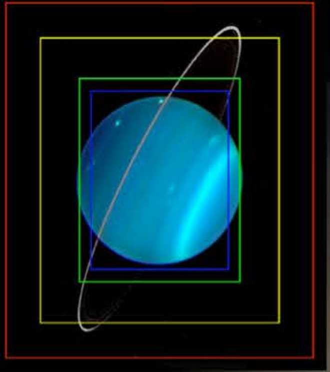
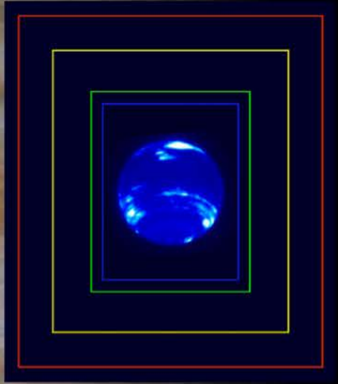
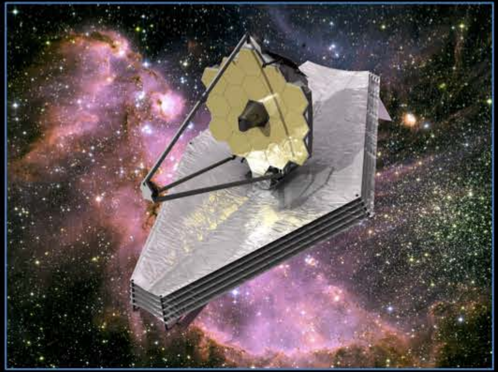
EXPLORING GIANT PLANETS WITH JWST







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H. Hammel, S. Milam, A. Glasse, T. Fouchet, I. de Pater, G. Orton, S. Guerlet, H. Melin, T. Greathouse, J. Moses, P. Irwin, J. Stansberry

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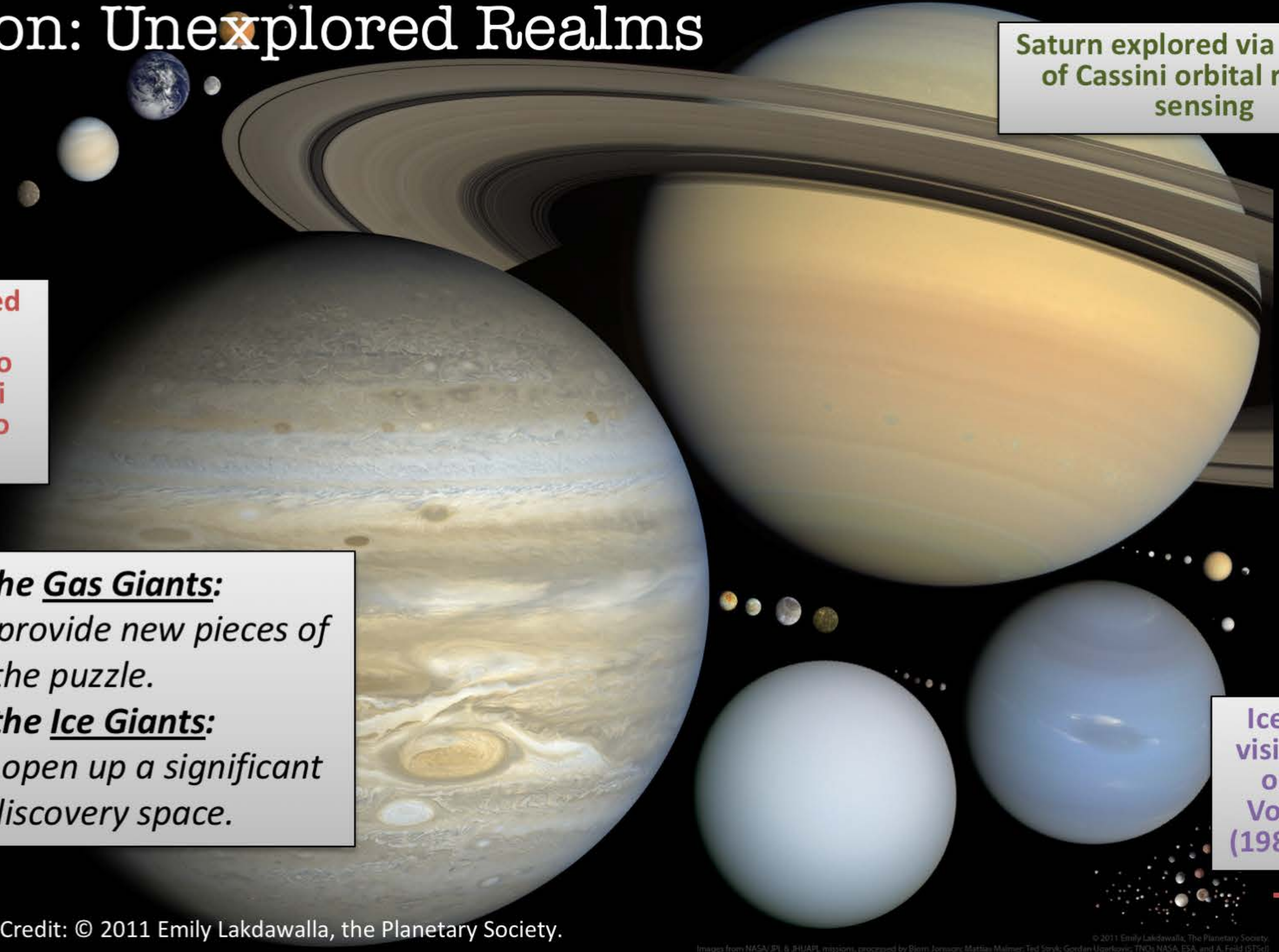
Motivation: Unexplored Realms



Saturn explored via 13 years of Cassini orbital remote sensing

Jupiter explored via Galileo orbiter, Galileo probe, Cassini flyby and Juno orbiter

For the <u>Gas Giants</u>:
…JWST will provide new pieces of the puzzle.

