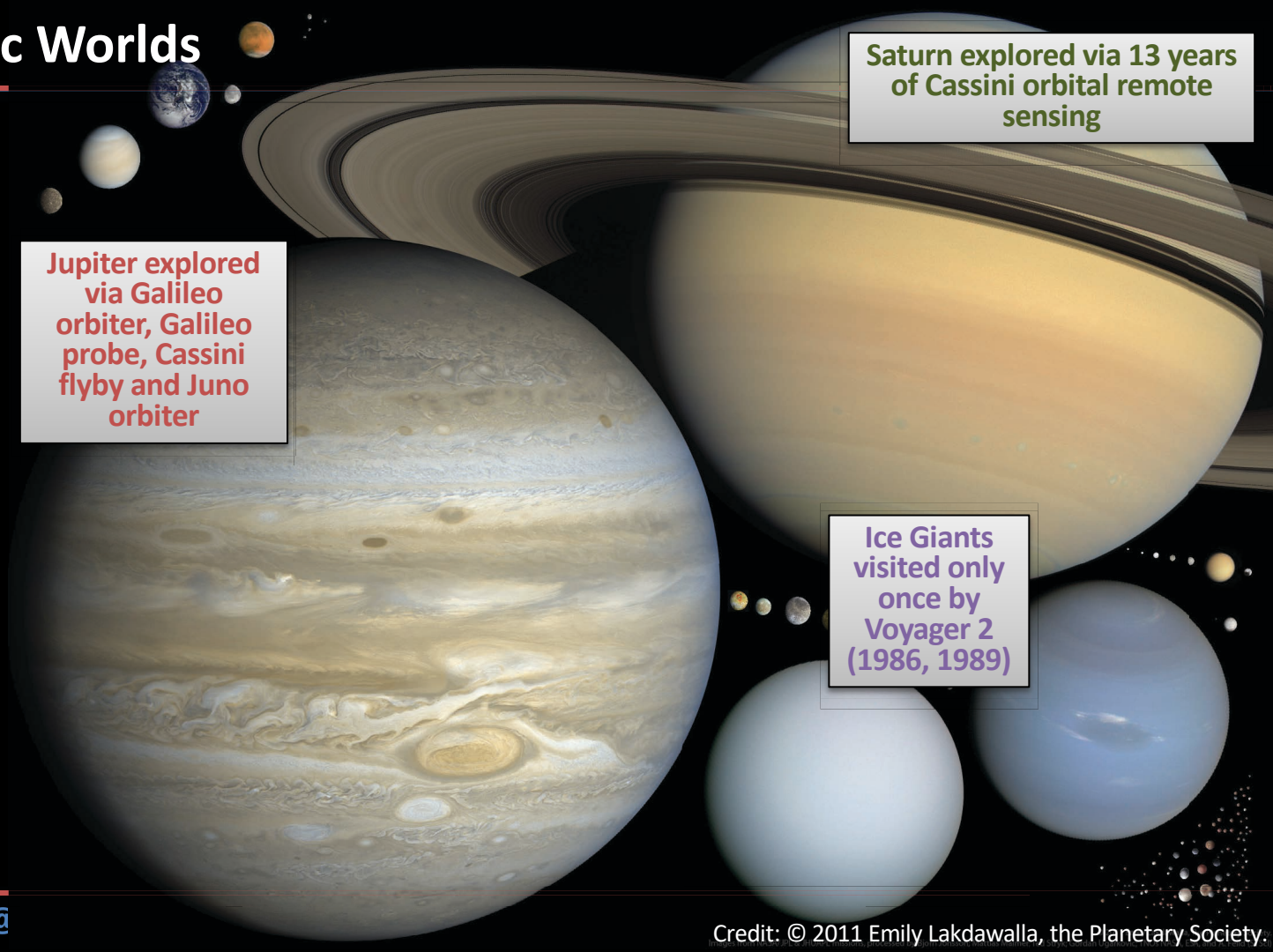
Giant Planets in the Thermal-IR

Leigh N. Fletcher

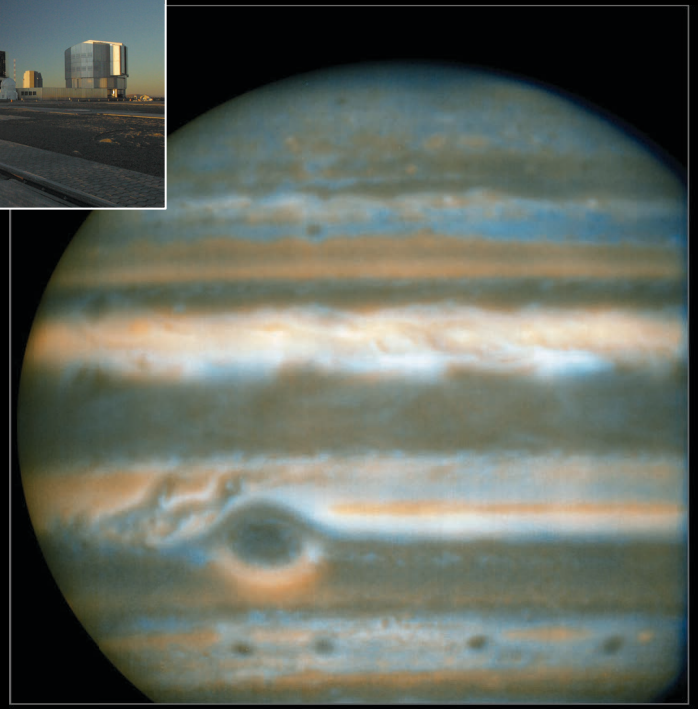
Thanks to: Glenn Orton, Tommy Greathouse, Arrate Antuñano, James Blake, Michael Roman, Padraig Donnelly, Naomi Rowe-Gurney, James Sinclair

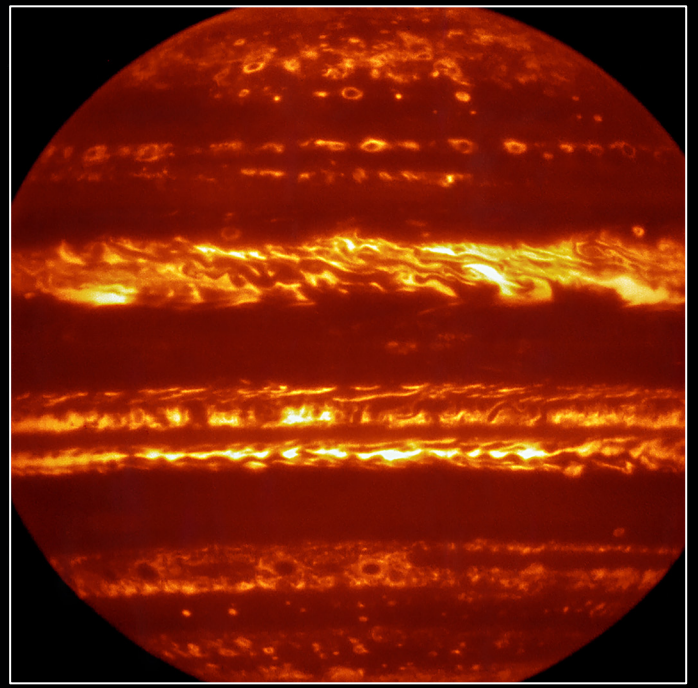
Evolving, Dynamic Worlds

- Planetary-scale laboratories.
- Time-capsules for planetary origins.
- Habitable satellites.
- Archetypes for giant exoplanets & Brown Dwarfs.



Thermal State of the Art: Jupiter Observations

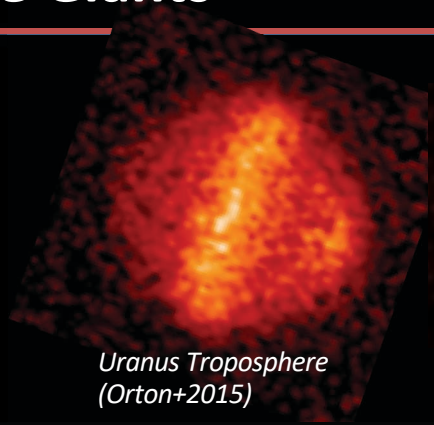




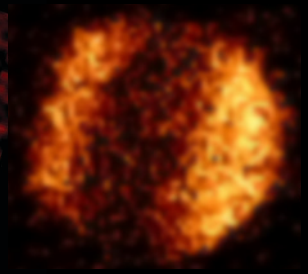
JUNO

Thermal State of the Art: Saturn and the Ice Giants

Saturn's 2011 storm plumes from VLT/VISIR (Fletcher+2012.)

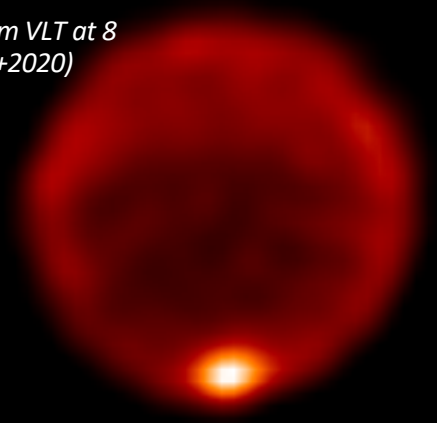


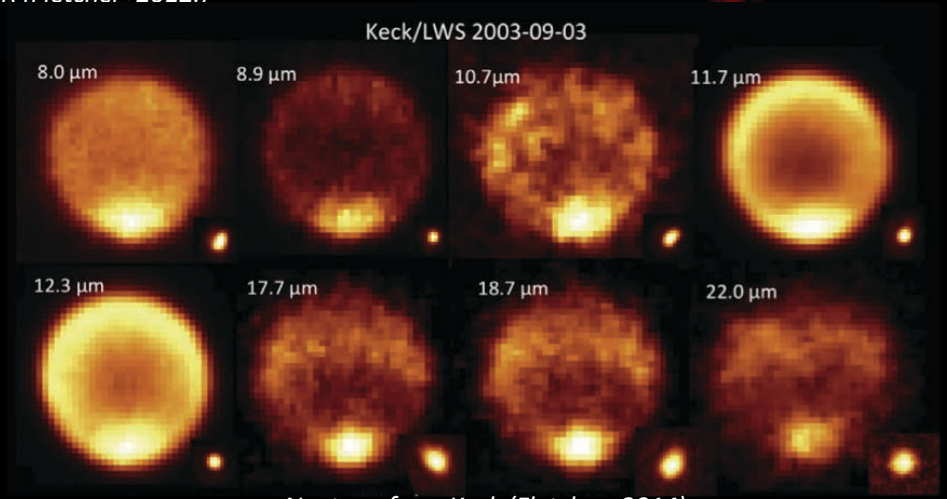
Uranus Troposphere (Orton+2015)



Uranus Stratosphere (Roman+2020.)

