Outer Solar System Science with MCAO

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SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

Collaborators

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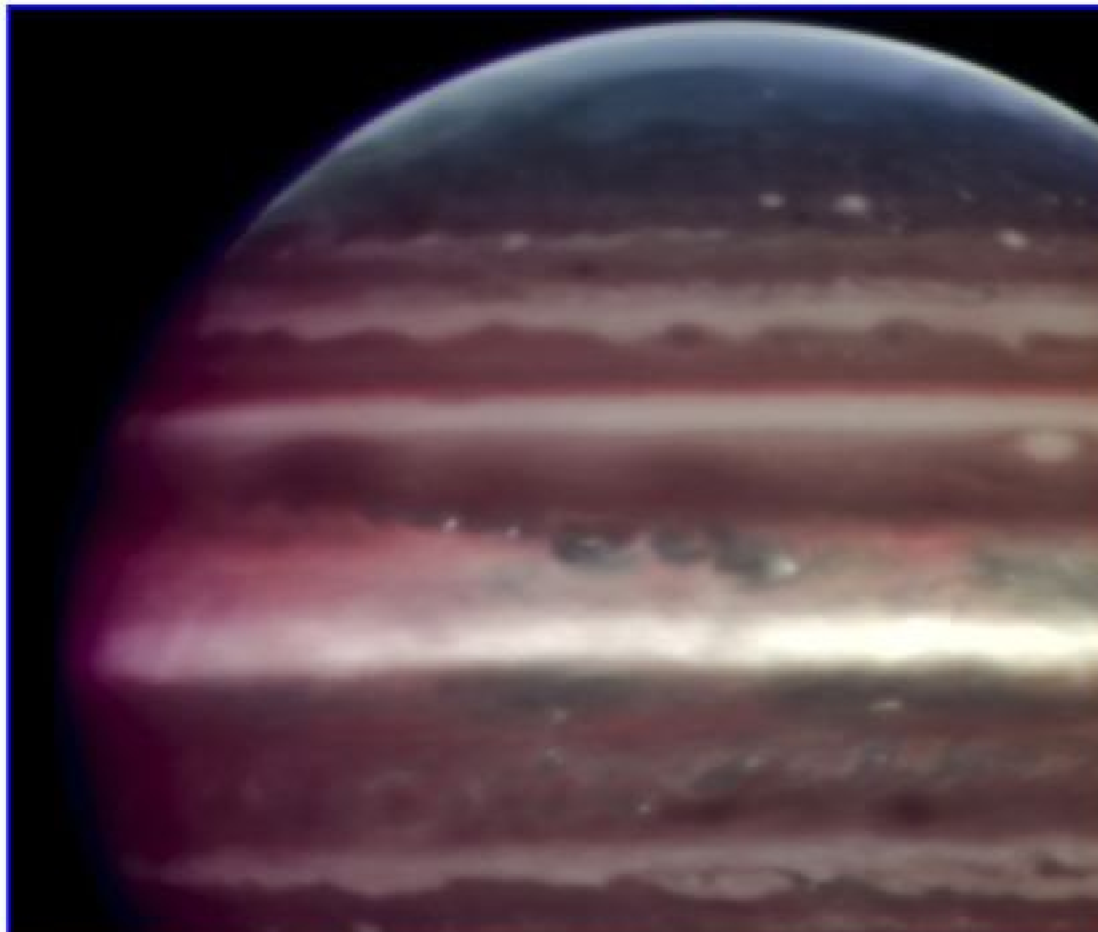
- Paola Amico (ESO Paranal)
- Hervé Bouy (IAC Tenerife)
- Patrick Lii (UCB/Cornell)
- Imke de Pater (UCB/Delft)
- Xylar Asay-Davis (UCB/Los Alamos)

Astronomy Picture of the Day

Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

2008 November 6



NATIONAL GEOGRAPHI

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NEW JUPITER IMAGE: Sharpest View Ever From Earth

back scatter

Adapting adaptive optics

For the past 20 years, adaptive optics techniques have provided ground-based astronomers with space-quality images. With rapid, real-time analysis of the time-varying spread of light from a star or other point source (termed a guide star), a computer-controlled deformable mirror corrects for the distortion introduced by atmospheric turbulence and restores crisp detail to images. But the corrections are effective only for light arriving from essentially the same direction, and that limits the field of view to only about 15 arcseconds. An international team led by Franck Marchis of the University of California, Berkeley, [OK?] has recently demonstrated one technique to overcome that limitation: the Multi-Conjugate Adaptive Optics Demonstrator, or MAD.