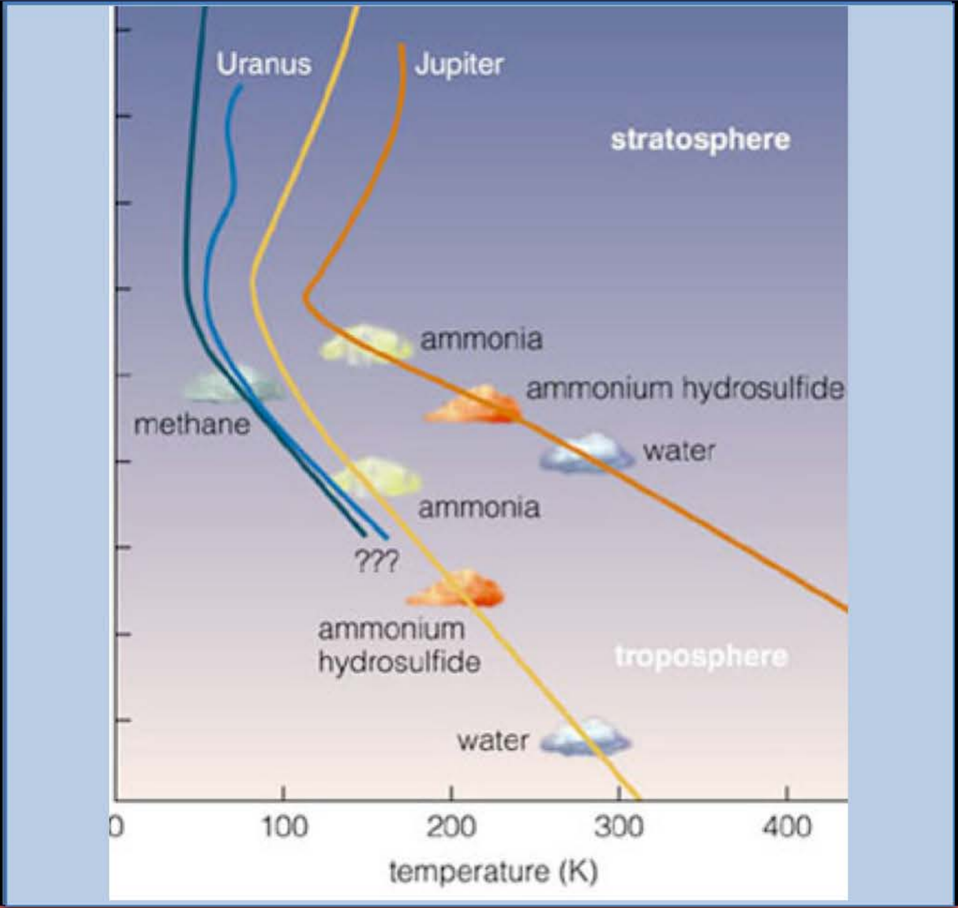
For the <u>Ice Giants</u>:
…JWST will open up a significant new discovery space.

Ice Giants visited only once by Voyager 2 (1986, 1989)

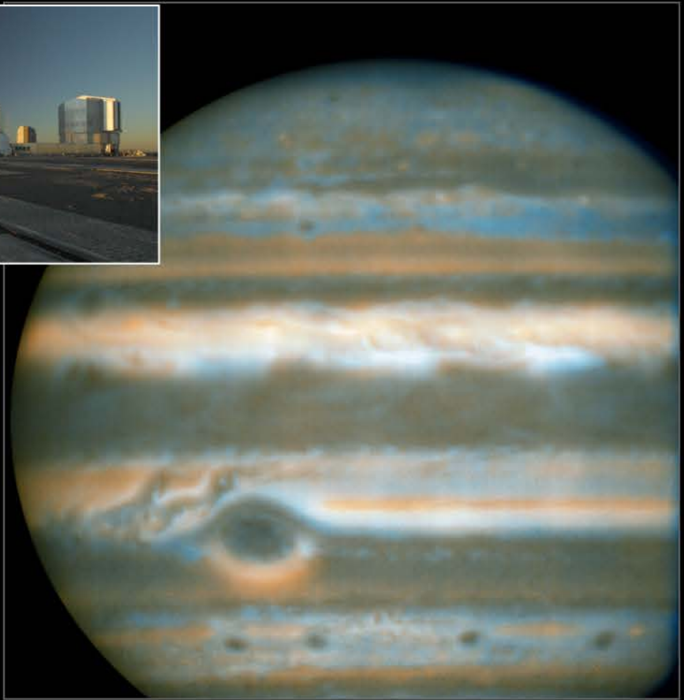
Motivation: Why the Thermal-IR?

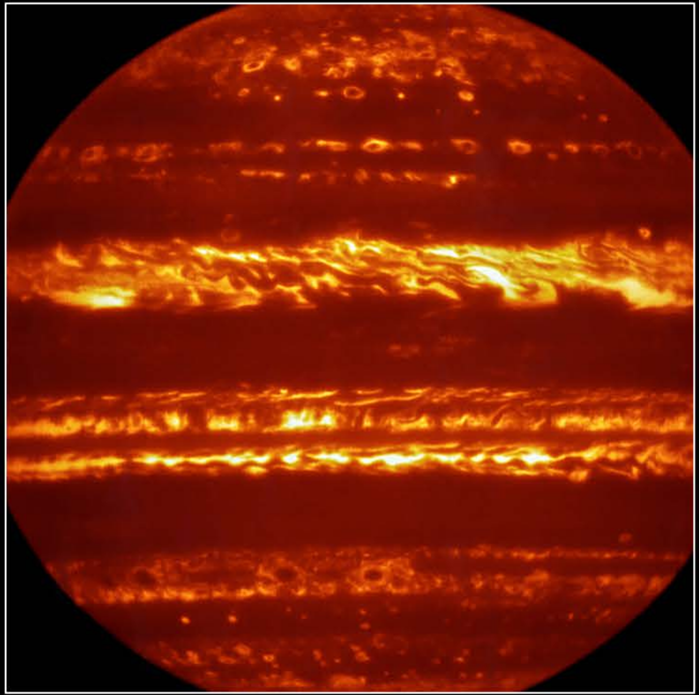
1. Origins
2. Chemistry
3. Clouds
4. Dynamics
5. Evolution

- 3D temperature & wind structure.
- Tropospheric and stratospheric composition & chemistry.
- Aerosol (cloud and haze) properties.
- Environmental conditions underpinning visible-light appearance.



Thermal State of the Art: Jupiter Observations

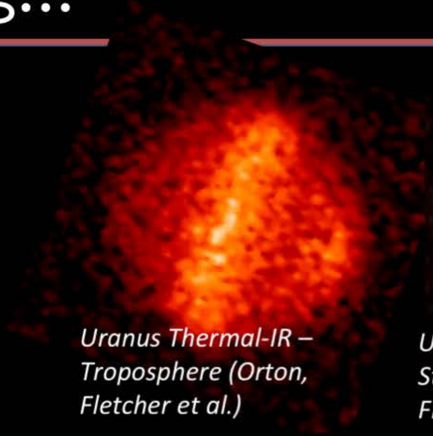




- Diffraction-limited imaging from 8-m facilities:
  - VLT/Subaru/Gemini.
  - Regular filters: 4.8, 7.9, 8.6, 10.7, 12.3, 13.0, 17.6, 18.7, 19.5, 24.5 μm

Other Giants Remain Challenging...

