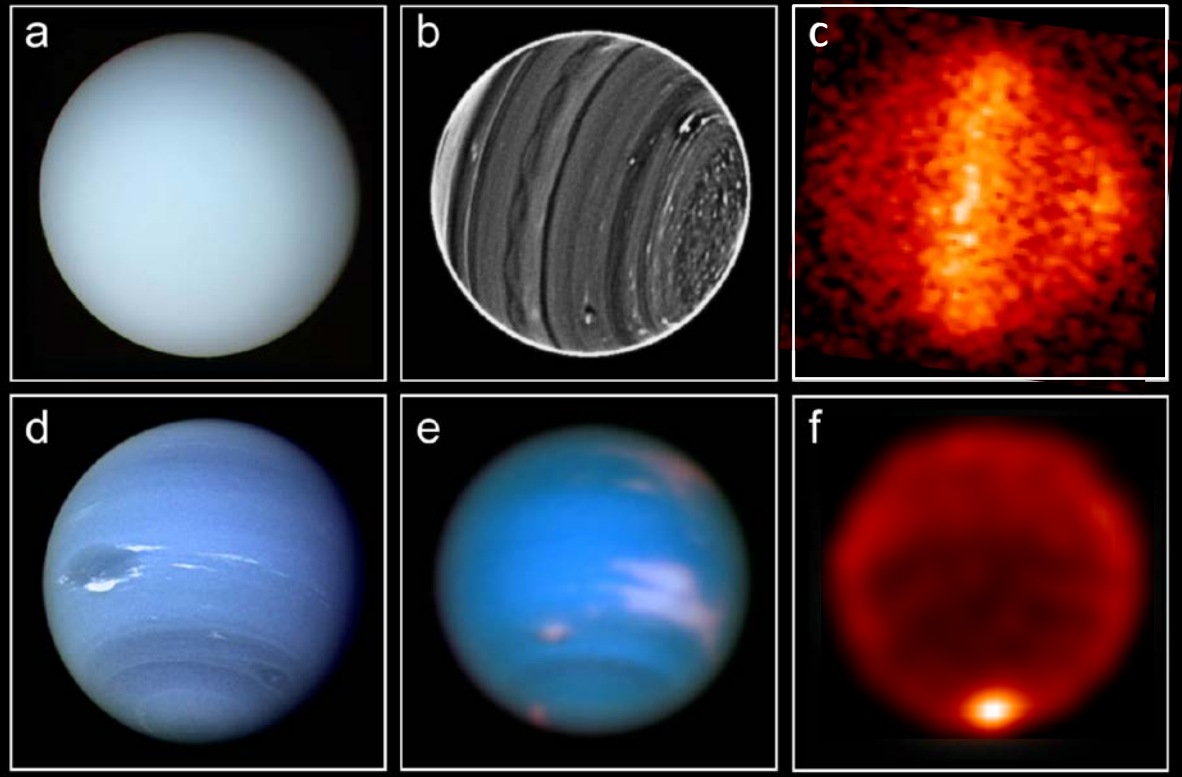
Ice Giant Circulation Patterns

Inferred From Infrared Remote Sensing:
Where to Target a Probe?



Leigh Fletcher (@LeighFletcher)

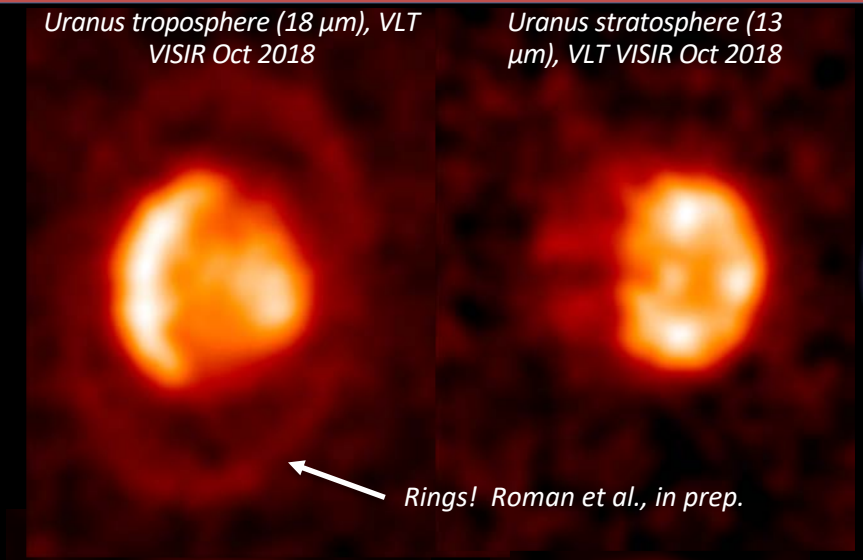
With thanks to: M. Roman, N. Rowe-Gurney, A. Simon, G. Orton, I. de Pater, H. Hammel, J. Sinclair, M. Hofstadter

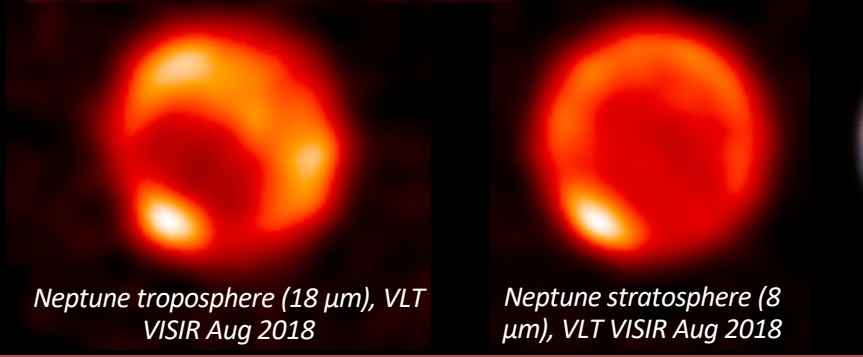
UNIVERSITY OF LEICESTER

European Commission erc European Research Council THE ROYAL SOCIETY

Motivation – Ice Giant Circulation in 2018

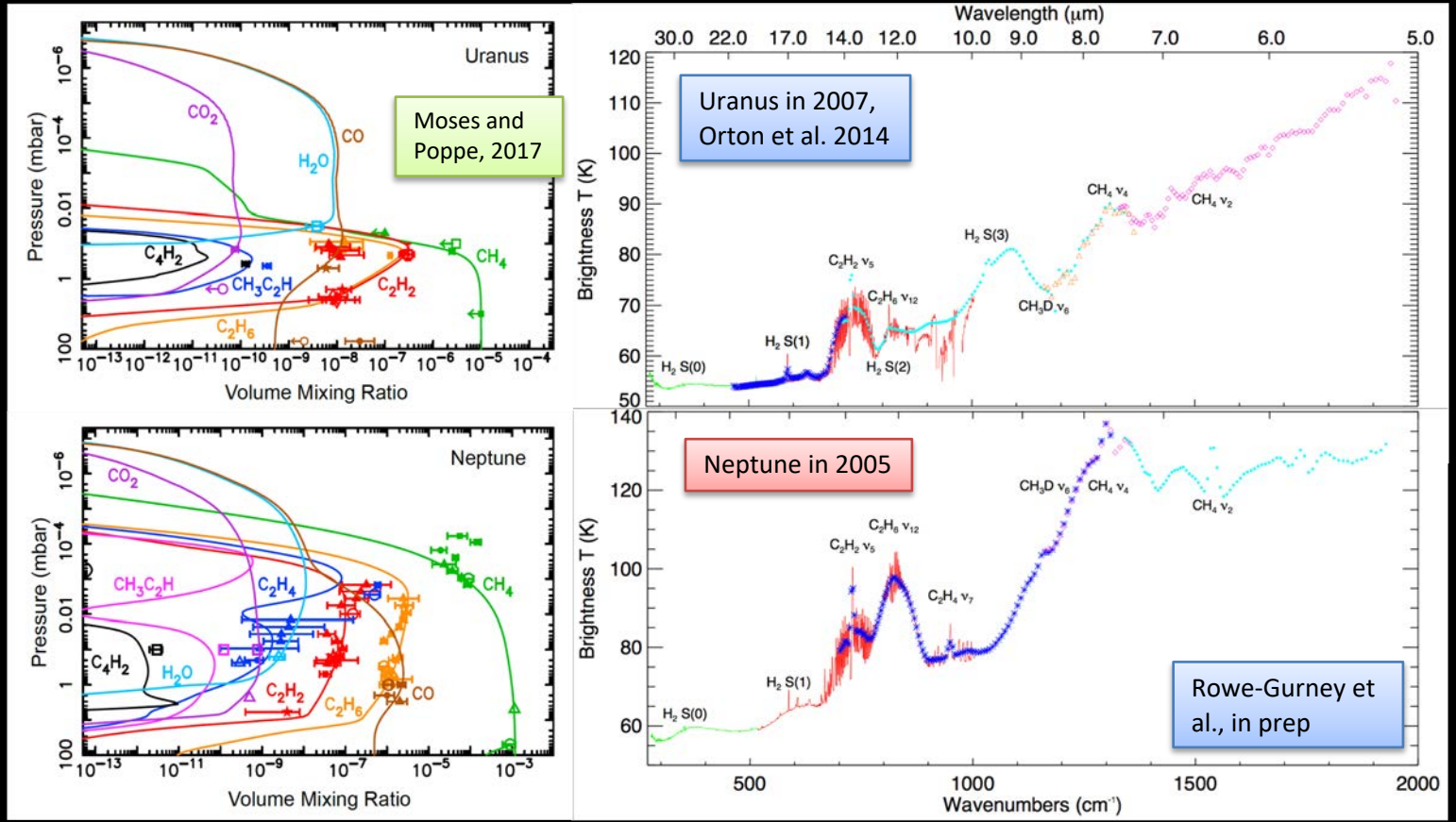
- Galileo probe interpretation **depended on local meteorology**.
- Meteorology influenced by **meridional overturning**.
- Spatially-resolved ice giant spectroscopy in its infancy.
  - …..and suggests puzzling circulation regimes.
- Need for Earth-based and JWST measurements in the coming decade.
- ***Probe equator, mid-lat, or poles?***