MAD uses multiple guide stars and two deformable mirrors to correct for phase distortions over a broader range of angles; the resulting field of view is 30 times larger. Shown here is a false-color IR image of Jupiter obtained with MAD at the European Southern Observatory's Very Large Telescope in August. The moons Io and Europa, on either side of Jupiter at the time, served as guide stars. The corrected angular resolution was less than a tenth of an arcsecond—details about 300 km across could be resolved. In the observed region of the IR, absorption by hydrogen and methane is strong. The image thus maps the distribution of the planet's high-altitude haze. A comparison with images taken three years ago by the *Hubble Space Telescope* reveals significant changes in the haze distribution; the researchers attribute those changes to a planet-wide upheaval last year. Michael Wong presented the team's results at the October meeting of the American Astronomical Society's Division for Planetary Science in Ithaca, New York. (Image courtesy of ESO/F. Marchis, M. Wong, E. Marchetti, O. Amico, and S. Tordo.)

To submit candidate images for Back Scatter, visit http://www.physicstoday.org/backscatter.html.

104 December 2008 Physics Today www.physicstoday.org

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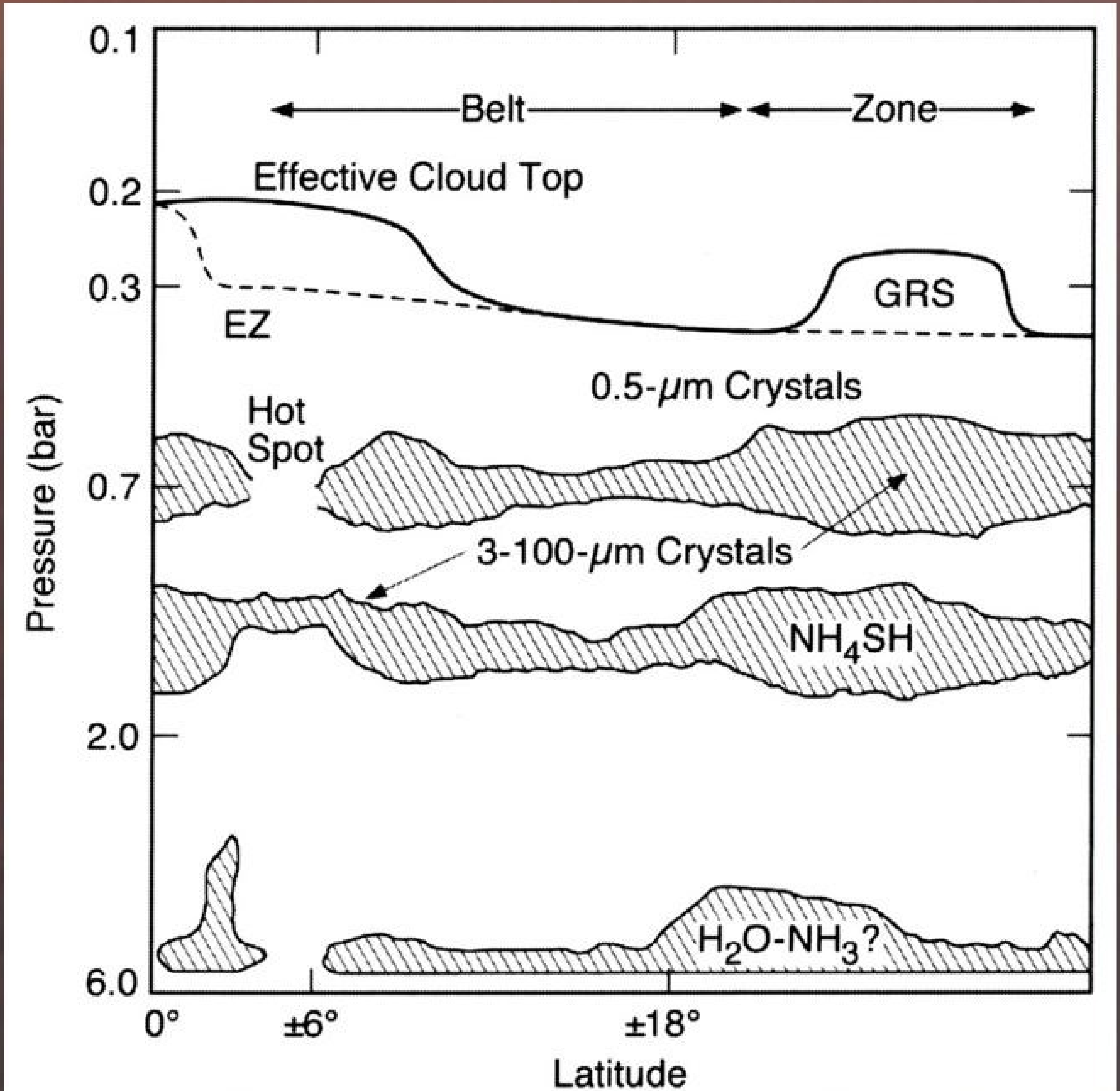
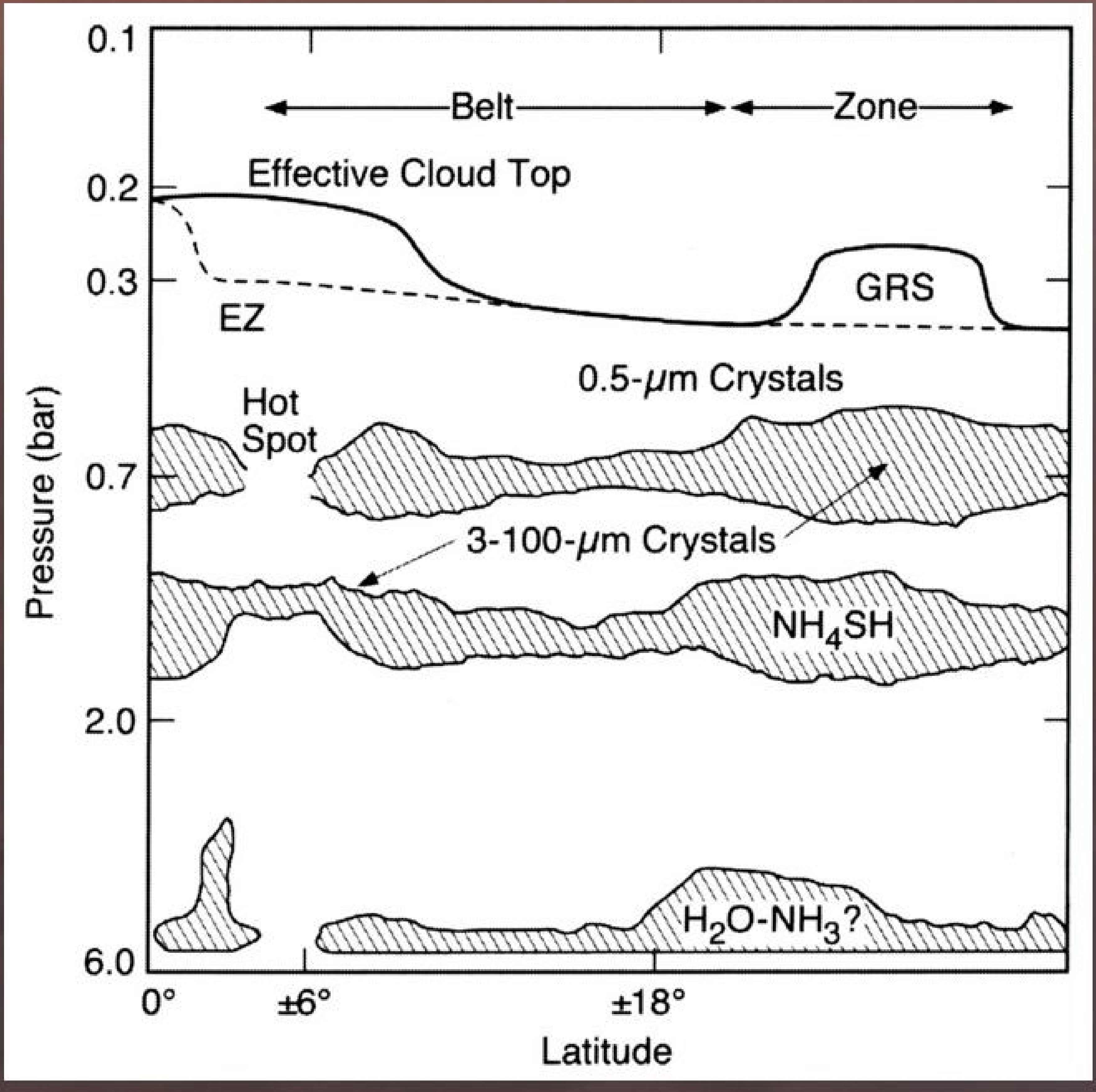
Observed cloud structure