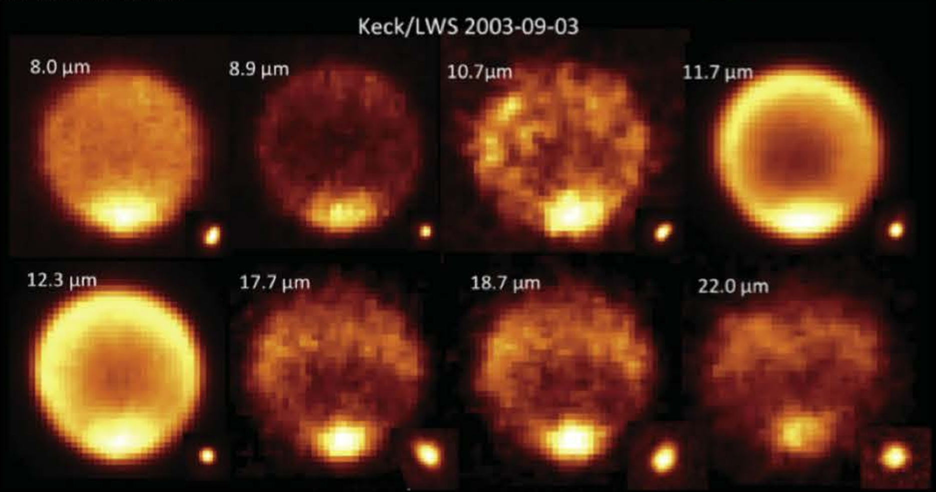
Saturn's 2011 storm plumes from VLT/VISIR (Fletcher et al.)



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

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

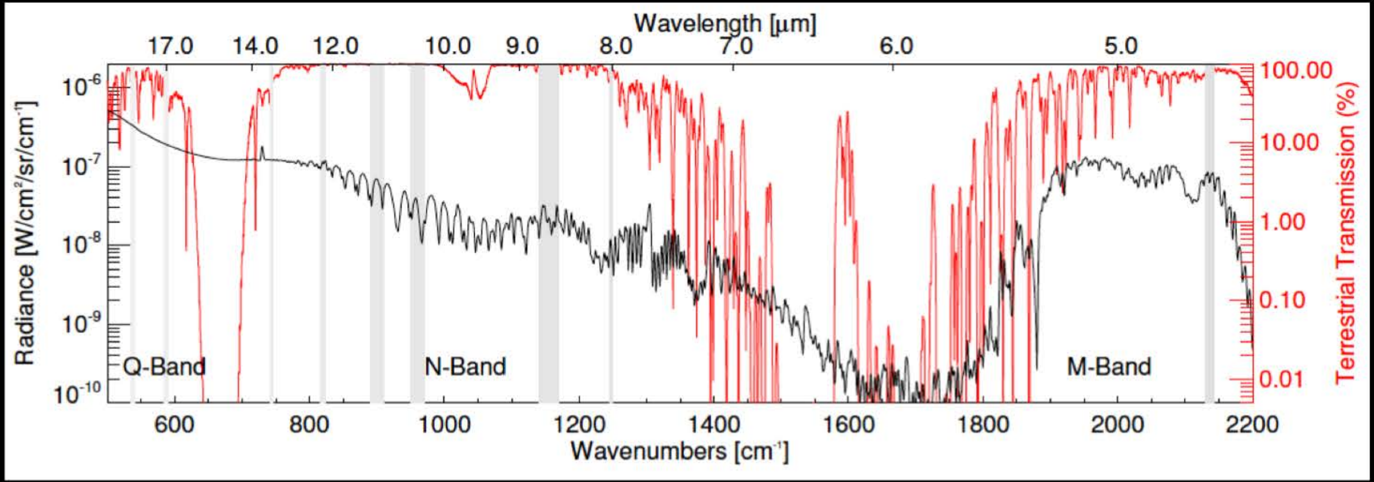
Neptune from VLT at 8 µm (Orton, Fletcher et al.)



Neptune from Keck (Fletcher, de Pater et al., 2014)

The Potential and Challenge for JWST

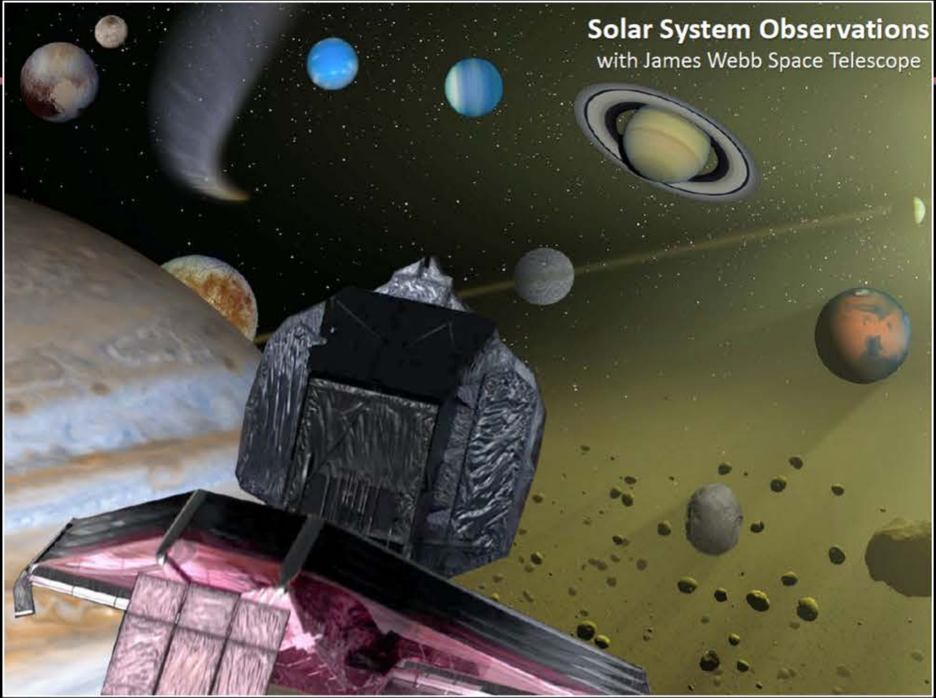
- **Sensitivity & Resolution:**
  - 1st spatial maps of conditions in ice giant stratospheres.
- **Spectral Range:**
  - signatures in regions hidden from Earth.



- **Dynamic range** 10^{-5} to 10^{2} Jy/arcsec^2
- **Extended**: Jupiter 40” to Neptune 2.2”
- **Rotating**: 10-17hr rotation period.
- *How to create mosaics of extended, bright, rotating and moving objects?*
- *How to calibrate near saturation limit?*

GTO Background

- Heidi Hammel – Interdisplinary Scientist for JWST (2002) with **110 hrs GTO time**.
- **Solar System GTO team** formed in 2016.
  - Develop science and technical cases for solar system targets.
  - June 2017: List of GTO targets released.
  - November 2017: APT finalised.
- **1246: Jupiter's Great Red Spot**
- **1247: Saturn's Summer Hemisphere**
- **1248: Uranus Atmosphere & Aurora**
- **1249: Neptune Atmosphere**
- **No proprietary period** for observation files and data.

