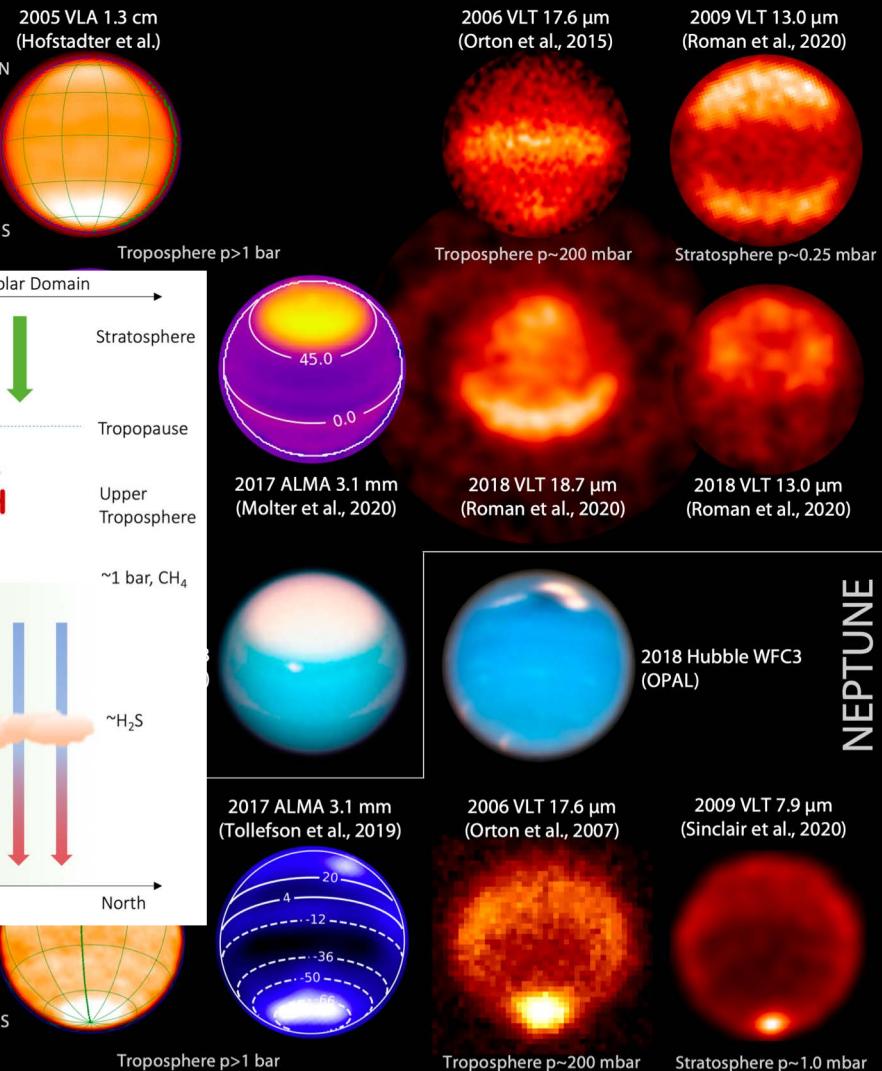
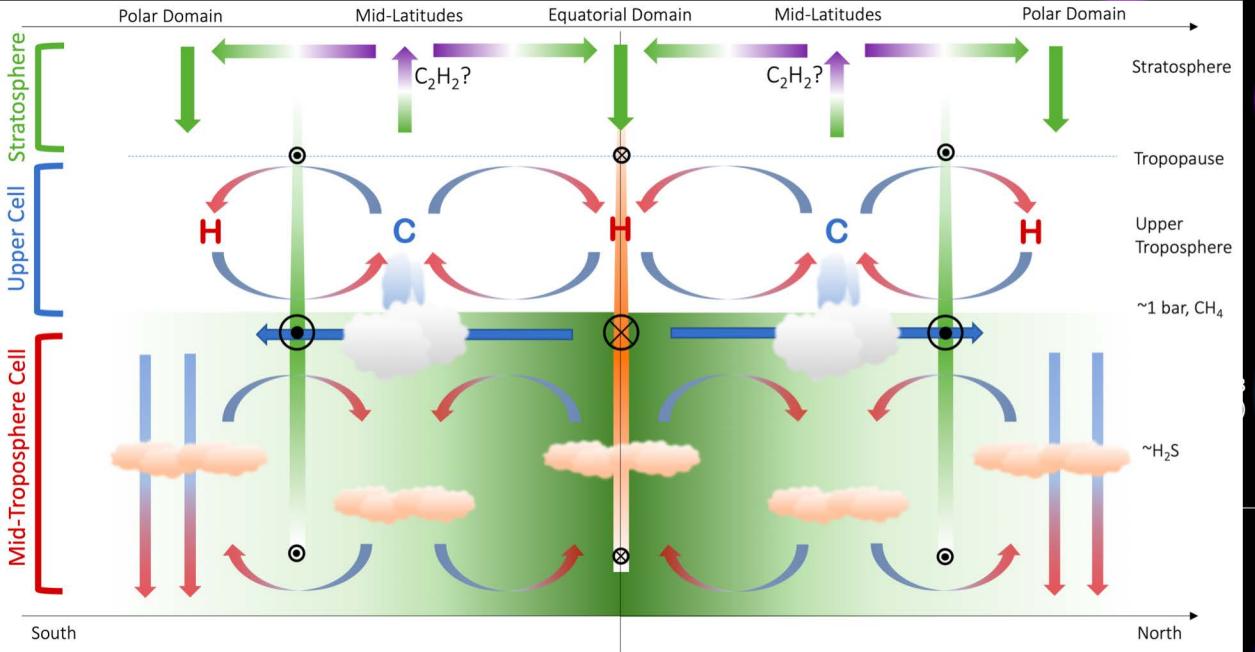
[2] What About the Ice Giants?

1989 AUG 16
8 UT



[2] What About the Ice Giants?

- Coarser banded structure, but added latitudinal gradients.