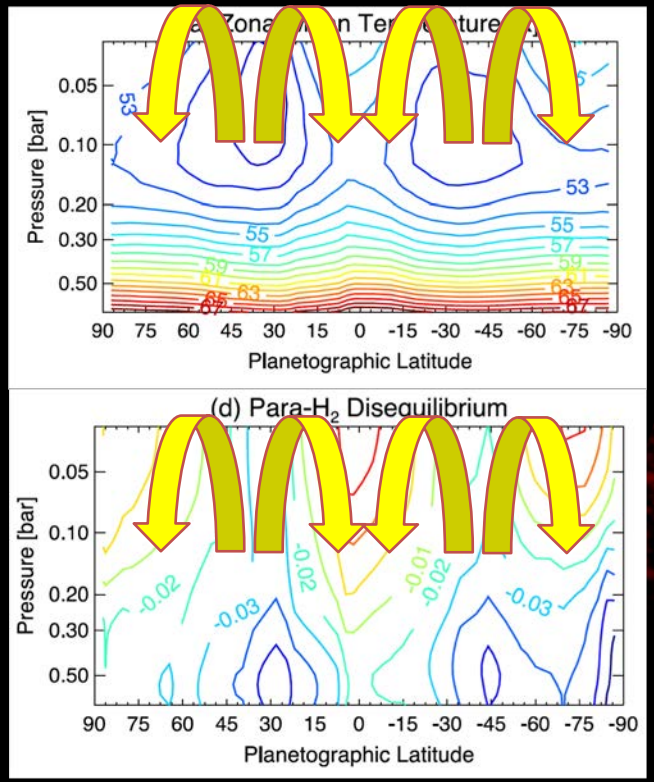


Best Spectroscopy: Spitzer/IRS 2004-2007

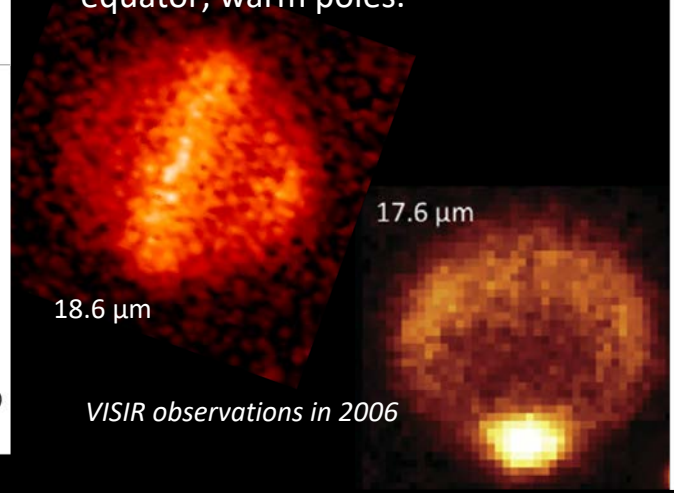
- IR Remote Sensing:
  - <5 μm aerosols reflectivity & methane.
  - >5 μm temperature & composition.
- Spitzer: Superb spectral coverage, but **disc-averaged** (0.85-m primary mirror).



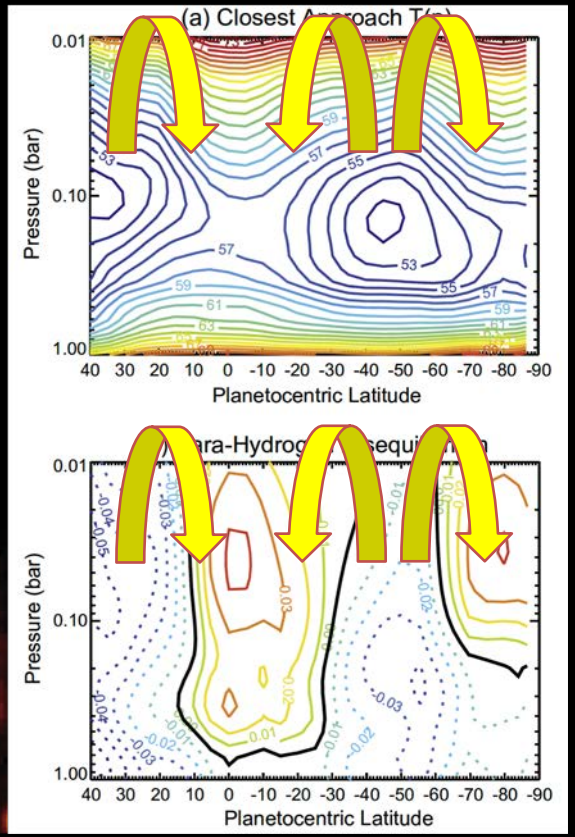
Spatial Resolution: The Voyager Picture



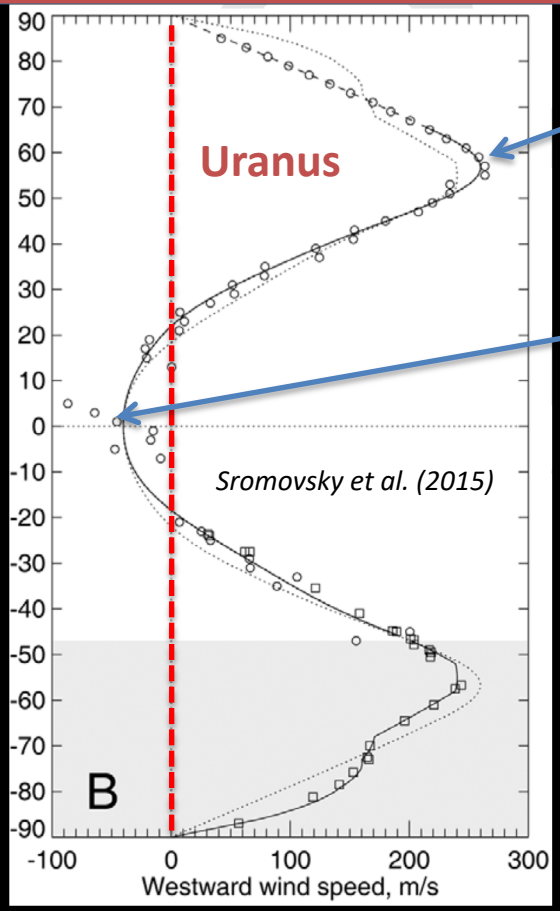
- 25-50 μm spectra (H_2-He continuum)
- Uranus 1986 (left, Orton et al., 2015)
- Neptune 1989 (right, Fletcher et al., 2014)
- 80-800 mbar only:
- Mid-latitude upwelling; warm equator; warm poles.