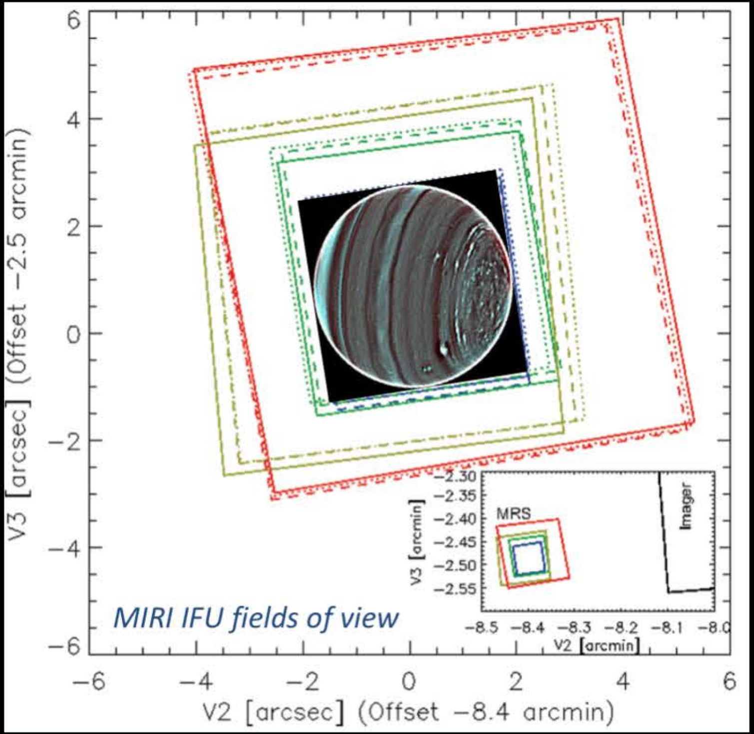


Additional Science Team

Andy Rivkin: Asteroids	**Lazlo Kestay**: Satellites
Cristina Thomas: NEOs	**Pablo Santos Sanz**: Occult'ns
Geronimo Villanueva: Mars	**Michael Kelley**: Comets
Leigh Fletcher: Giant Planets	**Alex Parker**: TNOs
Matt Tiscareno: Rings	
Conor Nixon: Titan	

Key Instruments for *New* Science: MIRI

- **Spectroscopic thermal mapping** will be the primary tool for GTO science.
  - Most challenging from Earth, best case for needing JWST.
- MIRI IFU R~3000 5-28 μm spectral maps
- Uranus (3.7") and Neptune (2.3") ideally suited to small FOV of MIRI.



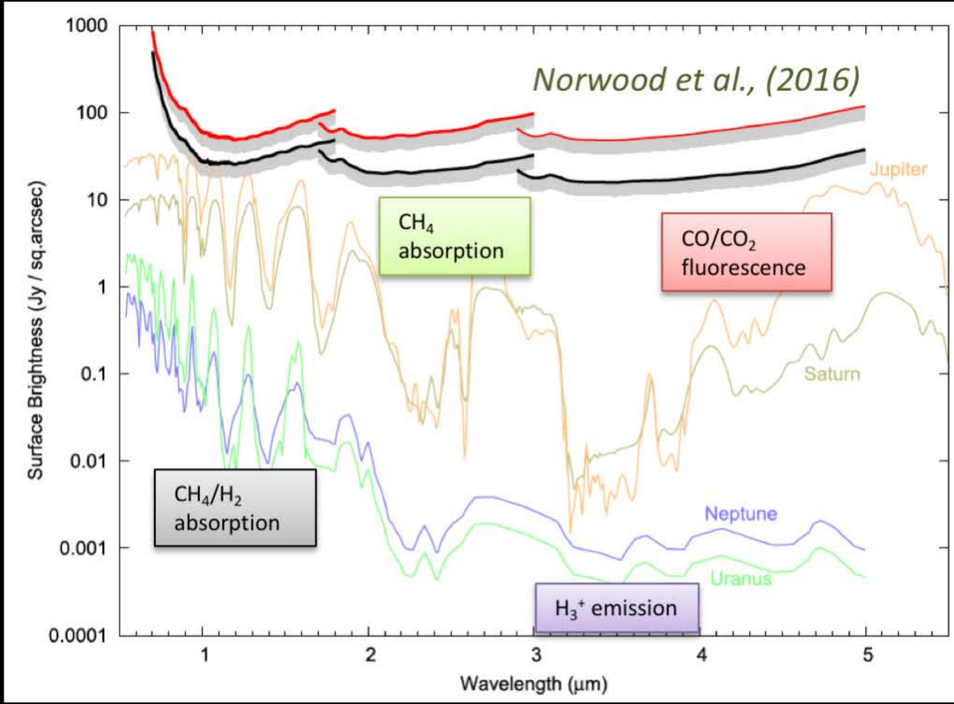
Channel	FoV (arcsec^2)	Slices	λ (μm)	$R_{spectral}$	Exposure
1	3.70×3.70	21	4.87 – 5.82	2450 – 3710	A
			5.62 – 6.73		B
			6.49 – 7.76		C
2	4.70×4.51	17	7.45 – 8.90	2480 – 3690	A
			8.61 – 10.28		B
			9.94 – 11.87		C
3	6.20×6.13	16	11.47 – 13.67	2510 – 3730	A
			13.25 – 15.80		B
			15.30 – 18.24		C
4	7.74×7.93	12	17.54 – 21.10	2070 – 2490	A
			20.44 – 24.72		B
			23.84 – 28.82		C

First opportunity to measure circulation, meteorology and chemistry of the ice giants.

Key Instruments for *New* Science: NIRSPEC

- **Reflected sunlight 1-5 μm mapping** is secondary priority and mainly covered by Cycle 1 proposals.
- 3x3" FOV, need mosaicking
- R=2700 spectra with 0.1"/spaxel