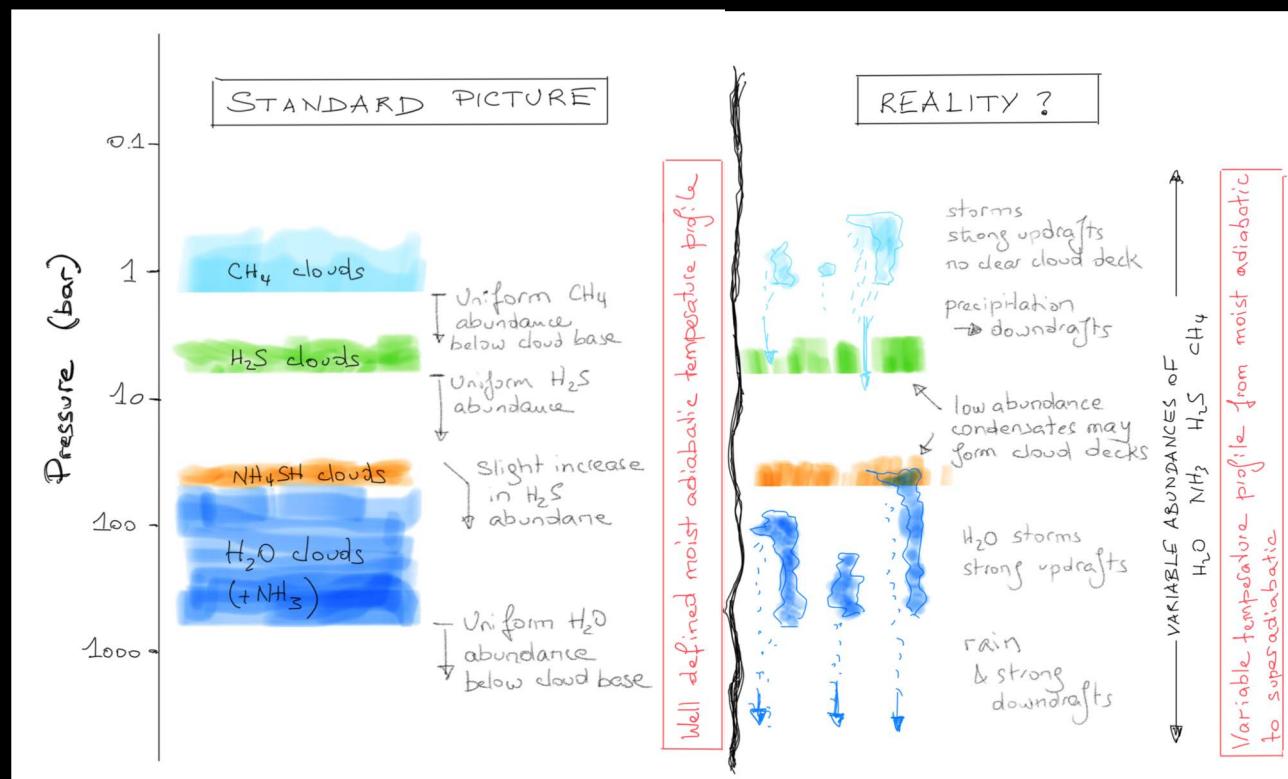


arXiv:1907.02901

@LeighFletcher, Exploring Giants, I

[2] Consequences of Circulation & Meteorology

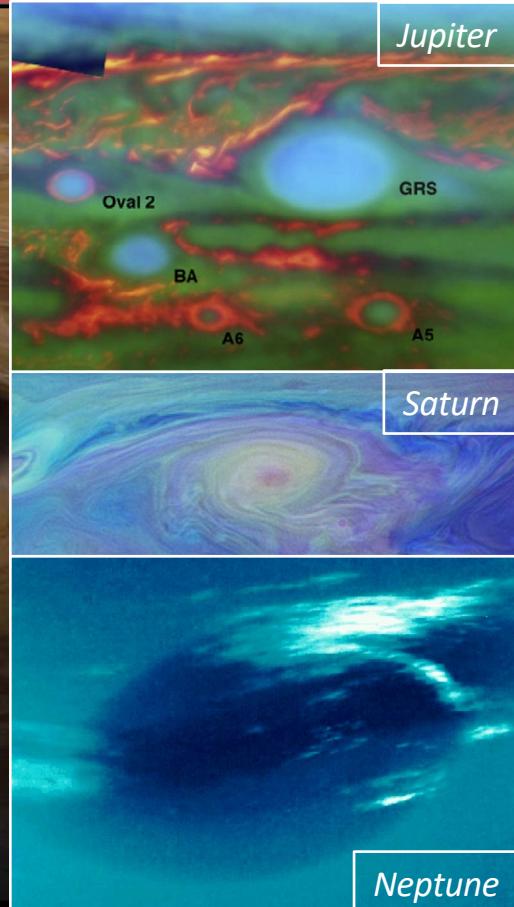
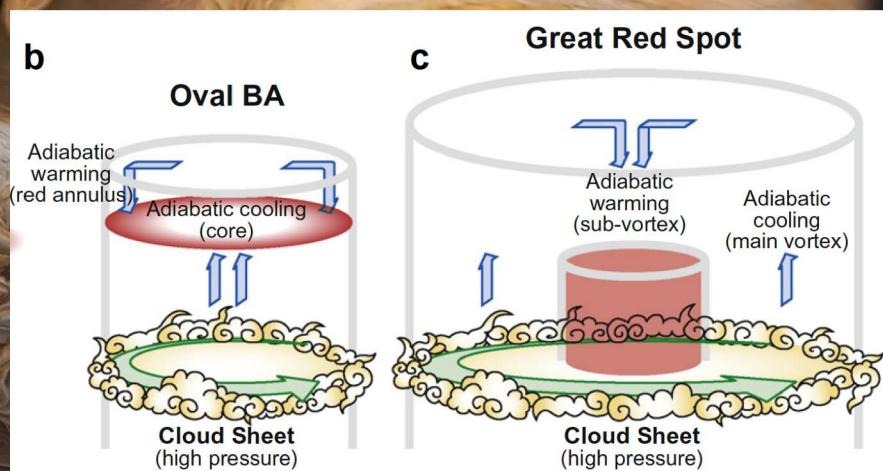
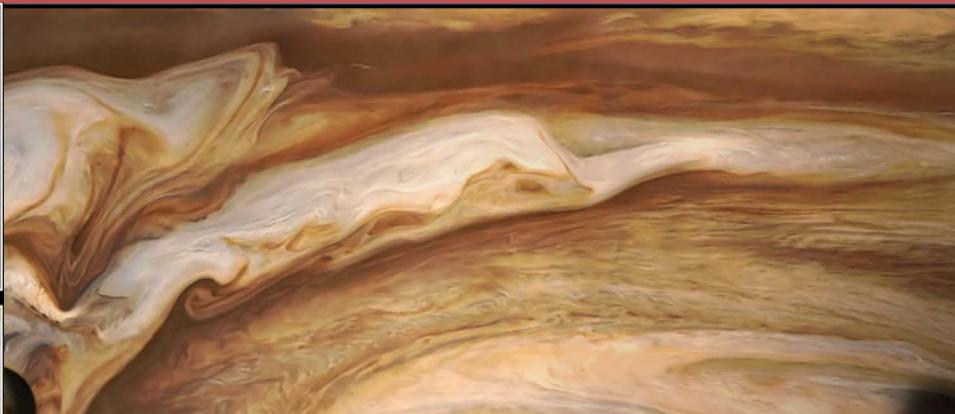
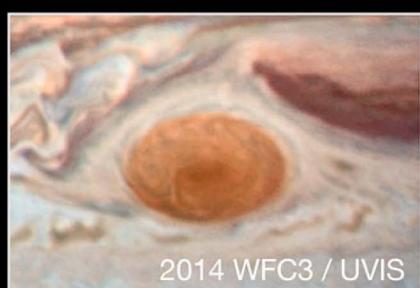
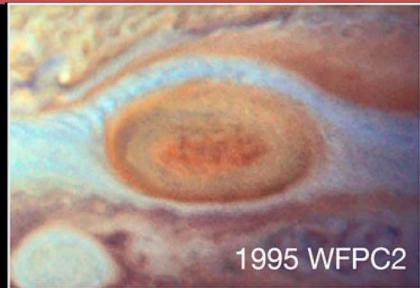
- Cloud altitudes are **not where you'd expect** from equilibrium condensation theory.
- Volatiles are **not well mixed** below the clouds.
- Spectroscopic signatures of 'fresh' NH₃/H₂O ice only observed in **very limited places**.
- Disequilibrium tracers do not always follow expected patterns.



