Jupiter's 3-dimensional atmosphere through JWST observations

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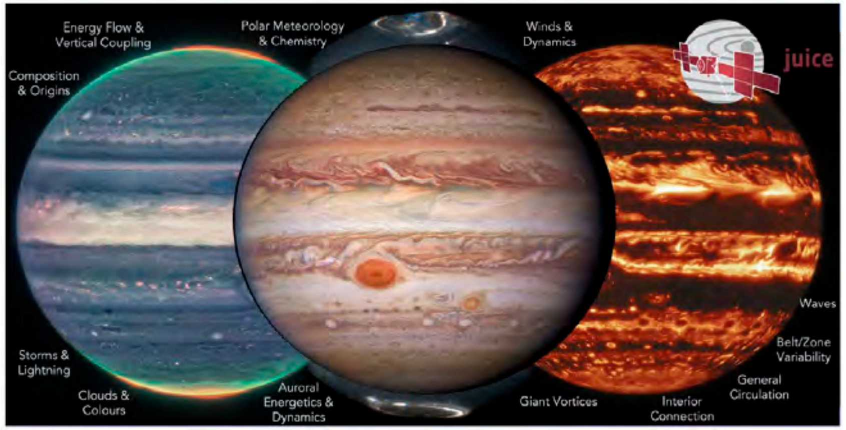
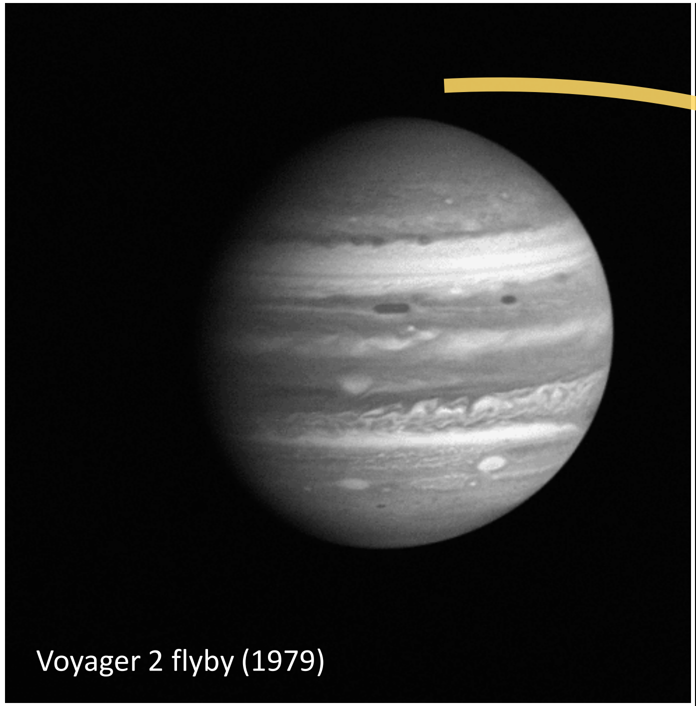
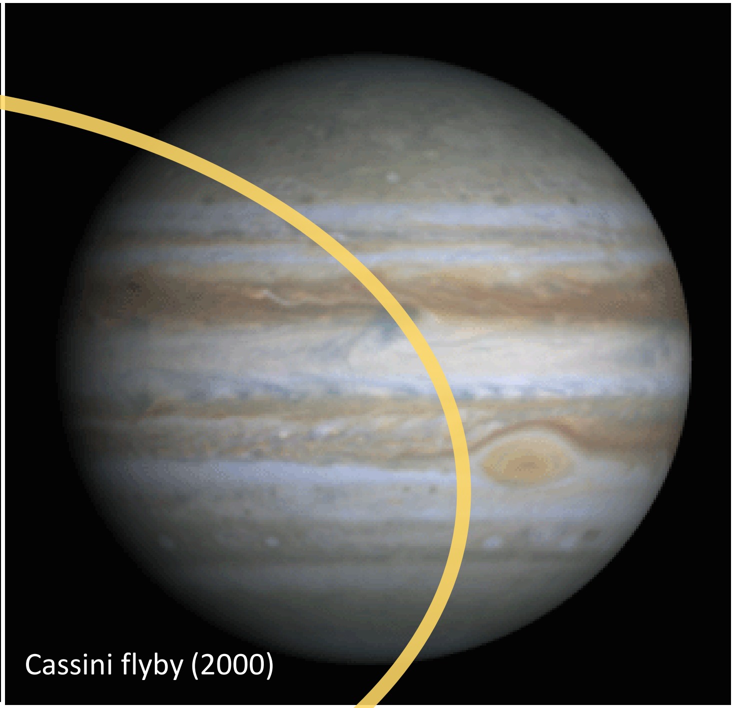
4. University of Leicester, Leicester, UK
5. JPL/Caltech, USA

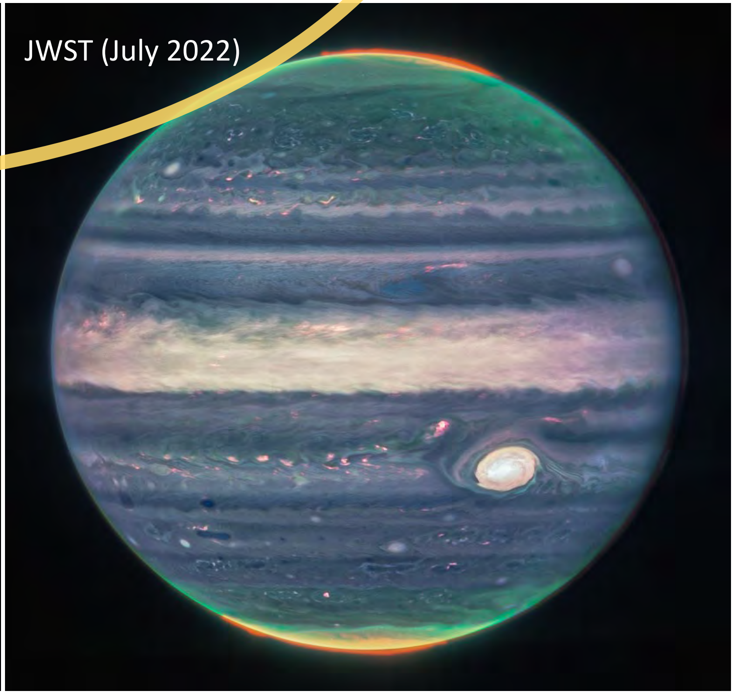
Jupiter's Belts, Zones and Winds
1979 to 2023 & 2032-2035



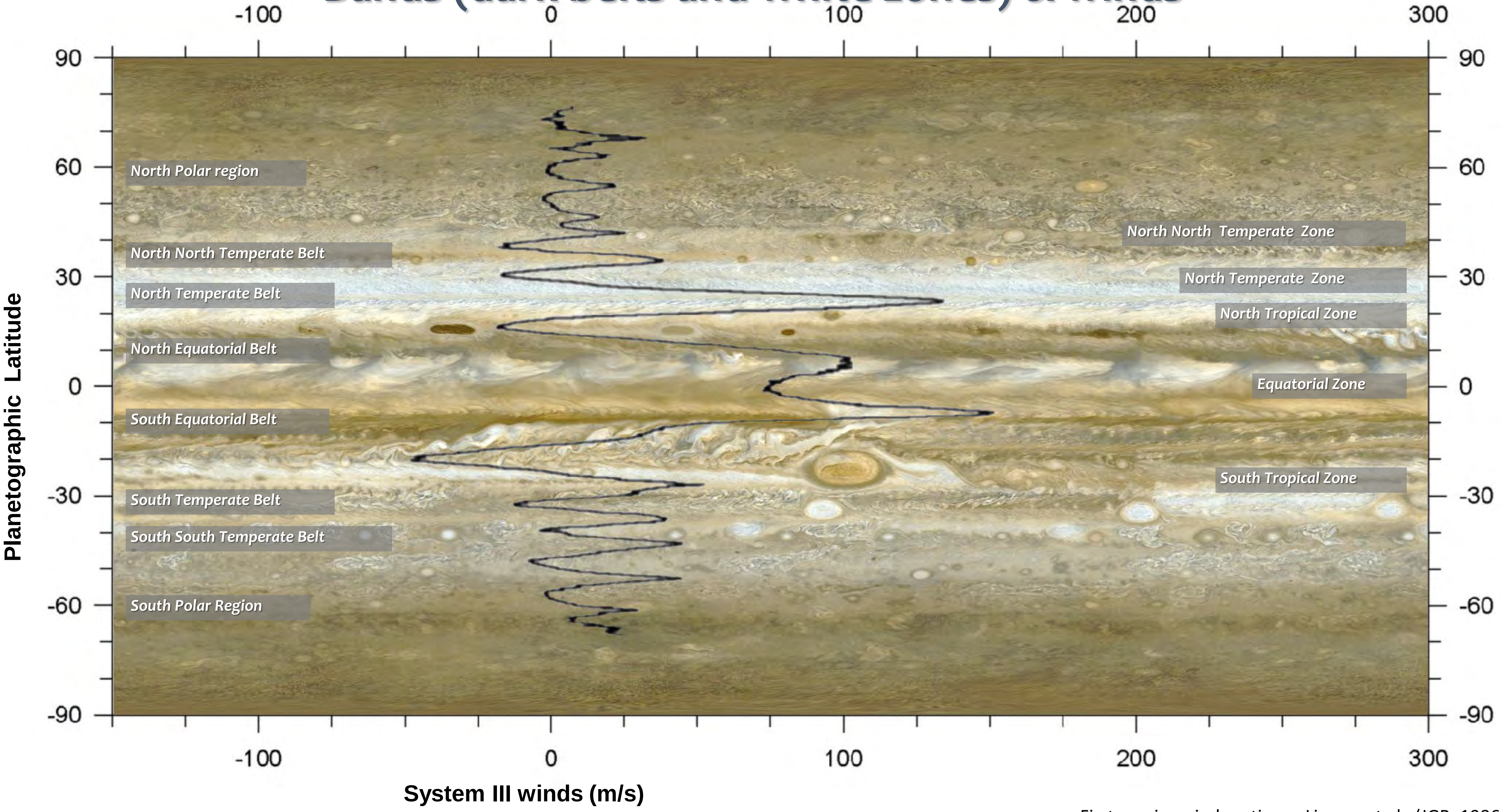

Voyager 2 flyby (1979)


Cassini flyby (2000)

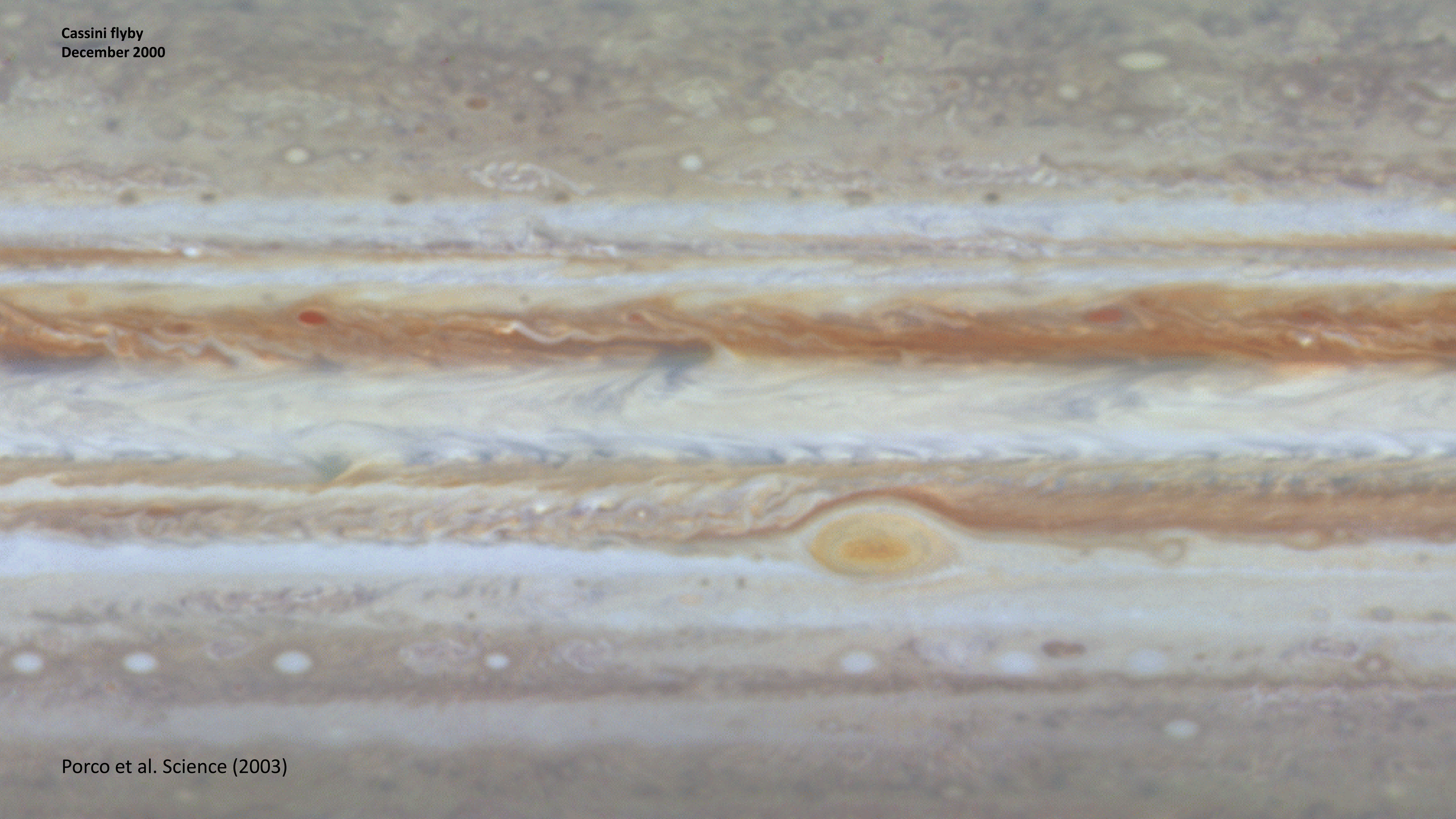

Juno (2016-2026)

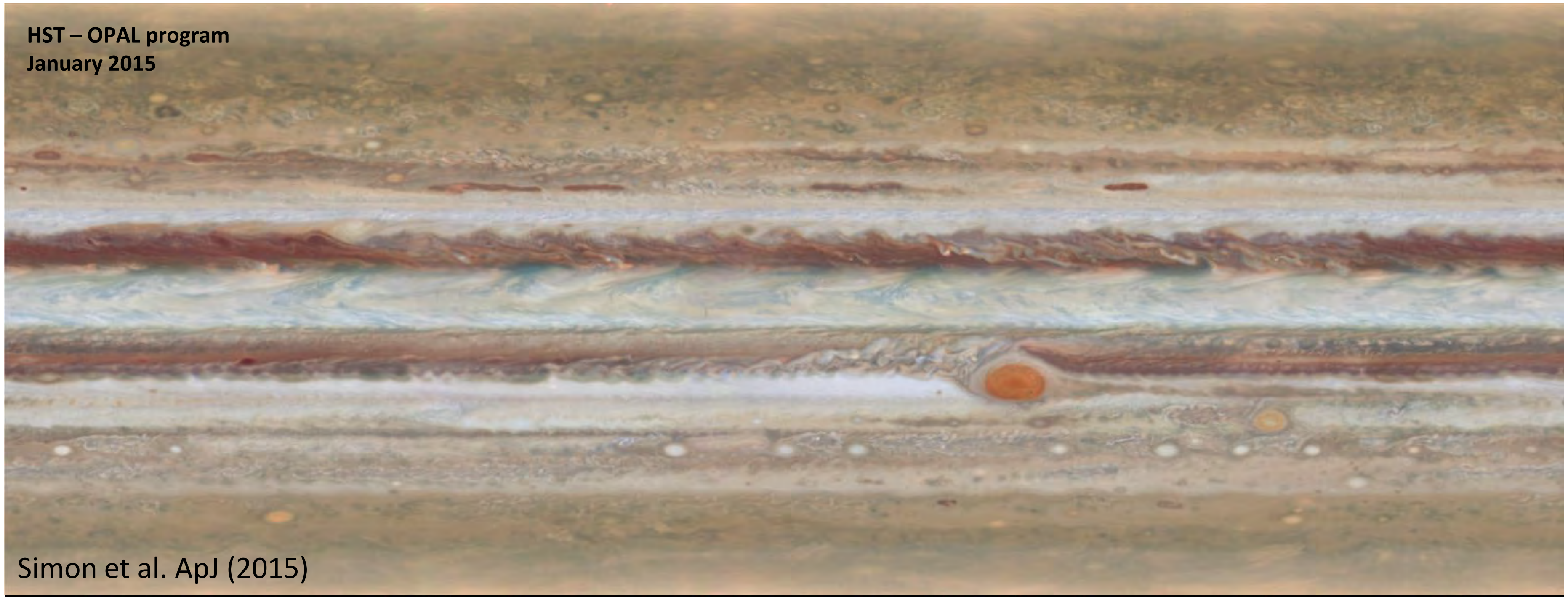

JWST (July 2022)