West et al. (2004)

- cartoon based on a review of a large colletion of observations
- top lines indicate top of haze in northern (dashed) and southern (solid) hemispheres

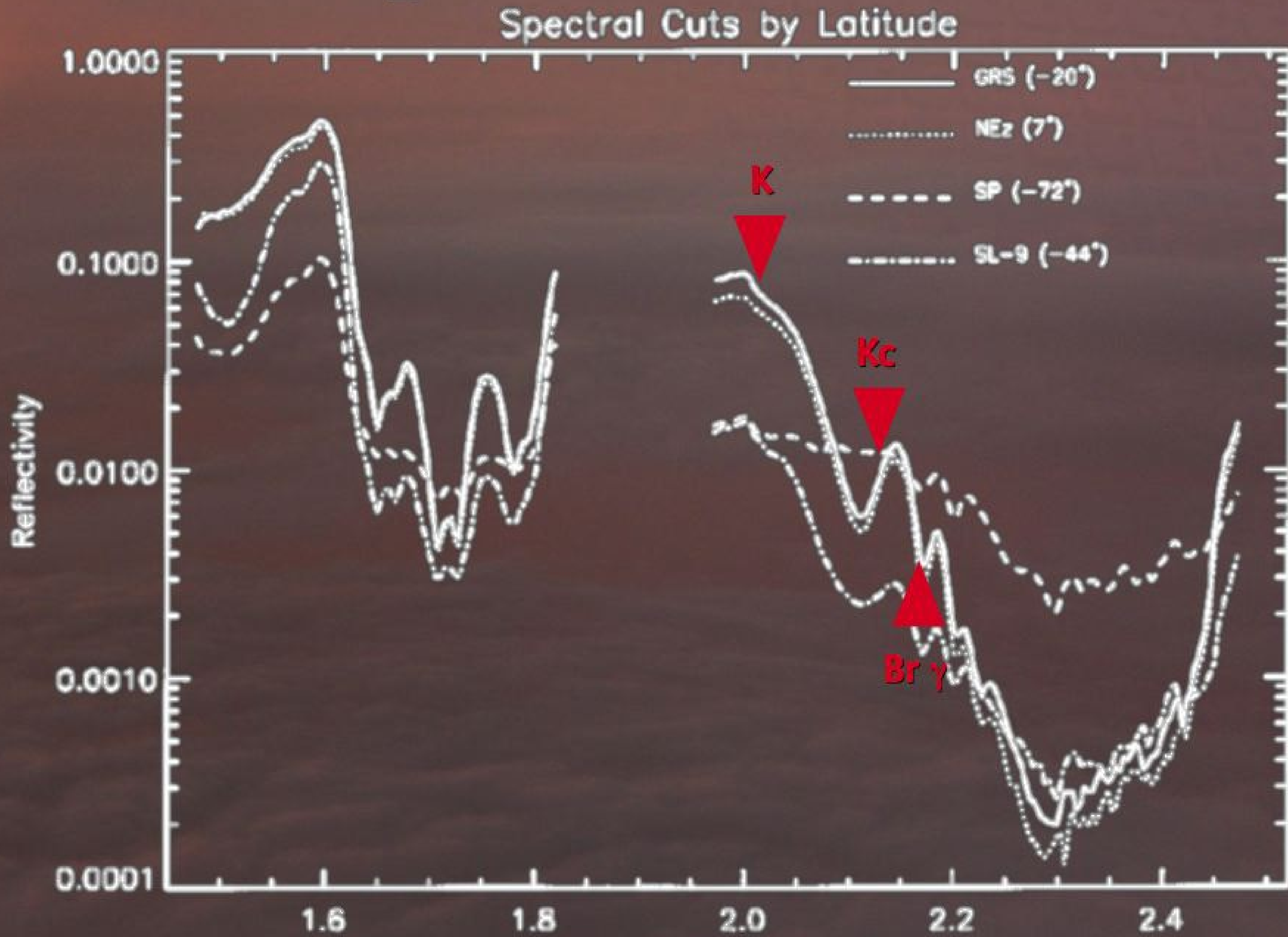