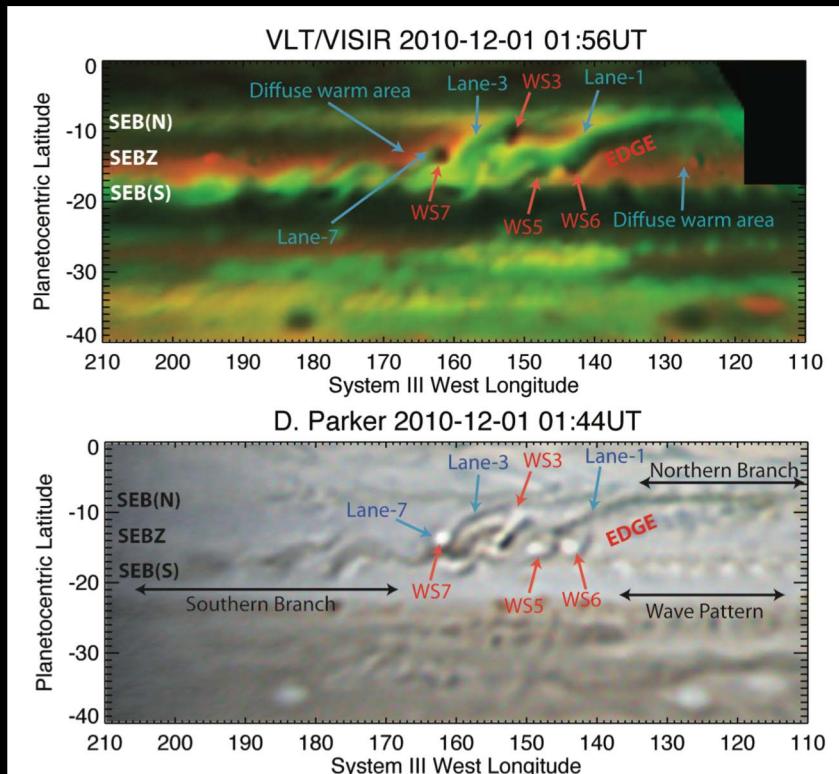
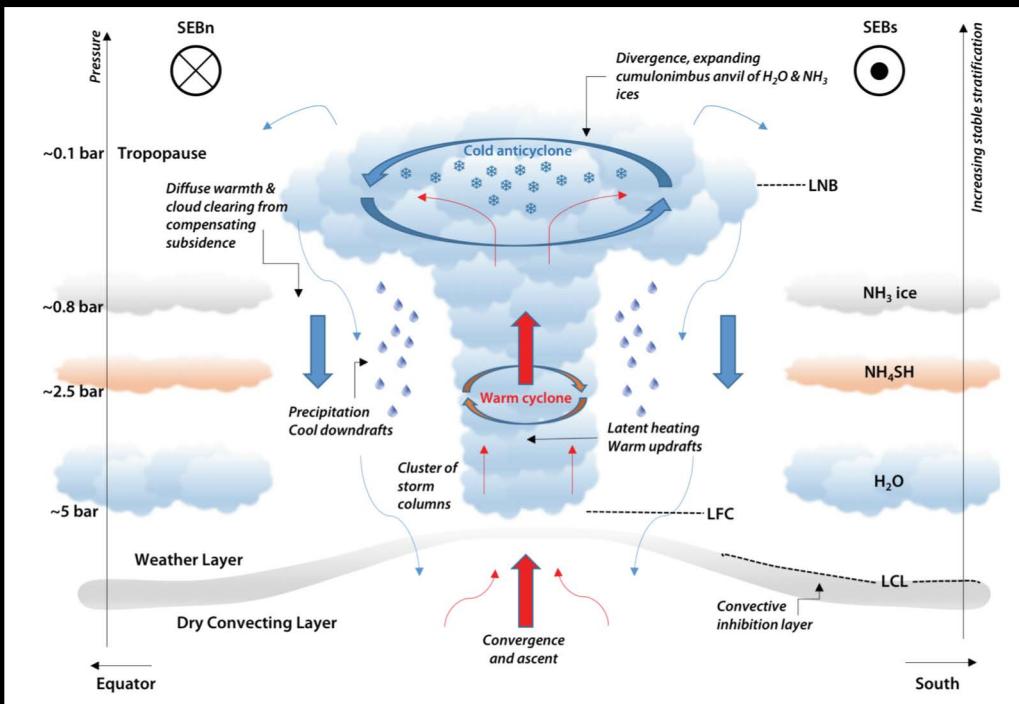
Guillot et al., 2019