VISIR observations in 2006



Spatial Resolution: Ice Giant Winds



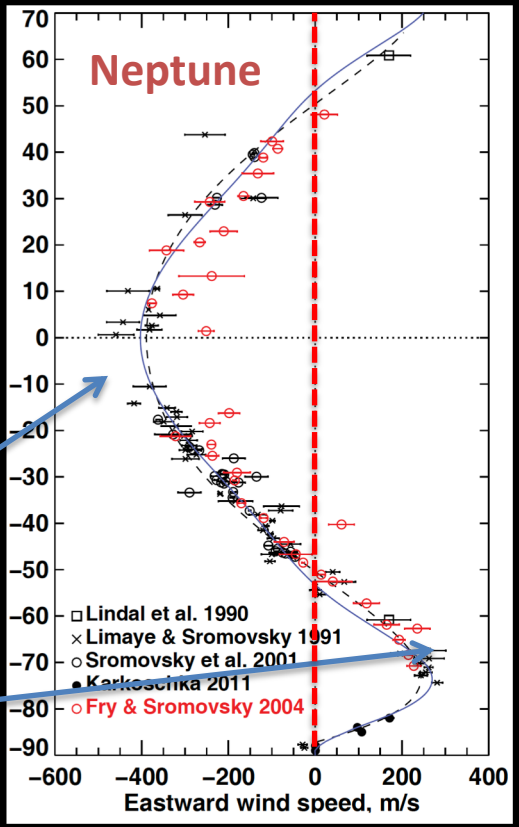
250 m/s prograde maxima

-50 m/s retrograde maxima

-400 m/s retrograde maxima

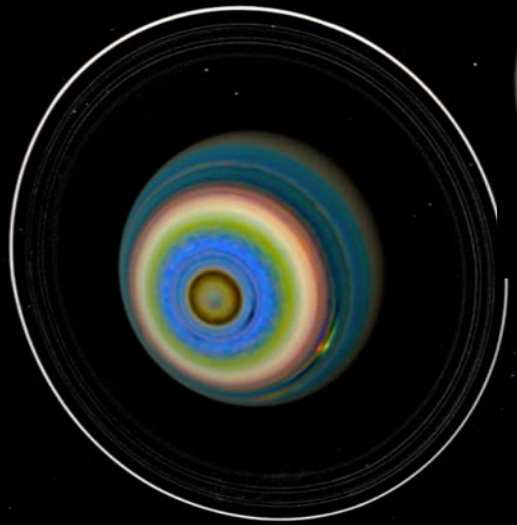
200 m/s prograde maxima

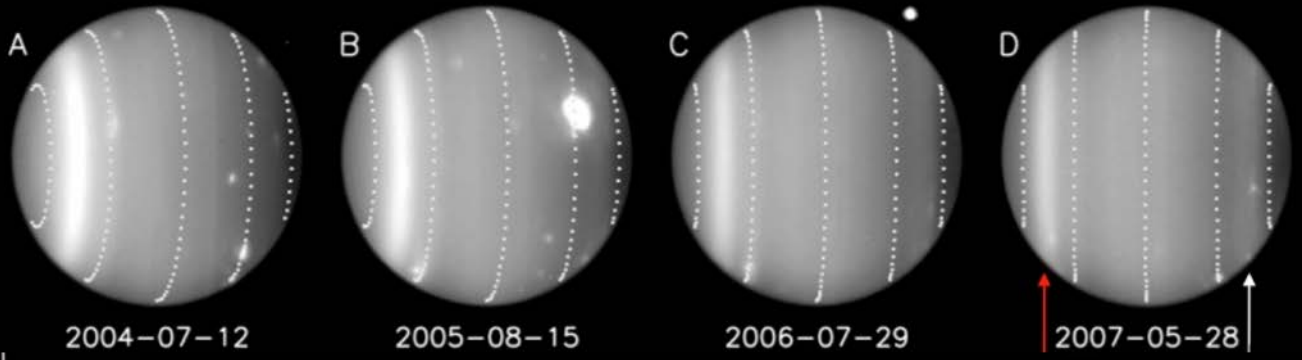
Sanchez-Lavega et al. (2018)



Seasonal Bands/Storms on Uranus

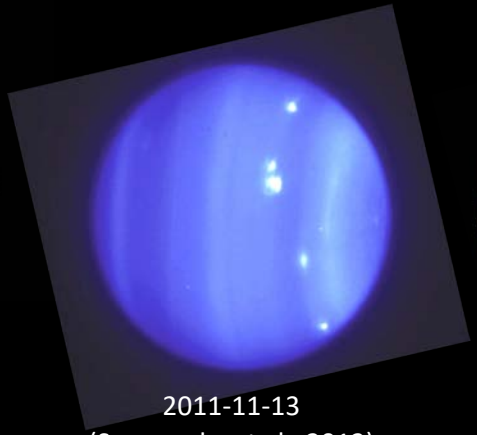
Karkoschka (2015)



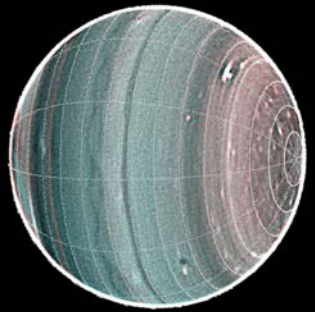


Uranus from Keck, de Pater, Sromovsky et al.

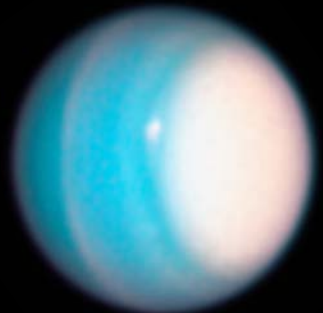
- Voyager, HST, Keck:
  - Storm outbreaks near 30°
  - 45-55° bands around autumn and springtime poles.
- Upwelling of CH_4 and H_2S-laden air?



2011-11-13
(Sromovsky et al., 2012)

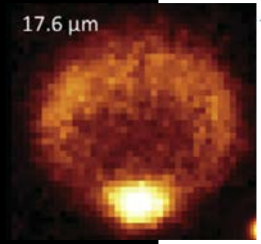


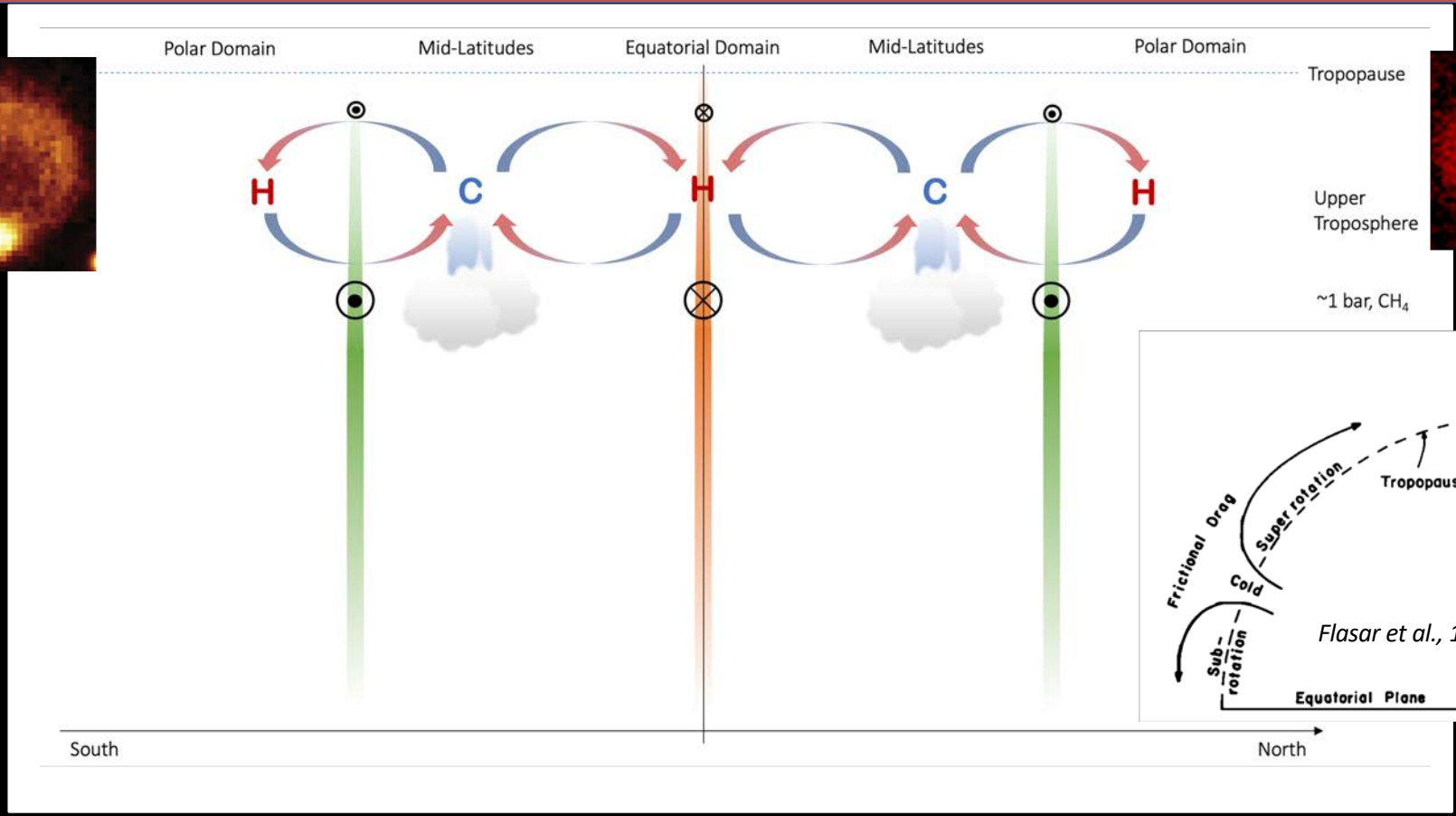
2012-07-25
(Sromovsky et al., 2015)