Haze composition/origin



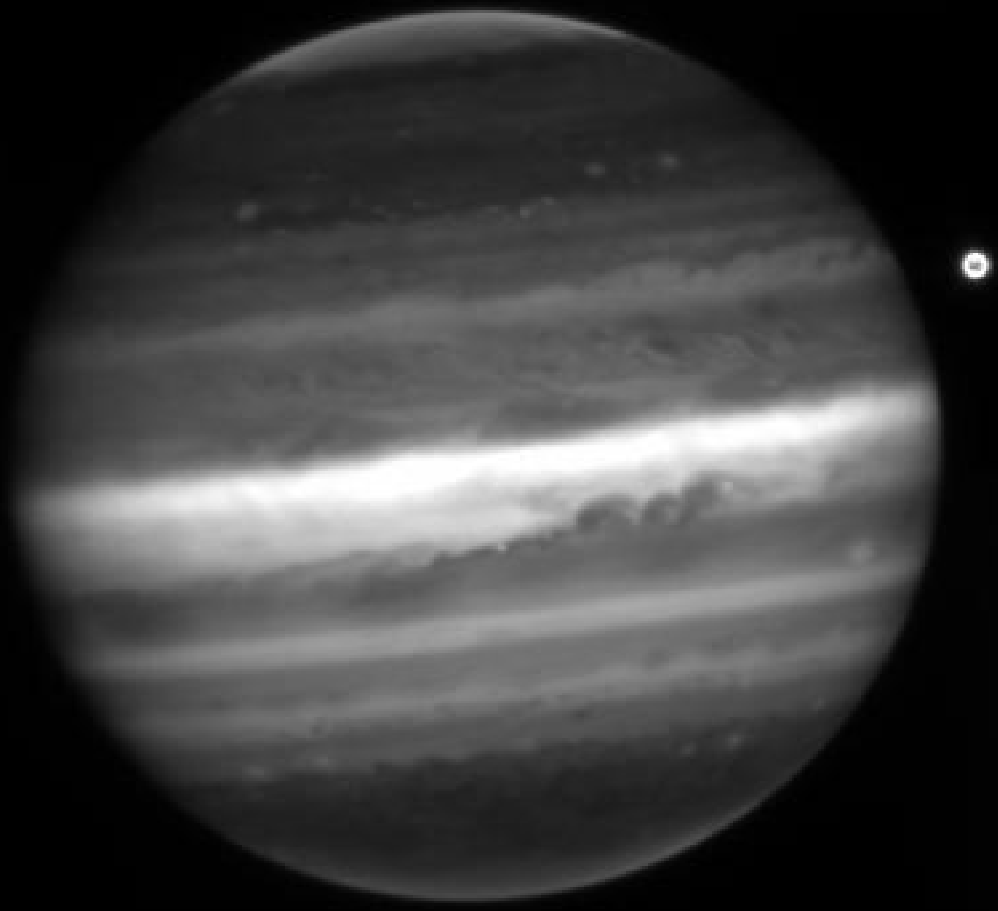
Two possibilities

- NH_3 ice lofted from below
- N_2H_4, a photolysis product of NH_3, condenses in the cold upper troposphere