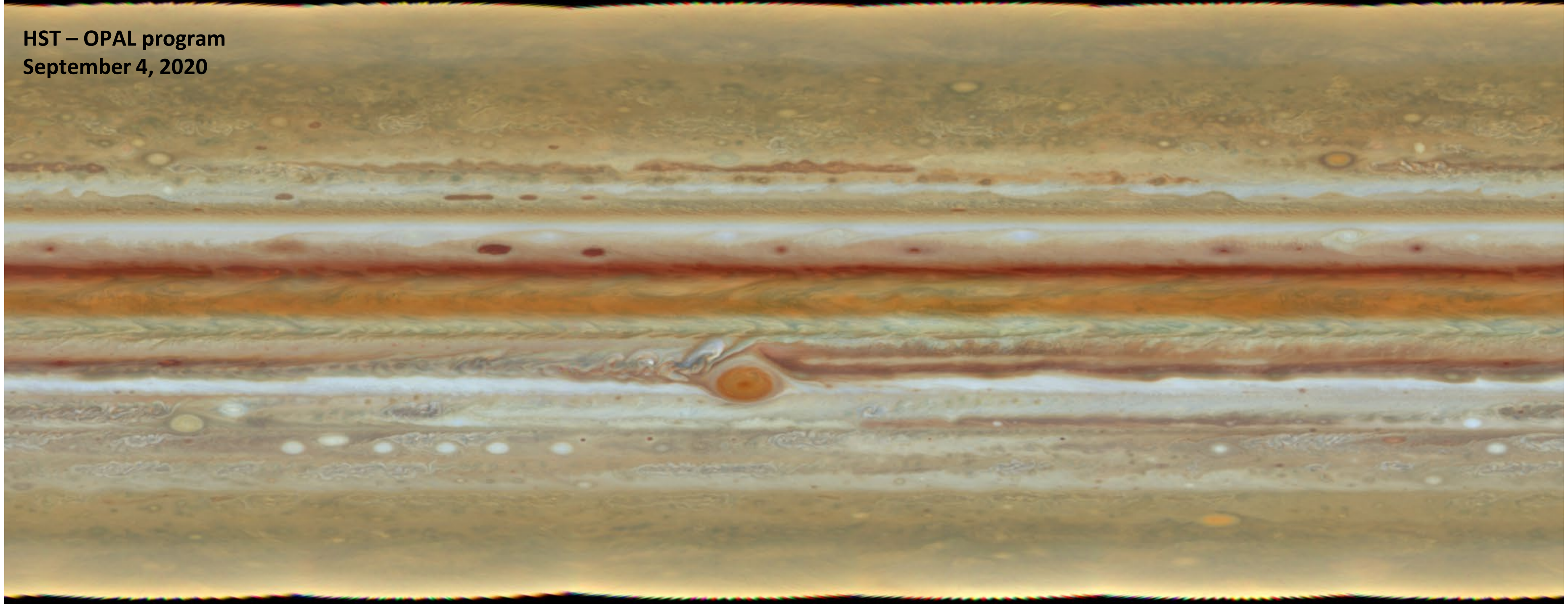
Bands (dark belts and white zones) & winds



First precise wind motions: Limaye et al. (JGR, 1986)


Cassini flyby
December 2000
Porco et al. Science (2003)

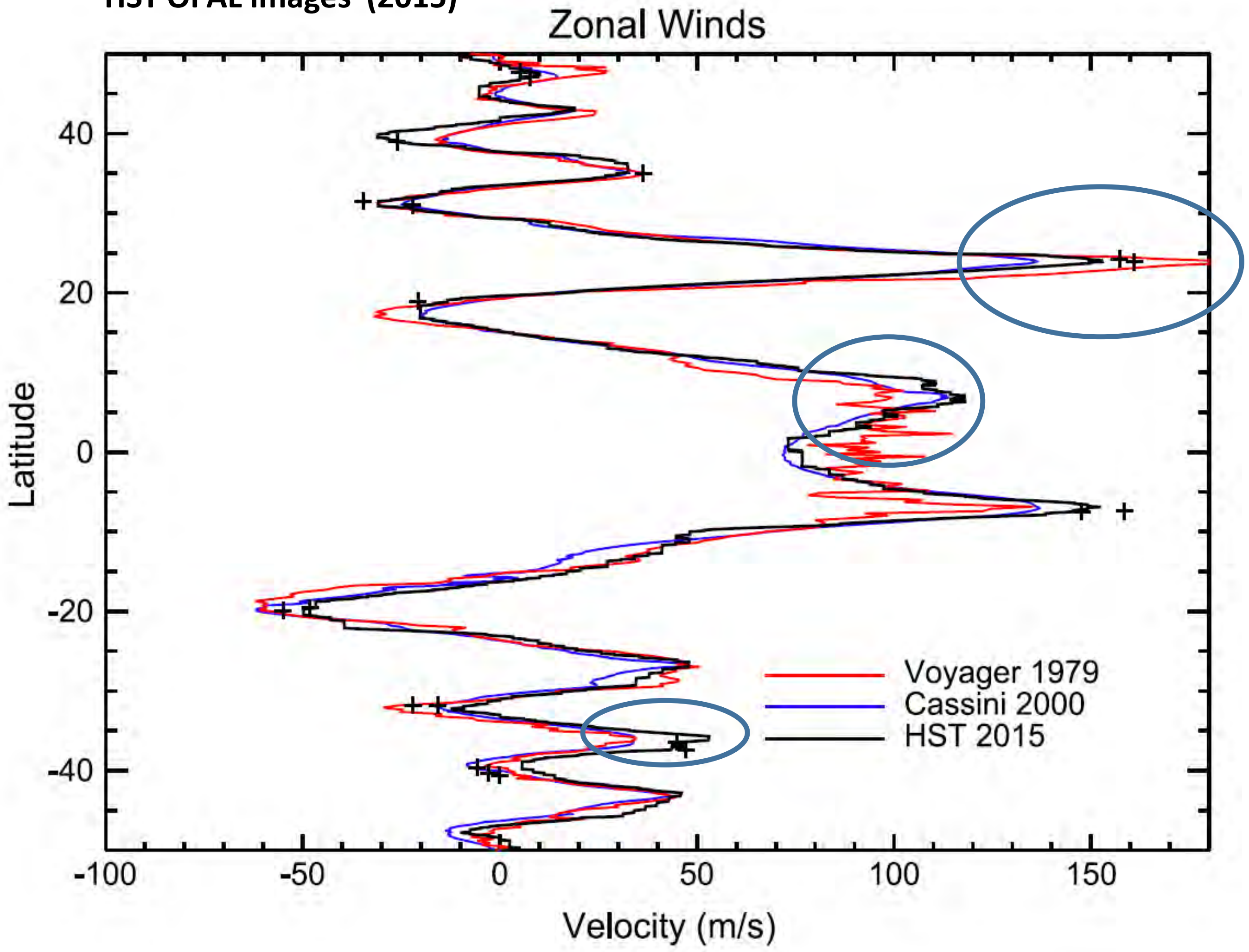

HST – OPAL program
January 2015
Simon et al. ApJ (2015)


HST – OPAL program
September 4, 2020

Studies of winds in Jupiter and their temporal variation

HST 1995-2000: García-Melendo et al. Icarus, 2001 | Overall wind stability. No major changes although small changes in the peak velocities of certain jets

HST OPAL images (2015)



Simon et al. ApJL, 2015

Barrado-Izagirre et al. A&A, 2013

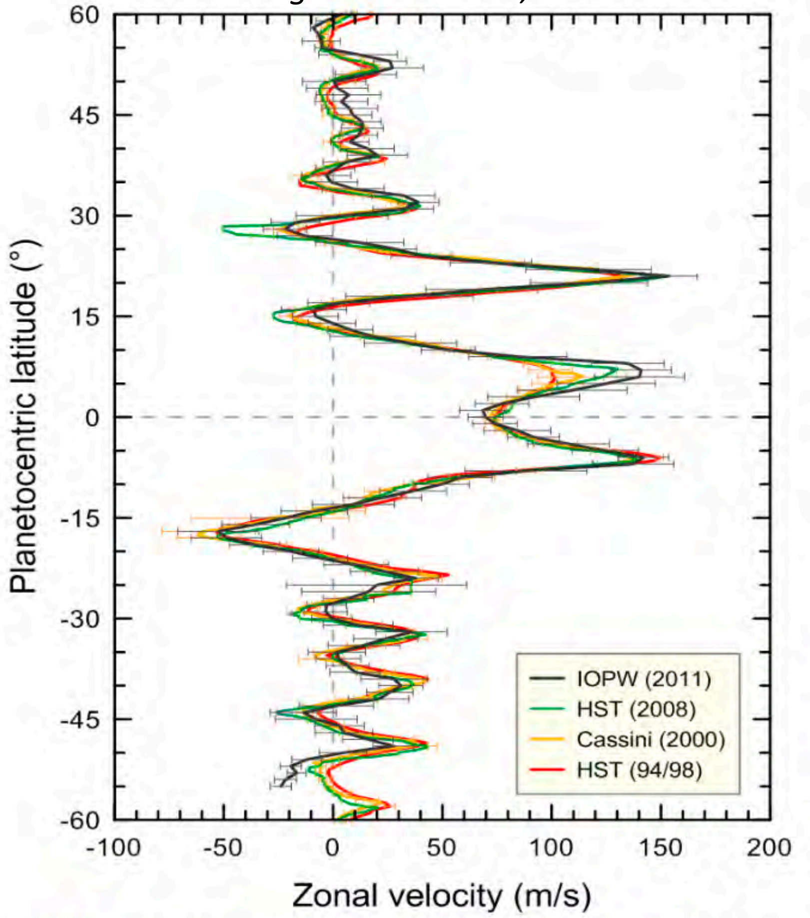
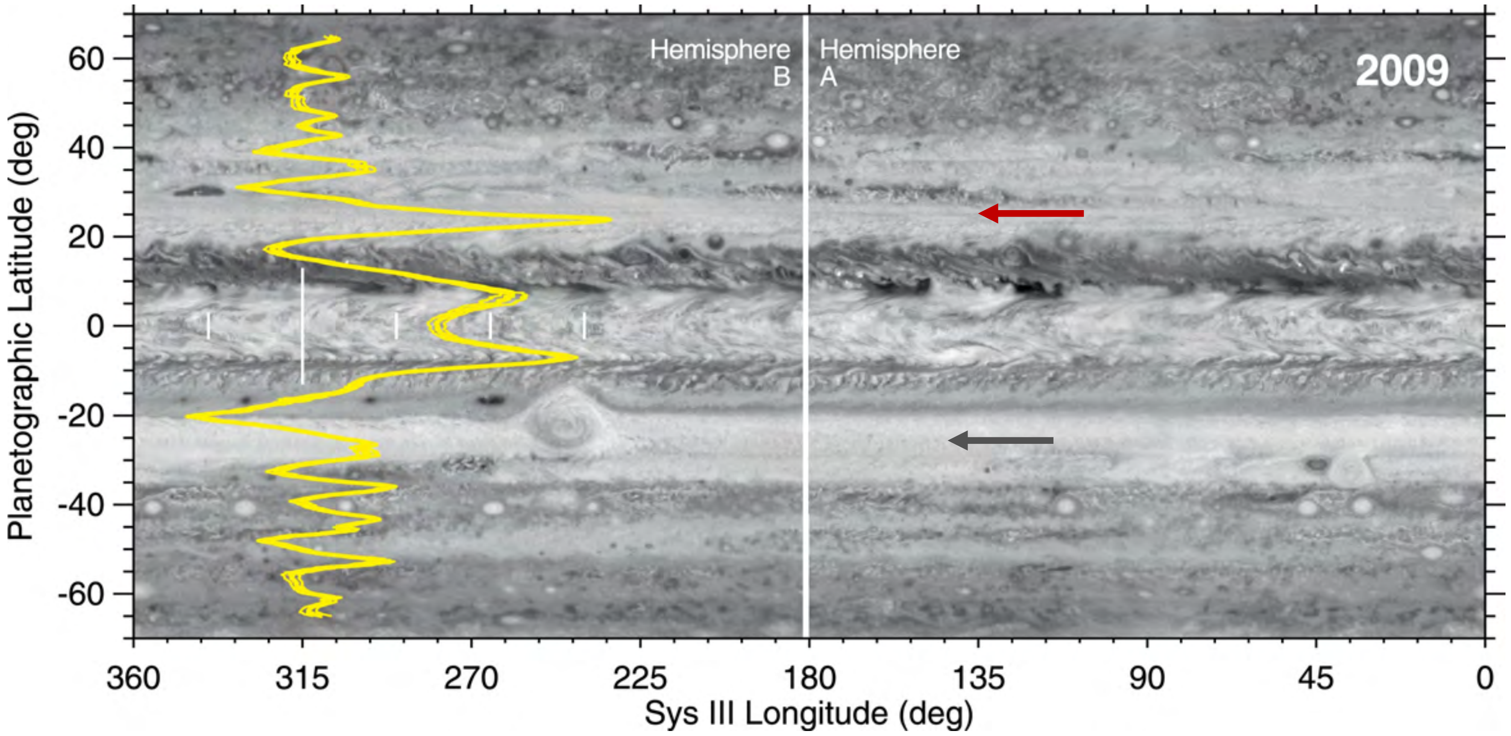


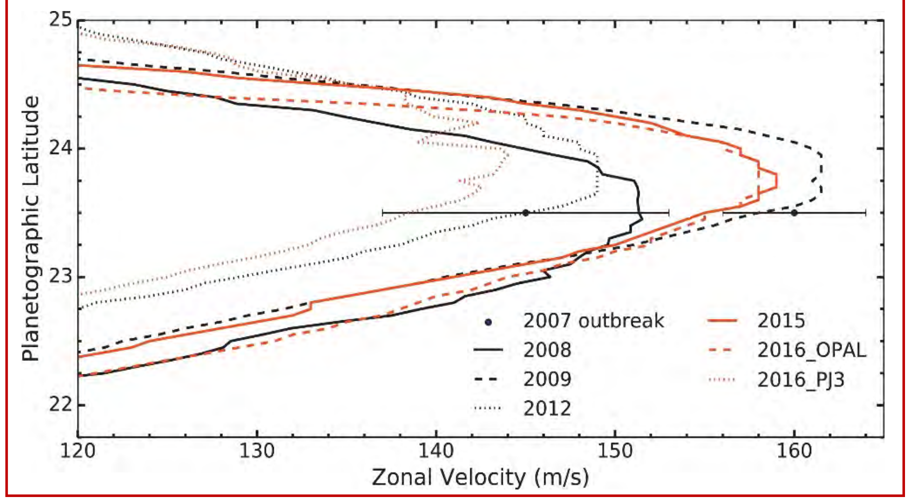
Fig. 9. Jupiter wind profiles in different years. Red line: mean wind profile retrieved by (García-Melendo & Sánchez-Lavega 2001) from HST observations in the period 1994 to 1998. Yellow line: wind profile from the Cassini flyby in 2000 (Porco et al. 2003). Green line: HST observations in 2008 (Asay-Davis et al. 2011). Black line: this work.

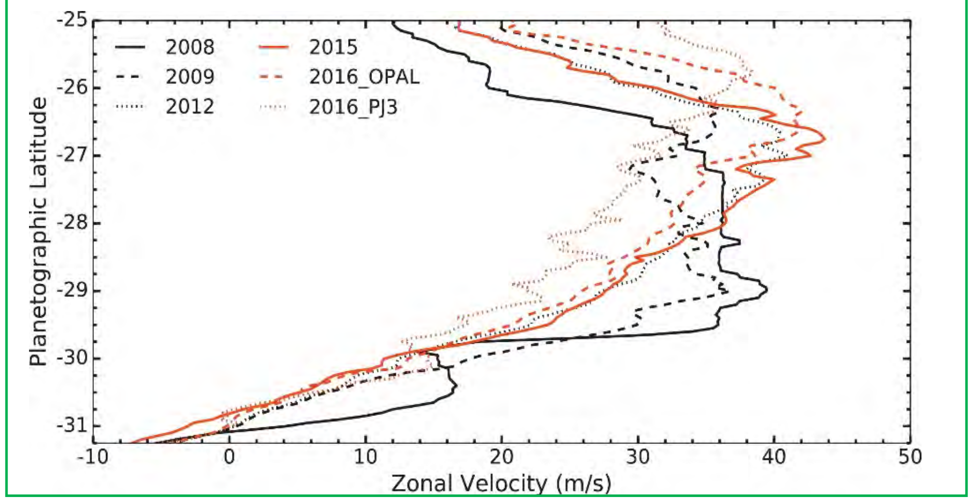
Studies of winds in Jupiter and their temporal variation



Tollefson et al., *Icarus, 2017 – "Changes in Jupiter's Zonal Wind Profile preceding and during the Juno mission"*

Longitudinal variability as the dominant source of uncertainty in zonal wind retrievals



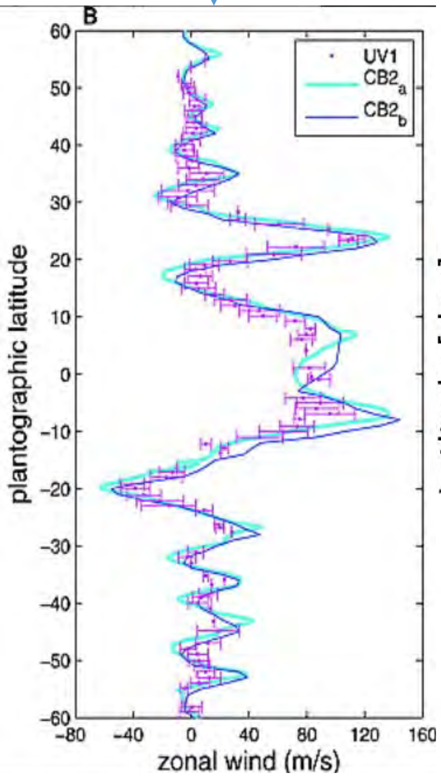


Limited capability to trace different winds on different wavelengths in the visible