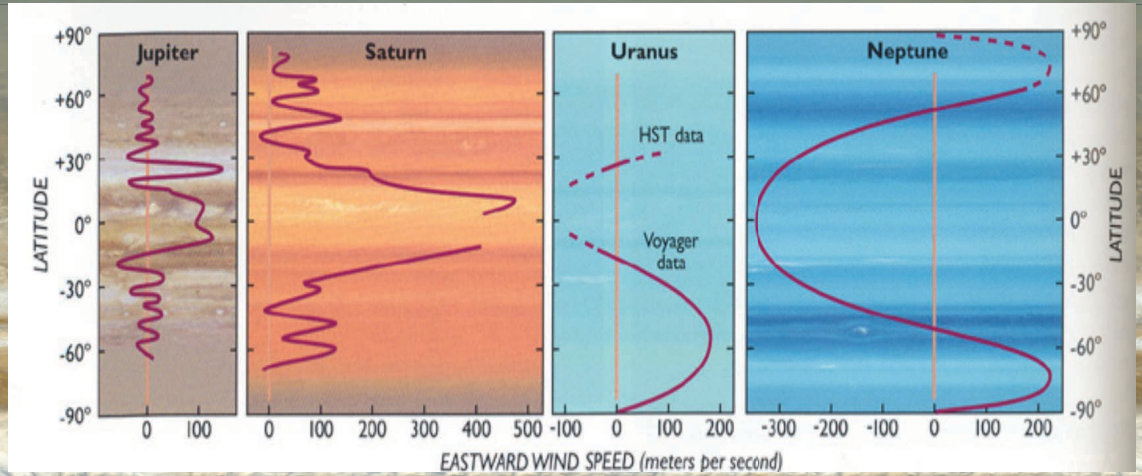
Neptune from VLT at 8 μm (Sinclair+2020)





Neptune from Keck (Fletcher+2014)

Anatomy of a Giant Planet



Anatomy of a Giant Planet

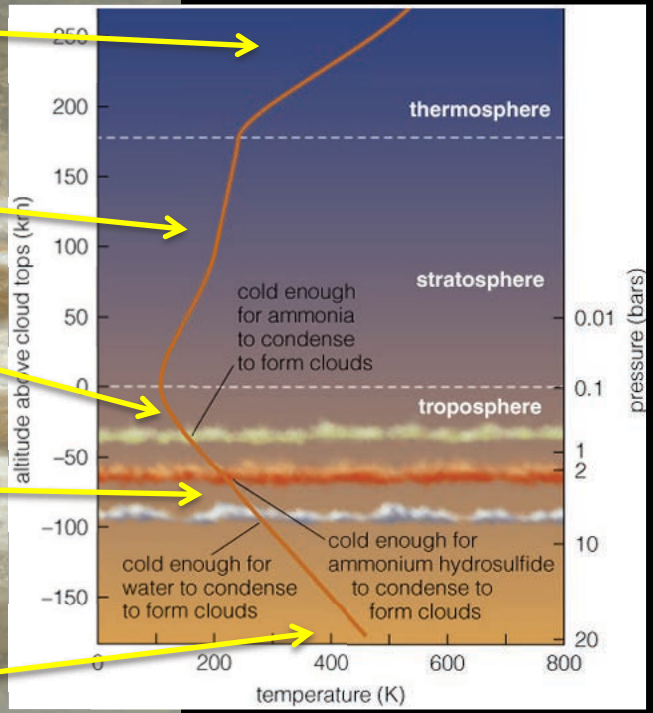
Upper Atmosphere:
Auroral energy deposition, ionosphere, exogenic sources…

Stratosphere:
Photochemical soup; hydrocarbon hazes; radiative control & waves.

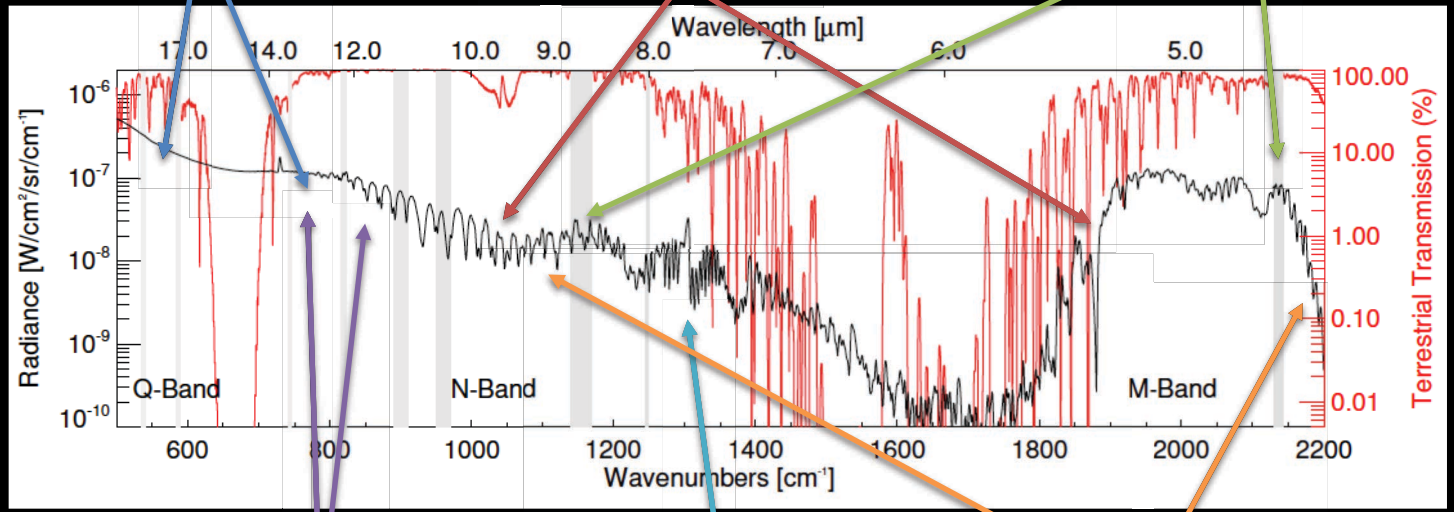
Upper Troposphere:
NH3/PH3 photolysis & hazes; zonal winds; belt/zone structure.

Cloud-Layer:
Condensable species; rising plumes; vortices; moist convection?

Sub-Cloud Troposphere:
Dry convection? Taylor Proudman columns? MHD drag & metallic H2? Smooth transition or discrete core?



Why the Thermal-IR?



Tropospheric Thermometer (H_2)

Volatiles (NH_3)

Tropospheric Clouds

Stratospheric Chemicals

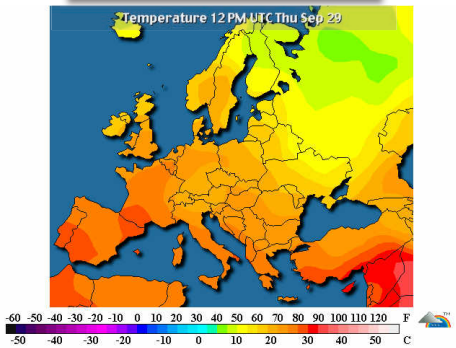
Stratospheric Thermometer (CH_4)

Disequilibrium Species (PH_3)

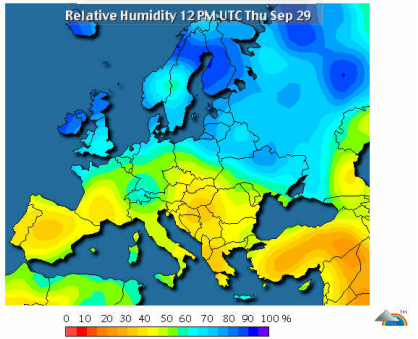
- 3D temperature & wind structure.
- Tropospheric and stratospheric composition & chemistry.
- Aerosol (cloud and haze) properties.
- Environmental conditions underpinning visible-light appearance.

Why the Thermal-IR?