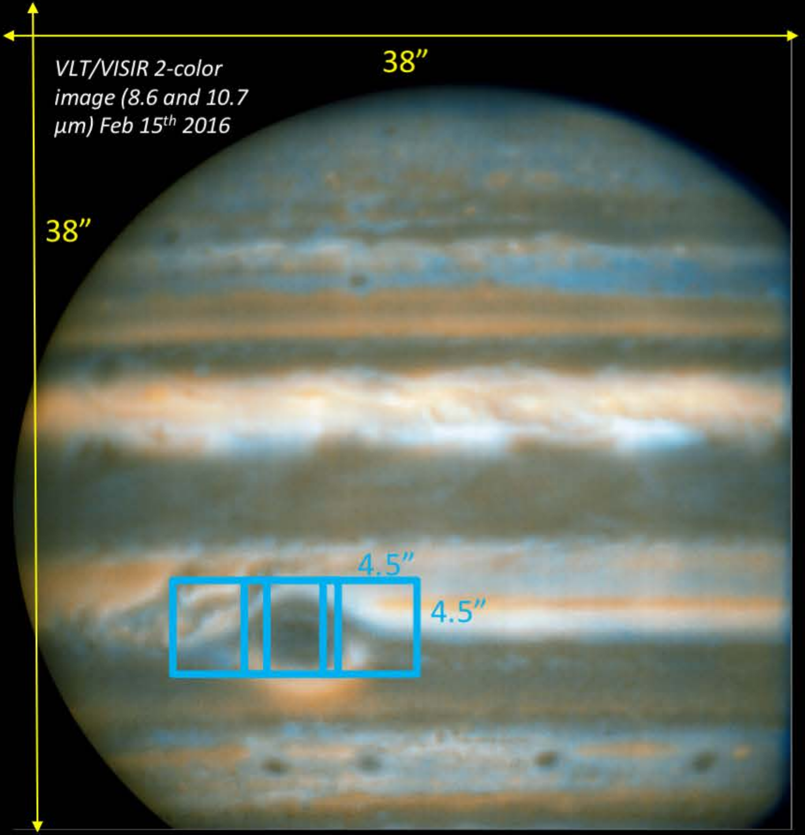
Disperser/filter combination	Nominal resolving power	Wavelength range (μm)
G140M/F070LP	~1000	0.7–1.27
G140M/F100LP		0.97–1.89
G235M/F170LP		1.66–3.17
G395M/F290LP		2.87–5.27
G140H/F070LP	~2700	0.7–1.27
G140H/F100LP		0.97–1.89
G235H/F170LP		1.66–3.17
G395H/F290LP		2.87–5.27
PRISM/CLEAR	~100	0.6–5.3



First opportunity to simultaneously measure properties of ice giant clouds, aurora, composition

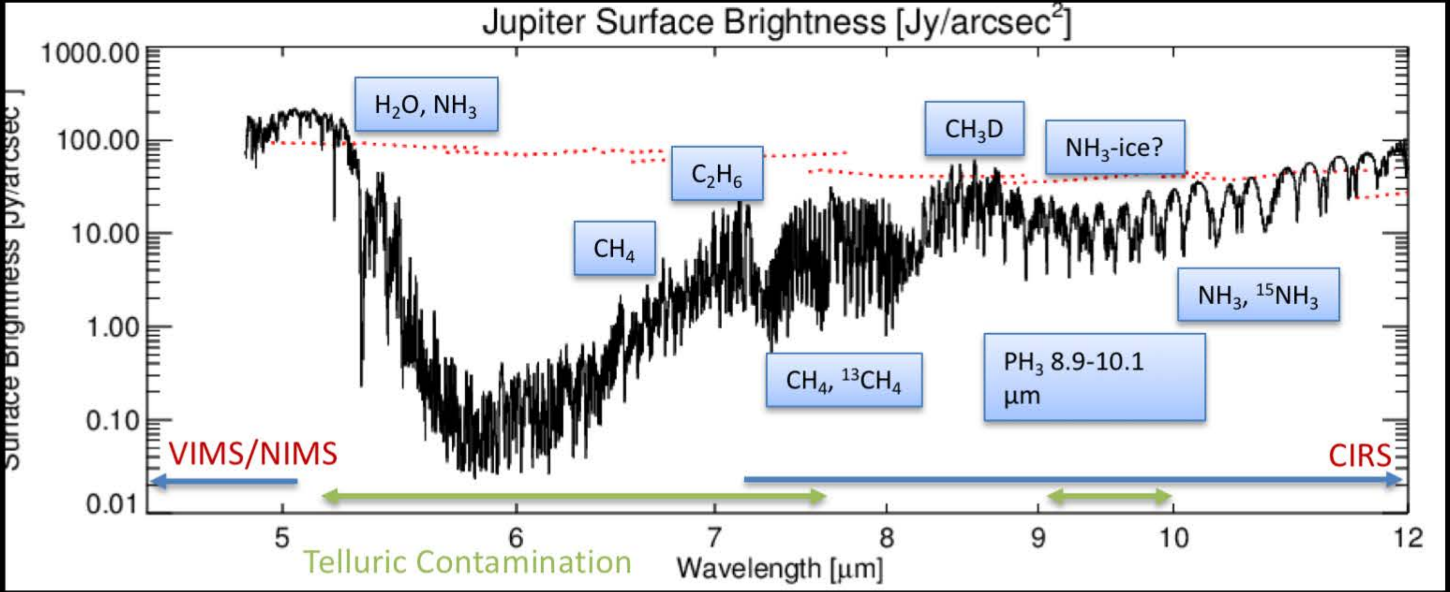
Jupiter – Great Red Spot (1246)

- MIRI Obs. of **Great Red Spot** and environs to test:
  - Mosaicking on rotating, moving, bright target.
  - Ability to calibrate when some channels saturate.
- **Complements ERS:**
  - NIRSPEC map of GRS.
  - NIRSPEC and MIRI observation of south polar region.



Jupiter – Great Red Spot (1246)

- **5-11 μm provides:**
  - Signatures of chromophore.
  - Stratospheric structure.
  - Access to fresh ice material.
  - Ammonia; ethane; phosphine as tracers.



BUT: Expect **saturation** beyond 11 μm.

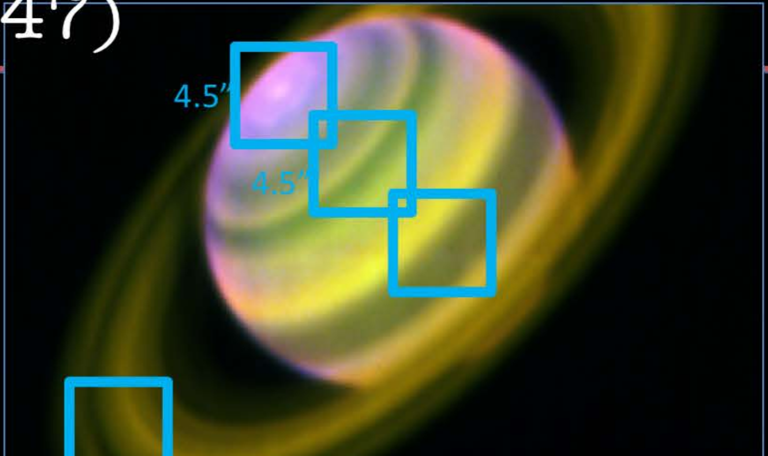
No H_2/He continuum for tropospheric temperatur

GRS centre dark, so should permit 5-μm spectroscopy.