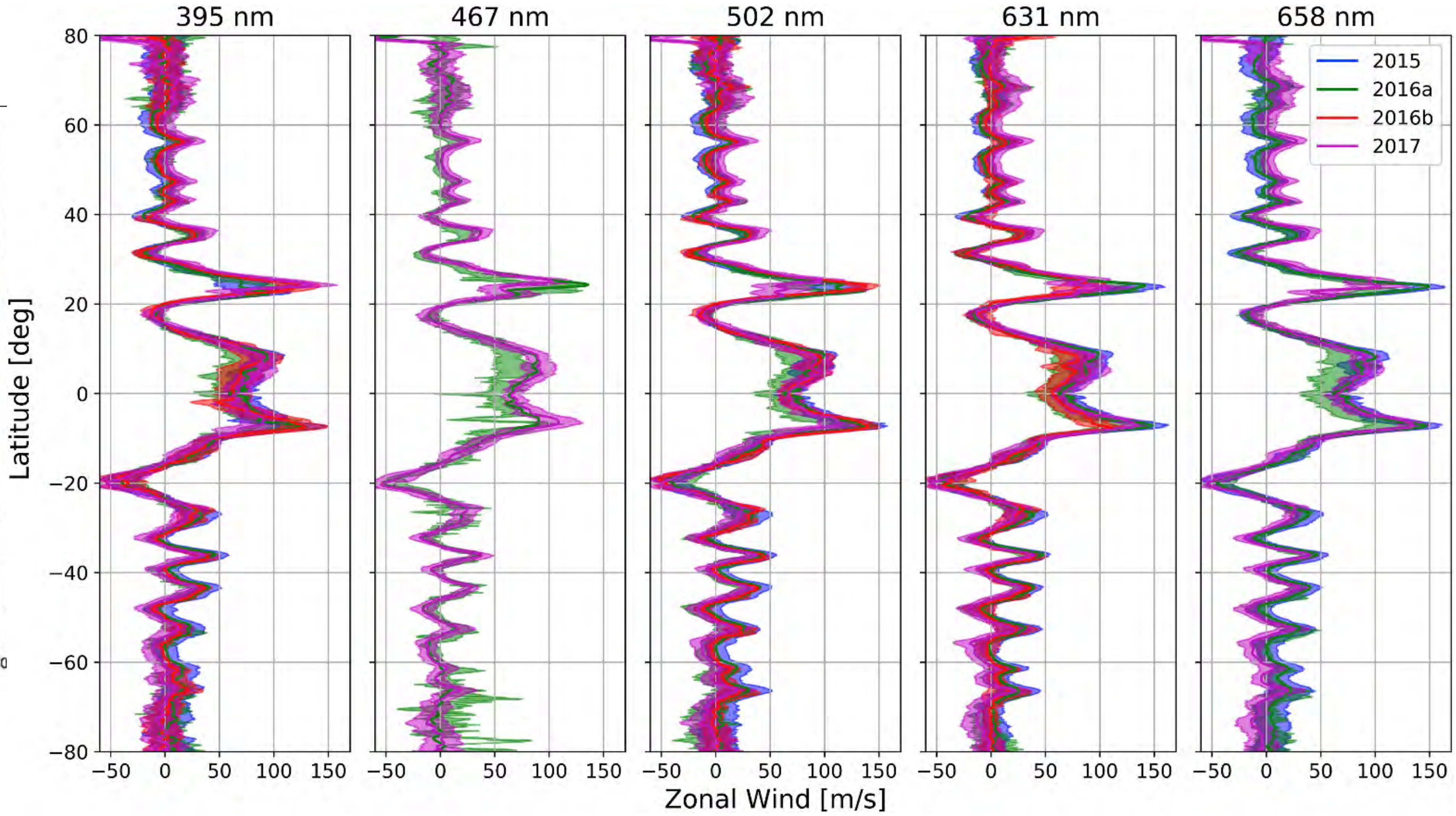
UV

890 nm & NIR

Li et al., PSS, 2018

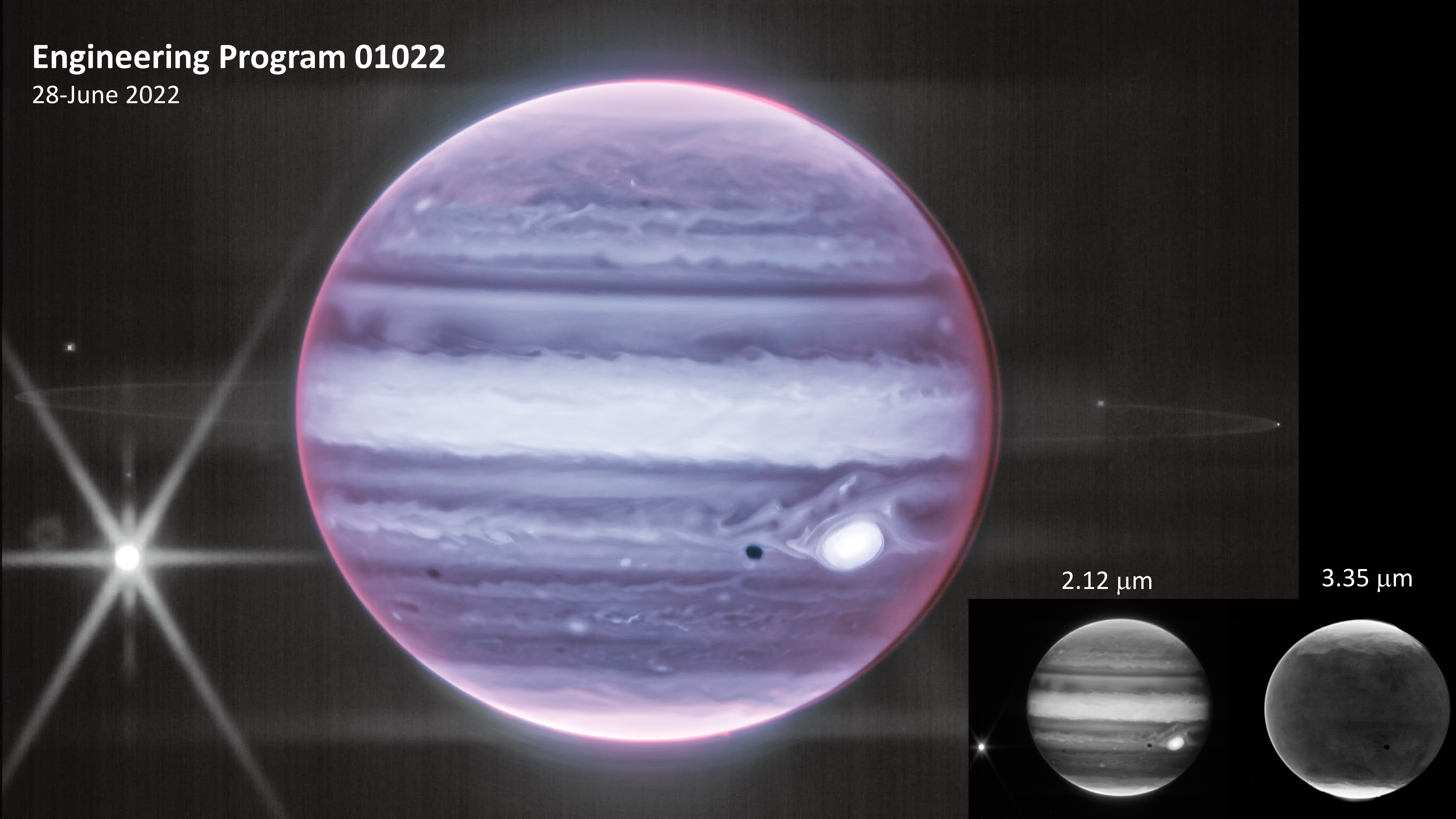


Johnson et al., PSS, 2018



Engineering Program 01022

28-June 2022



ERS observations of the Jovian System as a demonstration of JWST's capabilities for Solar System science (#1373)

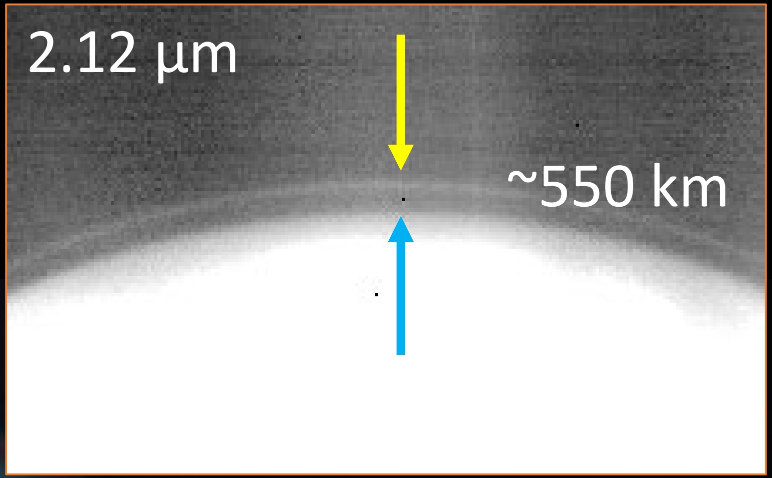
All JWST instruments & modes on different targets of the Jovian System

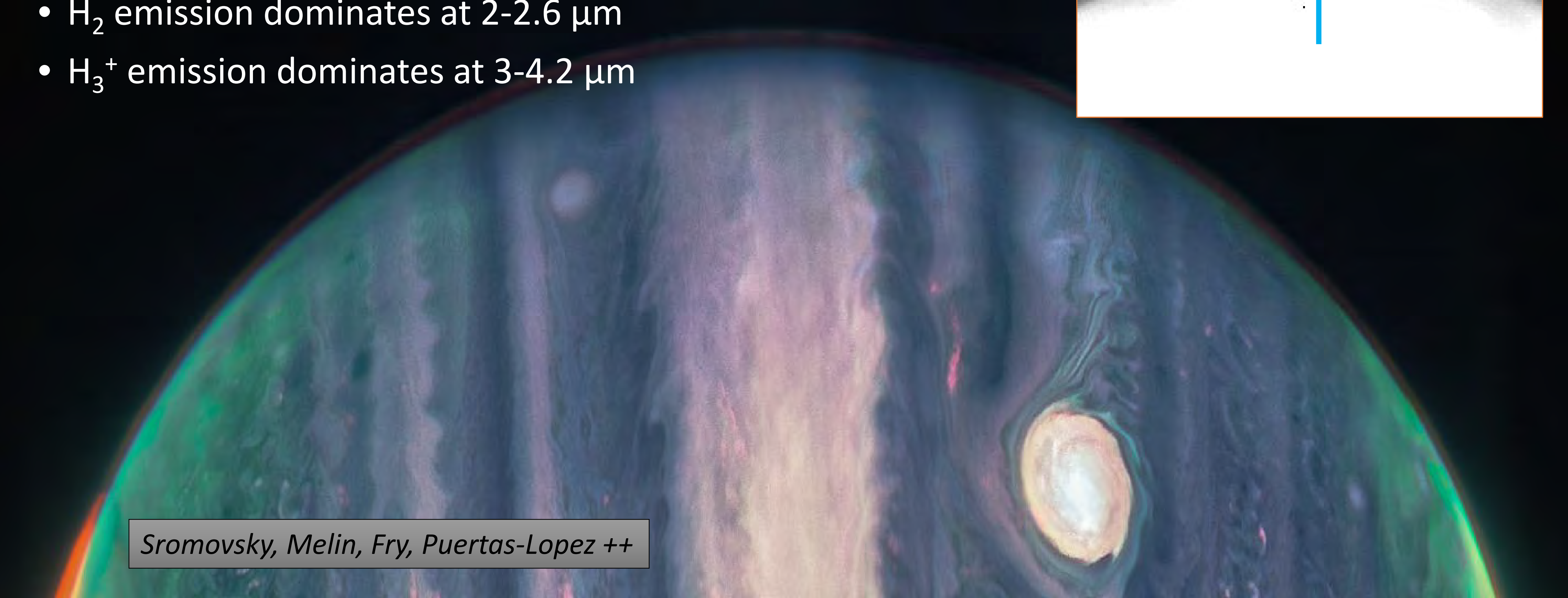
PIs: Imke de Pater (UC Berkeley)
Thierry Fouchet (Obs. Paris)
col: Ricardo Hueso (Jupiter atmosphere images)

Image credit: *NASA, ESA, Jupiter ERS team.*
Image processing: Ricardo Hueso & Judy Schmidt) F212N (orange), F335M (cyan)

Jupiter's "Unexpected" Limb Emission

- High altitude (500-600 km) emission layer in Jupiter's shadow
- Visible at 6 wavelengths (2.12 to 4.05 µm)
- H_2 emission dominates at 2-2.6 µm
- H_3^+ emission dominates at 3-4.2 µm





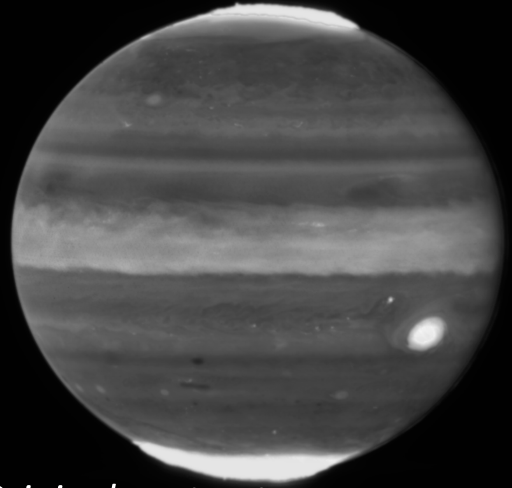
Sromovsky, Melin, Fry, Puertas-Lopez ++

Jupiter’s Clouds: Dynamics revealed by images separated by 10 hr

F212N

- Individual frames, de-rotation & combination, high-pass filtering.
- New altitudes whose dynamics we have never explored

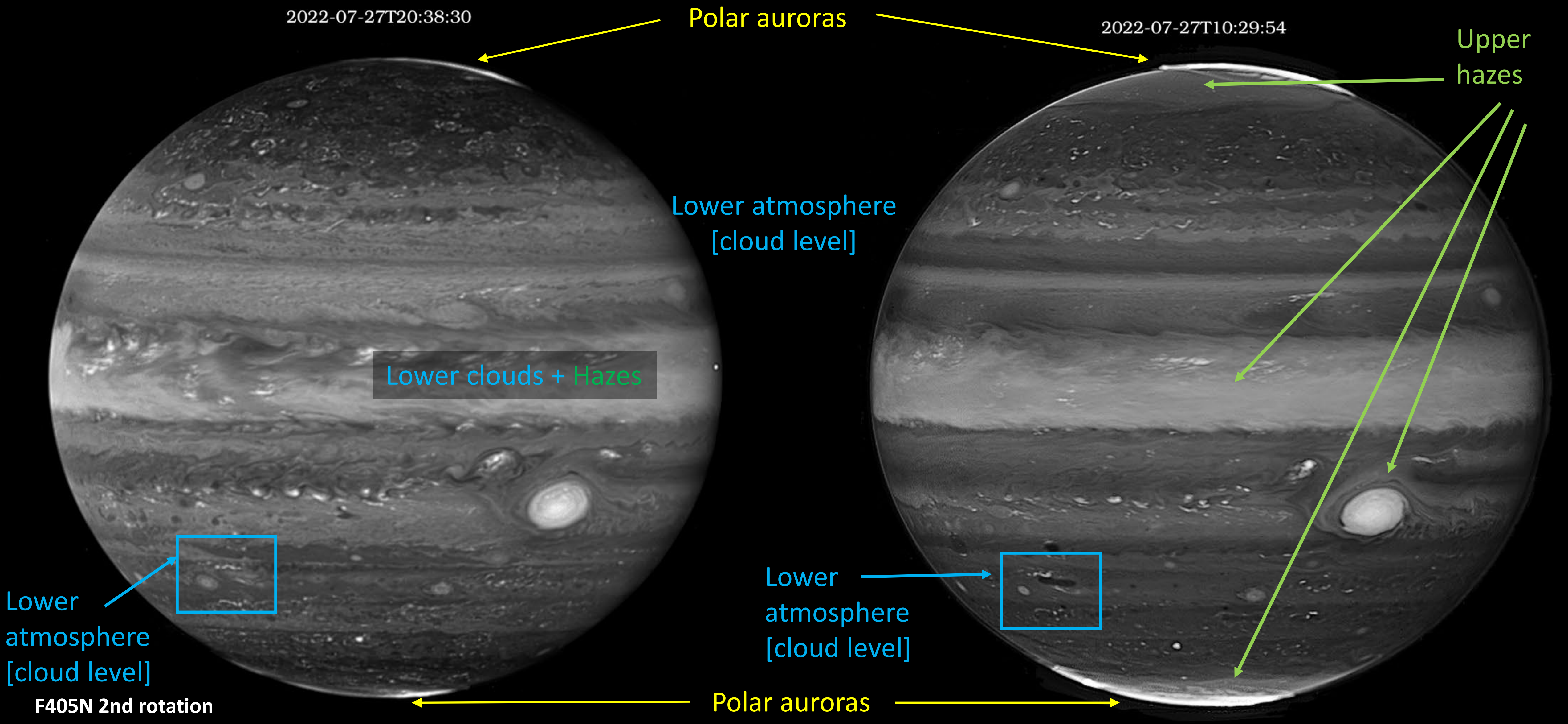
F335M



Original contrast

High-pass filtered

From the troposphere to the stratosphere

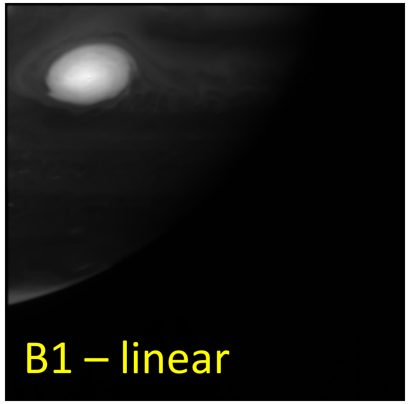


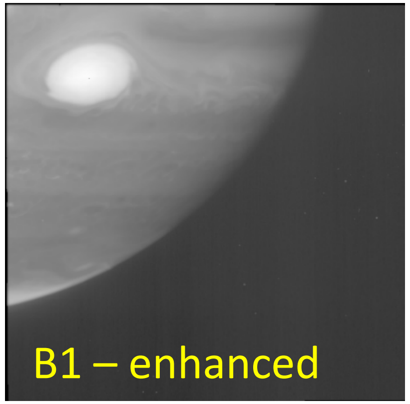
Dynamics from images acquired in SUB640 images

CHALLENGE: **F164N filter**. Planet too bright in full array!