(https://www.cosmos.esa.int/documents/1866264/3219248/GuillotT_esa_whitepaper.pdf)

[3] Local Meteorology: Vortices

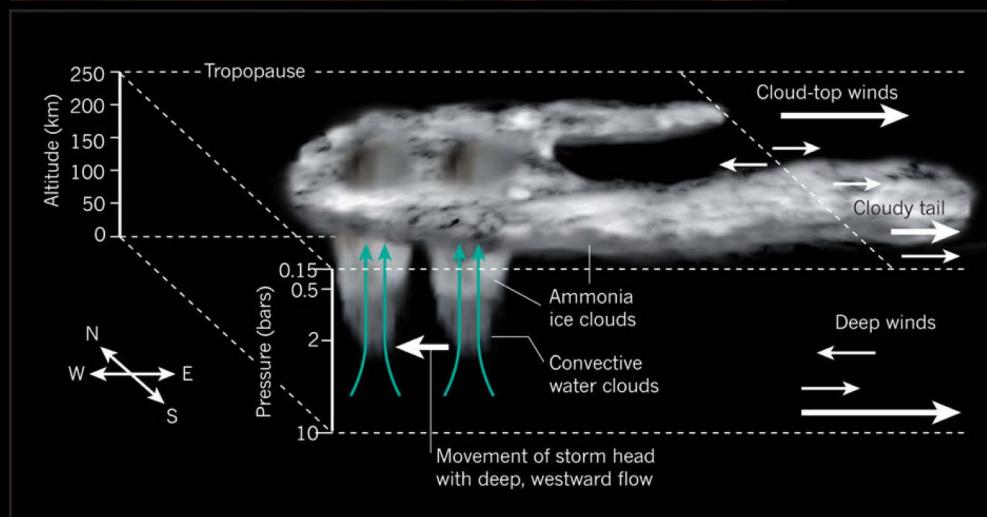


[3] Local Meteorology: Plumes

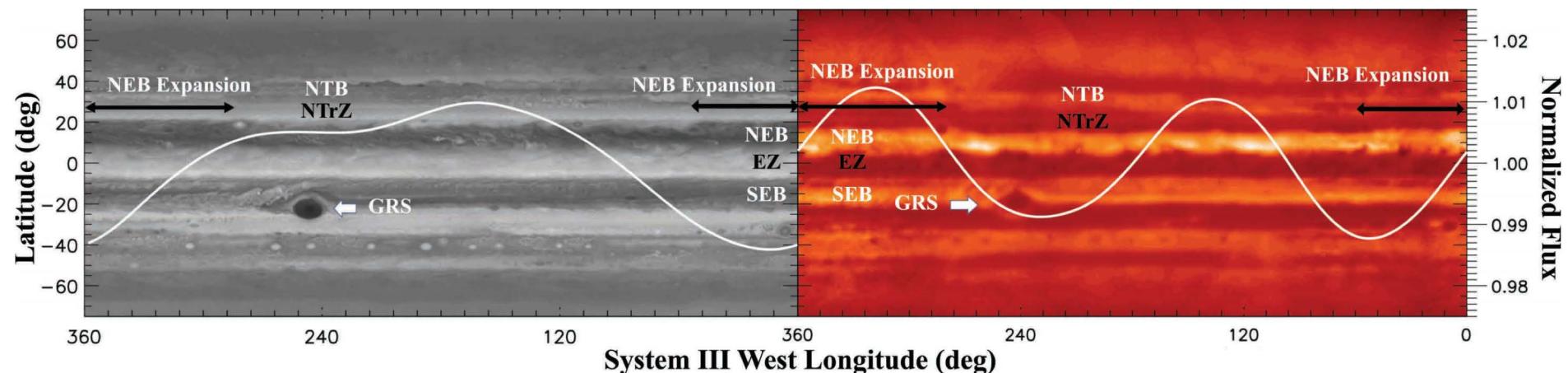


- arXiv:1701.00965

[3] Unexpected Consequences of Plumes



[3] Consequence: Rotational Variability

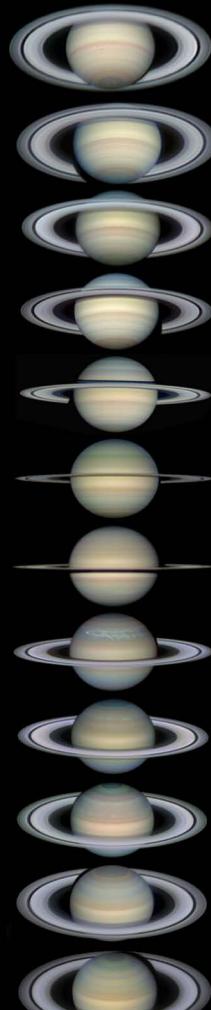
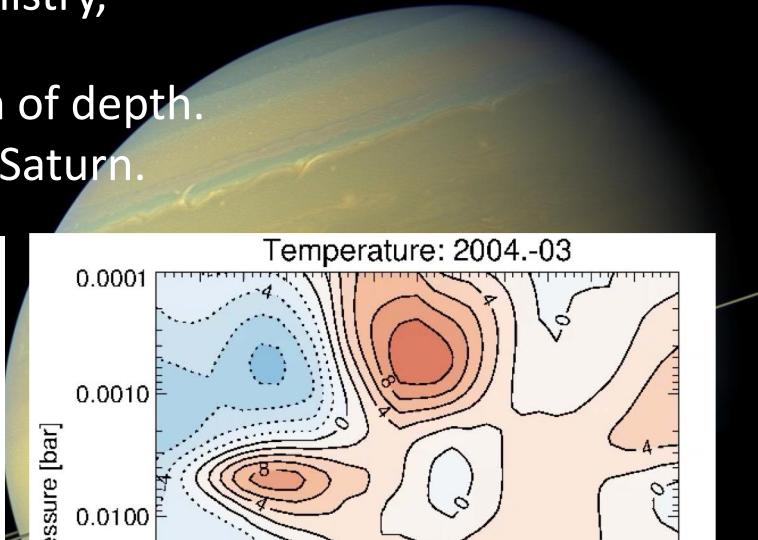
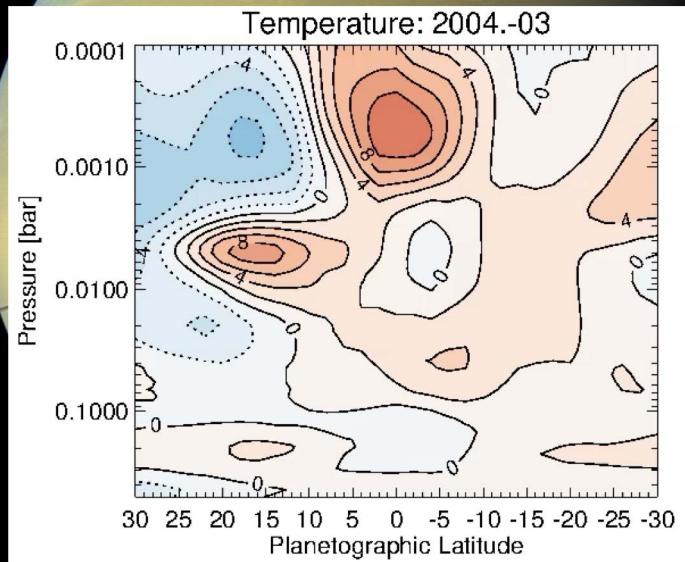