Temperatures

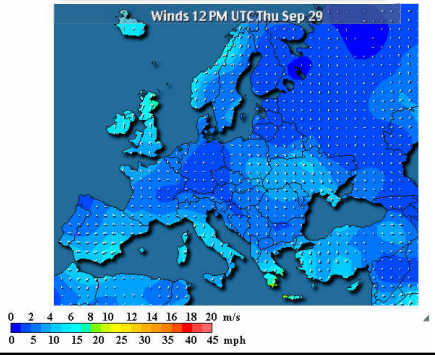


Humidity

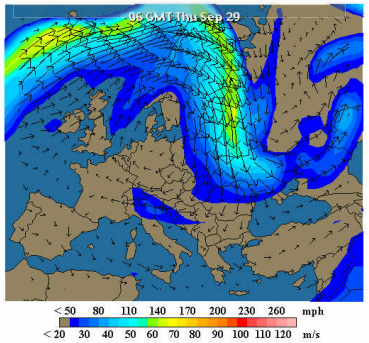


- Consider the information we derive from terrestrial weather satellites…

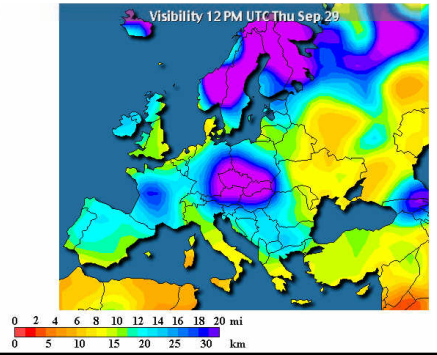
Surface Winds



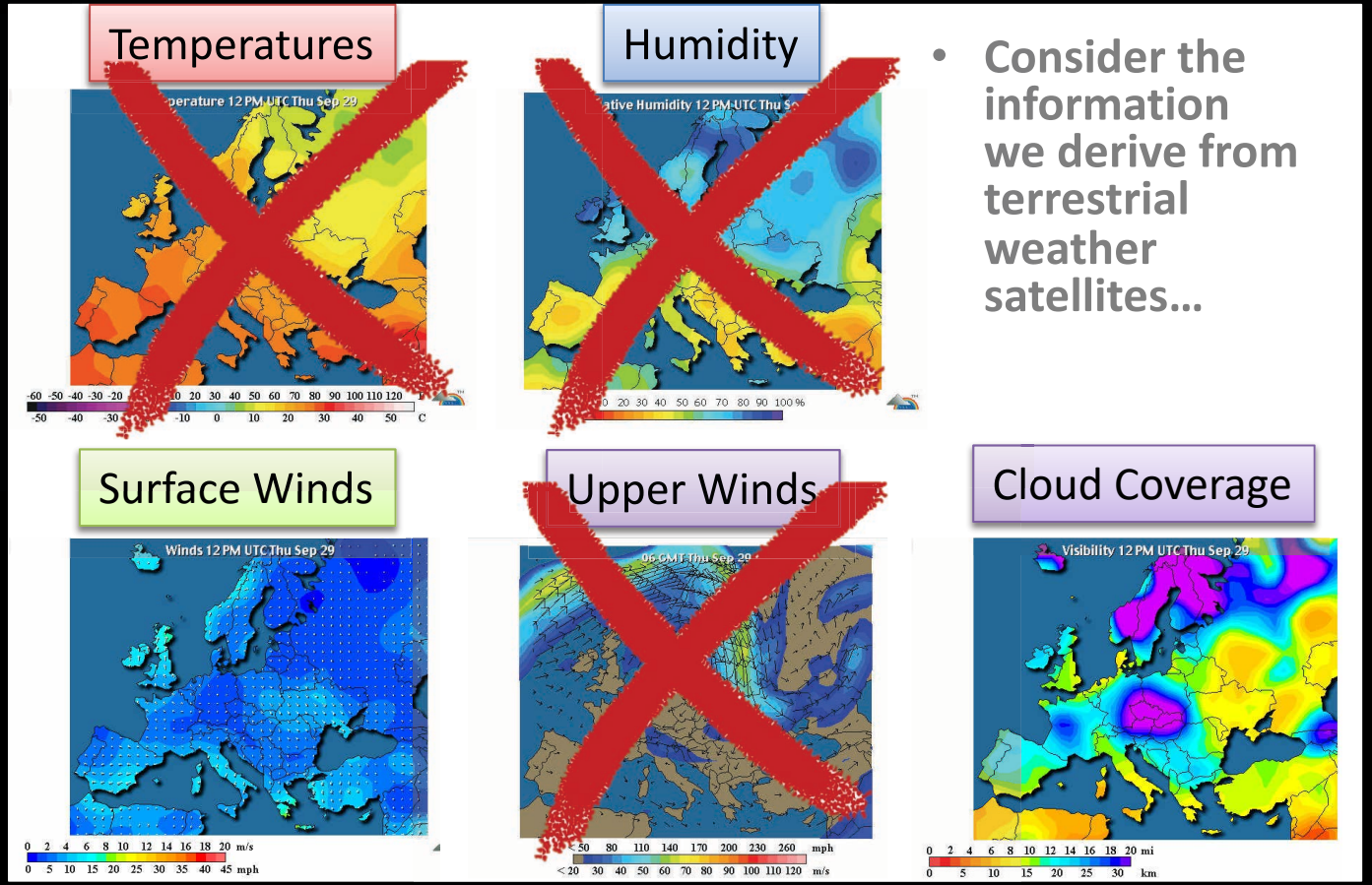
Upper Winds



Cloud Coverage

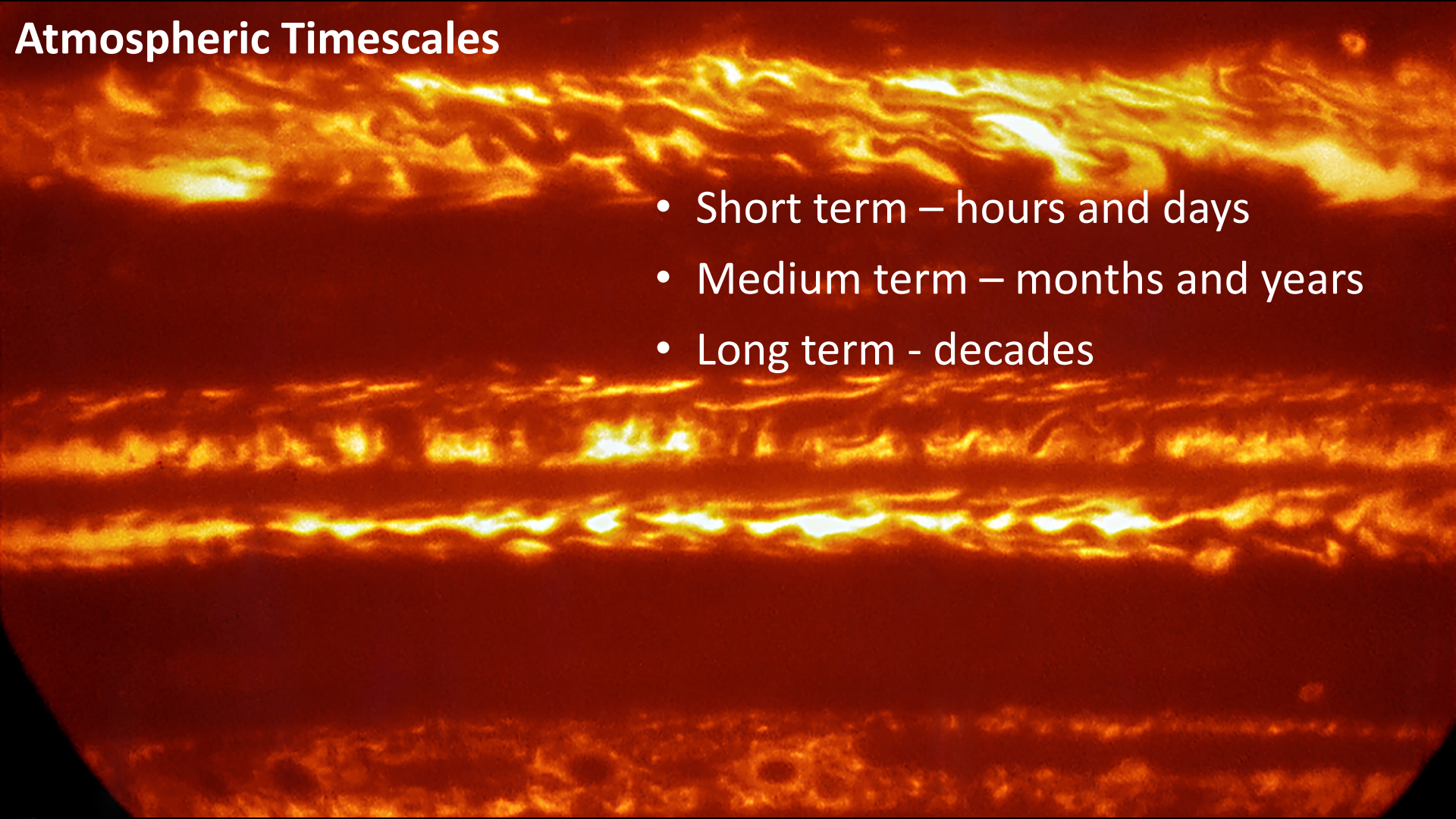


Why the Thermal-IR?



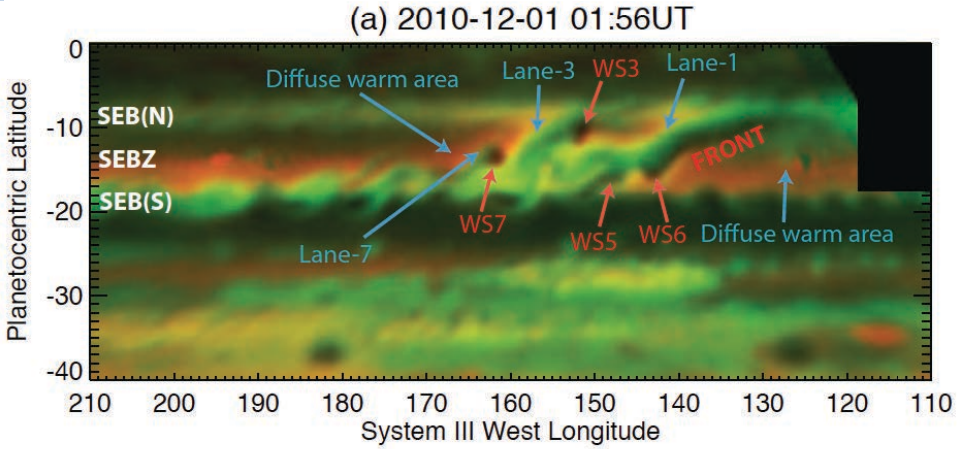
- Consider the information we derive from terrestrial weather satellites…

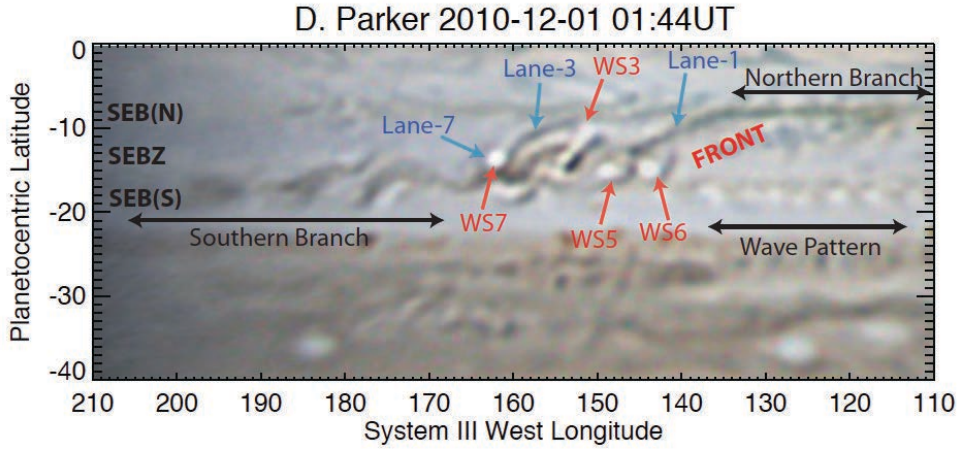
Atmospheric Timescales

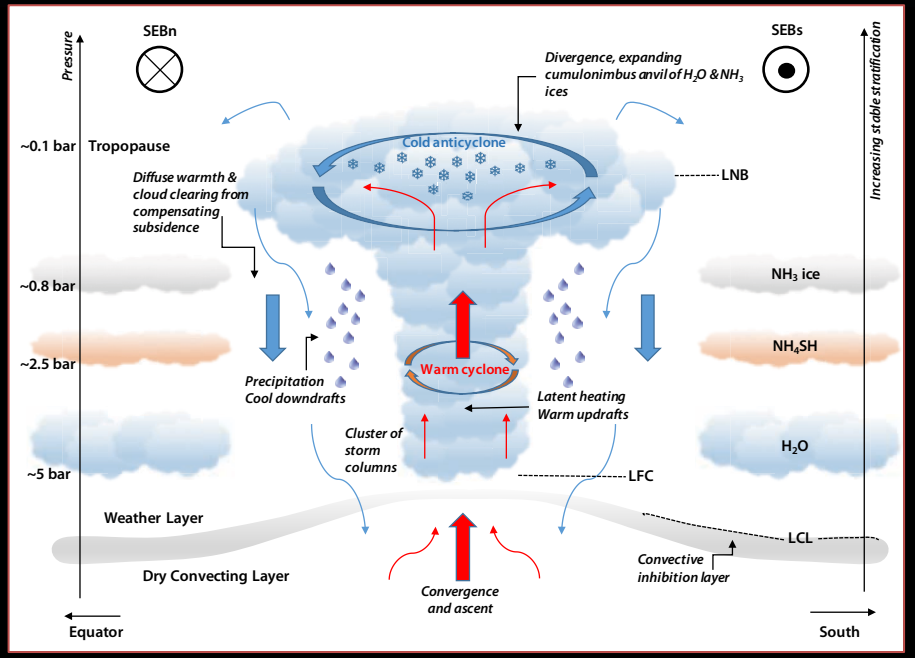


- Short term – hours and days
- Medium term – months and years
- Long term - decades