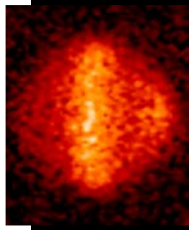


2018-11-05
A. Simon/OPAL

General Circulation of an Ice Giant - Schematic

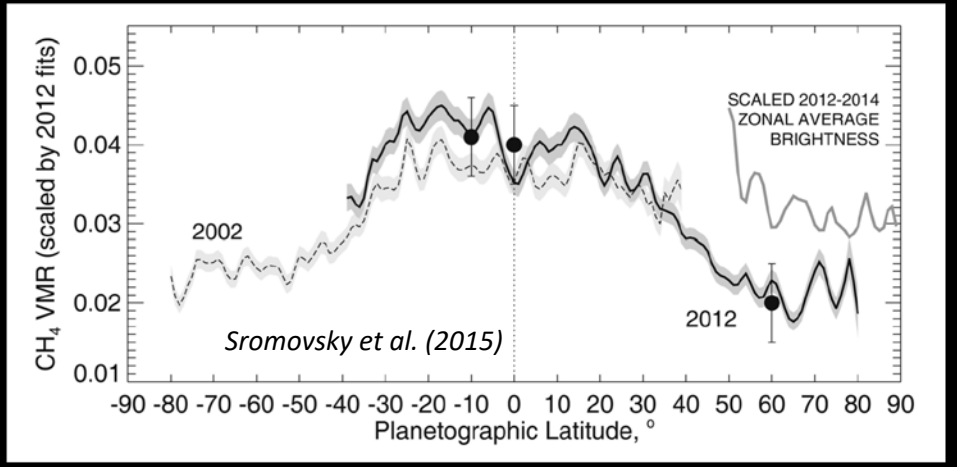




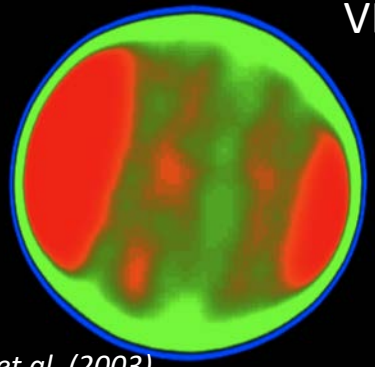


Equator-to-Pole Contrasts: Troposphere

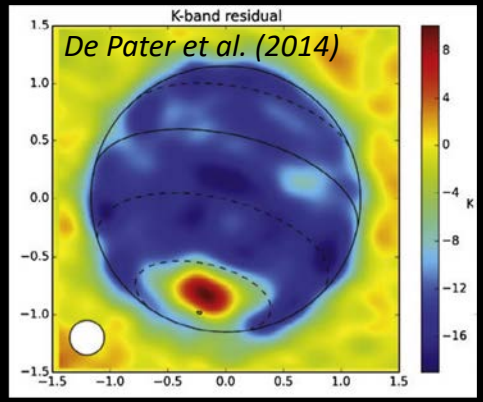
- Schematic doesn't explain equator-to-pole contrasts in gaseous composition:
  - Methane (from near-IR reflectivity – Karkoschka, Irwin, Sromovsky, et al.) in 1-4 bar range
  - NH_3/H_2S (from microwave emission - Hofstadter, de Pater, et al.)
- Contrasts are likely to be at p>1 bar, potentially very deep.



VLA

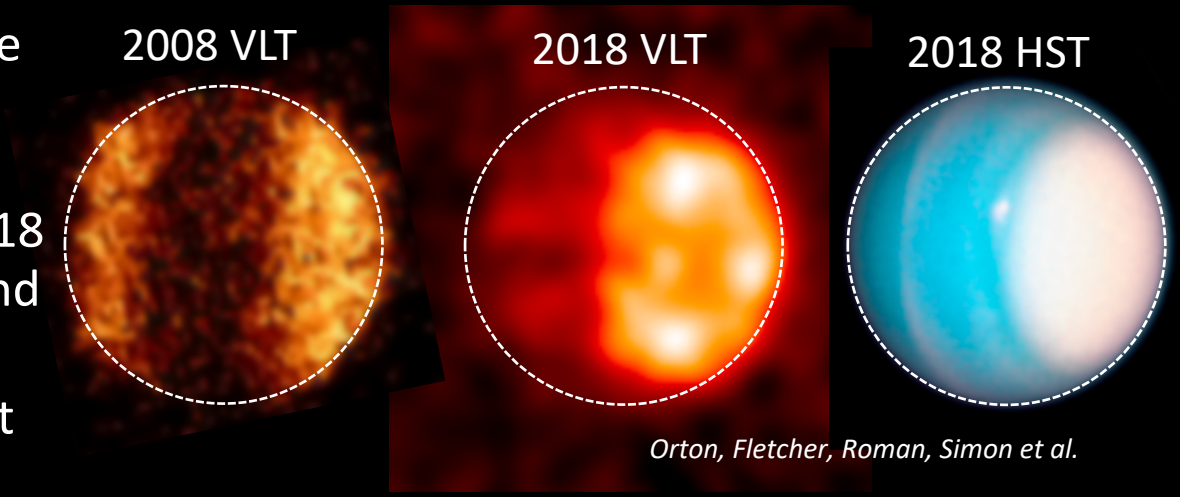


Hofstadter et al. (2003)

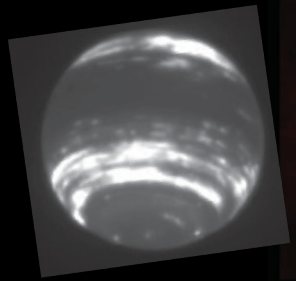


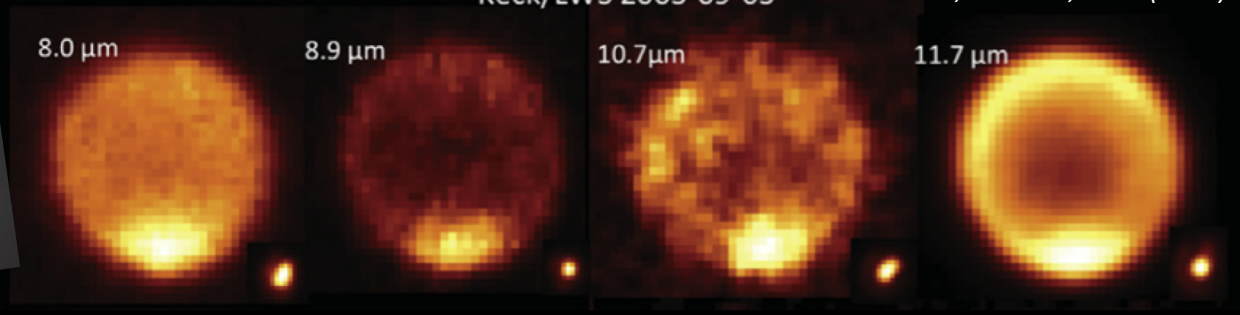
Equator-to-Pole Contrasts: Stratosphere

- Voyager could not resolve meridional stratospheric gradients.
- Uranus imaging 2008-2018 (13 μm C_2H_2 emission) and warm polar cap.
- Neptune imaging and hot stratospheric vortex (like Saturn).