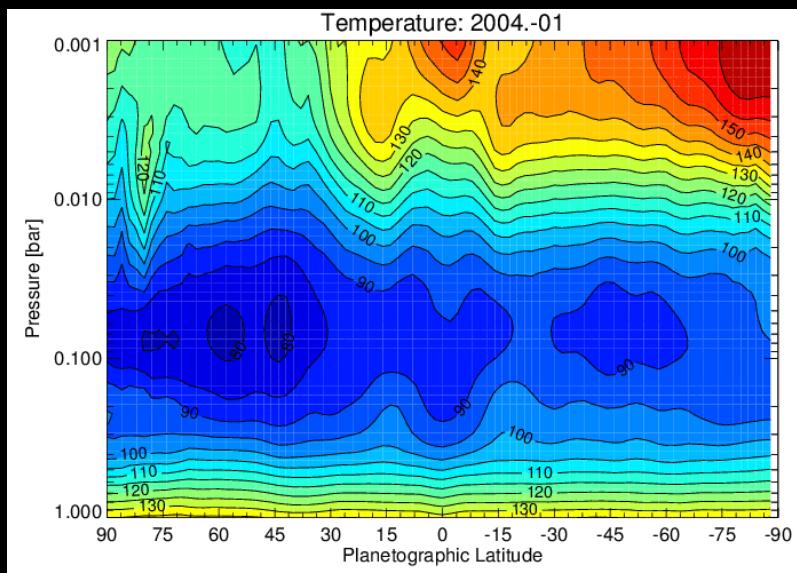


- Ge et al. *Rotational Light Curves of Jupiter from UV to Mid-Infrared and Implications for Brown Dwarfs and Exoplanets* ([arXiv:1901.01323](https://arxiv.org/abs/1901.01323))



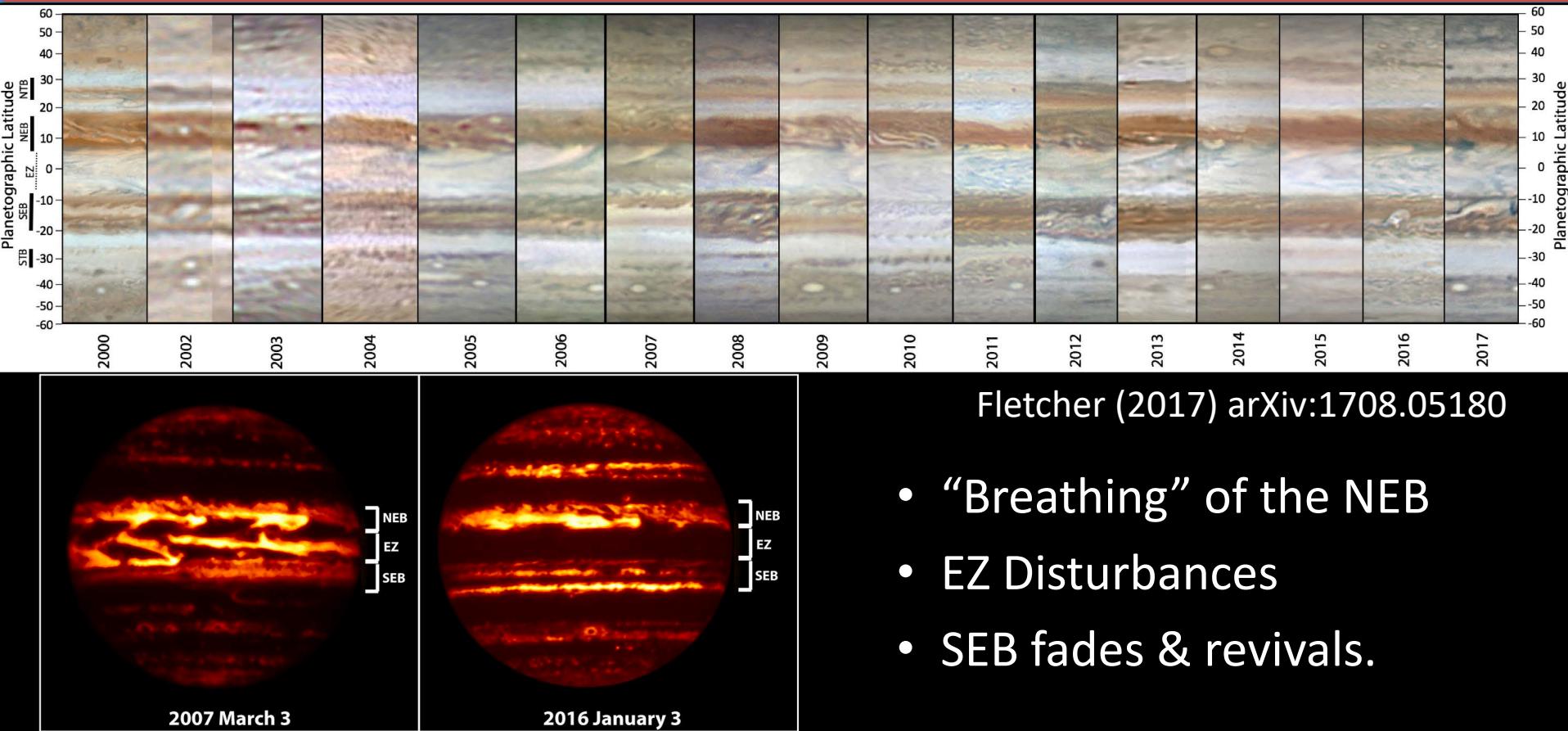
[4] Temporal Variability: Seasons

- Seasons change temperature, chemistry, aerosols.
- Seasonal lag increases as a function of depth.
- Equatorial oscillations on Jupiter & Saturn.