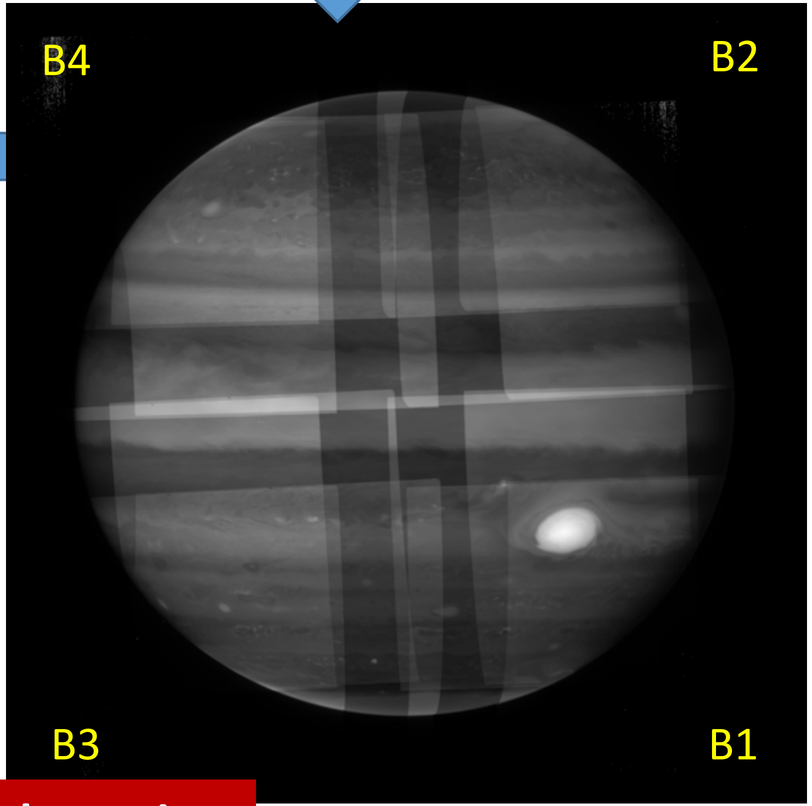
SOLUTION: SUB640 arrays with a dither pattern to cover gaps

DIFFICULTY: Frames acquired on different times in a rotating object. Image navigation and derotation to build a full image

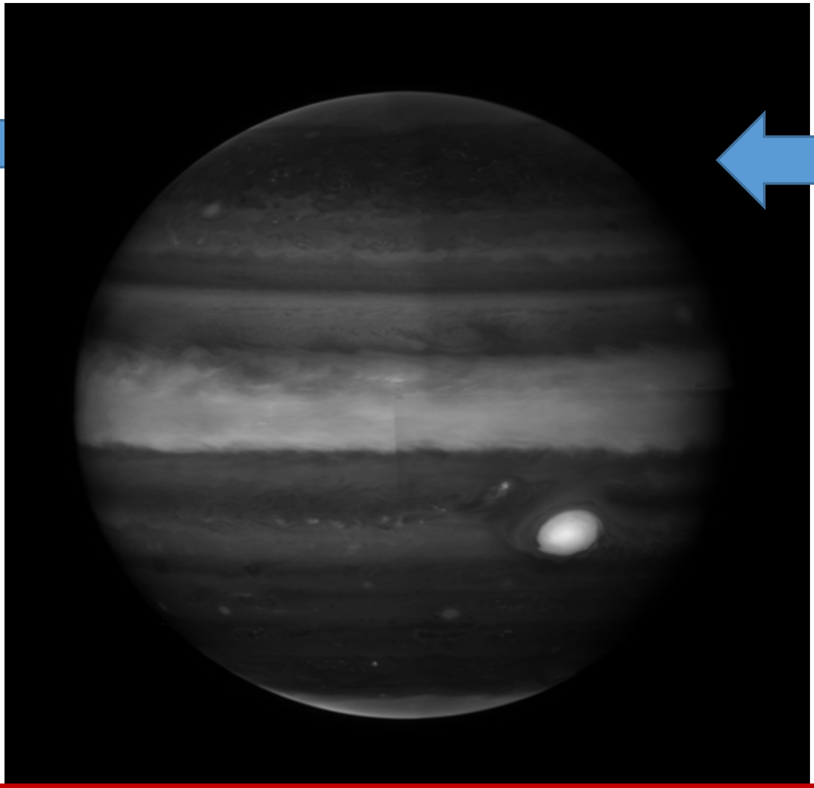




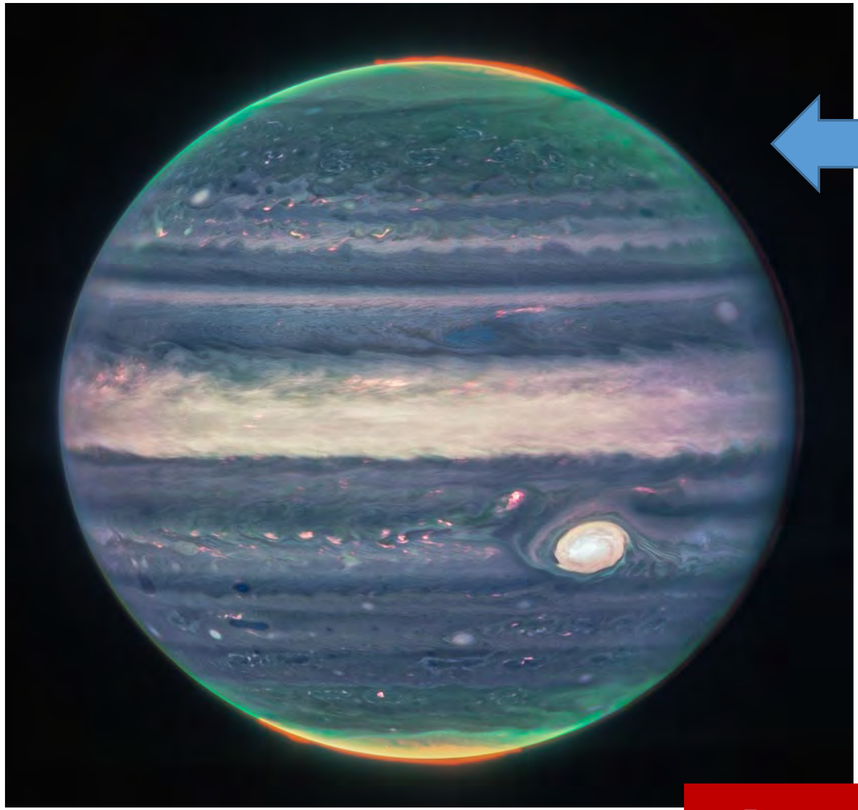
16 subimages



Full image



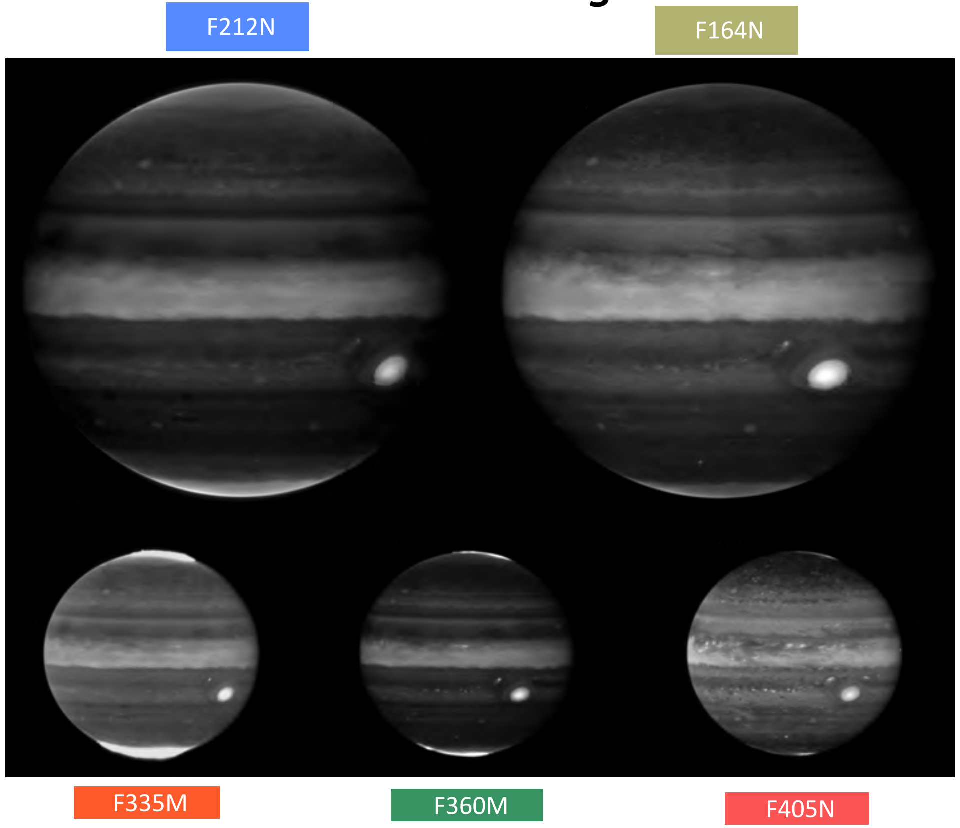
Color composites with other wavelengths



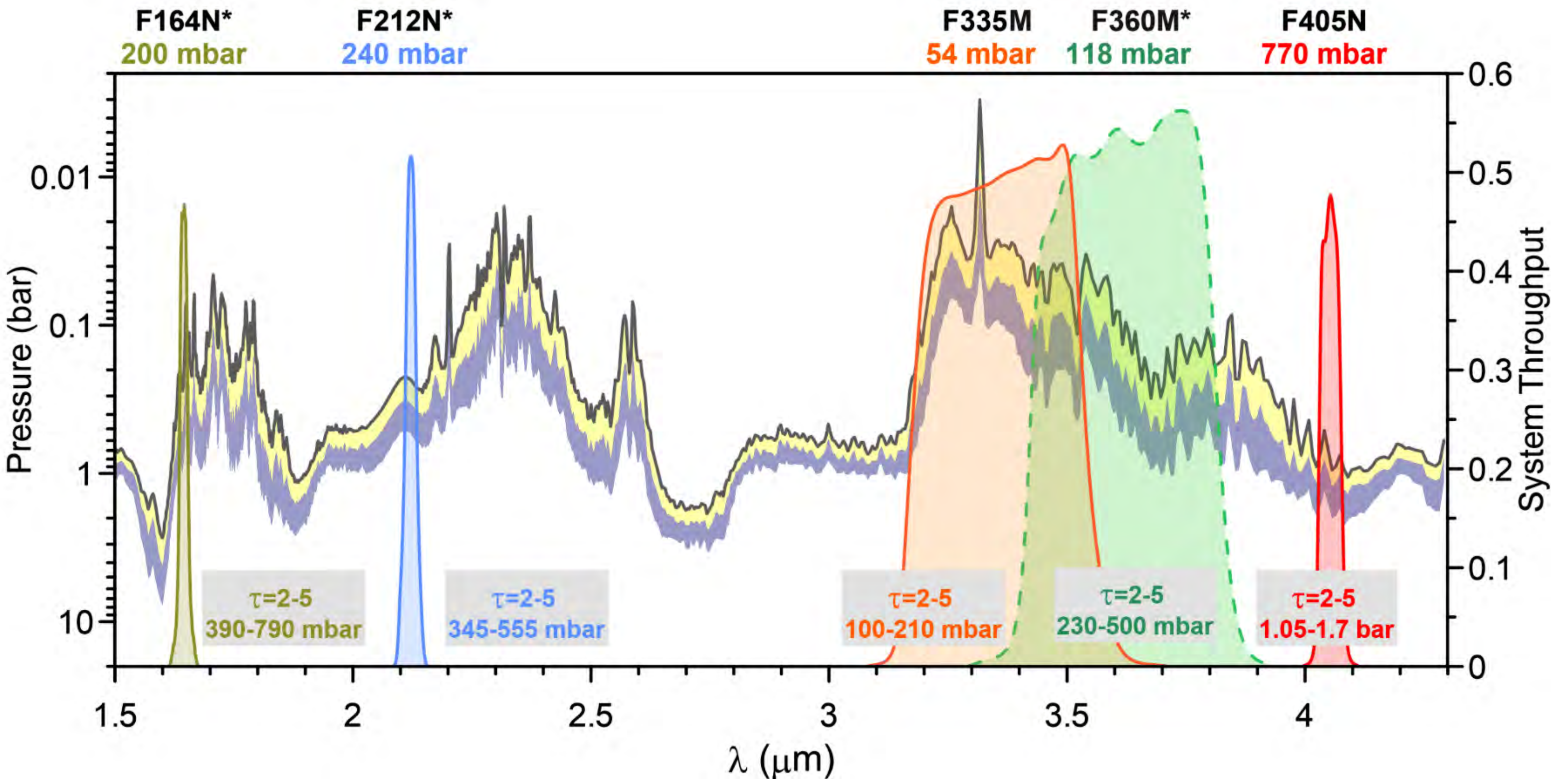
Repeated twice separated by 10 hrs to get dynamics

A fresh new look at Jupiter at altitudes where high-res. observations were never possible

Short-Wavelengths



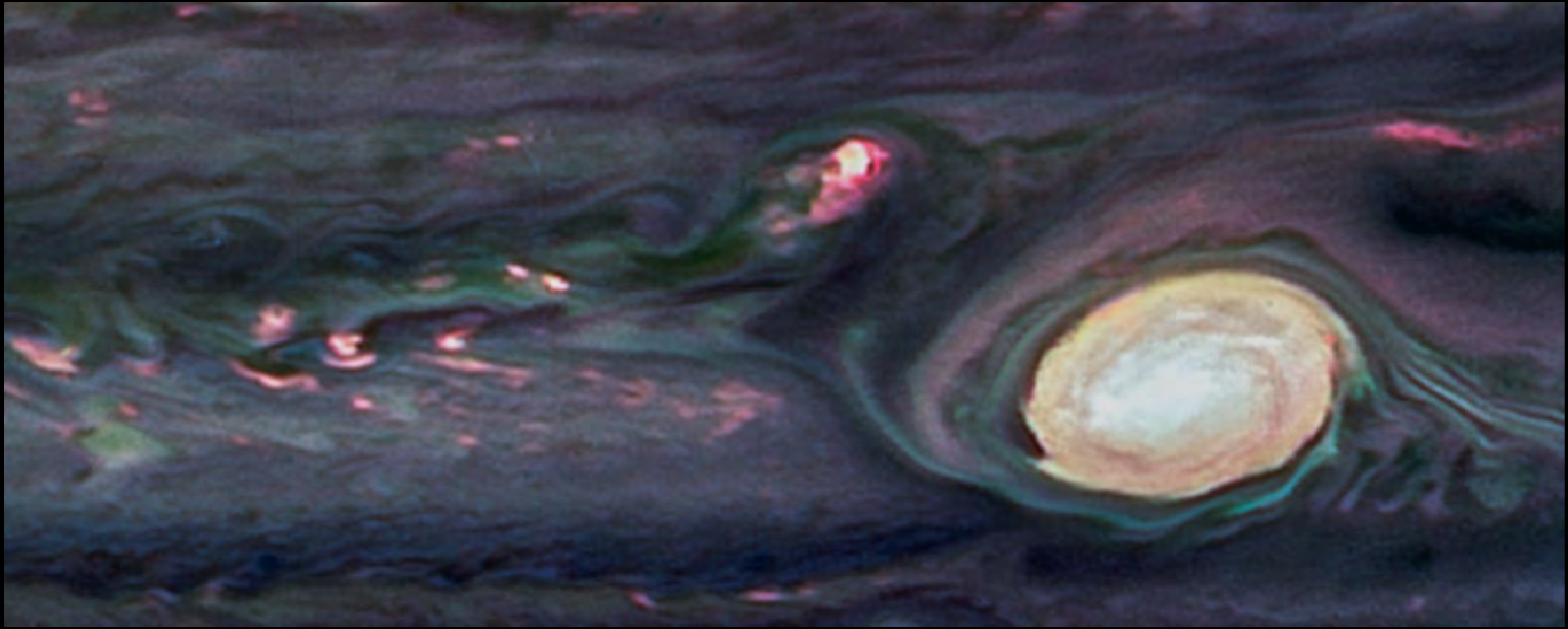
Long-Wavelengths (double pixel size)



Source	Filter	Pressure level (mbar) Equatorial Zone	Primary sensed aerosol layers Equatorial Zone
JWST / NIRCam	F212N	~ 240	Equatorial Haze
	F164N	~ 200	Equatorial Haze
	F335M	50 - 500	Equatorial Haze + Tropospheric clouds
	F360M	100 - 500	Equatorial Haze + Tropospheric clouds
	F405N	500 - 600	Tropospheric clouds

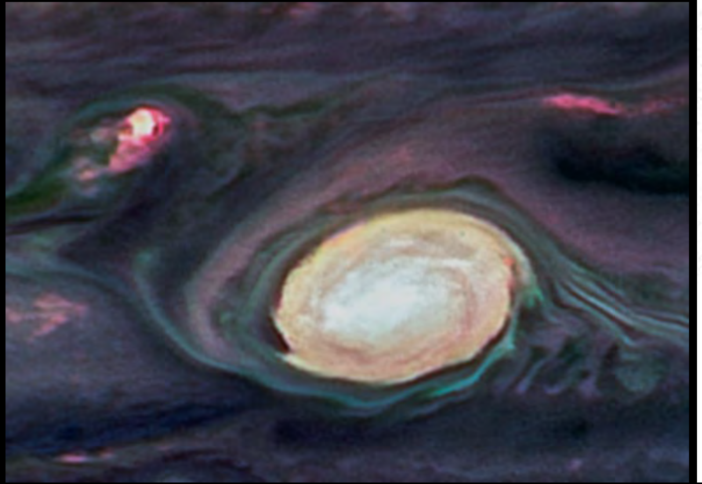
Superb spatial resolution data at a variety of wavelengths