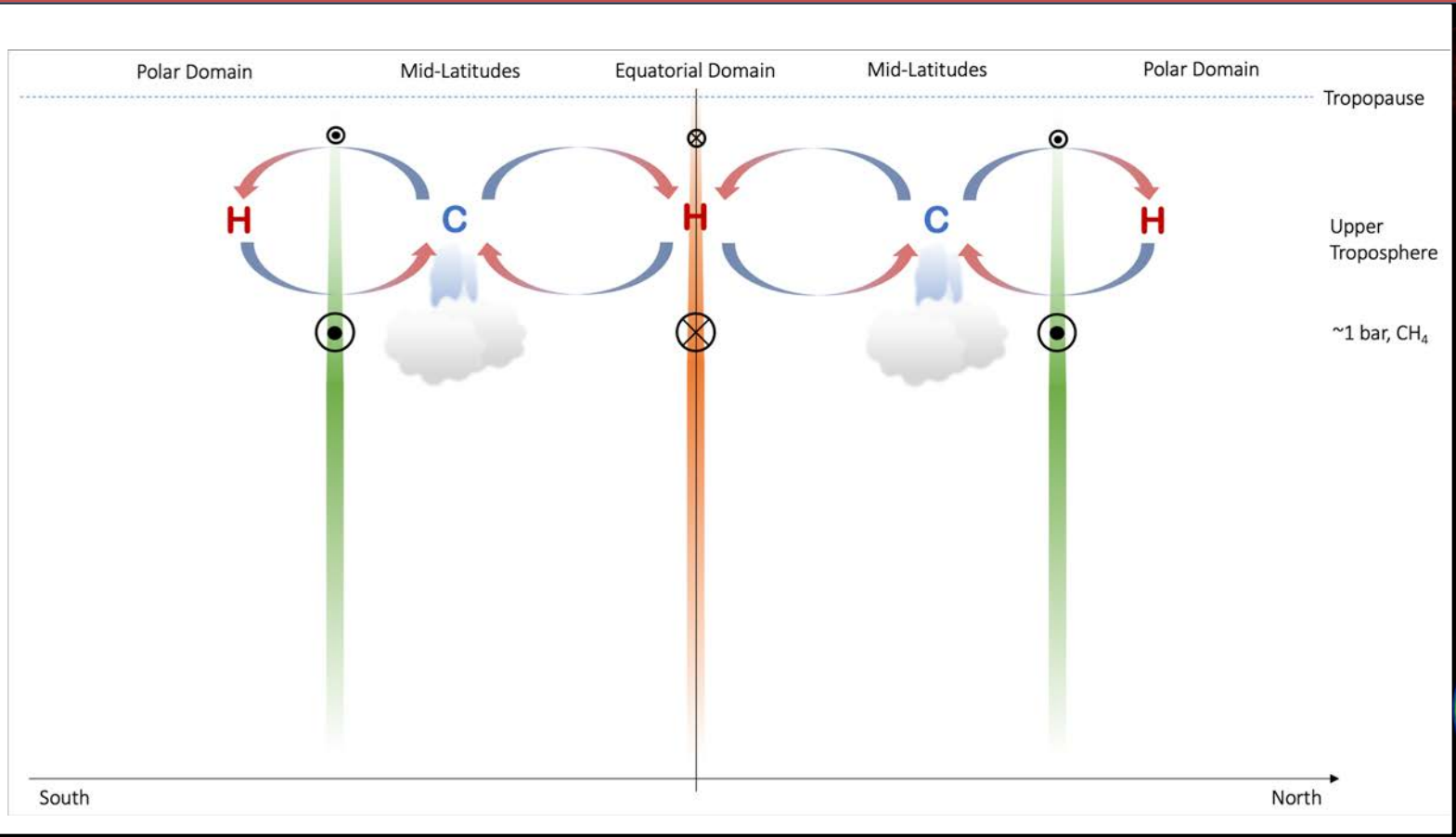
Orton, Fletcher, Roman, Simon et al.





Fletcher, de Pater, et al. (2014)

General Circulation of an Ice Giant - Schematic



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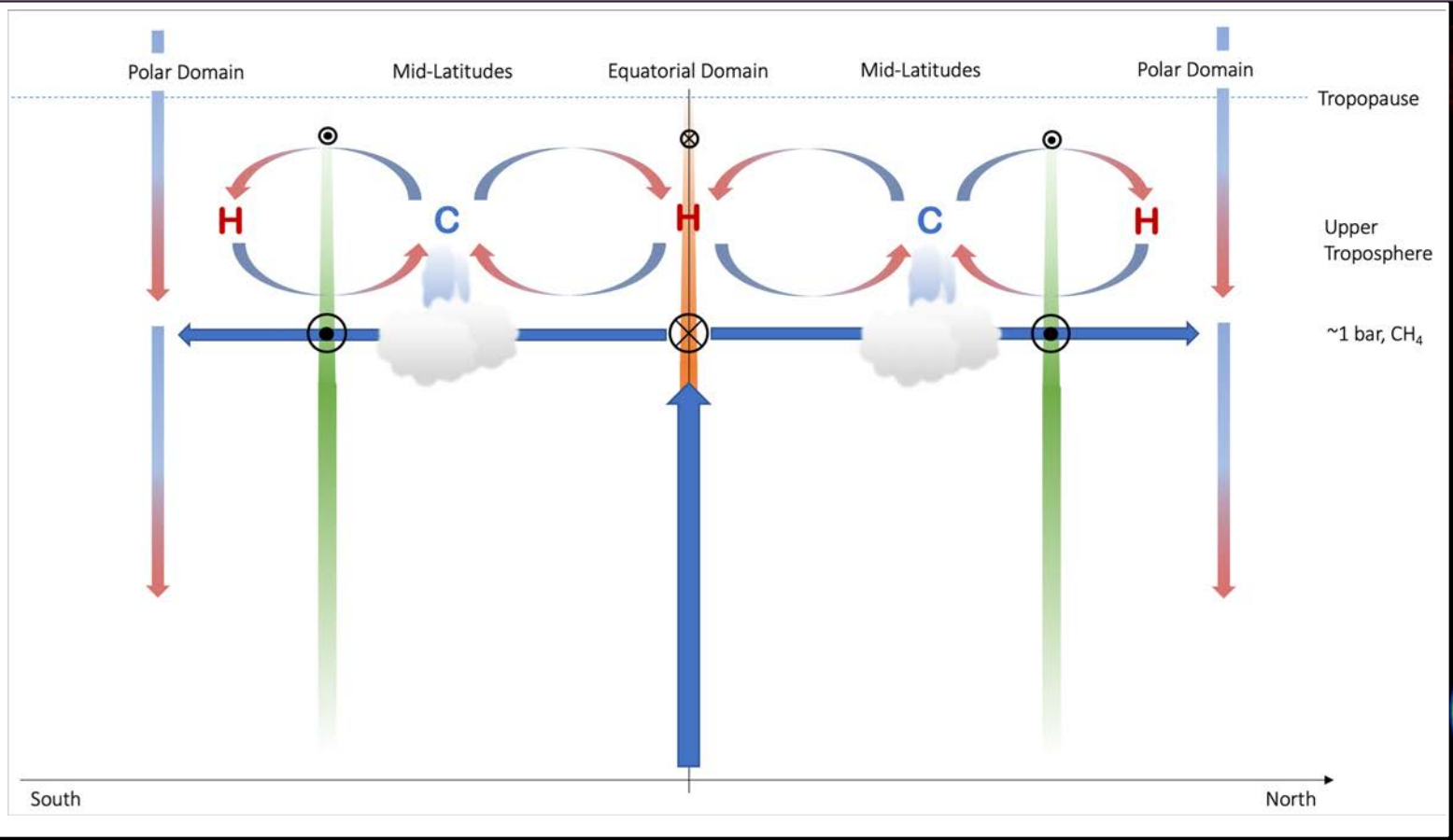
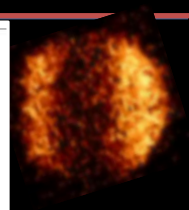
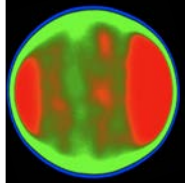
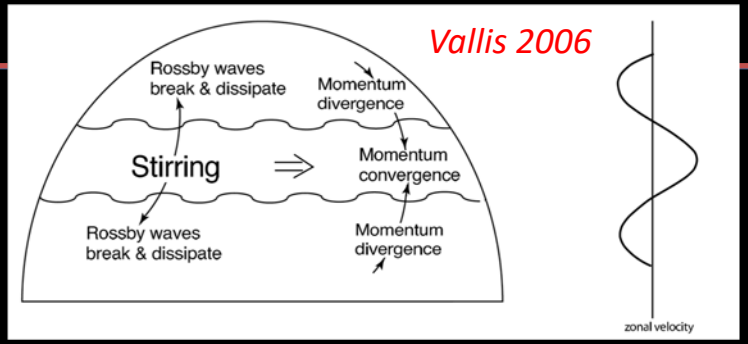




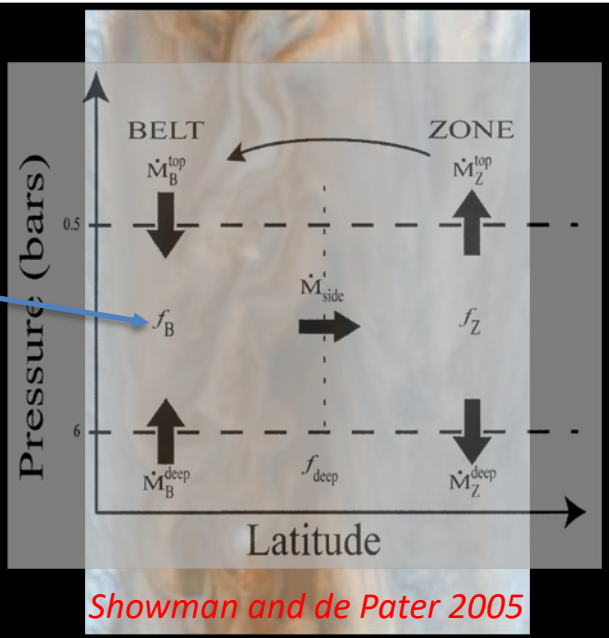


Gas Giant Prograde Jets

- …Are locations of eddy momentum flux convergence.
  - Balanced by Coriolis force on meridional flow, equatorward across prograde jet.
- **This is unknown for ice giants.**
- Would imply jets *strengthen* with height in mid-troposphere.
  - Warm mid-latitudes and cool equator.