arXiv:1803.07875

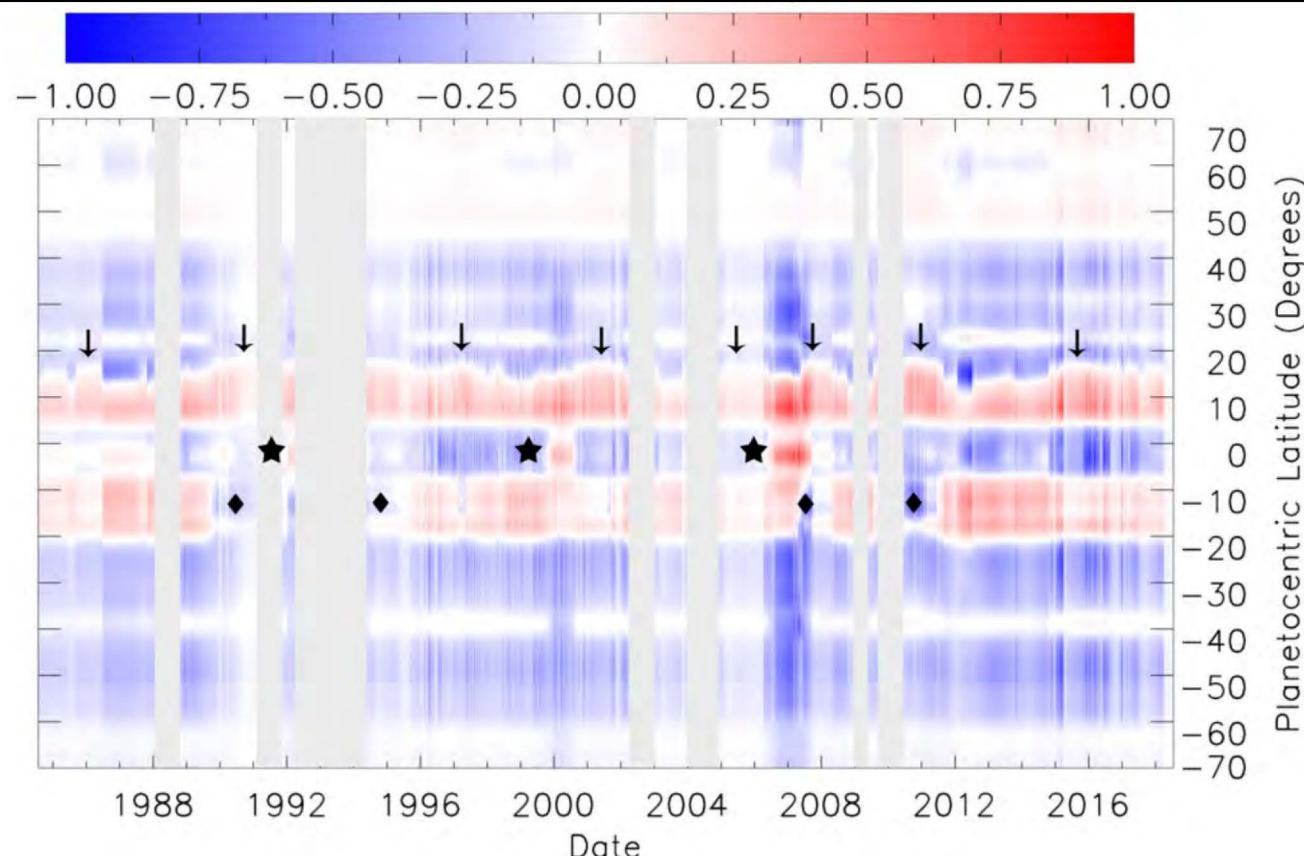
[4] Temporal Variability: Belt/Zone Changes



Fletcher (2017) arXiv:1708.05180

- “Breathing” of the NEB
- EZ Disturbances
- SEB fades & revivals.

[4] Temporal Variability: Belt/Zone Changes



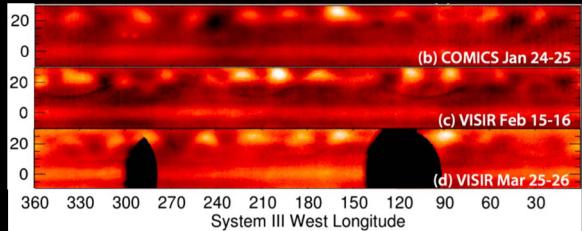
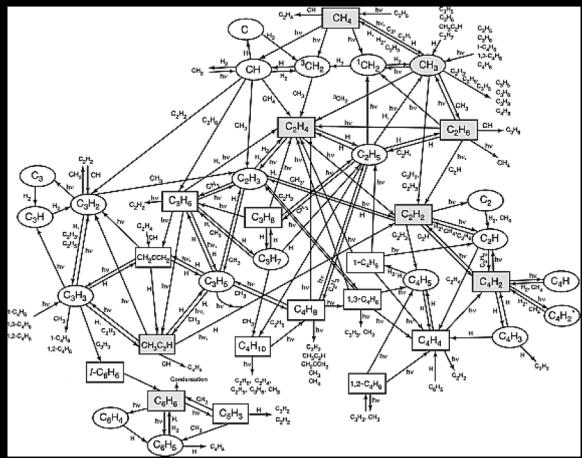
Consequence: Banded appearance can alter even though underlying jets are stable with time.

Variability on monthly, yearly, and decadal timescales.