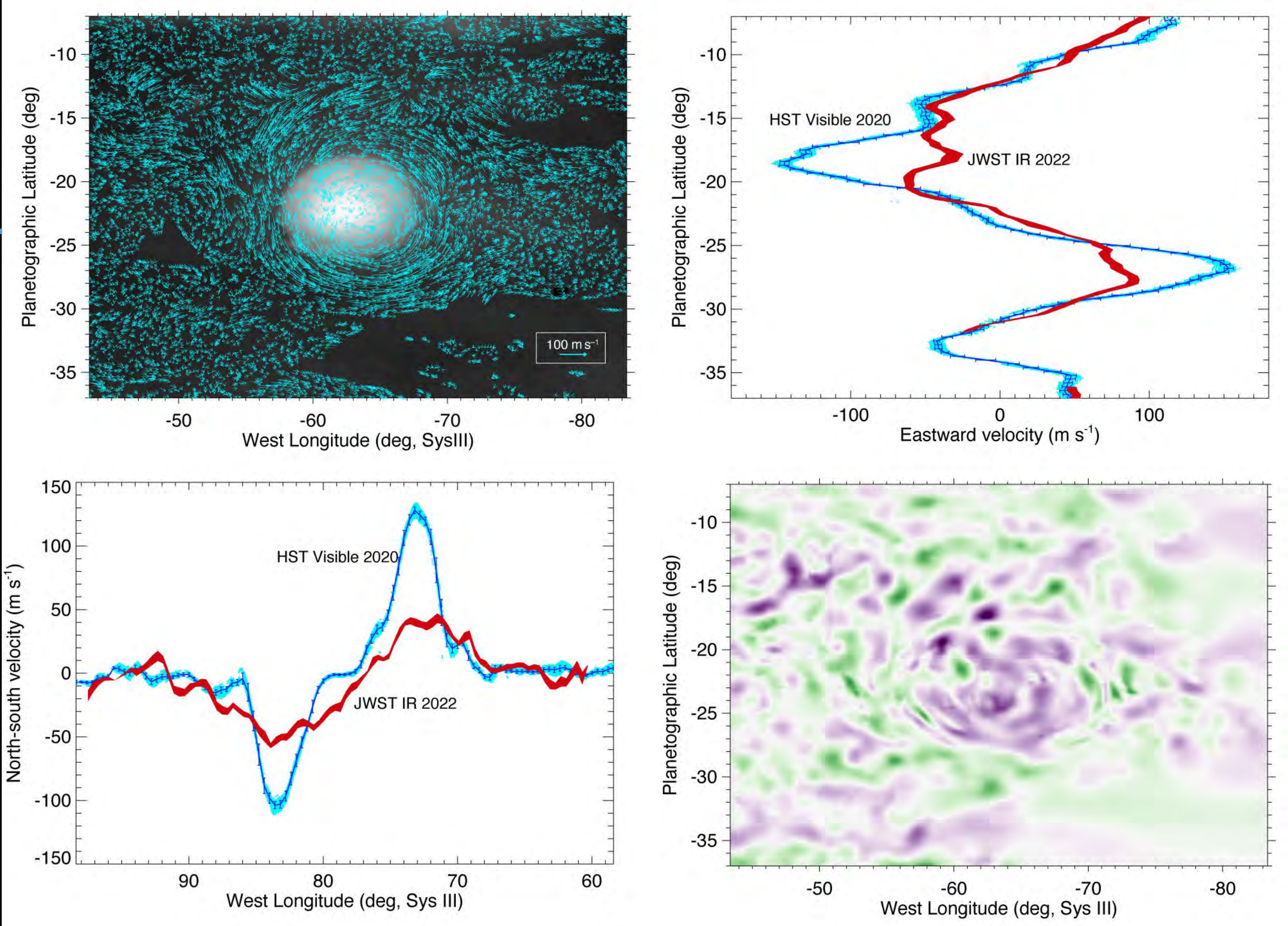
Short wavelengths: Pixel scale: 0.03087 arcsec/pixel (roughly 99 km/pix on Jupiter)
Long wavelengths: Pixel scale: 0.06303 arcsec/pixel (roughly 203 km/pix on Jupiter)



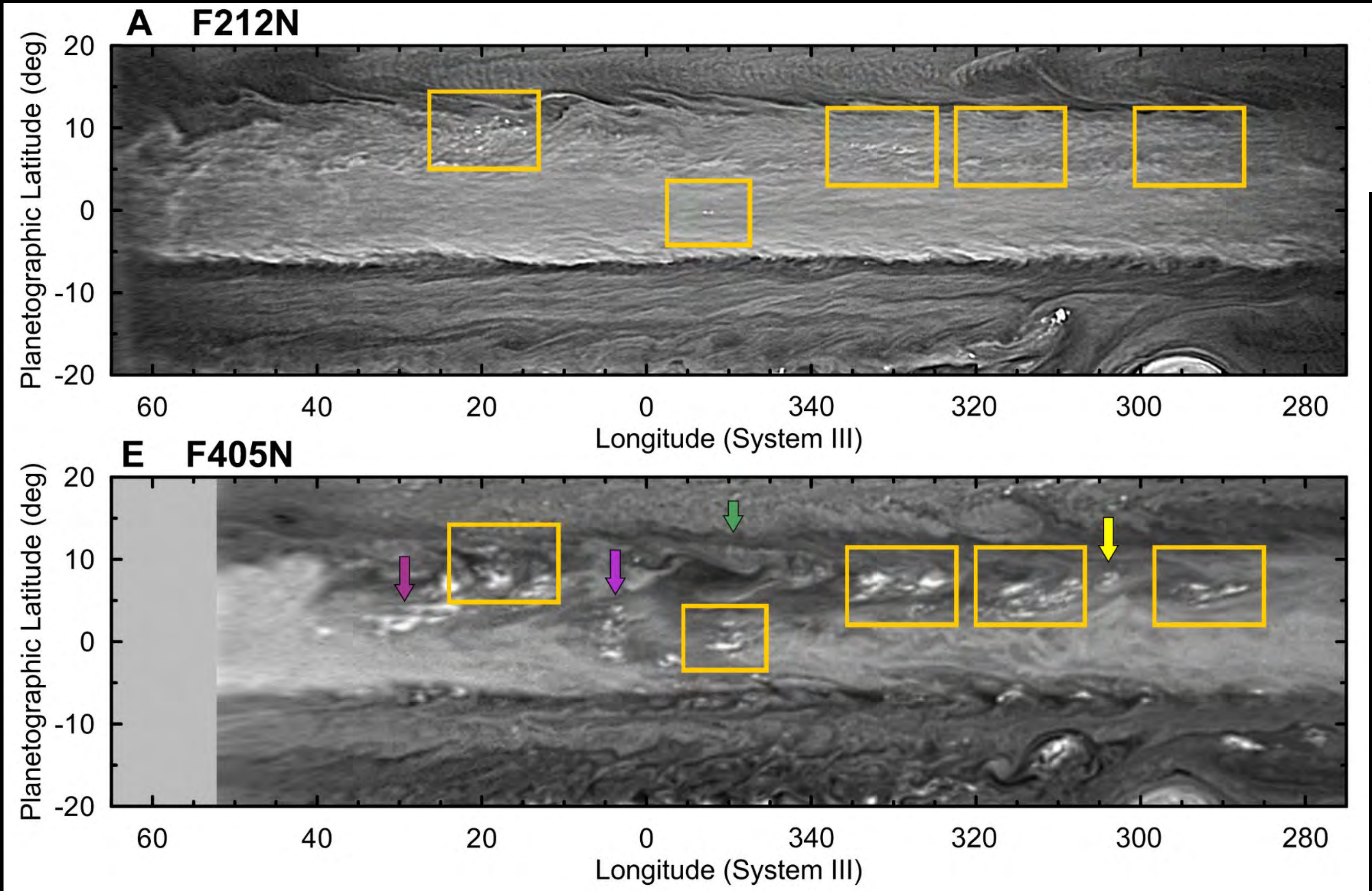
Additional results for Jupiter's GRS

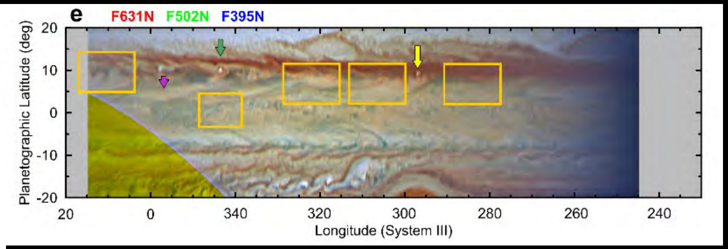
M. H. Wong, R. Hueso et al.





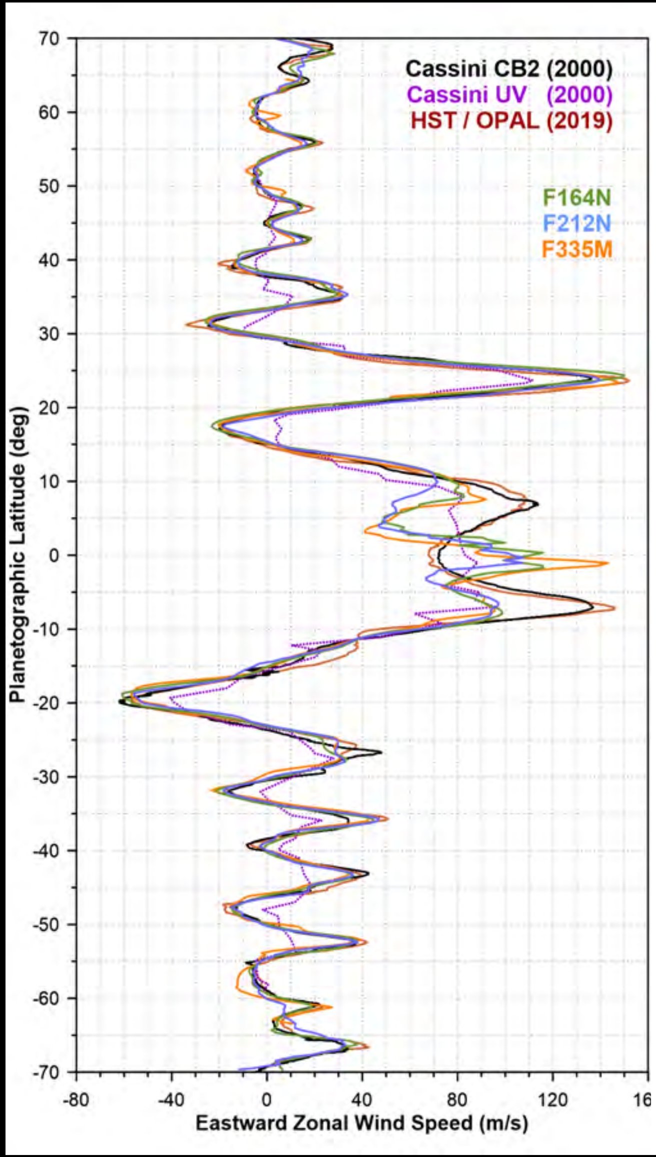
Superb spatial resolution data at a variety of wavelengths

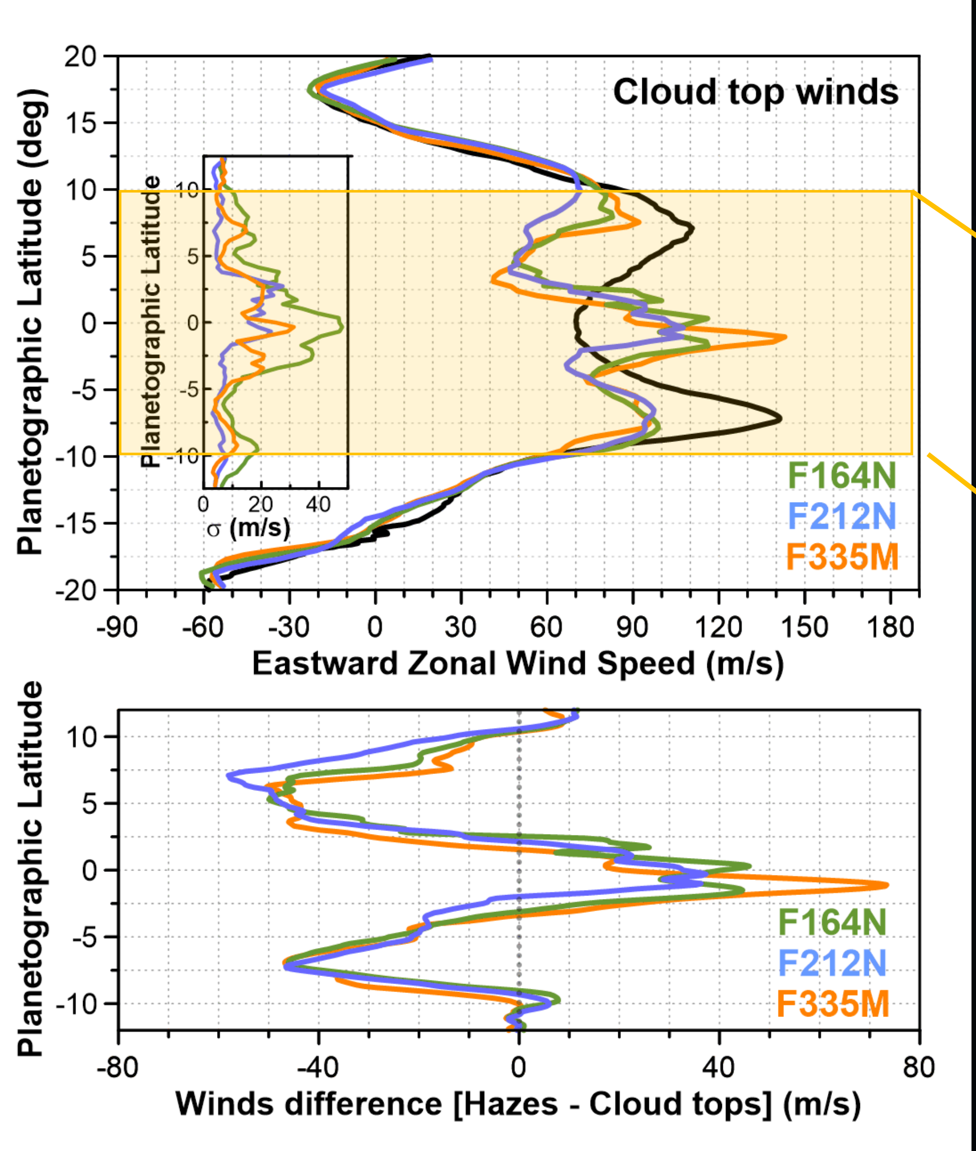


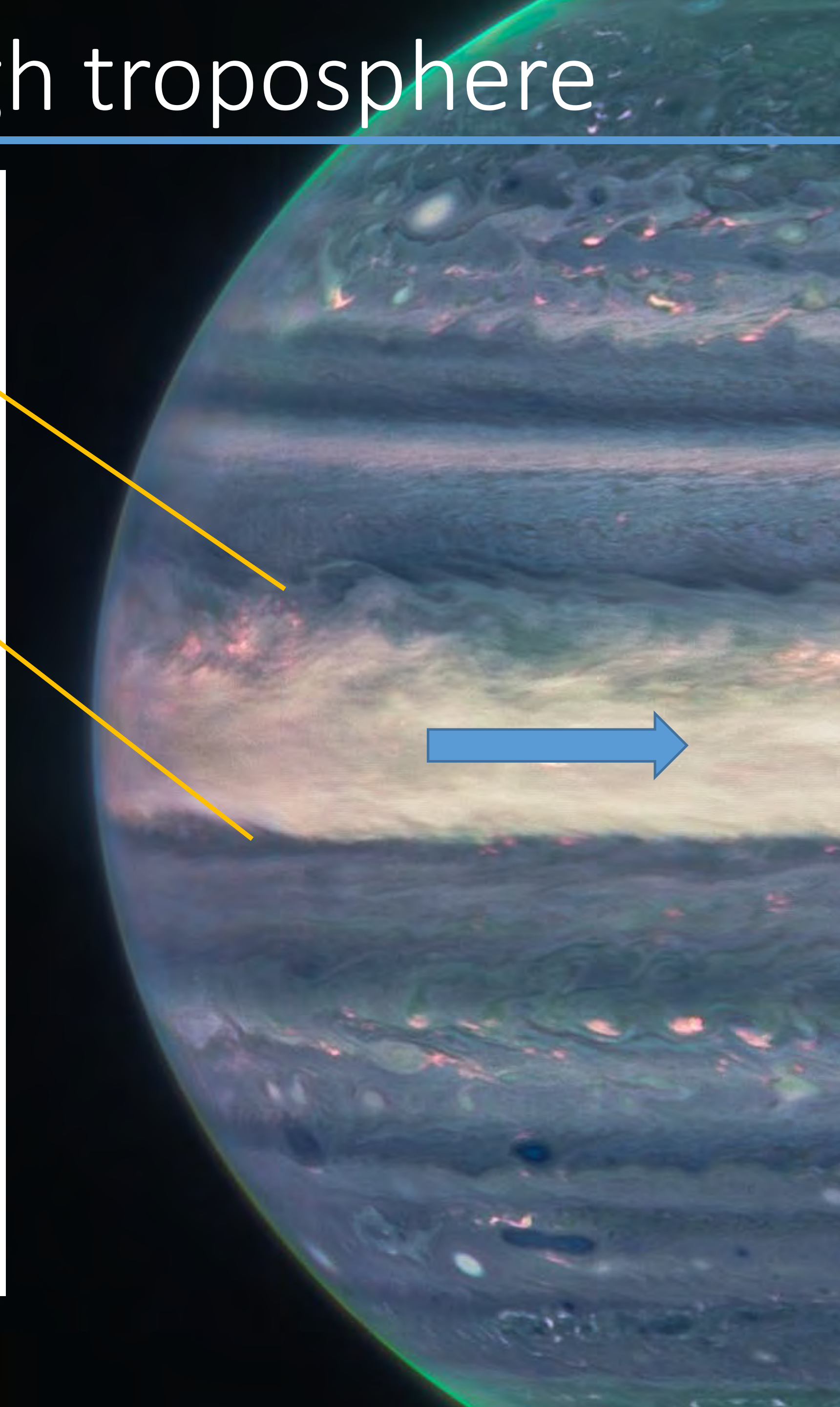


How different are the dynamics of these elevated hazes at 100-200 mbar (tropopause), when compared with the stable known winds in the cloud tops in the troposphere (700 mbar)?