Flow convergence between two cells at cloud-tops in belts



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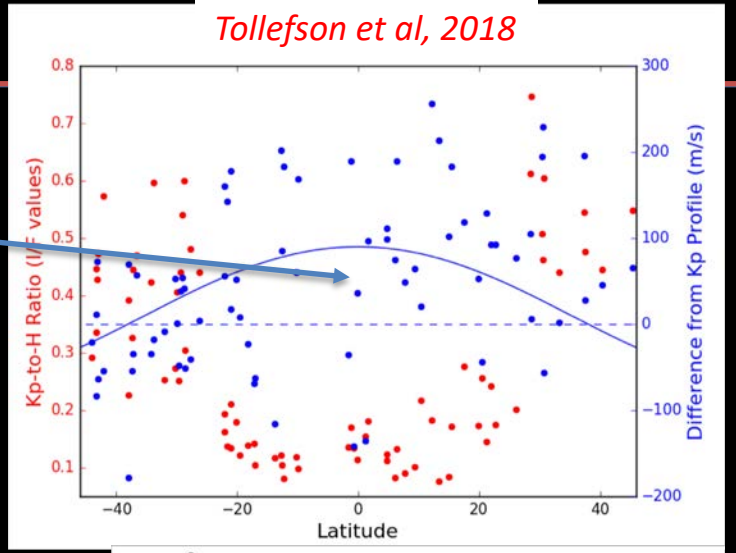
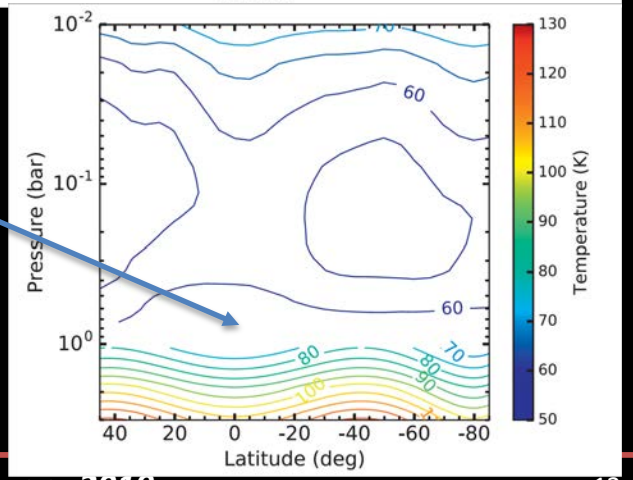
Tollefson et al, 2018

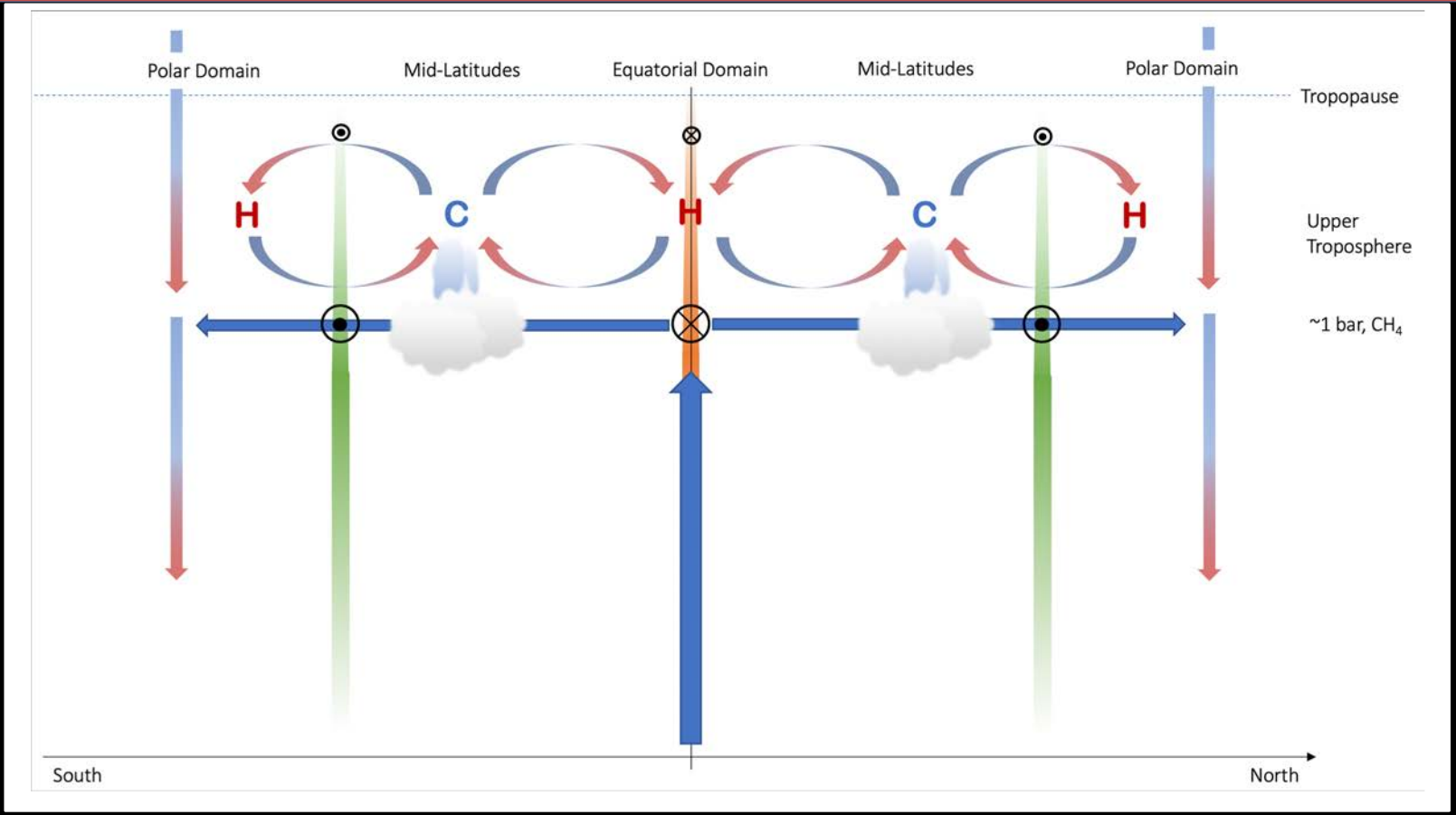
H-band (1 bar) shows winds ~100 m/s more eastward than K'-band (10 mbar) – retrograde winds strengthen with height



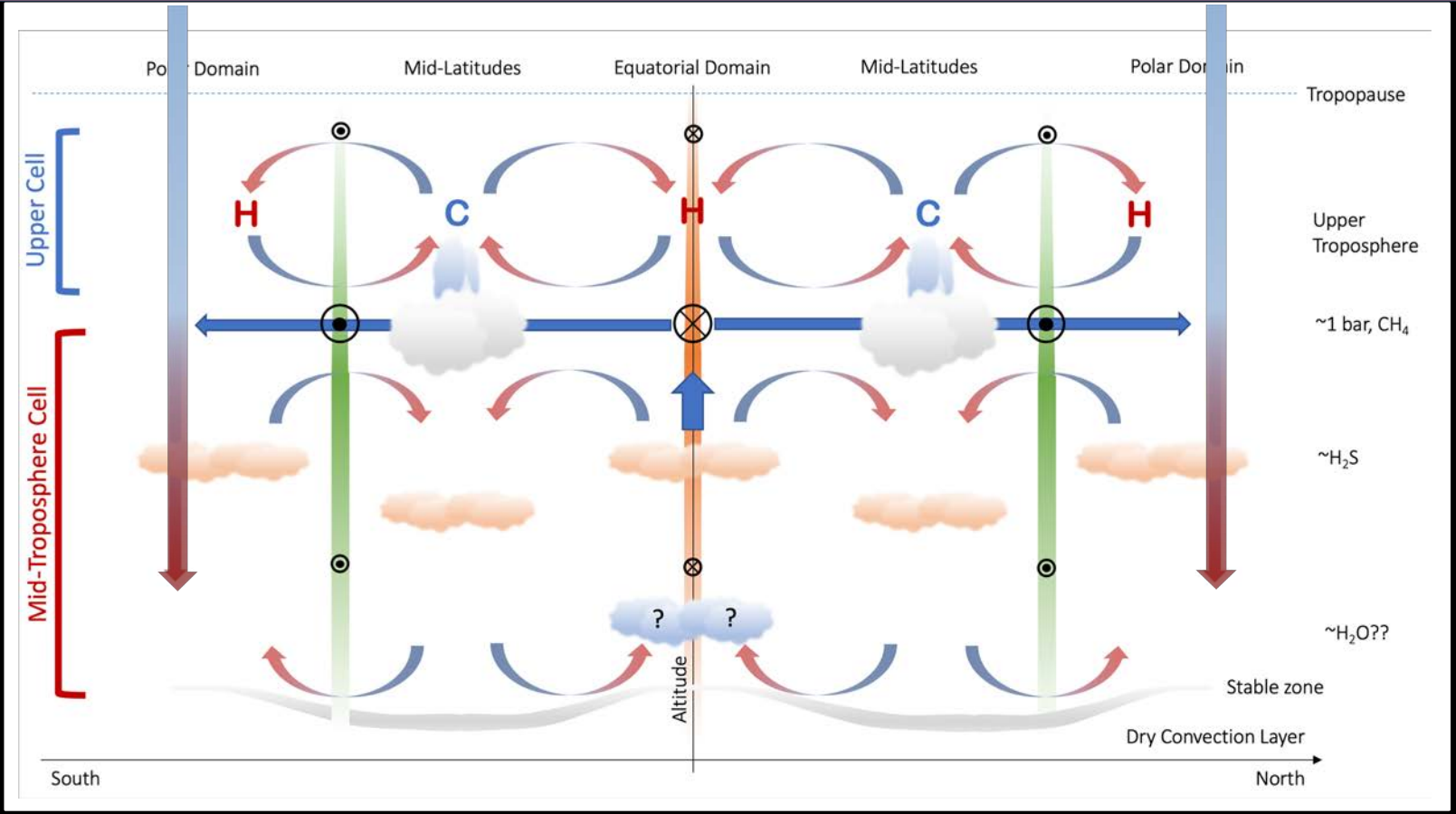
Windshear needs to be opposite to that found by Voyager – cool equator, warm mid-latitudes.