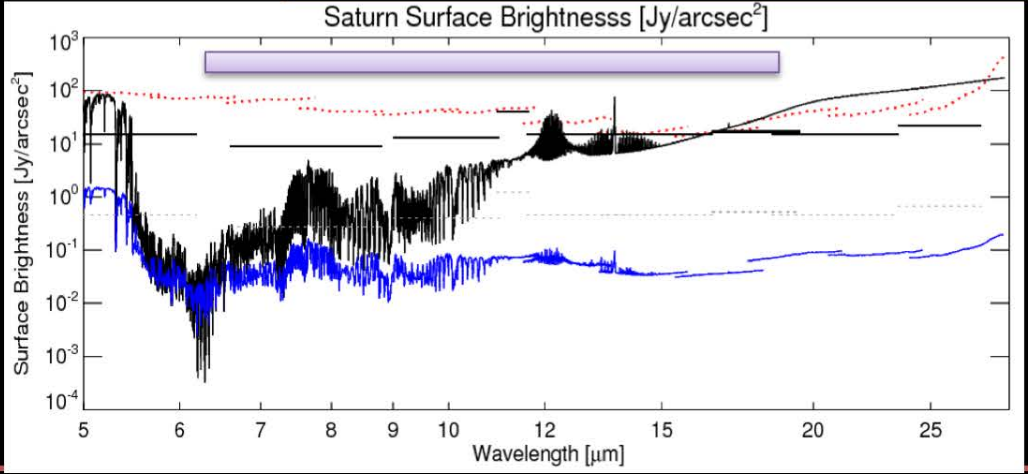
Total time: ~4 hours for 3 positions

Saturn – Northern Summer (1247)

- **Scan from north to south in summer hemisphere & ring pointing:**
  - Polar hexagon, cyclone, stratospheric vortex.
  - Seasonal contrasts.
  - Equatorial oscillation.
- **Expect saturation beyond 16 μm.**
  - Still get stratospheric temperatures, aerosols (e.g., 5-7 μm range unexplored), hydrocarbons, phosphine.
- ***Total time: 6 hours for 4-point mosaic.***

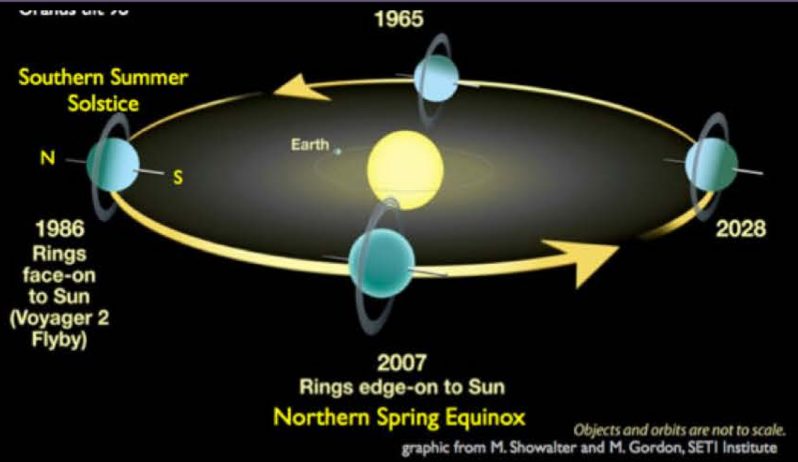


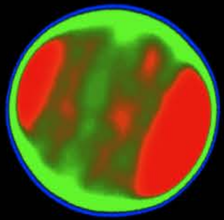
VLT/VISIR 3-color image (7.9, 17.6, 18.7 μm) Sep 7th 2017



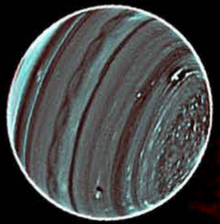
Uranus (1248) and Neptune (1249)

- **Extreme Contrasts:**
  - JWST will contrast influence of obliquity/insolation between two ice giants.
- **Internal heat:**
  - Neptune self-luminous, Uranus has no detectable internal heat.
  - Different driving forces for meteorological activity.

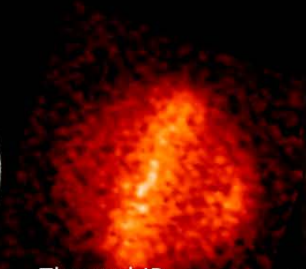




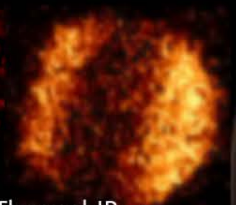
Microwave (Hofstadter et al.)



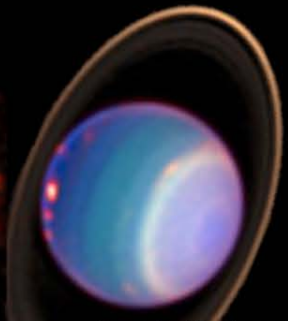
Near-IR (Fry, Sromovsky et al.)



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

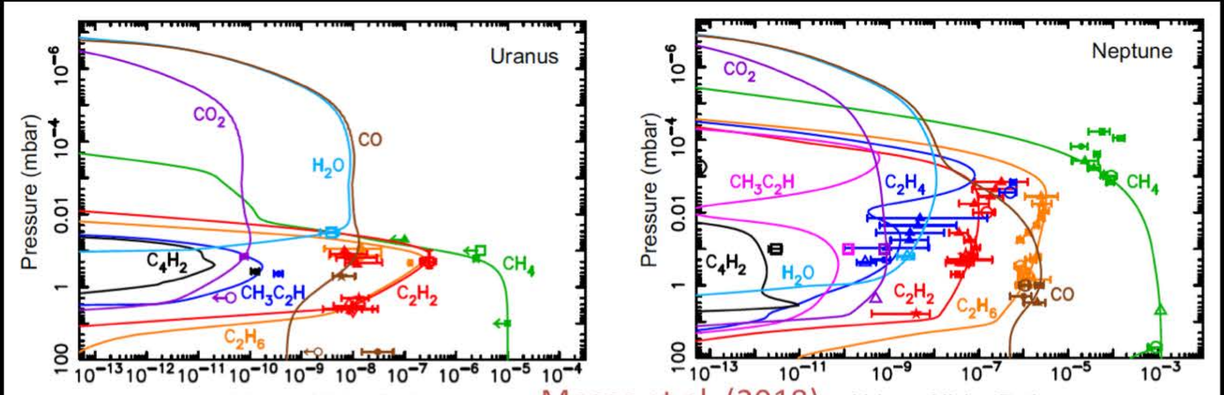


Thermal-IR – Stratosphere (Orton, Fletcher et al.)