A narrow zonal jet at the equatorial high troposphere

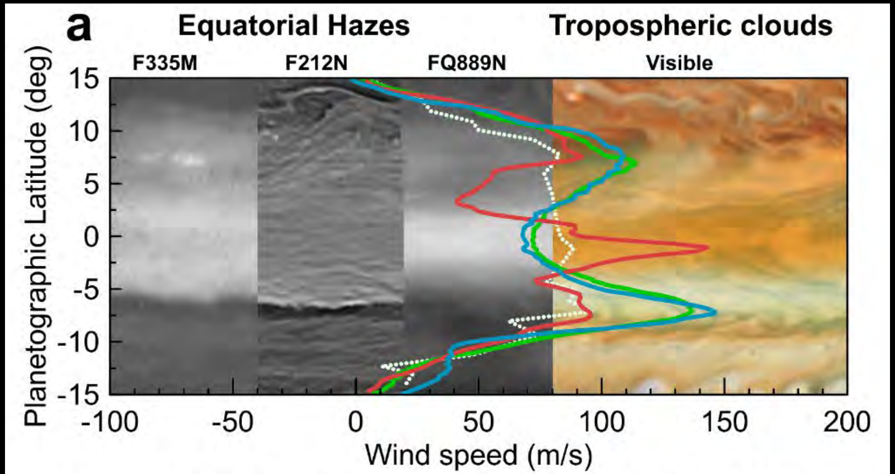






The jet is just below Jupiter's Equatorial Stratospheric Oscillation (JESO) [4-6 yrs period]

$$\frac{\partial u_g}{\partial p} = -\frac{R}{fp}\frac{\partial T}{\partial y}$$



- *The narrow equatorial jet at 100-200 mbar resides just below Jupiter's Equatorial Stratospheric Oscillation*

Leovy et al. Nature (1991), …,
Antuñano et al. Nature Astronomy (2022)

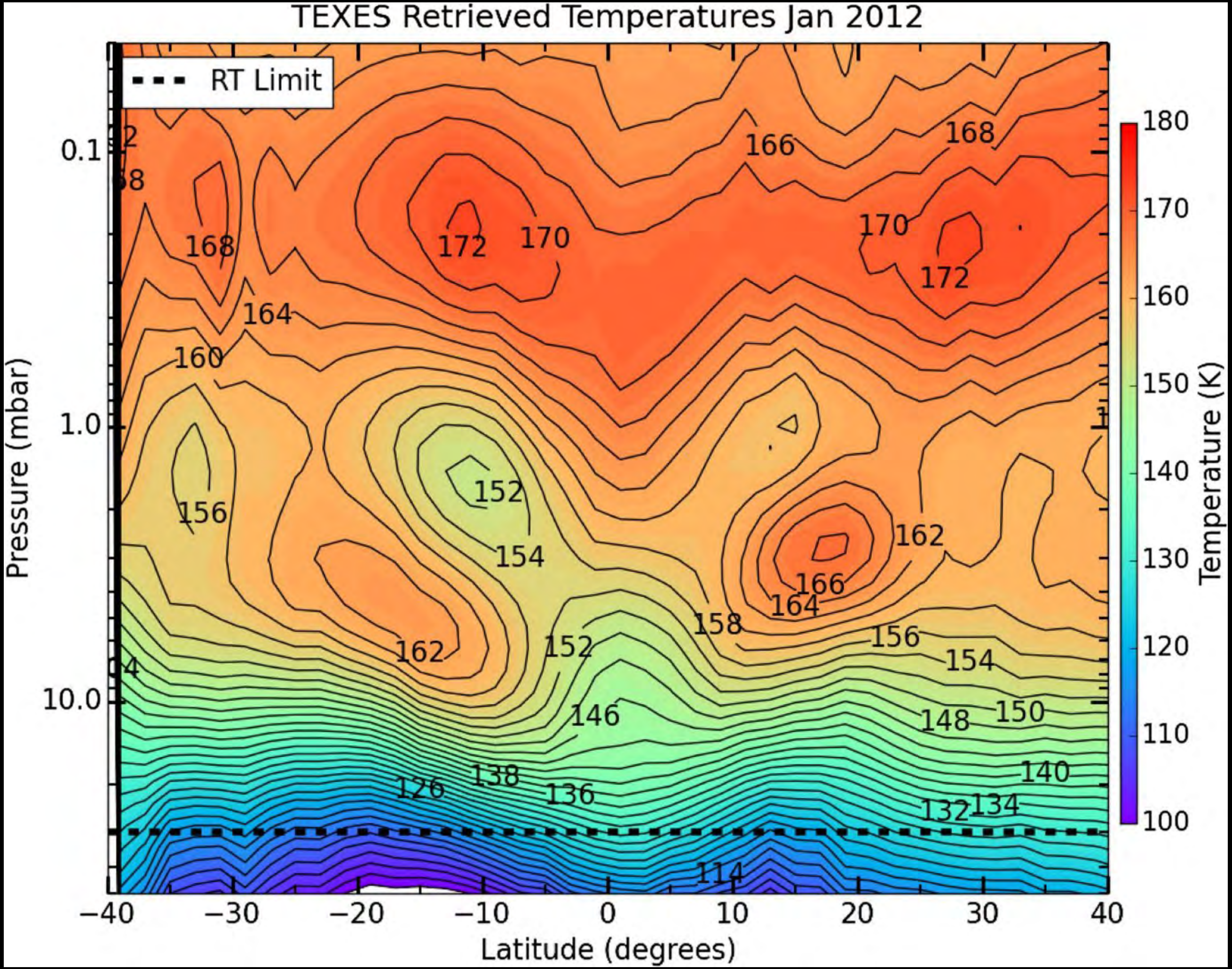
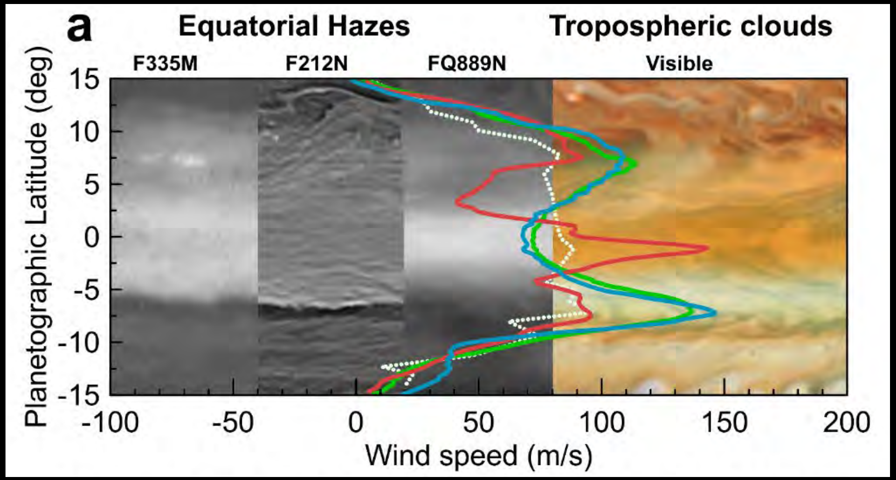


Figure from Fletcher et al. (2017)

Infrared spectroscopy does not provide valid data below 30 mbar

The jet is just below Jupiter's Equatorial Stratospheric Oscillation (JESO) [4-6 yrs period]



- *The equatorial oscillation descends from the upper stratosphere over time changing temperatures and winds at least down to 30 mbar*

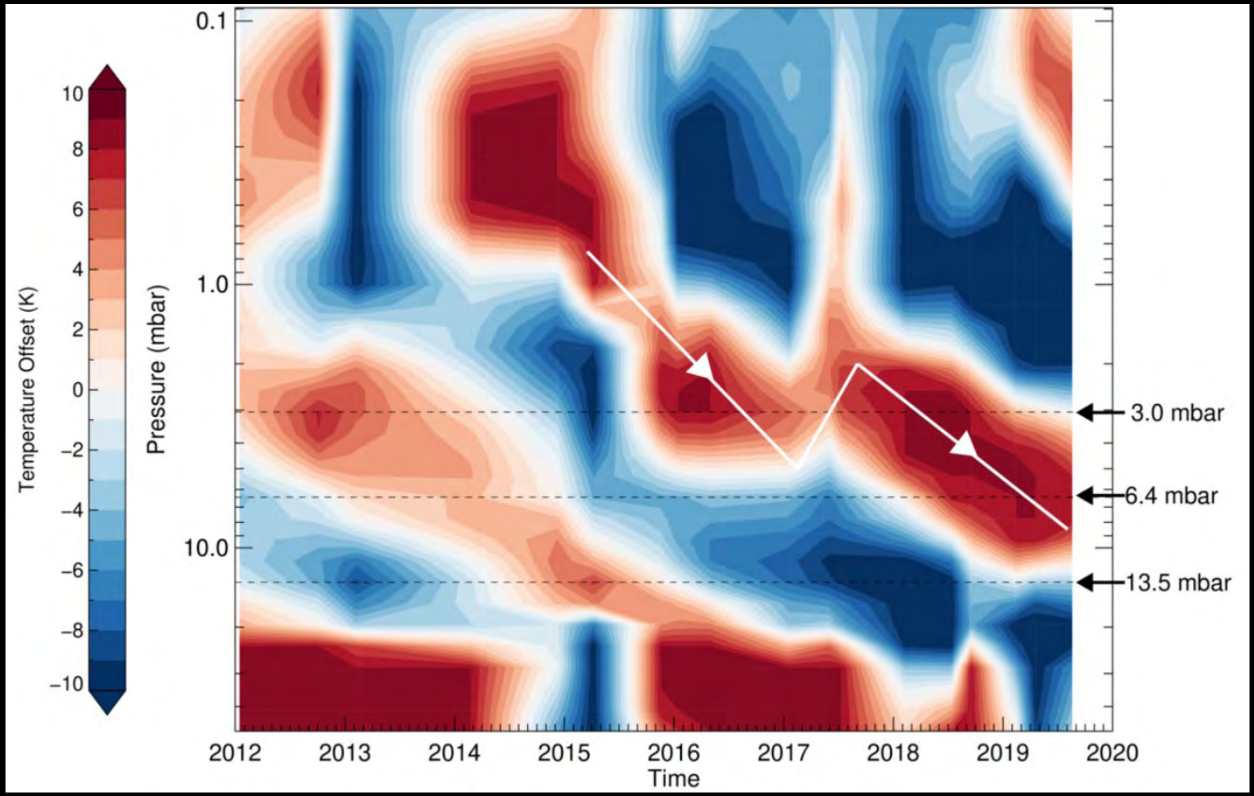
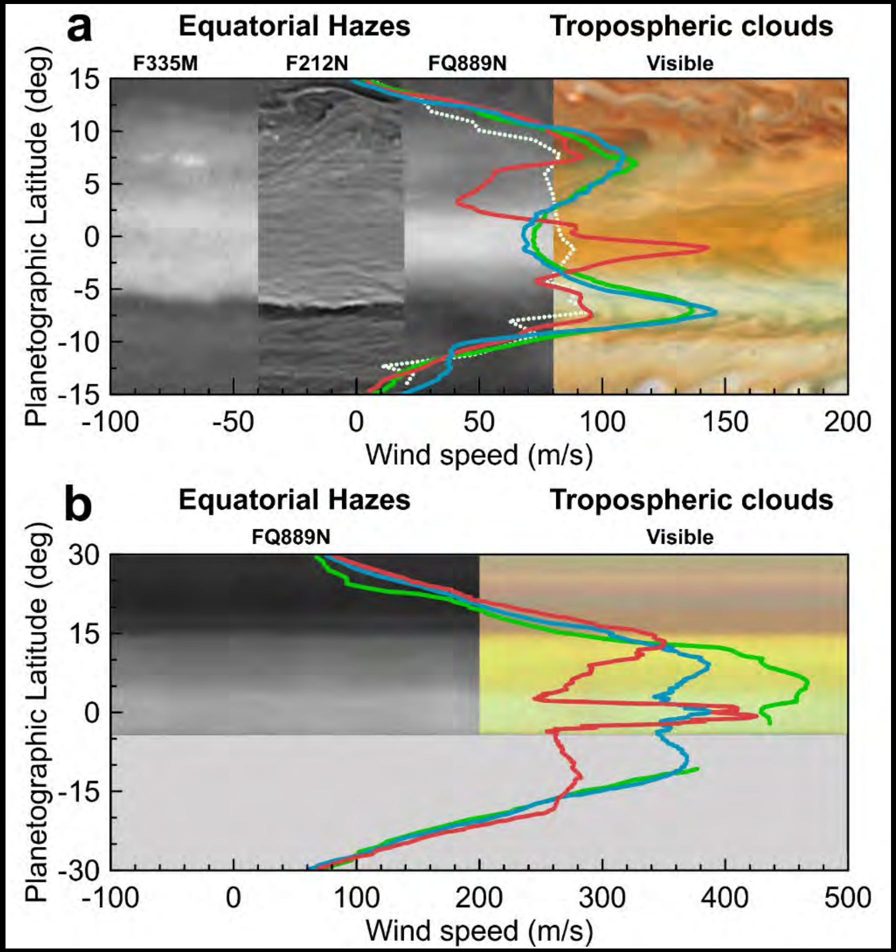


Figure from Giles et al. (2020)

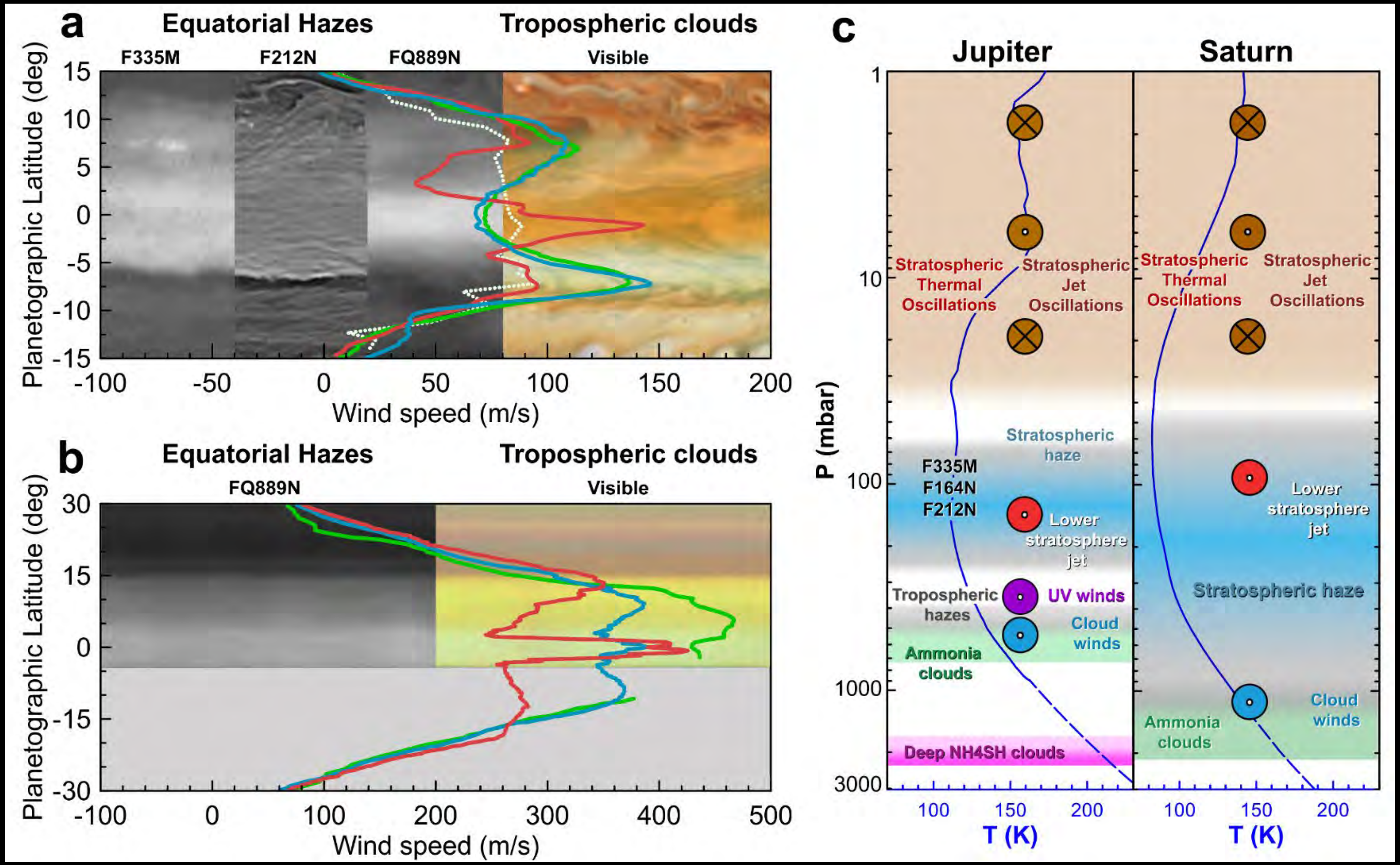
And is similar to Saturn's stratospheric jet which it is located below Saturn's Semiannual Oscillation



- *Equatorial winds in Saturn also have unexepected narrow jets in the altitudes covered by the hazes (60-100 mbar) (García-Melendo et al., 2009, Sánchez-Lavega et al. 2016)*

- *Saturn's equatorial stratosphere also has oscillating temperaturas with a semiannual period*

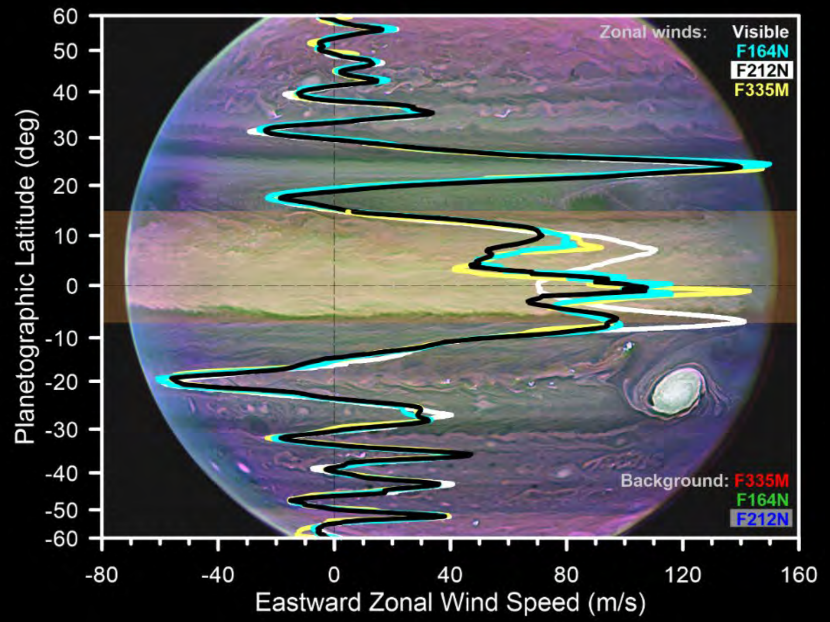
The newly found jet in Jupiter should be time-variable