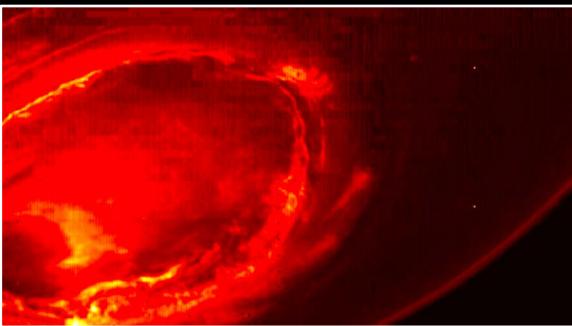
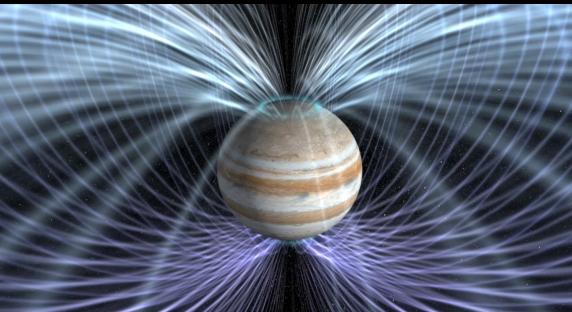
Antunano et al. (2019)
arXiv:1906.11088

Things we haven't talked about

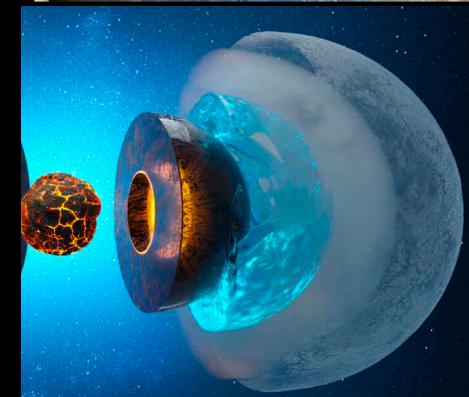
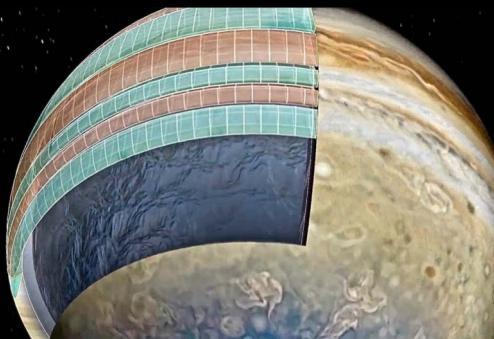
Stratospheric Dynamics & Chemistry