Short Timescales: Storms



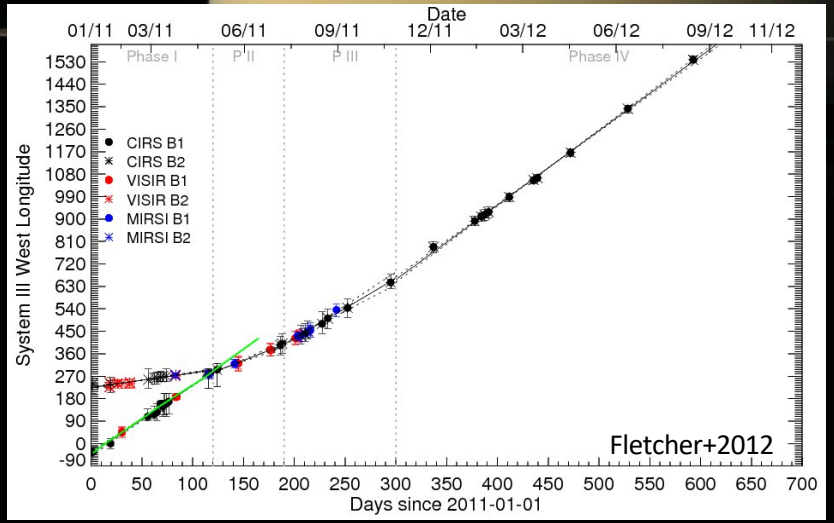


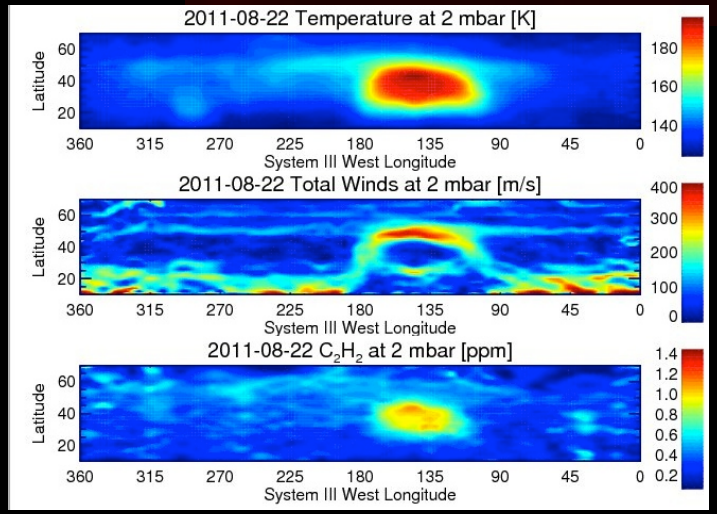


- Meteorology in H2-rich atmospheres.
- VISIR observations characterize the 3D structure of storm plumes (Fletcher+2017)

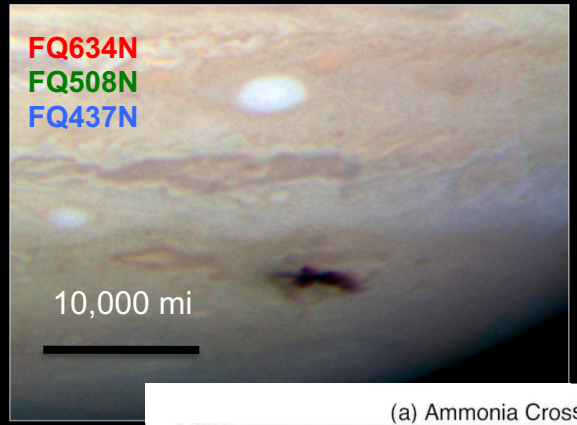
Short Timescales: Saturn's Great Storms

VLT/VISIR 13 μm, July 24 2011

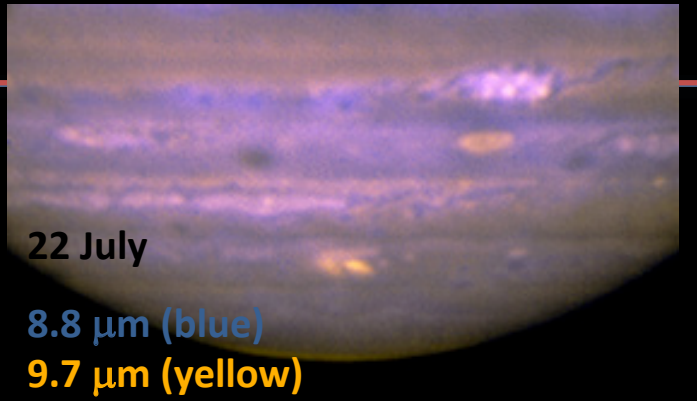




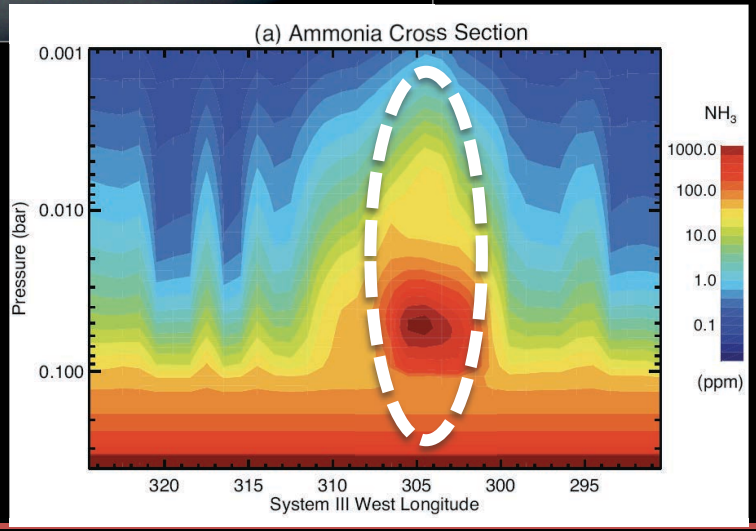
Short Timescales: Impacts

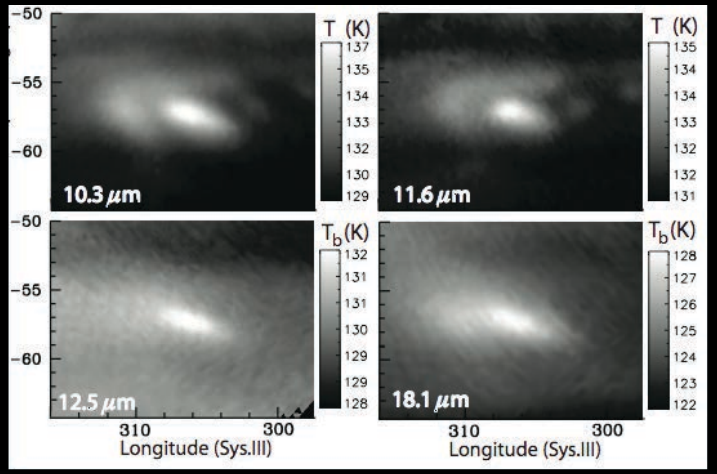


- Aerosols/soot.
- Reducing chemistry – no water.
- Ammonia in the stratosphere.
- Impactor dynamics
- Fletcher+2010; Orton+2011