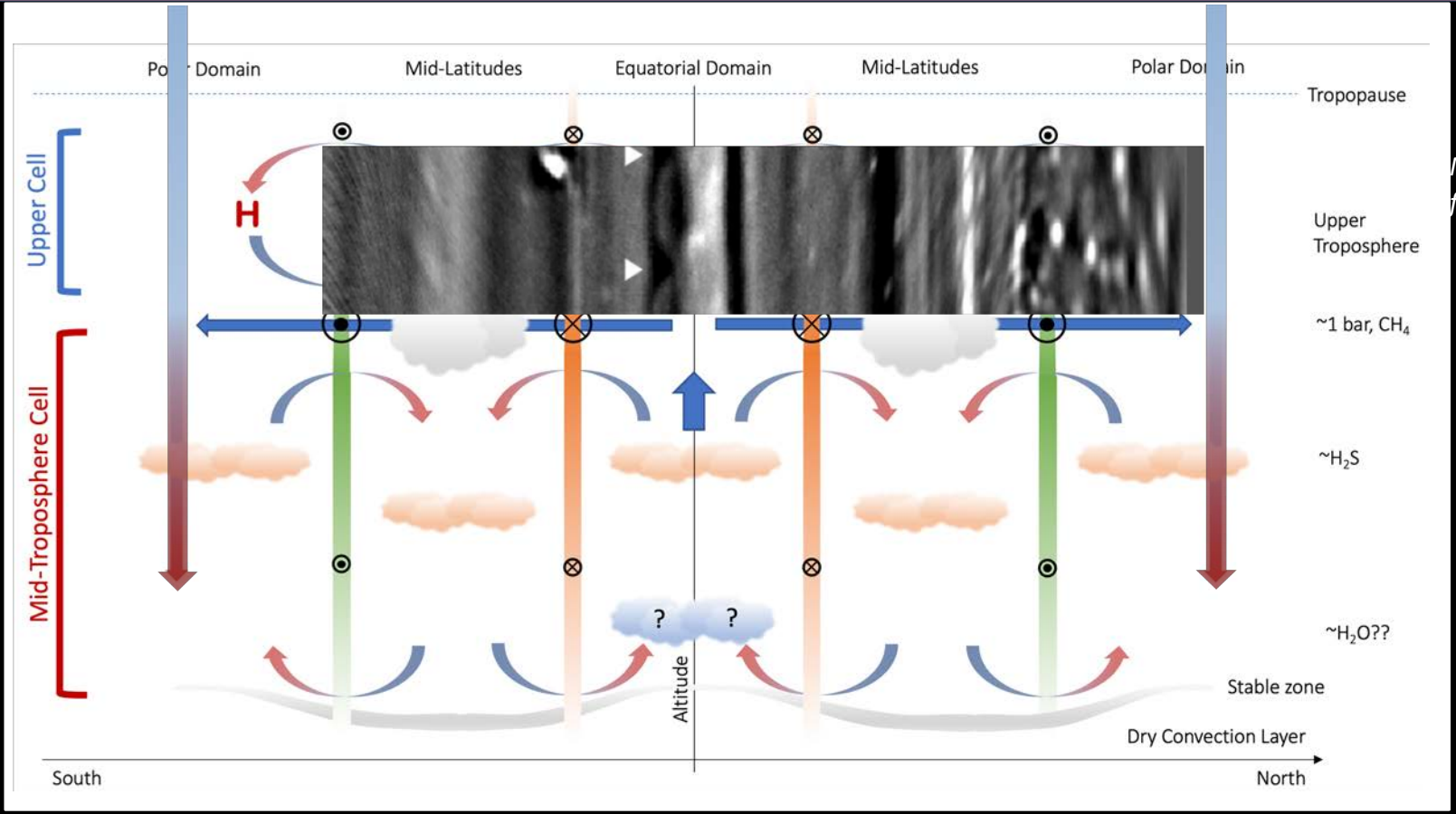
General Circulation of an Ice Giant - Schematic



General Circulation of an Ice Giant - Schematic



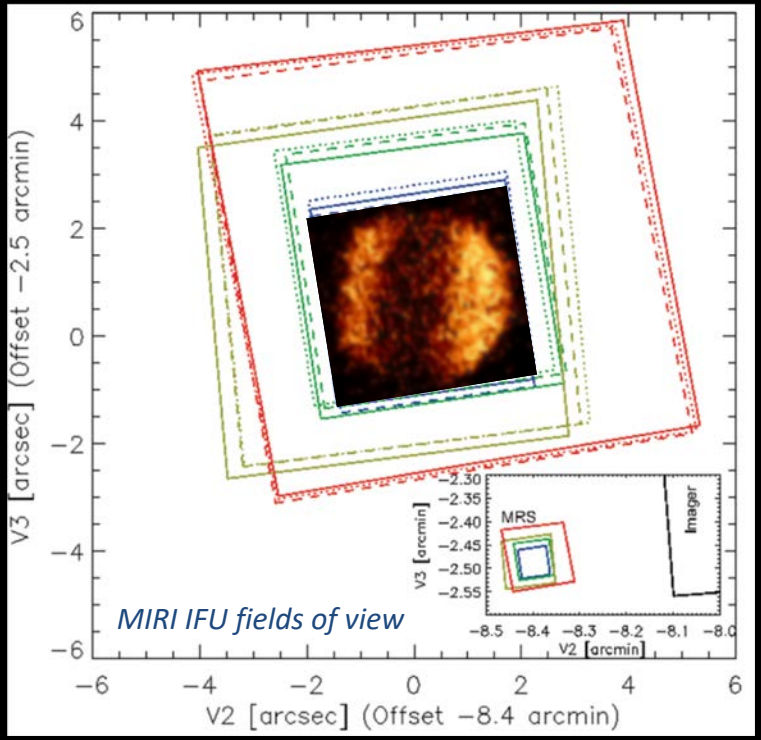
Splitting the Retrograde Jet? Equatorial "Belt"