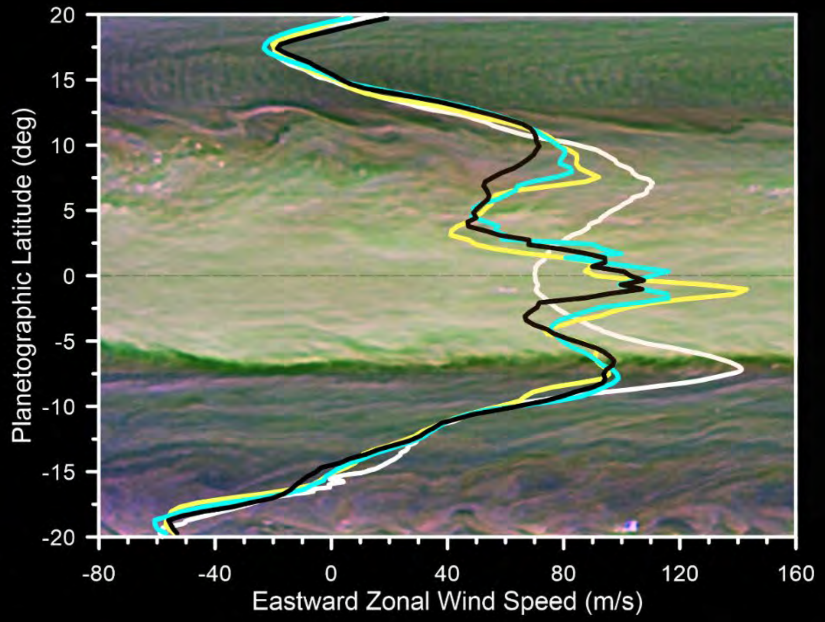


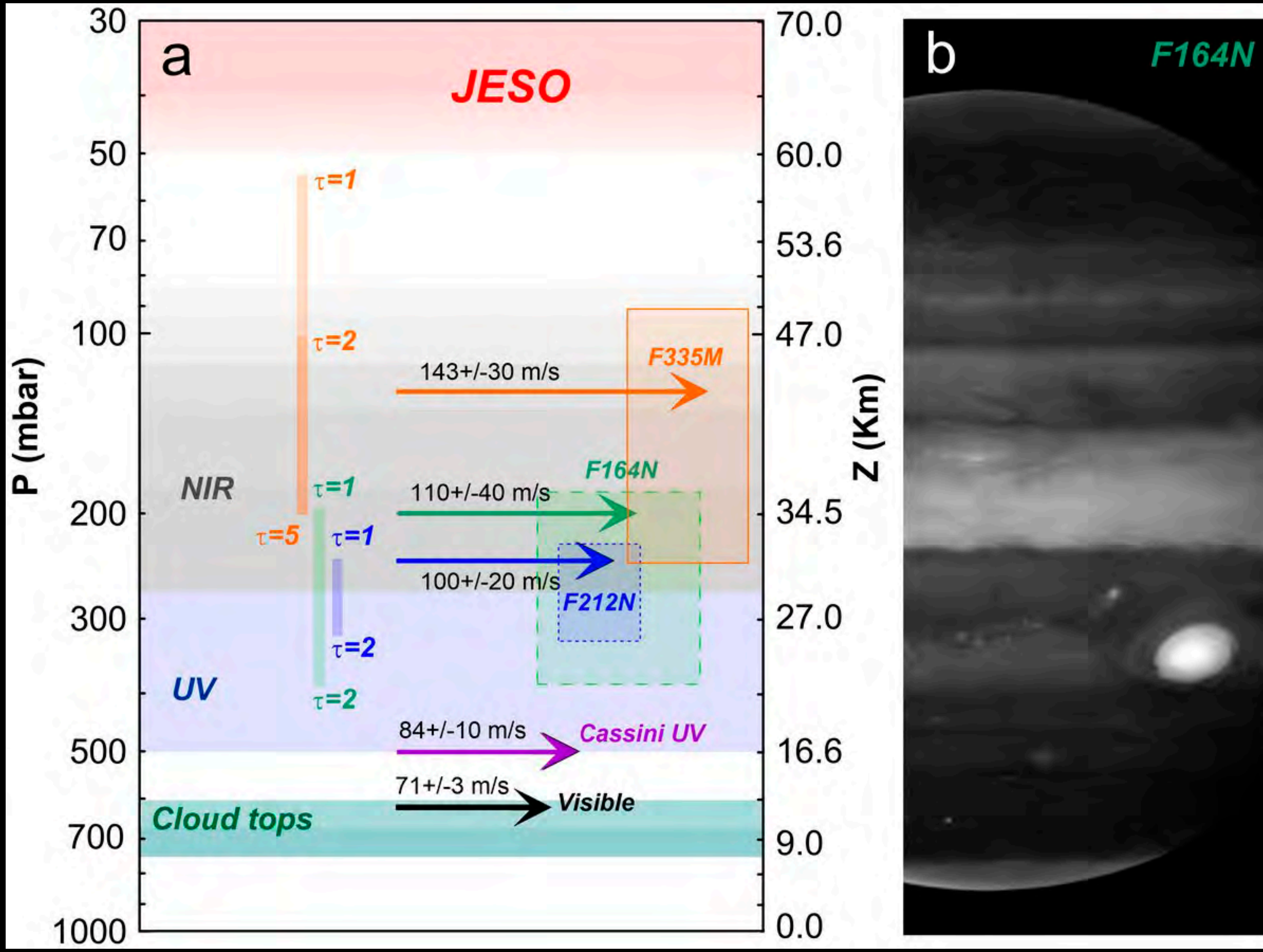
Hueso et al. Nature Astronomy 2023

- *The new jet in Jupiter equatorial atmosphere should be time-variable and linked to the stratospheric thermal oscillations.*
- *Its existence is a mistery not predicted and its possible variability should give us information on processes occurring on Gas Giant Planets beyond Jupiter and Saturn*

Time Variable phenomena and strong vertical wind shear

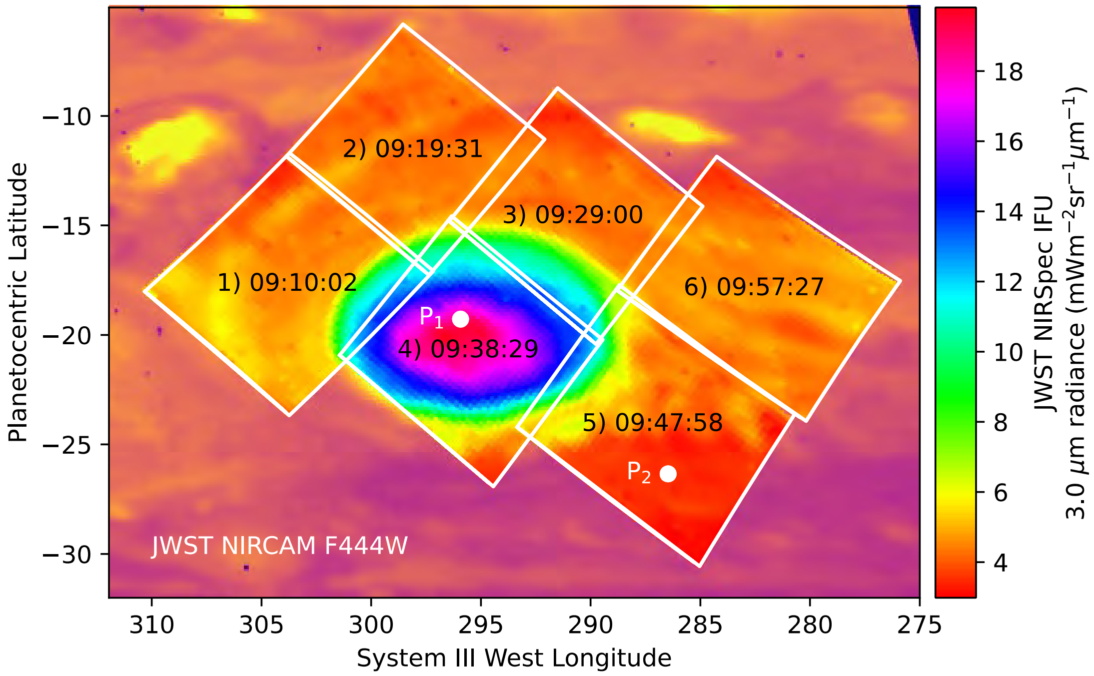




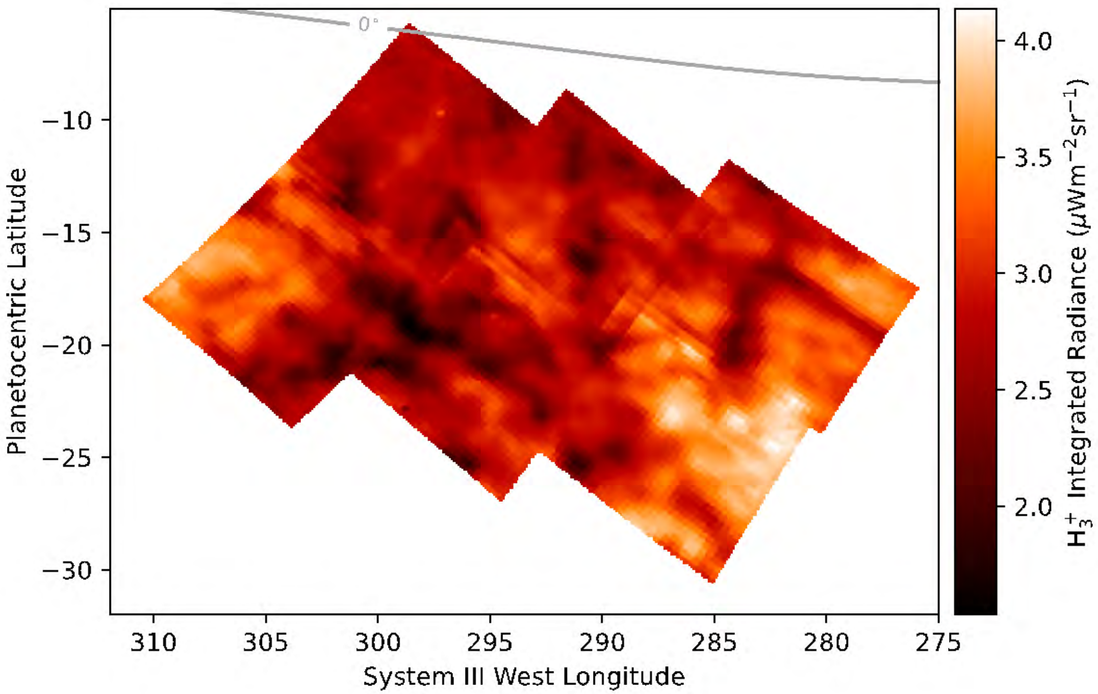


Jupiter's Ionosphere above the GRS [NIRSpec] – Melin et al.

Geometry of NIRSpec IFU observations



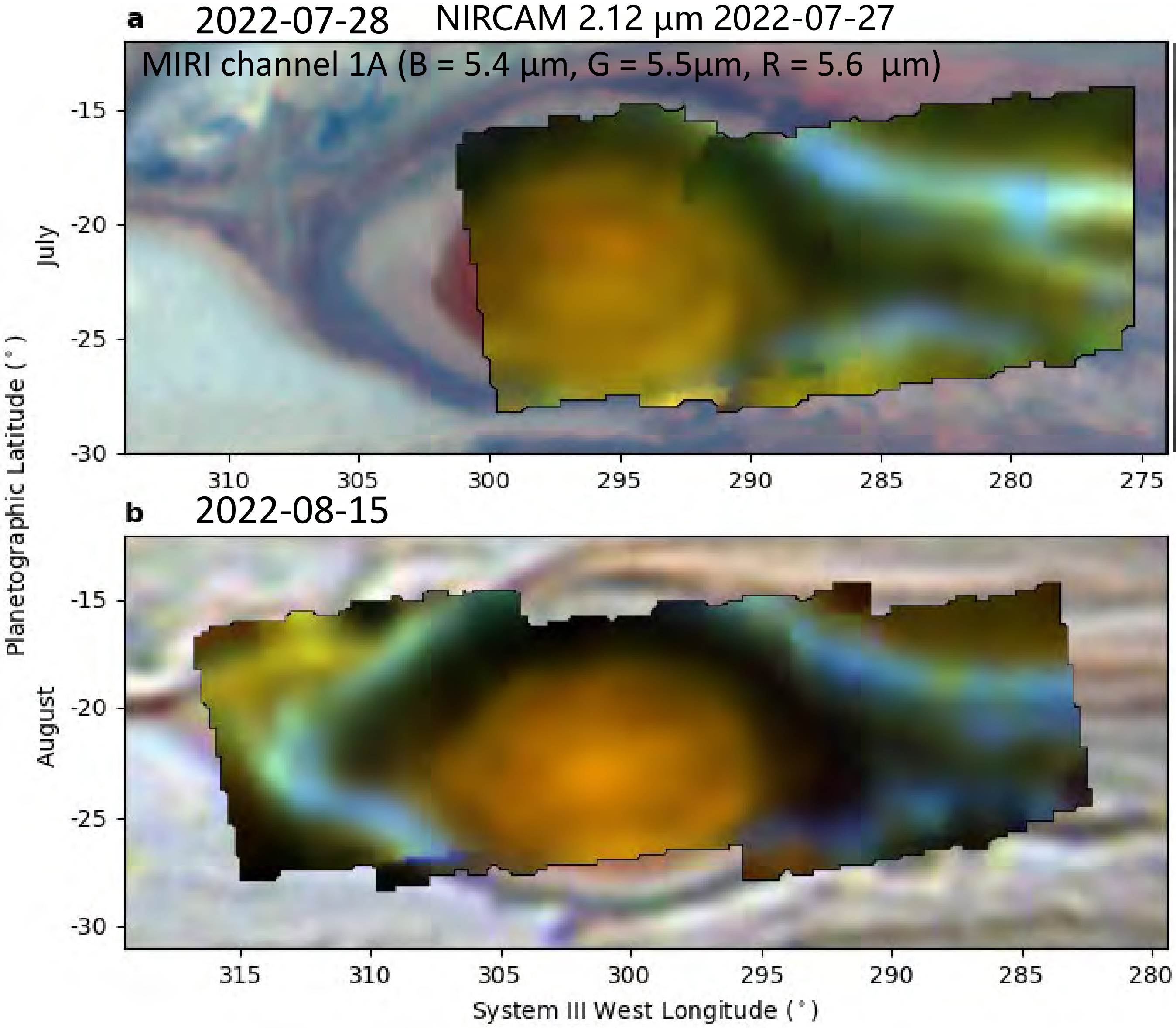
Extracted ionospheric H_3^+

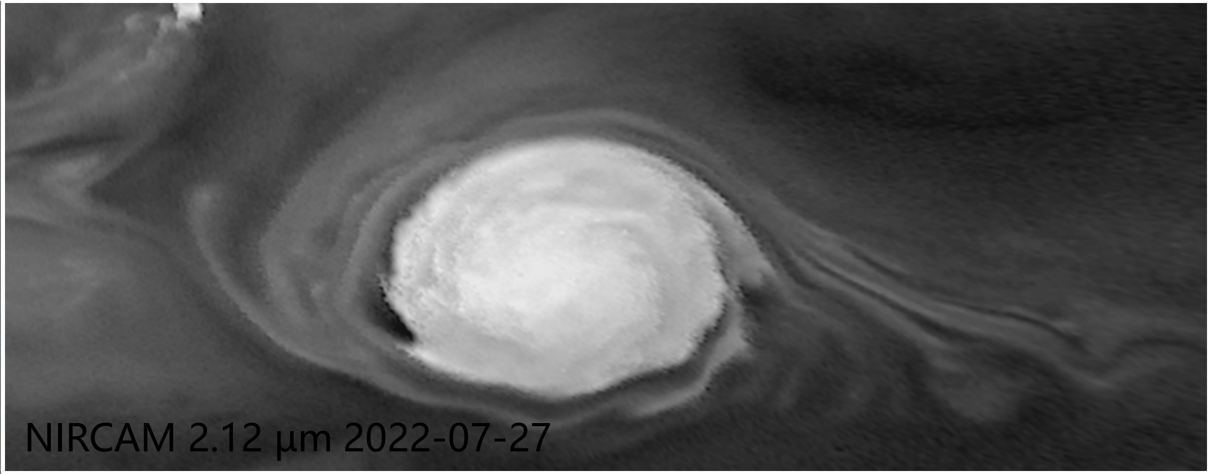


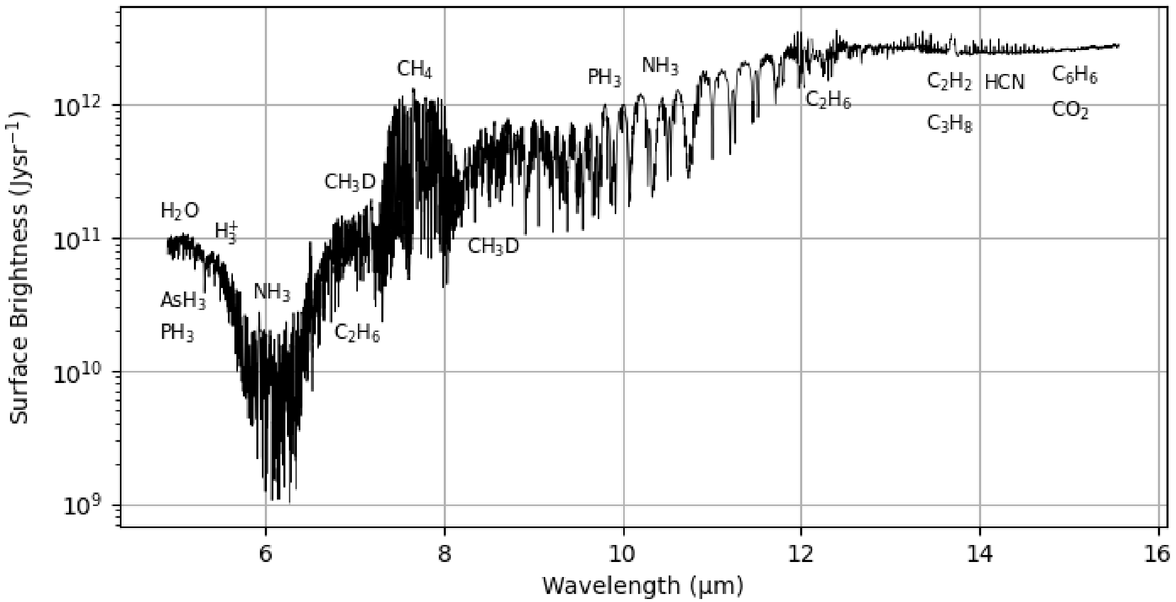
Example NIRSpec IFU G395H spectra

- Ionosphere above GRS replete with intricate features, bands, arcs, and spots.
- The primary driver is the H_3^+ density, and not temperature, suggesting that these are gravity waves from lower atmosphere altering the structure of the ionosphere.
- No strong heating above the GRS.
- Melin et al., in prep.