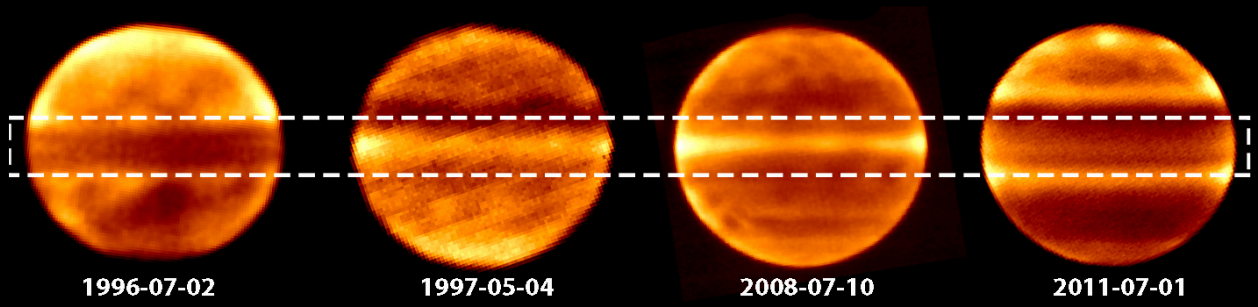


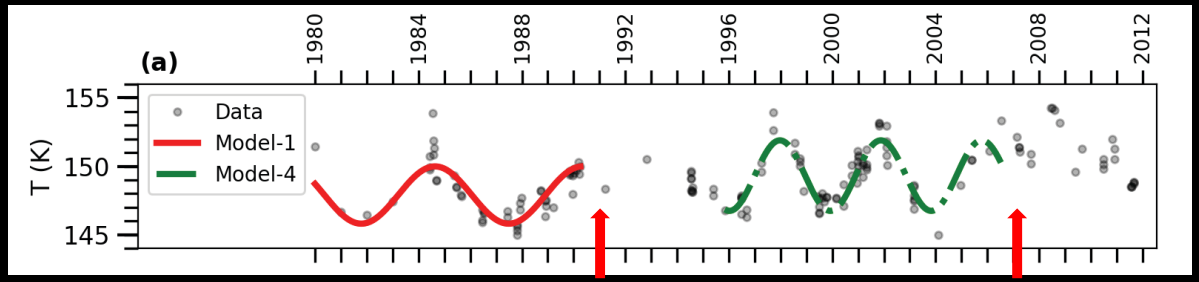
Gemini/MICHELLE & TRECS





Medium Timescales: Stratospheric Oscillations



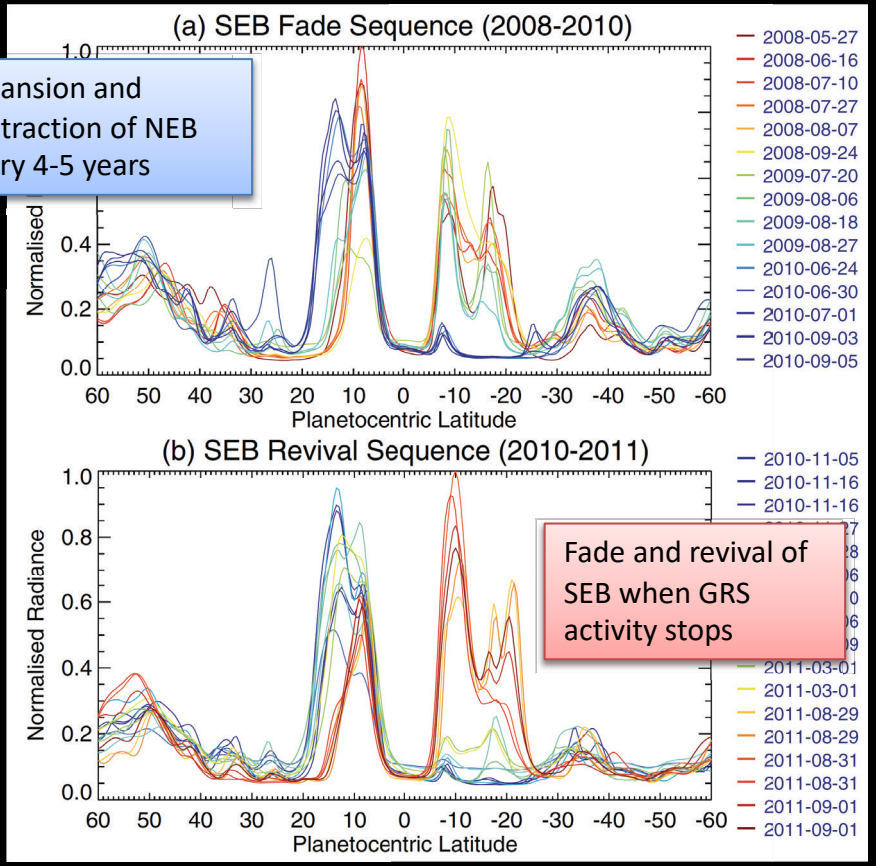


NASA/IRTF

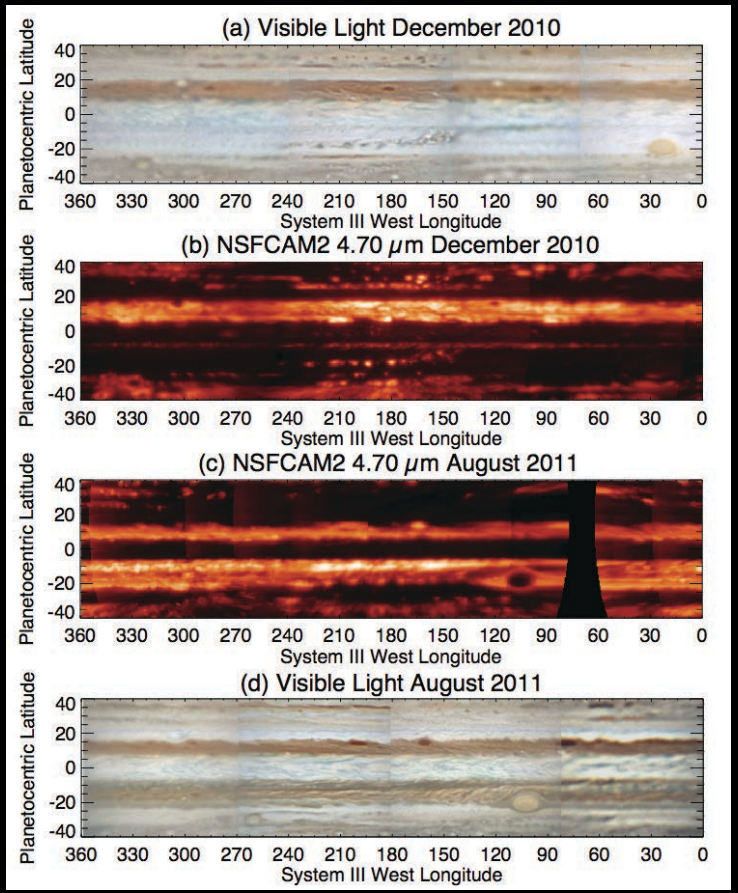
- Periodic oscillation of the equatorial winds and temperatures at ~10 mbar pressure level (Orton+1991, Leovy+1991).
- Analogous to Earth's QBO.
- 5.7±1.0-year period between 1980 and 1990.
- 3.9±0.7-year period between 1996 and 2006.
- Antuñano+2020a

Medium Timescales: Tropospheric Cycles

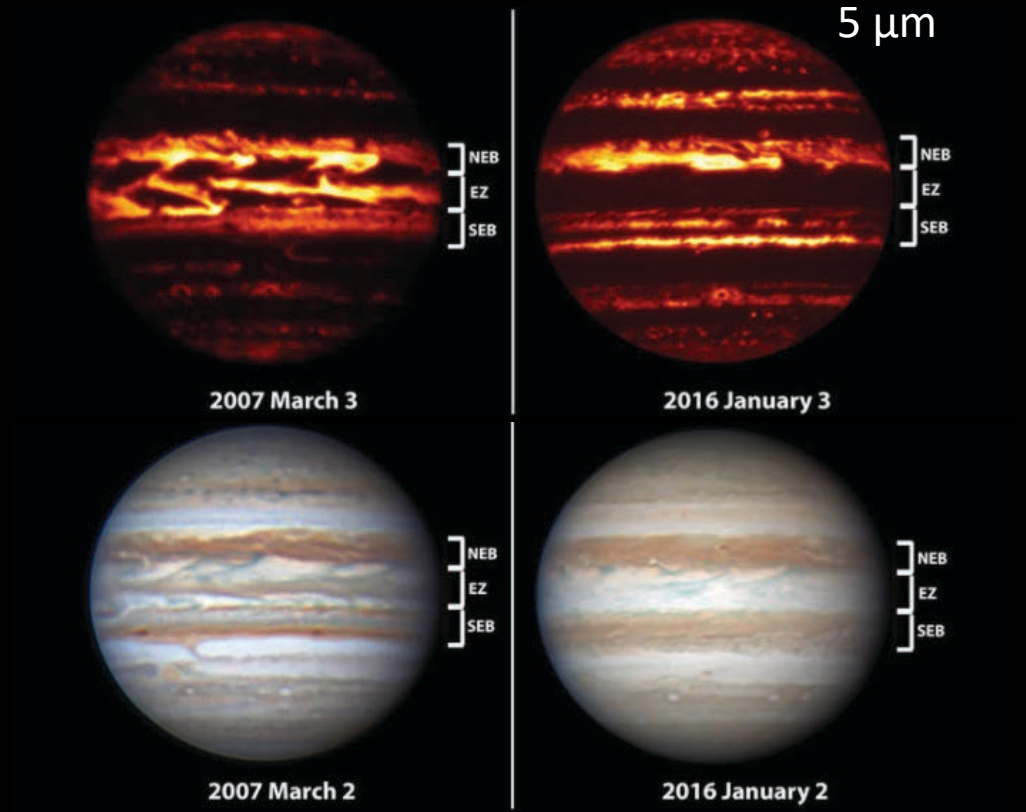
Expansion and contraction of NEB every 4-5 years



Fade and revival of SEB when GRS activity stops

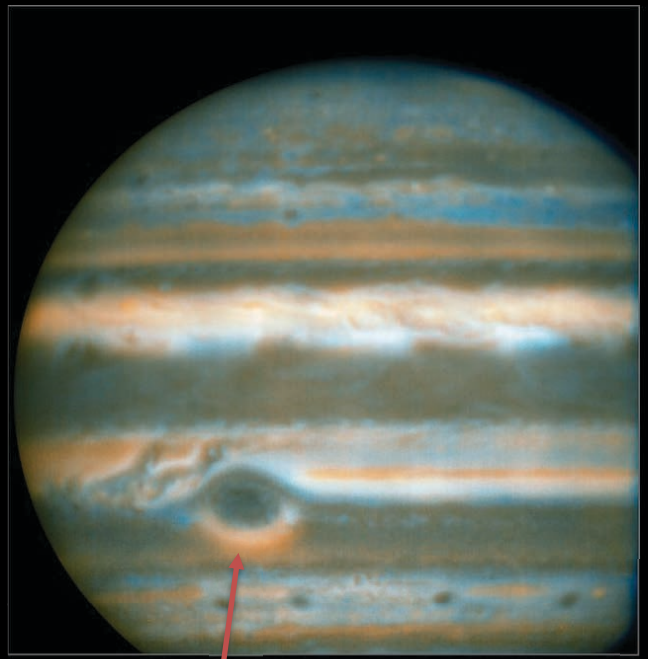


Medium Timescales: Equatorial Cloud Clearing

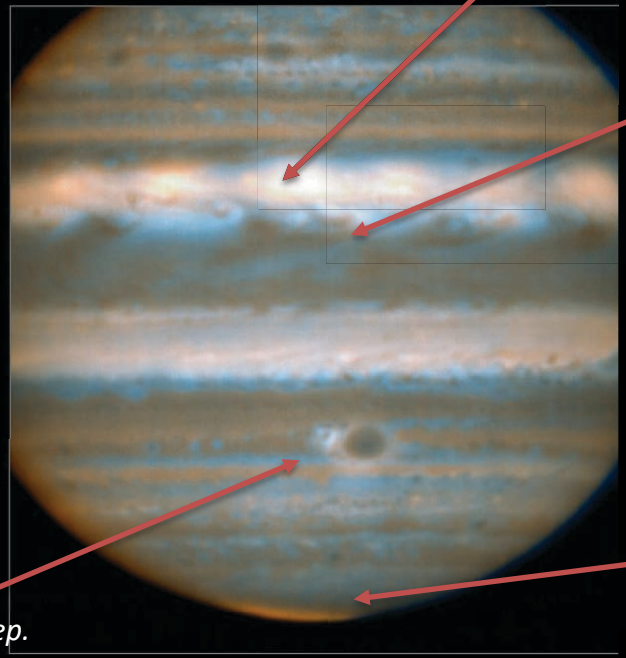


- Cloud-clearing events at the equator every 6-7 years (1973, 1979, 1992, 1999, 2007, 2019-20) – Antuñano+2018.
- VISIR characterized T/aerosol changes during 2006-07 event (Antuñano+2020b).
- 2019-20 event captured (partly) by Subaru, no VISIR ☹

Medium Timescales: Great Red Spot & Waves



Great Red Spot, Li+2020



Thermal NEB wave, Fletcher+2017

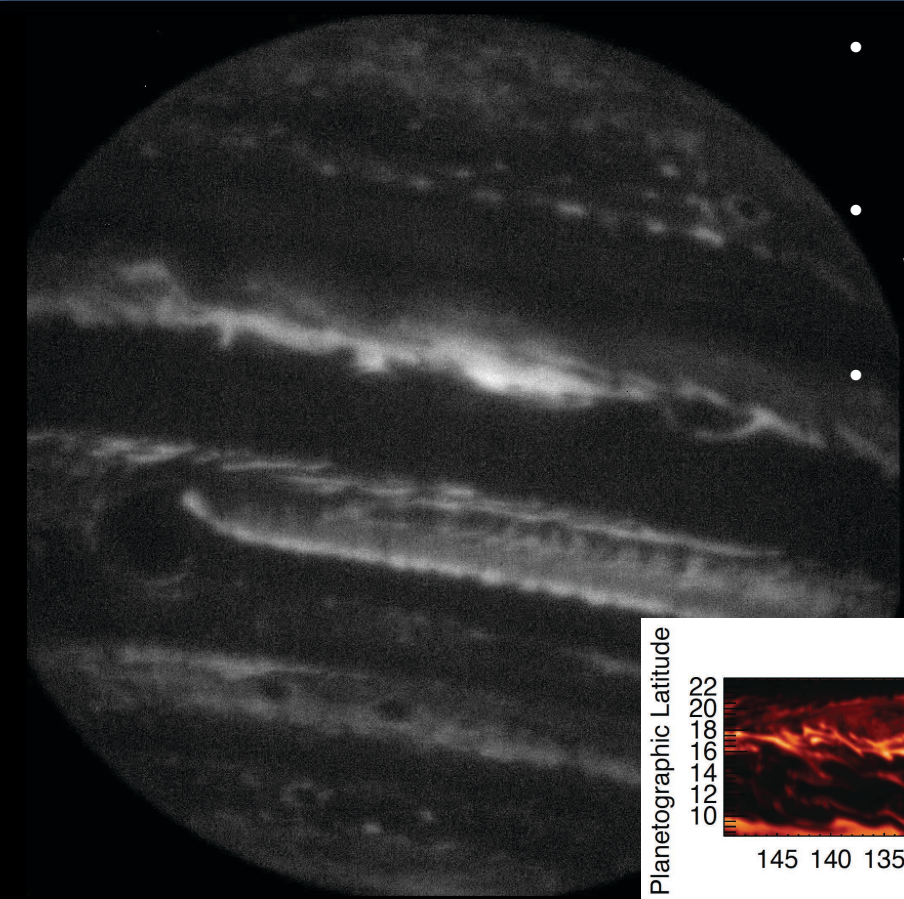
Hotspots and plumes, Fletcher+2020

Oval BA, Donnelly, in prep.