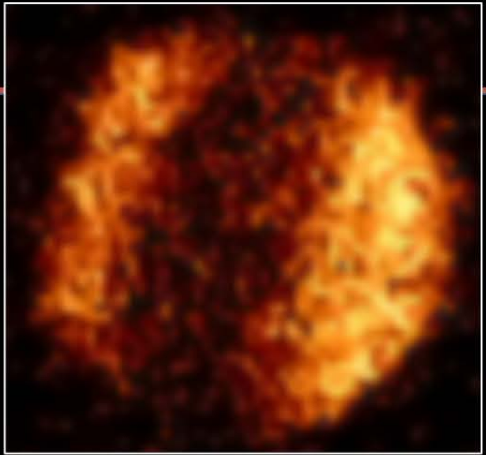


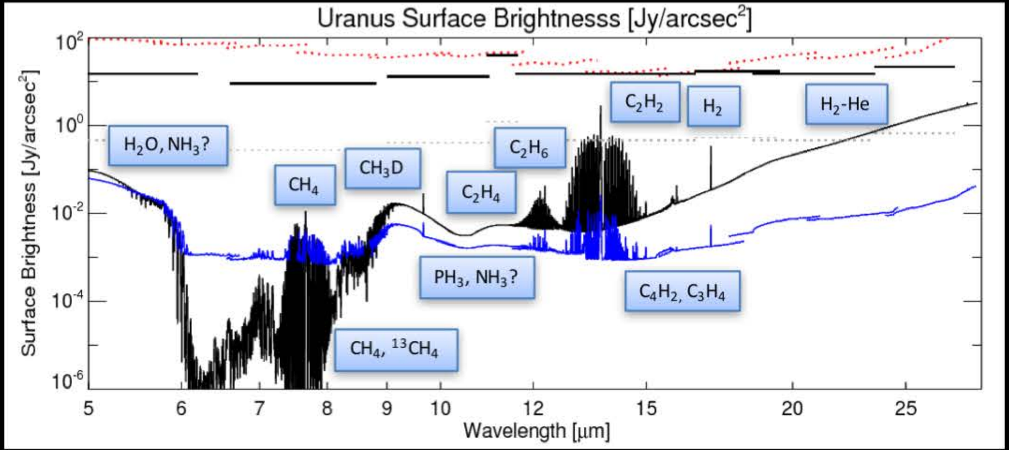
Near-IR (Karkoschka et al.)

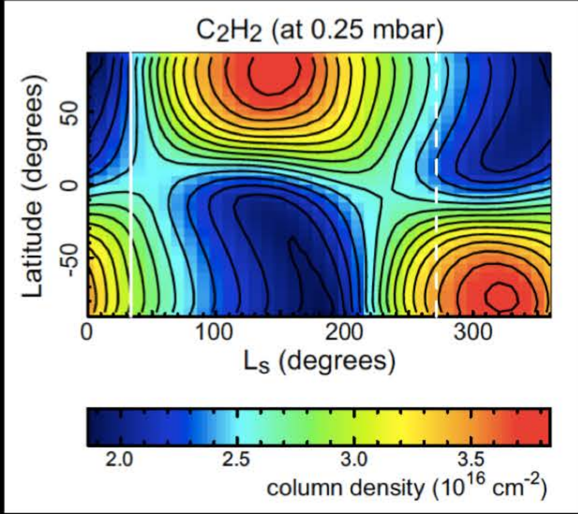
Testing Ice Giant Photochemistry



Moses et al. (2018)