Nov 2012 from Keck

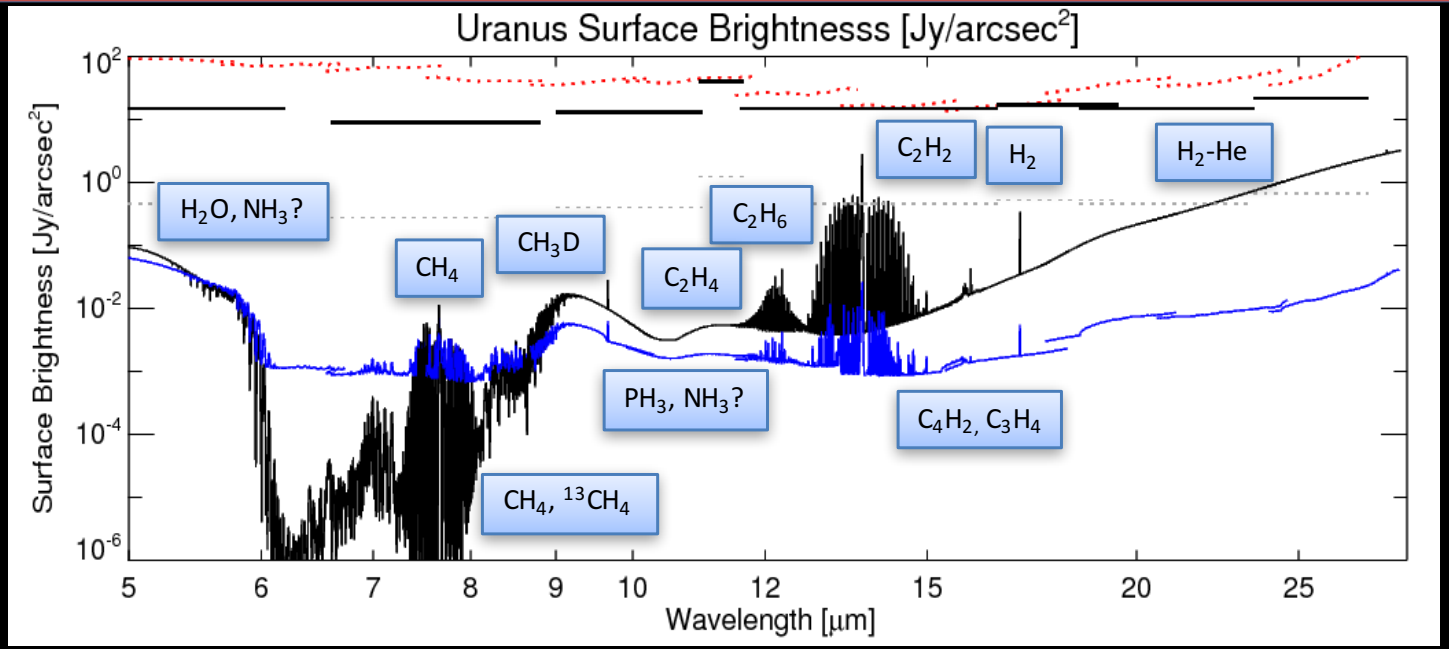
Beyond State of the Art - JWST

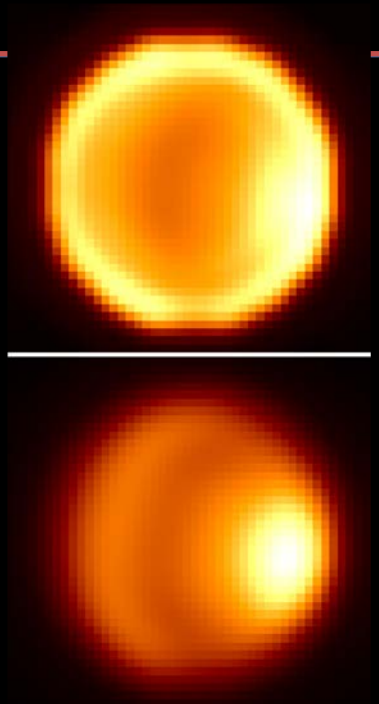
- Heidi Hammel – Interdisplinary Scientist for JWST (2002) with **110 hrs GTO time**.
- **1246: Jupiter's Great Red Spot**
- **1247: Saturn's Summer Hemisphere**
- **1248: Uranus Atmosphere & Aurora**
- **1249: Neptune Atmosphere**



MIRI IFU fields of view

JWST Simulation Toolkit





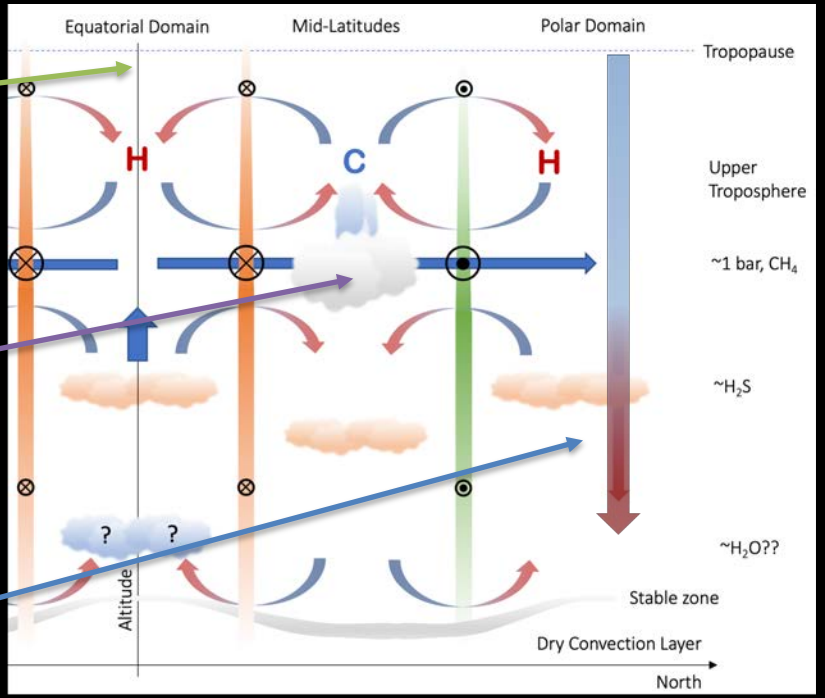
- Use Moses et al. (10.1016/j.icarus.2018.02.004) seasonal photochemistry model, no K_{yy} mixing.
- Use Voyager T(p) in troposphere; uniform T(p) in stratosphere.
- Prepared for JWST/MIRI 5-30 μm, R~3000
- Compared to NEFD in 5mins (blue) and saturation (red).

Summary I: Where to Target a Probe?

Equator: "Belt-like", high altitude subsidence (warm); low-altitude upwelling (enhanced CH4); waves; wind variation with height

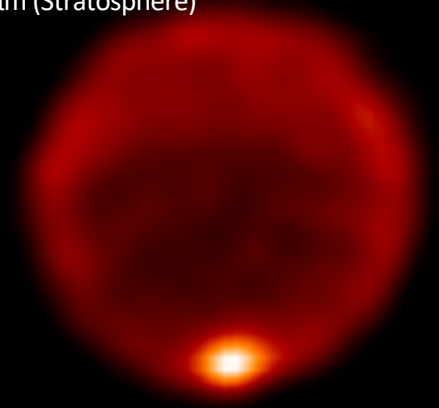
Mid-Lat: "Zone-like", high altitude upwelling & sporadic storms (cold); low-altitude subsidence

Poles: Strong subsidence (depleted CH4 & volatiles); aerosol cap & puffy clouds.

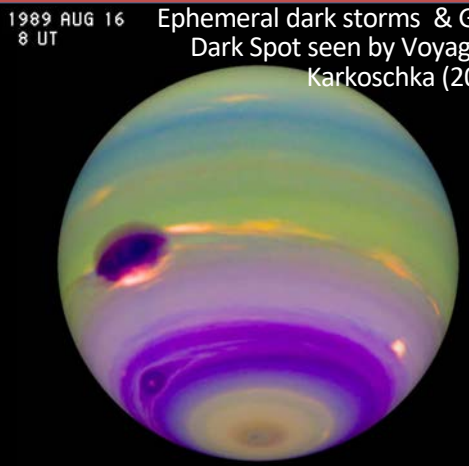


Summary II: Need Supporting Remote Sensing

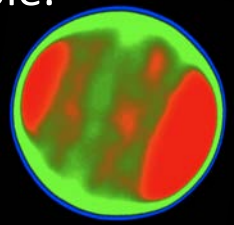
- IR **remote sensing of probe entry location** is essential:
  - Reflected sunlight for aerosol/methane properties.
  - Thermal emission for temperatures & gaseous species.
- **Earth-based support** will be a challenge:
  - Galileo, Juno & Cassini heritage.
  - JWST will lack spatial resolution.
- Infrared imager/spectrometer on carrier S/C highly desirable.



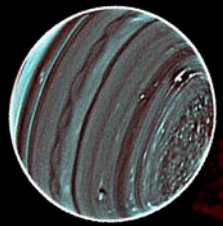
Neptune, VLT/VISIR, 2008, 7.9 μm (Stratosphere)



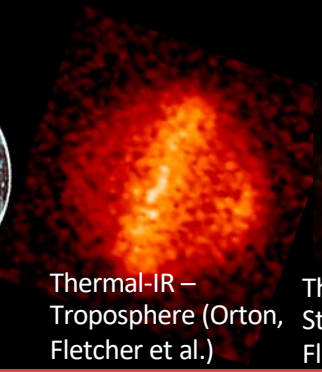
Ephemeral dark storms & Great Dark Spot seen by Voyager 2, Karkoschka (2011).



Microwave (Hofstadter et al.)

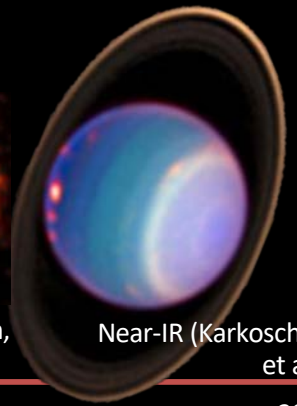


Near-IR (Fry, Sromovsky et al.)



Thermal-IR – Troposphere (Orton, Fletcher et al.)

Thermal-IR – Stratosphere (Orton, Fletcher et al.)



Near-IR (Karkoschka et al.)

Backup Slides