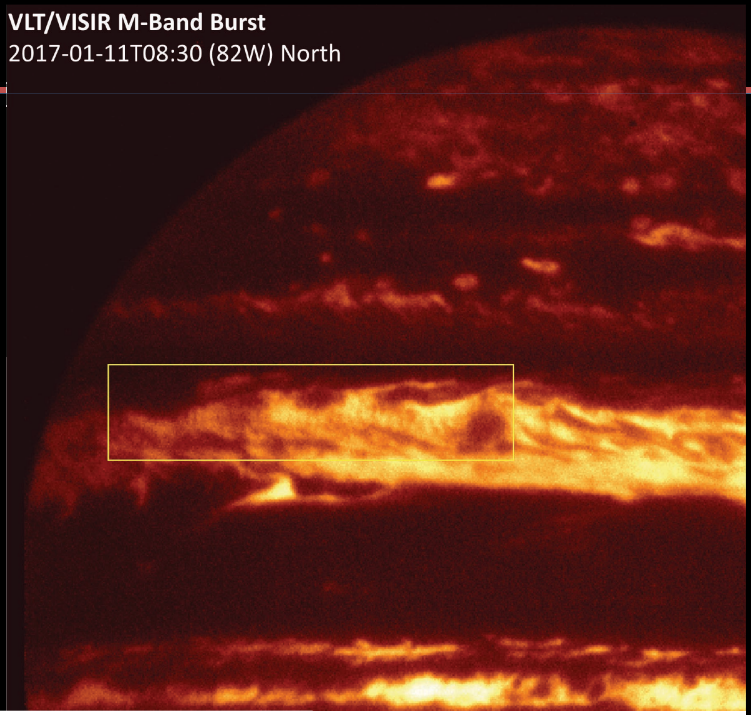
Auroral ethylene glowing, Sinclair+2018

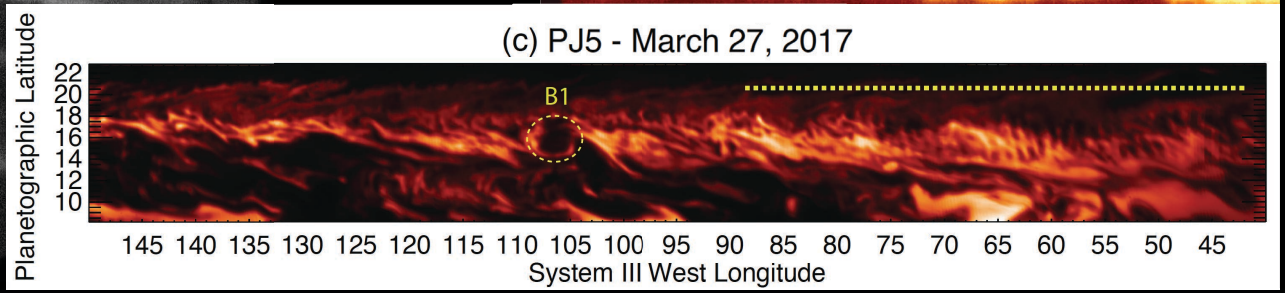
- Juno Support programme – mapping close to every 53-day perijove.
- Spatial, temporal, and spectral context.

VISIR Lucky Imaging Since 2016

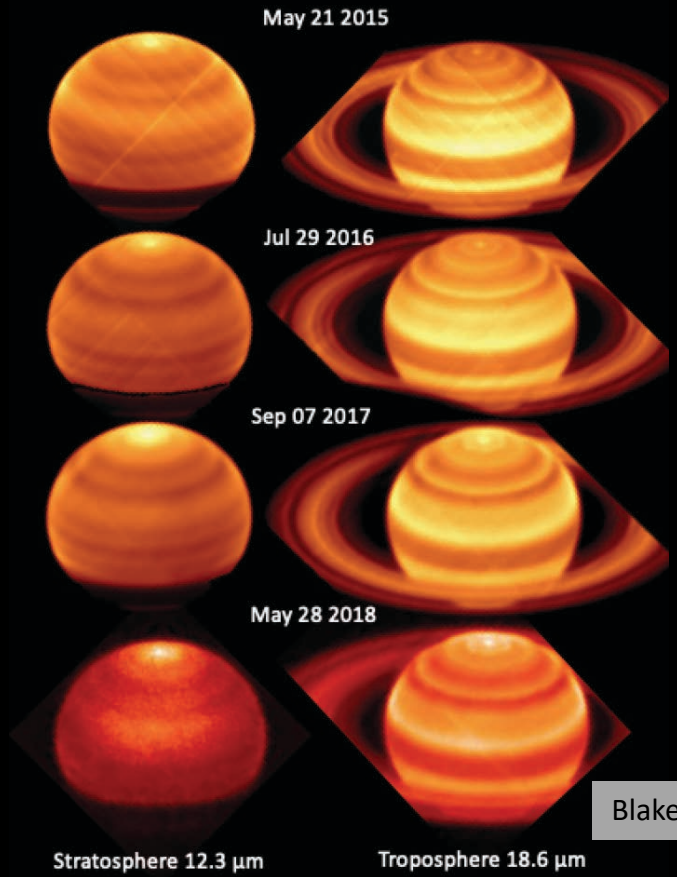


- Use of burst mode for lucky imaging.
- Detection of waves O(1000 km).
- Fletcher+2018.

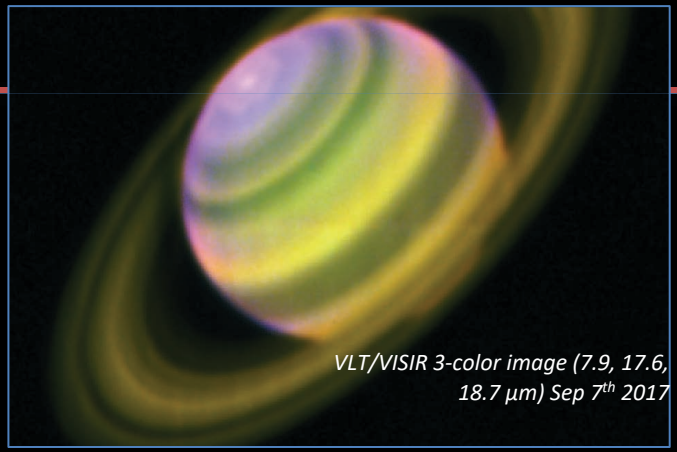




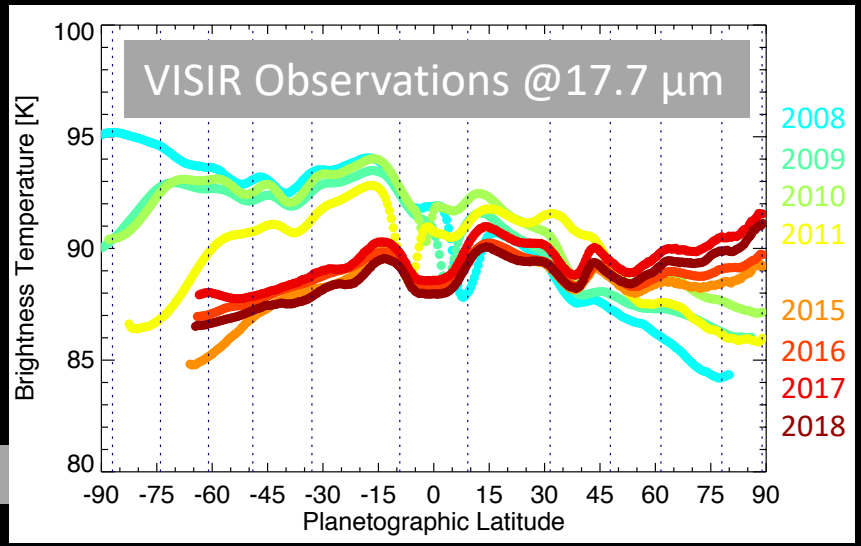
Long Timescales: Seasons



- 30-year orbit, 2009 equinox, 2025 solstice.
- Tracking Saturn's seasonal evolution beyond Cassini.

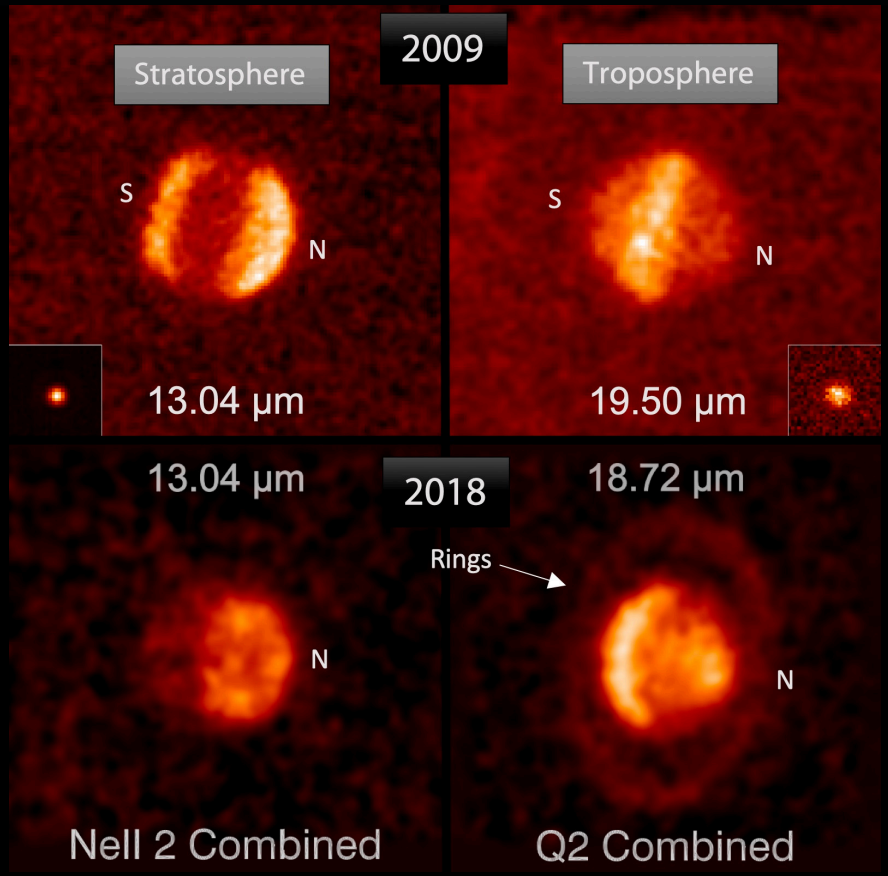


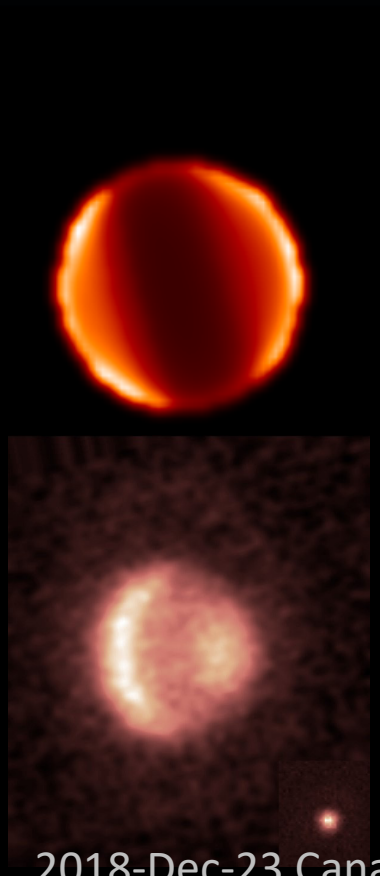
VLT/VISIR 3-color image (7.9, 17.6, 18.7 µm) Sep 7th 2017



Blake et al., in prep.