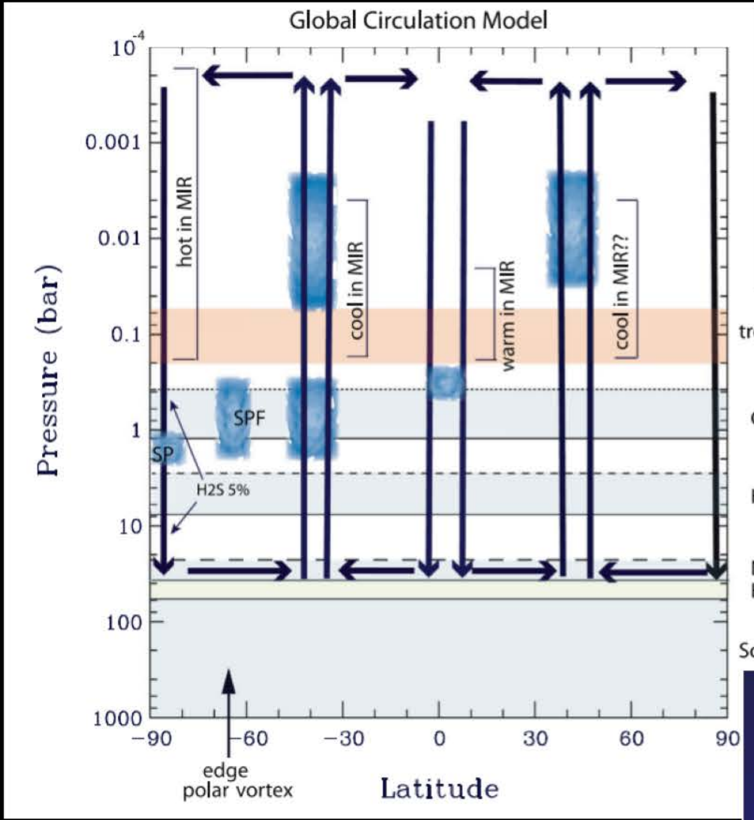


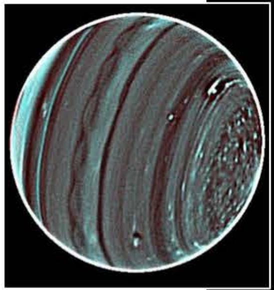




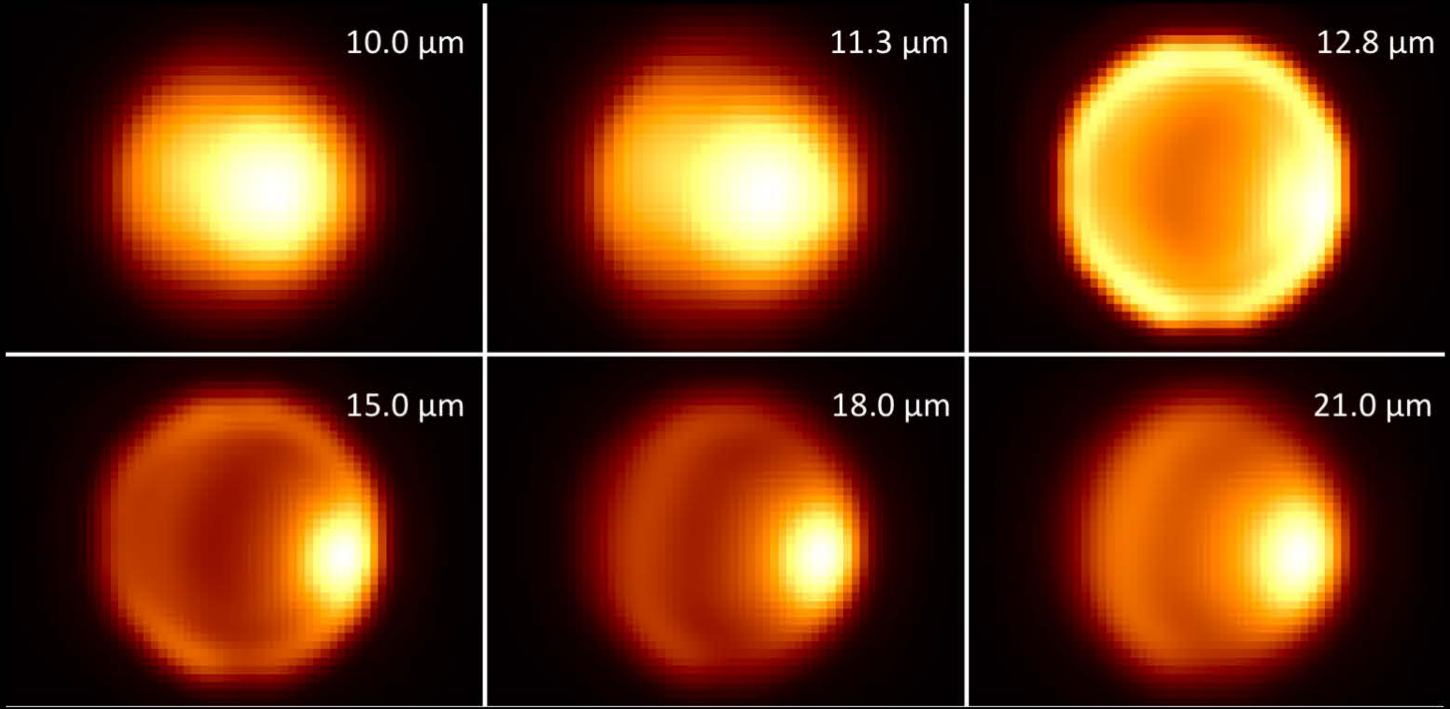
Measuring Ice Giant Global Circulation

- JWST will ***reconstruct temperature & winds as a function of altitude to relate circulation to banded weather activity***.
- No spatial-spectral maps of Uranus available for 5-30 µm.
- **Atmospheric circulation** from:
  - Temperature field.
  - Ortho/para-H2 ratios.
  - Stratospheric hydrocarbons.
  - Volatile distribution (e.g., NH_3, H_2S)
  - Disequilibrium species (PH_3).
  - Clouds and aerosols.





Does Uranus have a Polar Vortex?

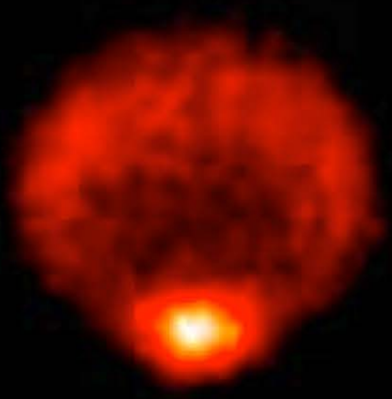


- JWST sees Uranus during northern spring.
- Assumes 0.11” plate scale; images convolved with JWST PSF.
- Assumes zonal homogeneity, but longitudinal structure could easily be detected.
- **~8 hours for global thermal map and NIRSPEC H_3^+ imaging of aurora.**

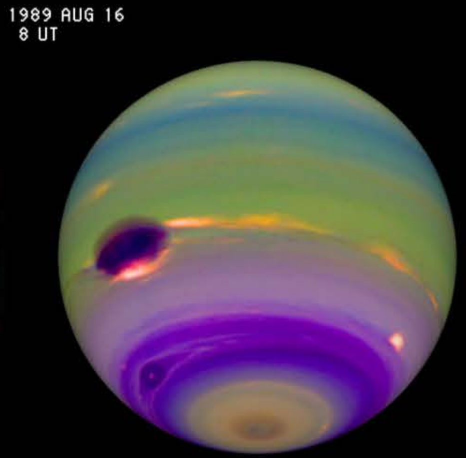
Testing Ice Giant Meteorology (Neptune 1249)

- Storms are a significant component of energy transport from deep interior.
- Search for thermal perturbations associated with Neptune's ever-changing weather.
- **~6 hours for 3 longitudes.**

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



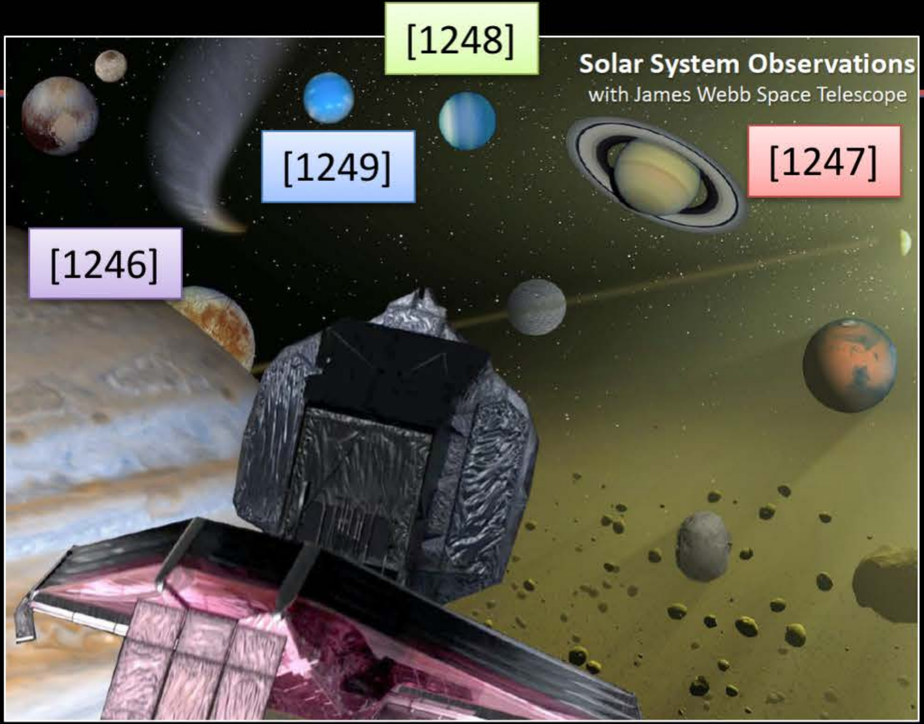
Neptune, 2006 VLT/VISIR 17.6 µm (Troposphere)



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

Summary of GTO

- JWST opens up ***spectro-spatial mapping of giant planets*** with a sensitivity that is unsurpassed.
- **Challenge:**
  - GTO proposal contains 3-5 μm and 5-30 μm spectral maps as a test of capabilities.
  - Mosaics of bright, extended, moving targets close to saturation limit!
- Key science from 4 different worlds:
  - Ice giant **circulation** patterns, banded structure.
  - Influence of extreme **seasons** and differences in internal heat.
  - Differences in atmospheric **chemistry** and **auroras**.
  - Bulk **composition** and **cloud** formation processes
- Start of a long-term legacy programme for the ice giants ahead of future missions in the 2030s?



JWST Giant Planet tools (spectral calculations, APT files, ETC workbooks) are available to help with GO planning – please contact leigh.fletcher@le.ac.uk