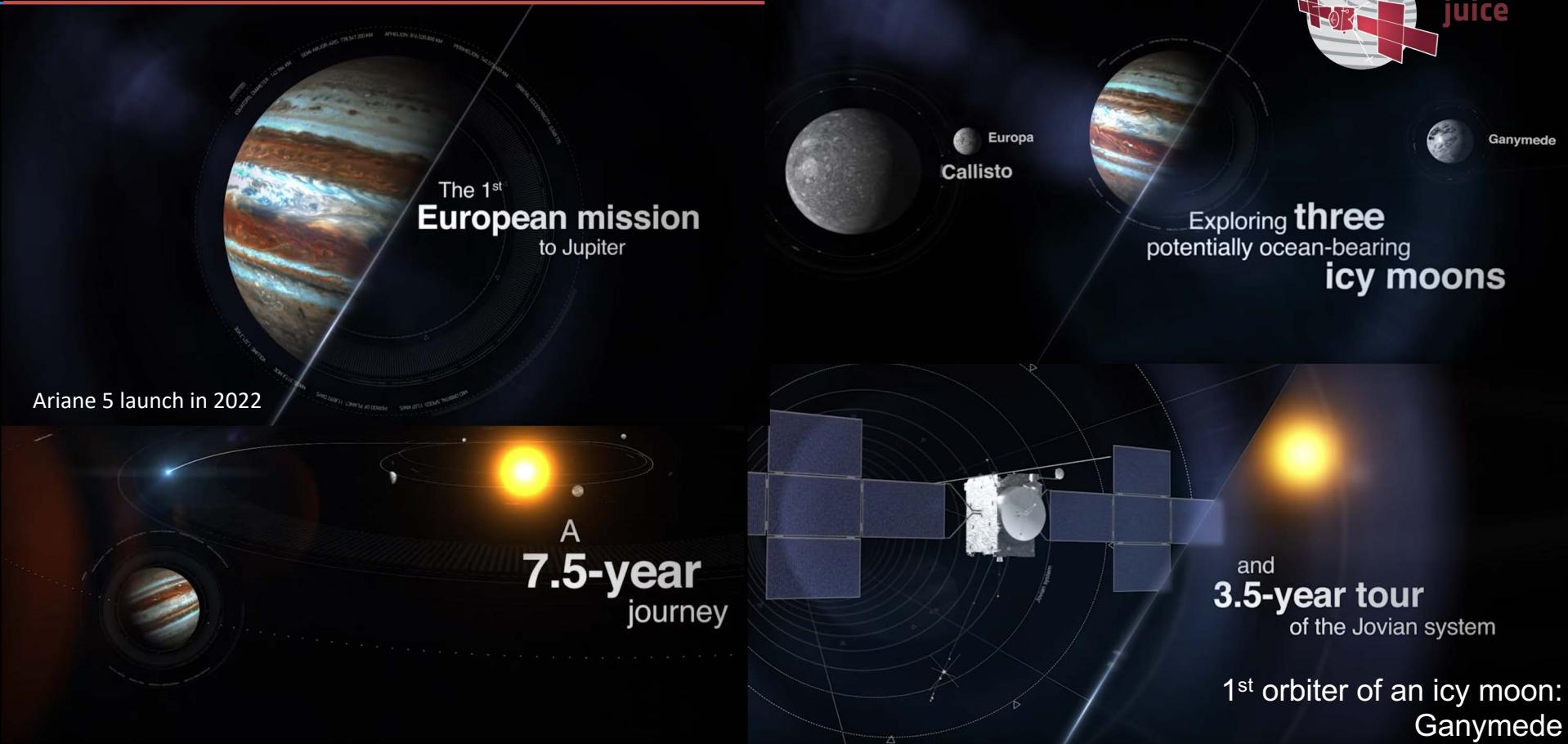
Upper Atmosphere



Interior Connection



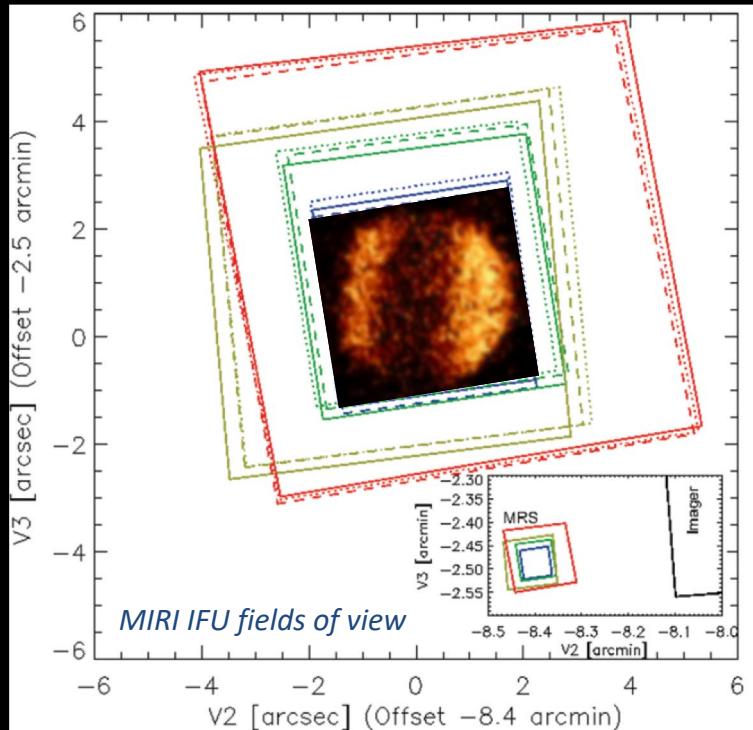
[5] The Future: Jupiter Icy Moons Explorer



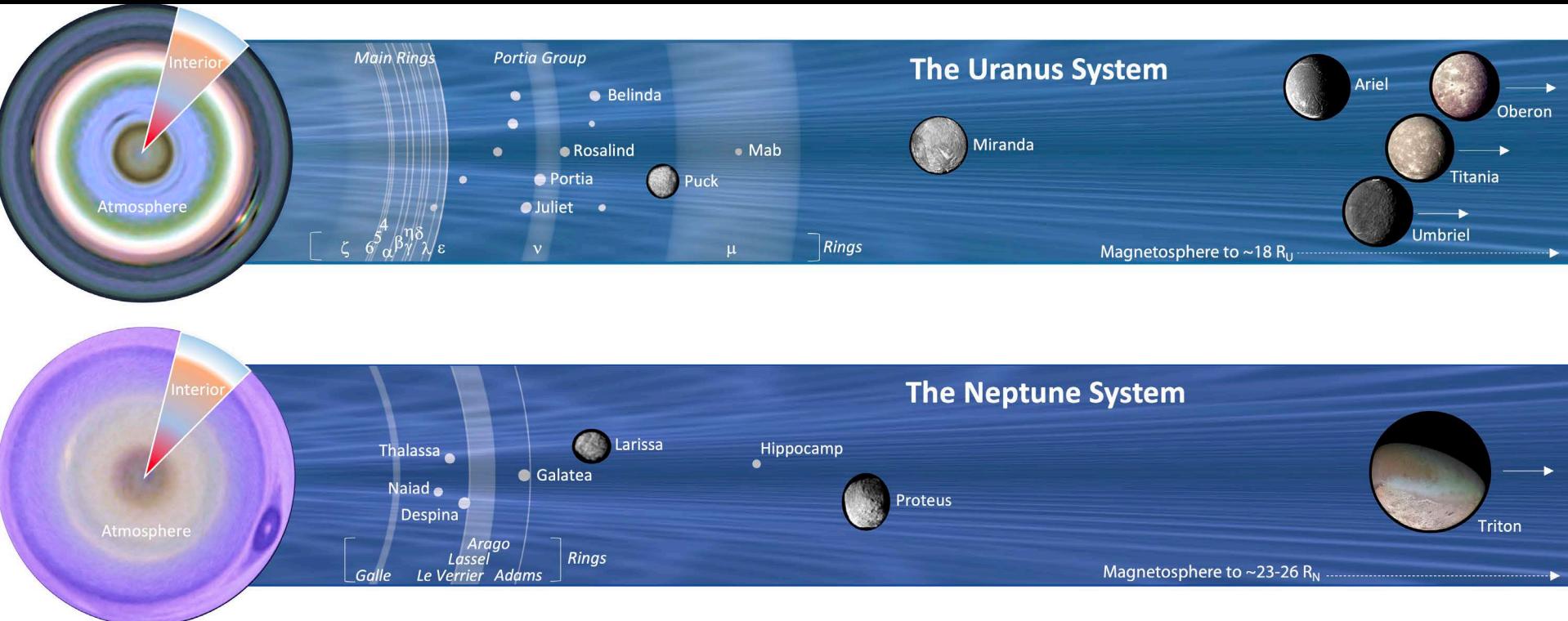
[5] The Future: James Webb Space Telescope



- Heidi Hammel – Interdisciplinary Scientist for JWST (2002) with **110 hrs GTO time**.
- **1246: Jupiter's Great Red Spot**
- **1247: Saturn's Summer Hemisphere**
- **1248: Uranus Atmosphere & Aurora**
- **1249: Neptune Atmosphere**



[5] The Future: Onwards to the Ice Giants



Fletcher et al., (2019), arXiv:1907.02963

Summary: Perspectives on “Unresolved Objects”

- **Circulation** is depth dependent:
 - Eddy-driven, convection, waves, radiative...
 - Don't trust global conclusions from one wavelength.
- **Clouds** are never where they're supposed to be:
 - ...and we don't know what they're made of....
 - ...and volatiles aren't well mixed below cloud decks.
- **Meteorology** can alter light curves in unexpected ways.
- **Atmospheres are variable** over multi-year cycles we don't yet understand.
- **Future missions** need:
 - Multi-spectral remote sensing from troposphere to thermosphere.
 - “Monitoring” is not a dirty word.