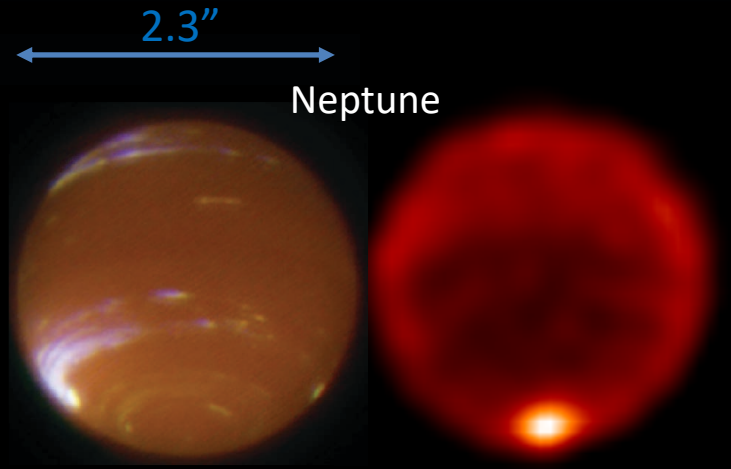
Long Timescales: Changes on Uranus





- 84-yr orbit, N. spring equinox 2007.
- Uranus thermal changes over a decade from VISIR.
- Troposphere: limited change since 1986 V2 observations (Orton+2015)
- Stratosphere: first glimpse of stratospheric structure (Roman+2020).
- First thermal-IR views of the rings! (Molter+2019)

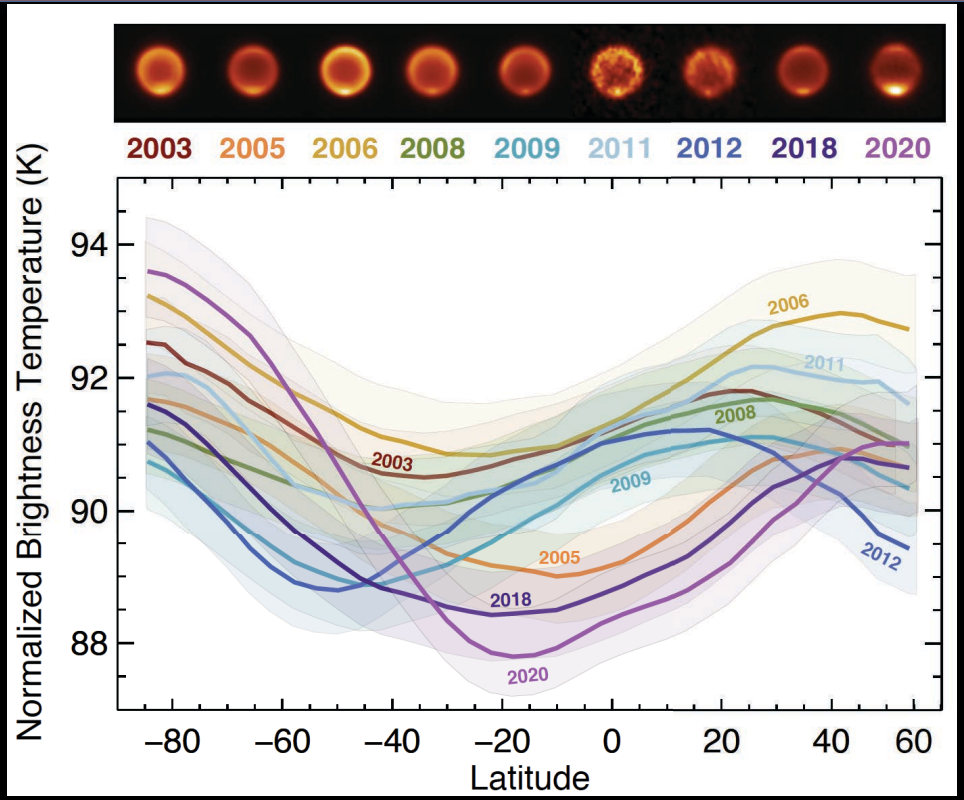
Long Timescales: Changes on Neptune



Near-IR (de Pater et al.)

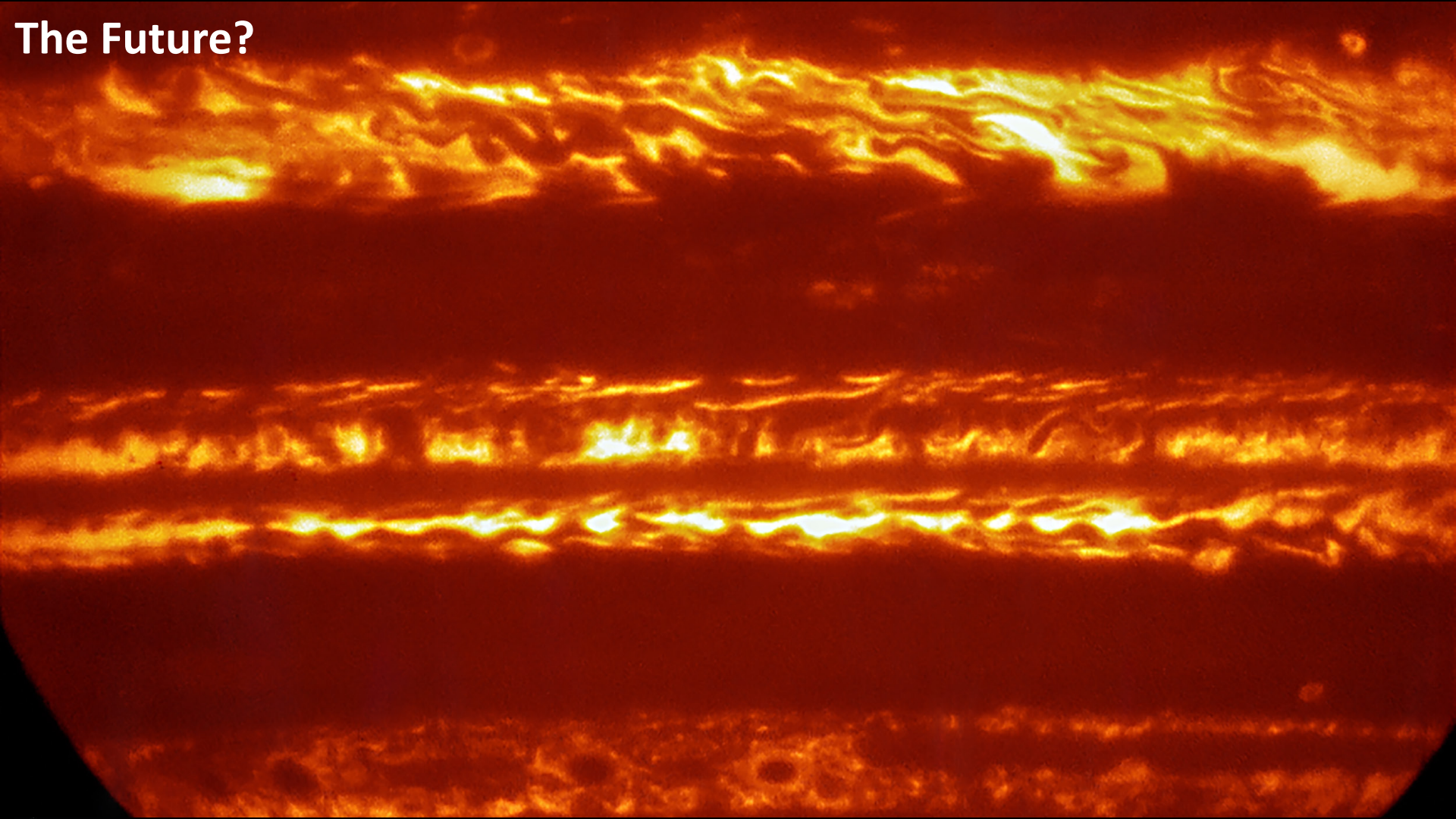
VISIR 7.9 μm 2008 (Sinclair+2020)

- 165-yr orbit, summer solstice 2005.
- Troposphere largely unchanged since V2 1989 with exception of warm pole (Fletcher+2014).
- Connection between tropospheric weather and stratospheric methane (Sinclair+2020).



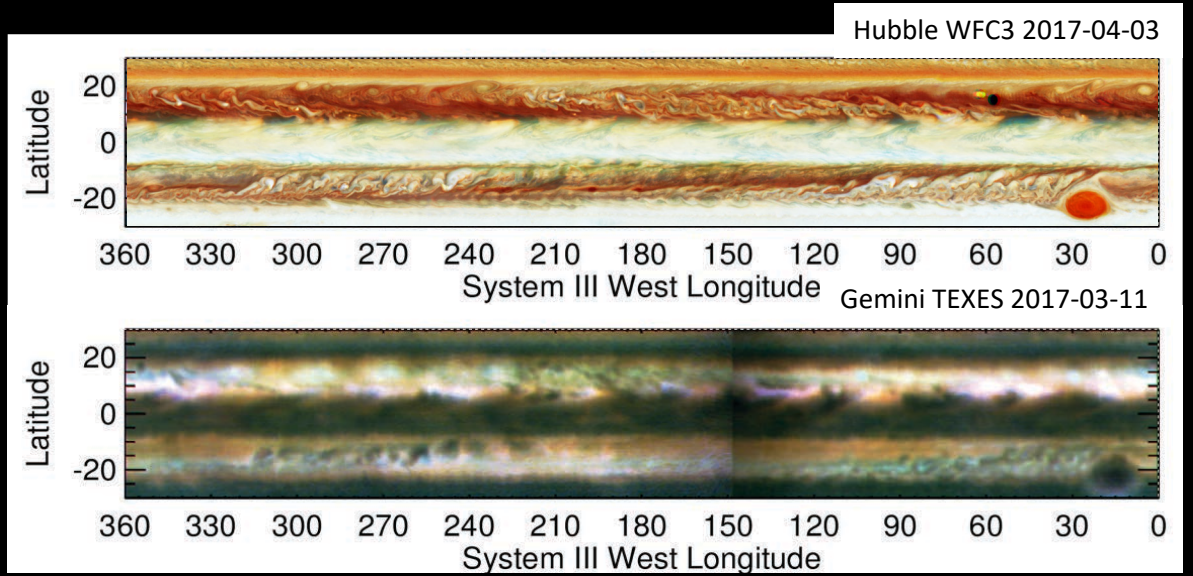
- Unexpected sub-seasonal change in the stratosphere (Roman, in prep.)