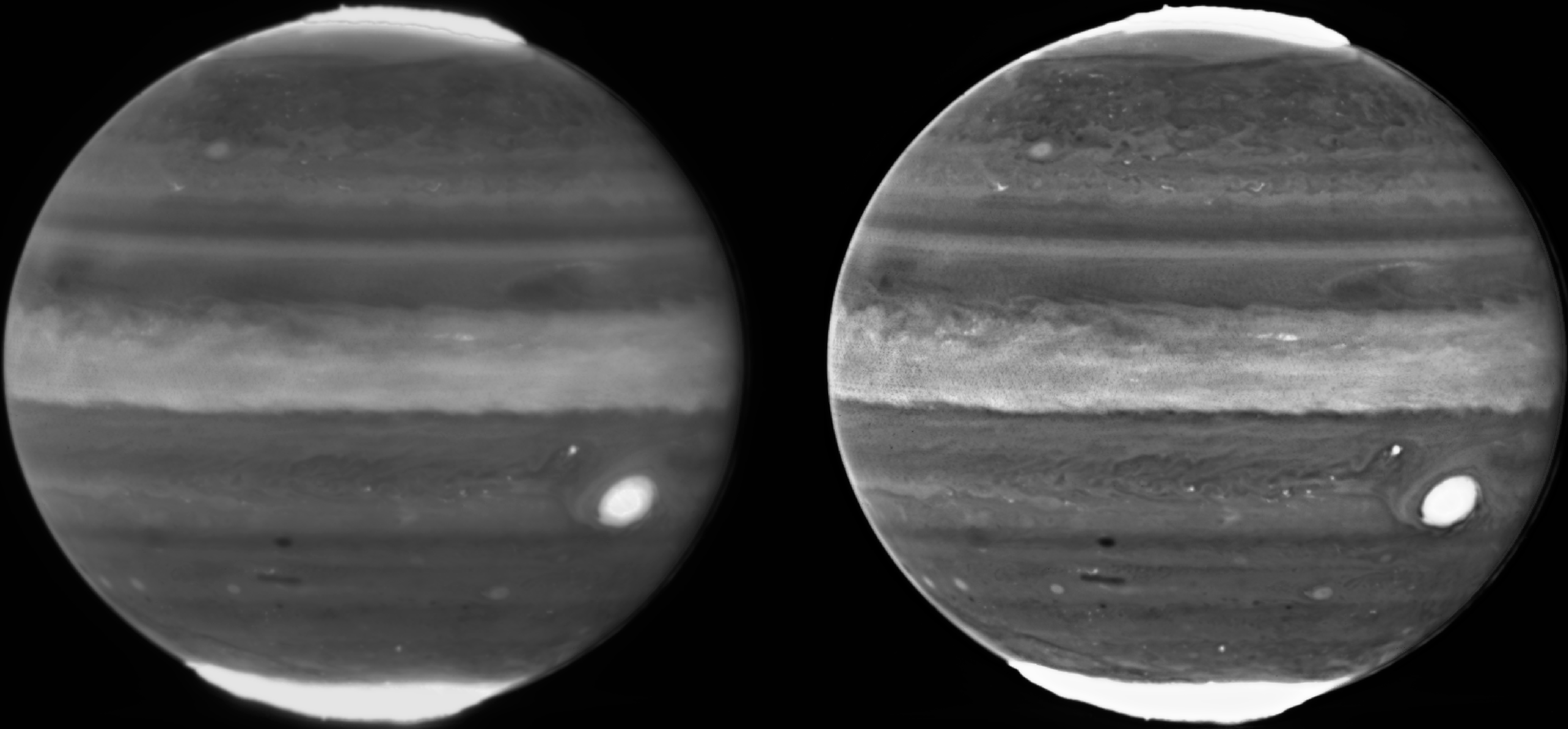
Thermal Maps of Great Red Spot [Harkett et al., in prep]

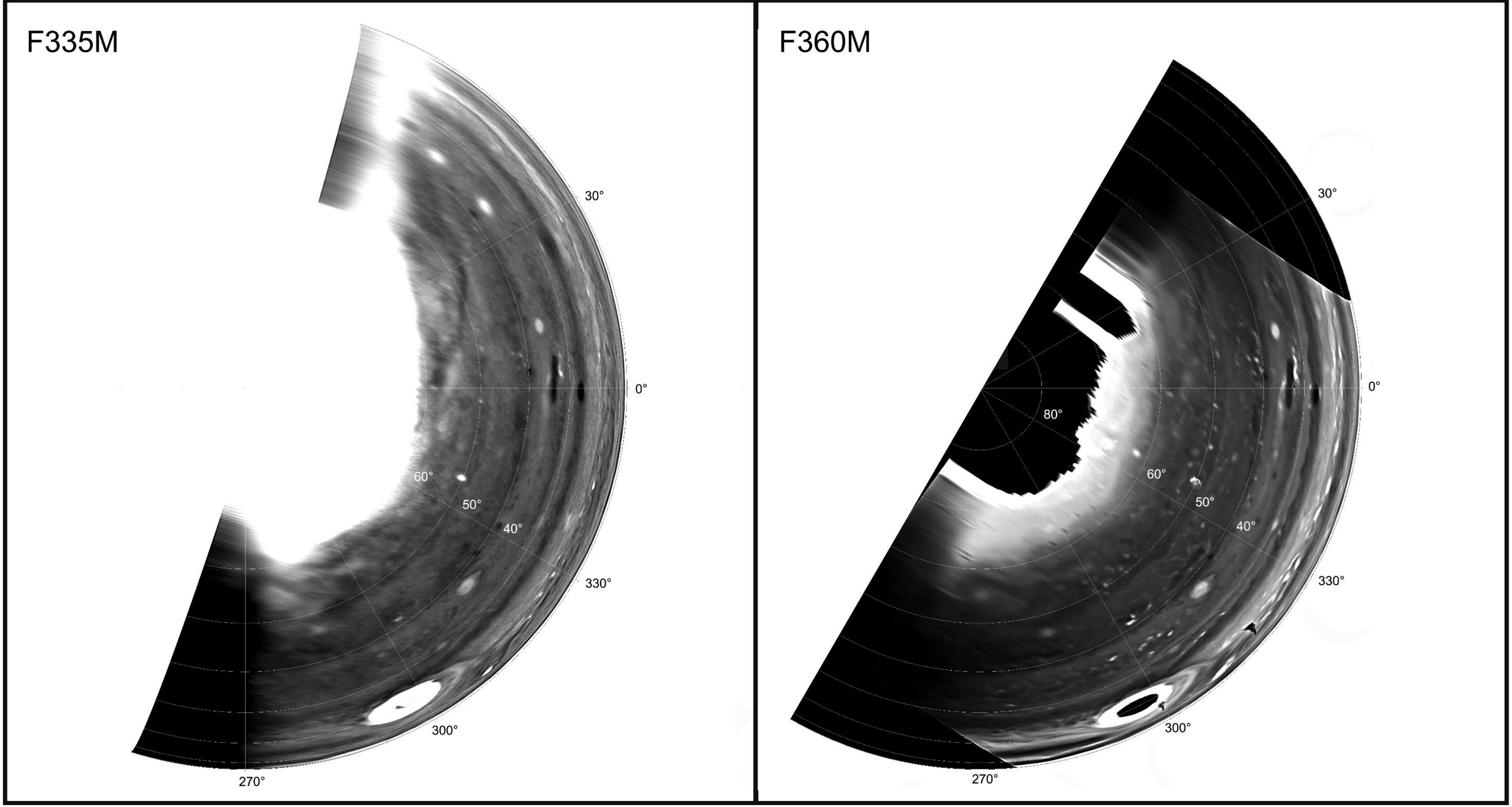




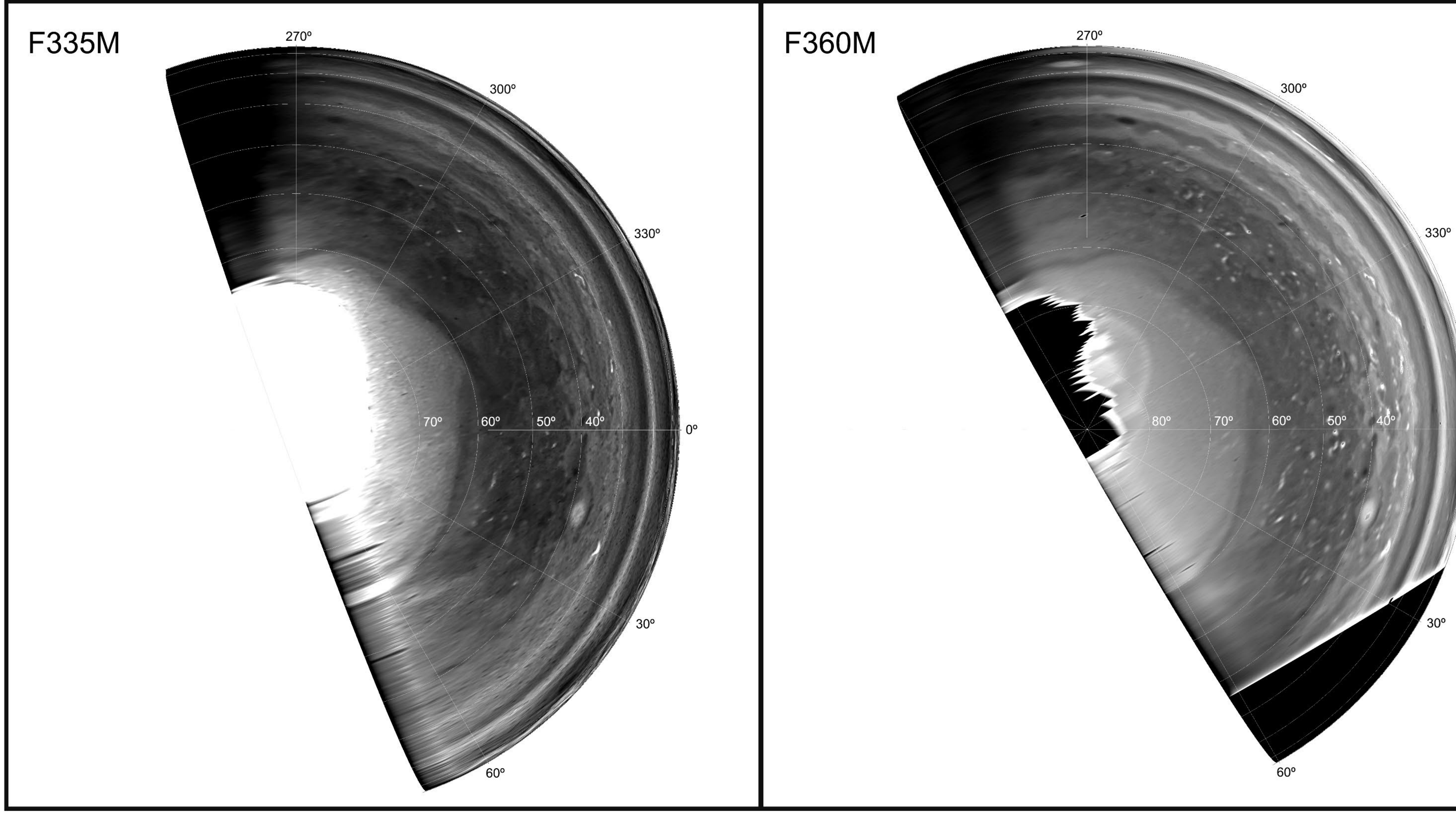


Plus detailed spectroscopy and retrievals of chemical species

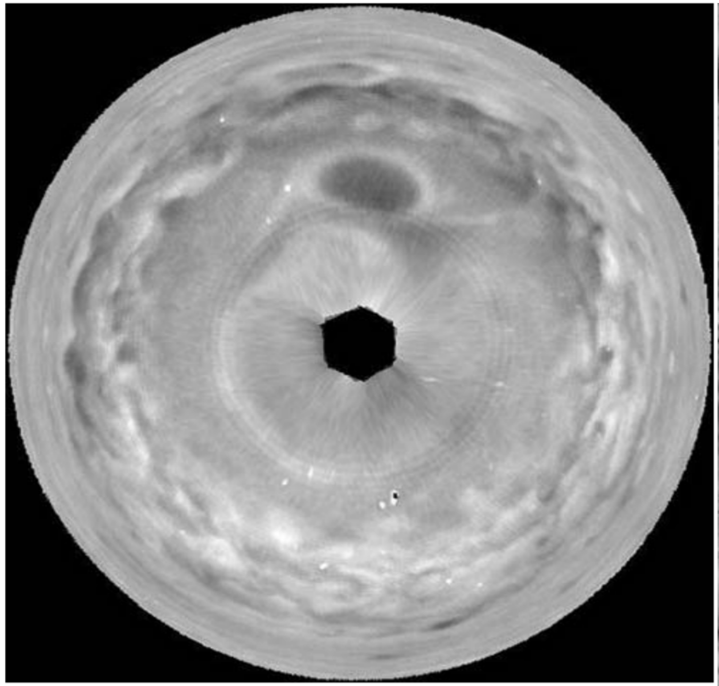




F335M
30°
0°
60°
50°
40°
330°
300°
270°
F360M
30°
0°
80°
60°
50°
40°
330°
300°
270°

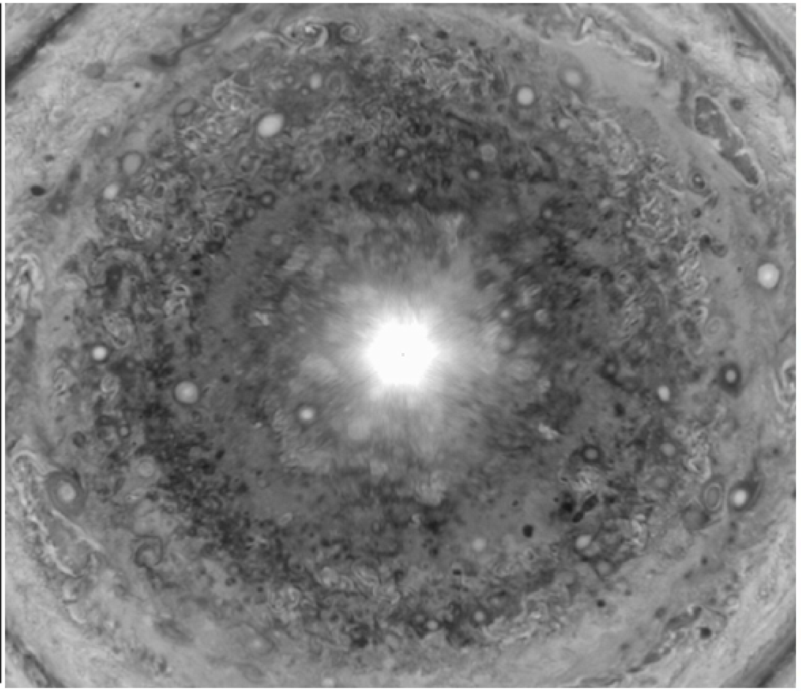

F335M
270°
300°
330°
70°
60°
50°
40°
0°
30°
60°
F360M
270°
300°
330°
80°
70°
60°
50°
40°
30°
60°

Cassini UV



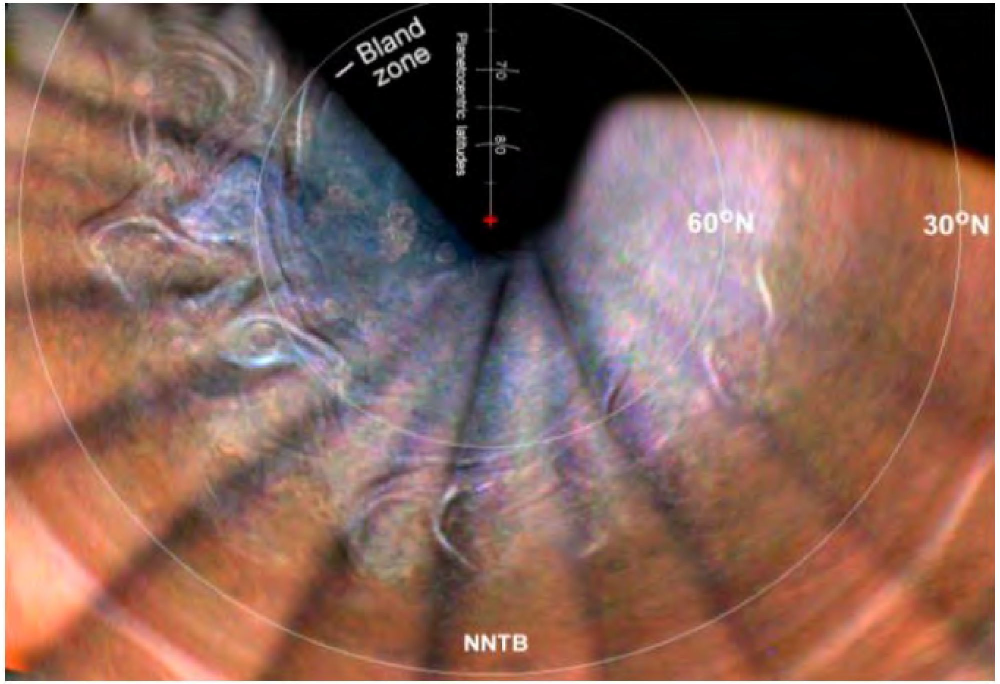
Vincent et al. (Icarus, 2000)

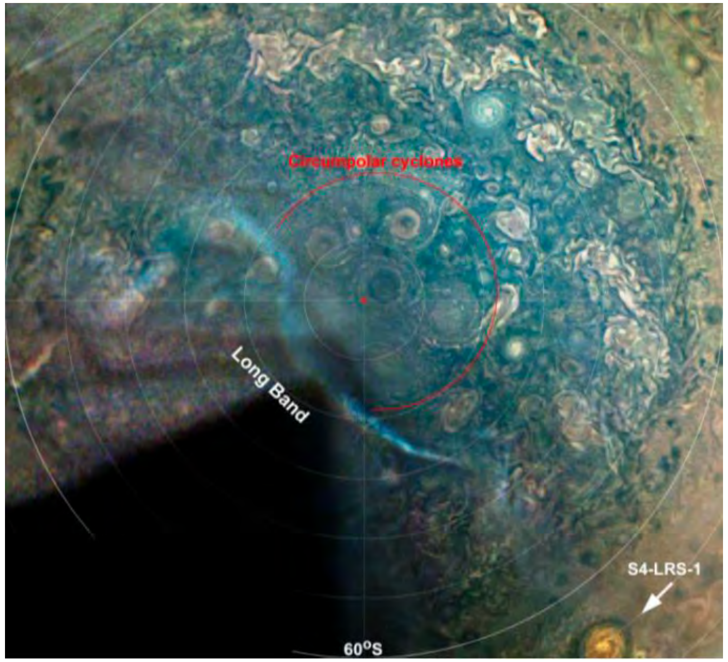
Cassini Visible



West et al. Jupiter book (2004)

Junocam Visible





Rogers et al. (2018)