The Future?



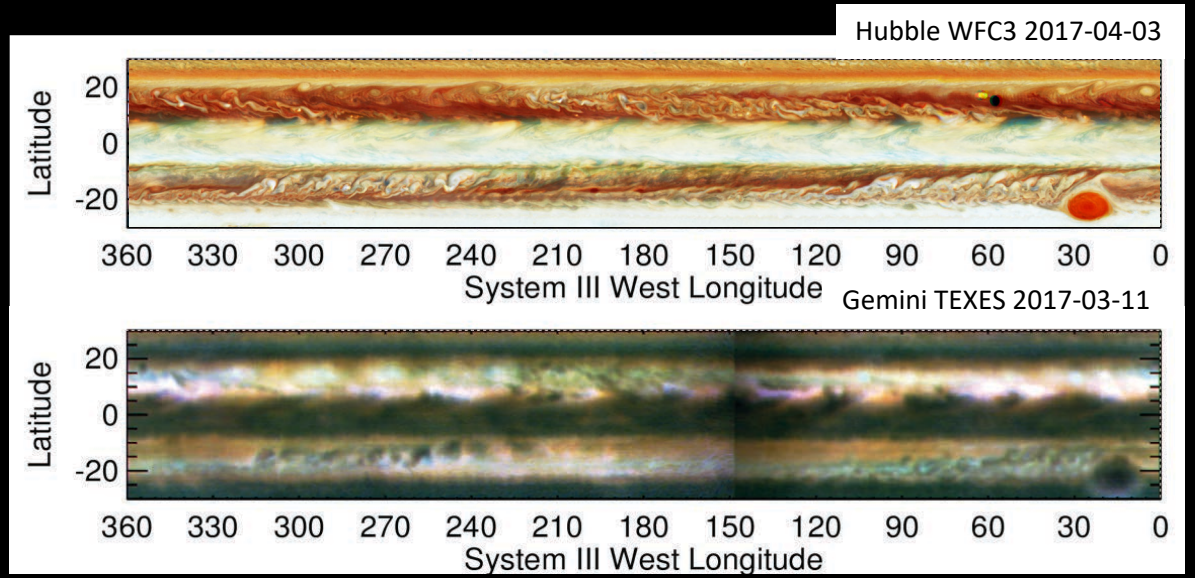
Long-Term Studies: It takes a village…

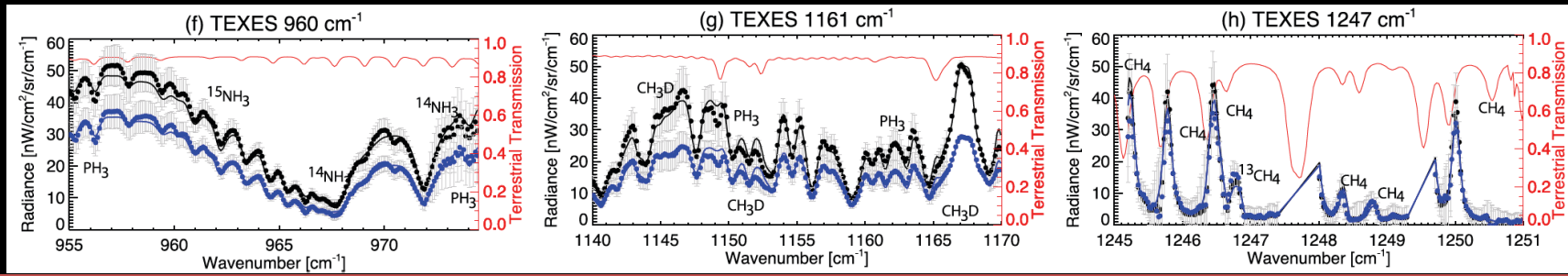
- **IRTF:**
  - BOLO-1, AT1, Protocam
  - MIRLIN, MIRAC, MIRSI
  - TEXES
- **VLT:** VISIR
- **Subaru:** COMICS
- **Gemini:**
  - TRECS, MICHELLE
  - TEXES
- **Keck:** LWS
- **Grantecan:** CanariCam



Long-Term Studies: It takes a village…

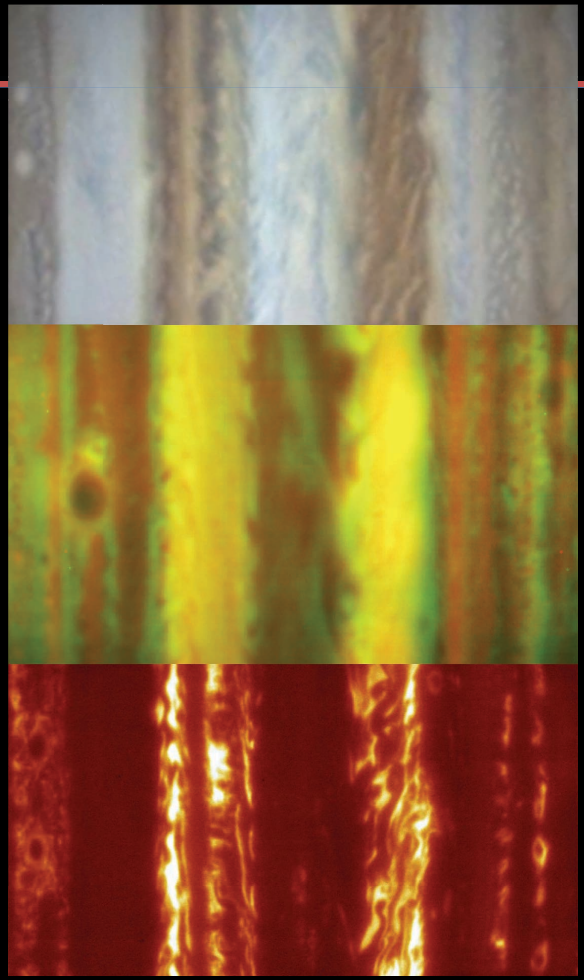
- **IRTF:**
  - TEXES
- **VLT:** VISIR
- **Gemini:**
  - TEXES





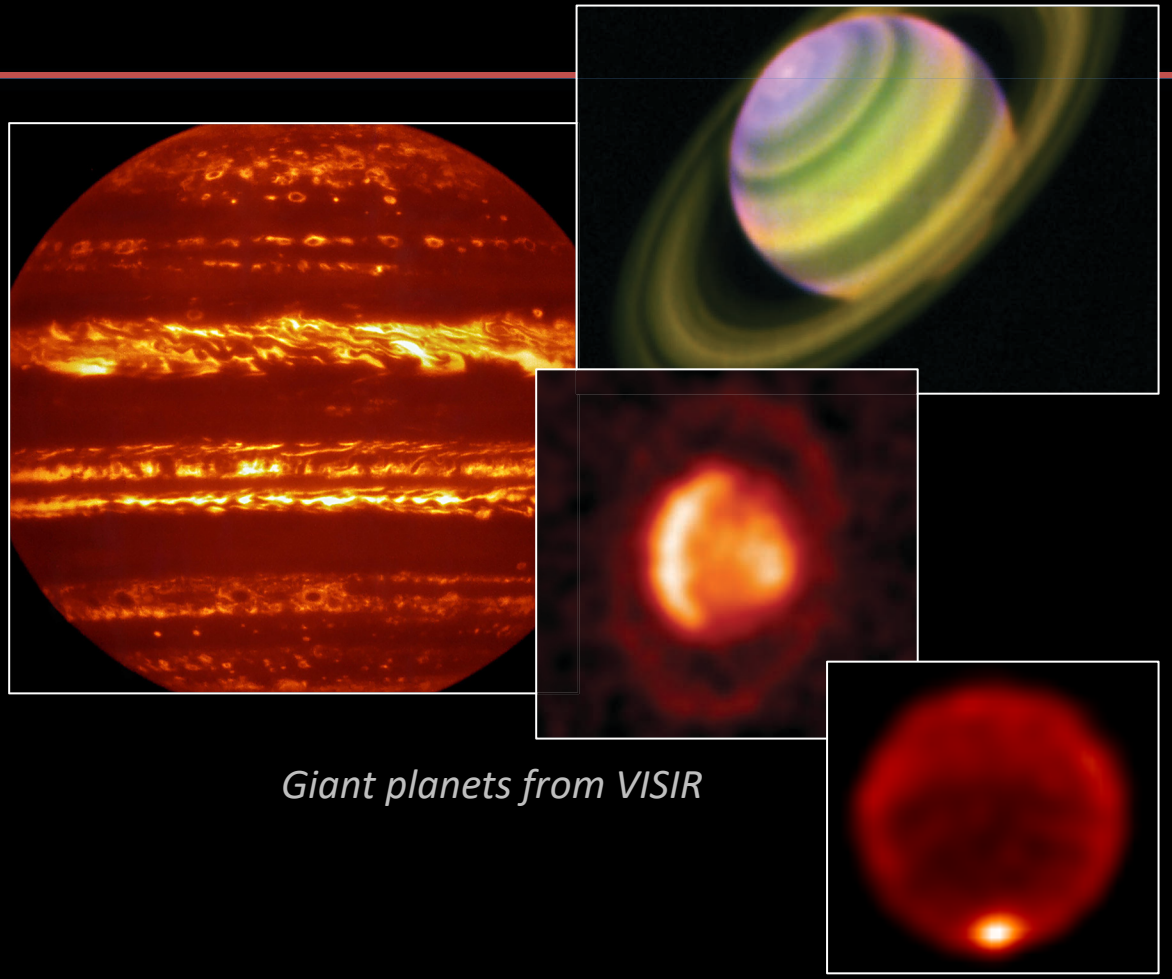
Needs for the Future: A Wish-List

- ✓ Wide FOVs (1 arcmin) and high chop/nod throws.
- ✓ A pathway for mission support for NASA/Juno, ESA/JUICE.
- ✓ Regular (and short) monitoring runs.
- ✓ Rapid response (DDT) route.
- ✓ Broad spectral coverage at mid-to-high resolution (R~1,000-100,000).
- ✓ Spectral & spatial coverage (IFUs like JWST/MIRI?).
- ✓ IRTFs and VLTs to support ELTs.



Summary & Perspectives

- Mid-IR observations reveal **environmental conditions in planetary atmospheres**.
  - Short term: impacts/storms
  - Medium term: belt/zone cycles
  - Long term: seasons.
- Identifying **natural cycles** requires long-term monitoring…
  - …but threats of mid-IR dark period extremely worrying.
- **Mid-IR mission support** needed for Juno, JWST, JUICE, Europa Clipper…



Giant planets from VISIR