Jovian spectrum in the NIR

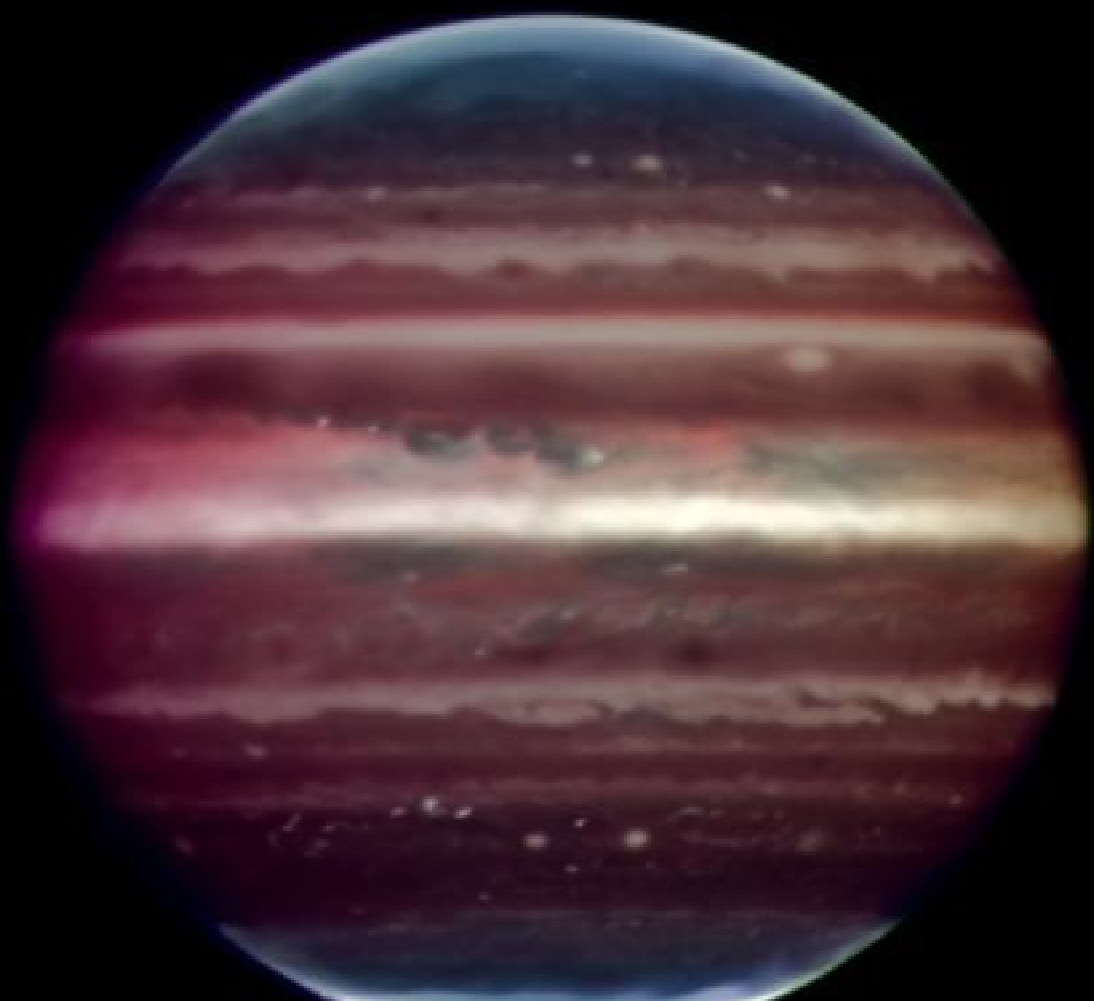


Banfield et al. (1998)



MAD (2008)

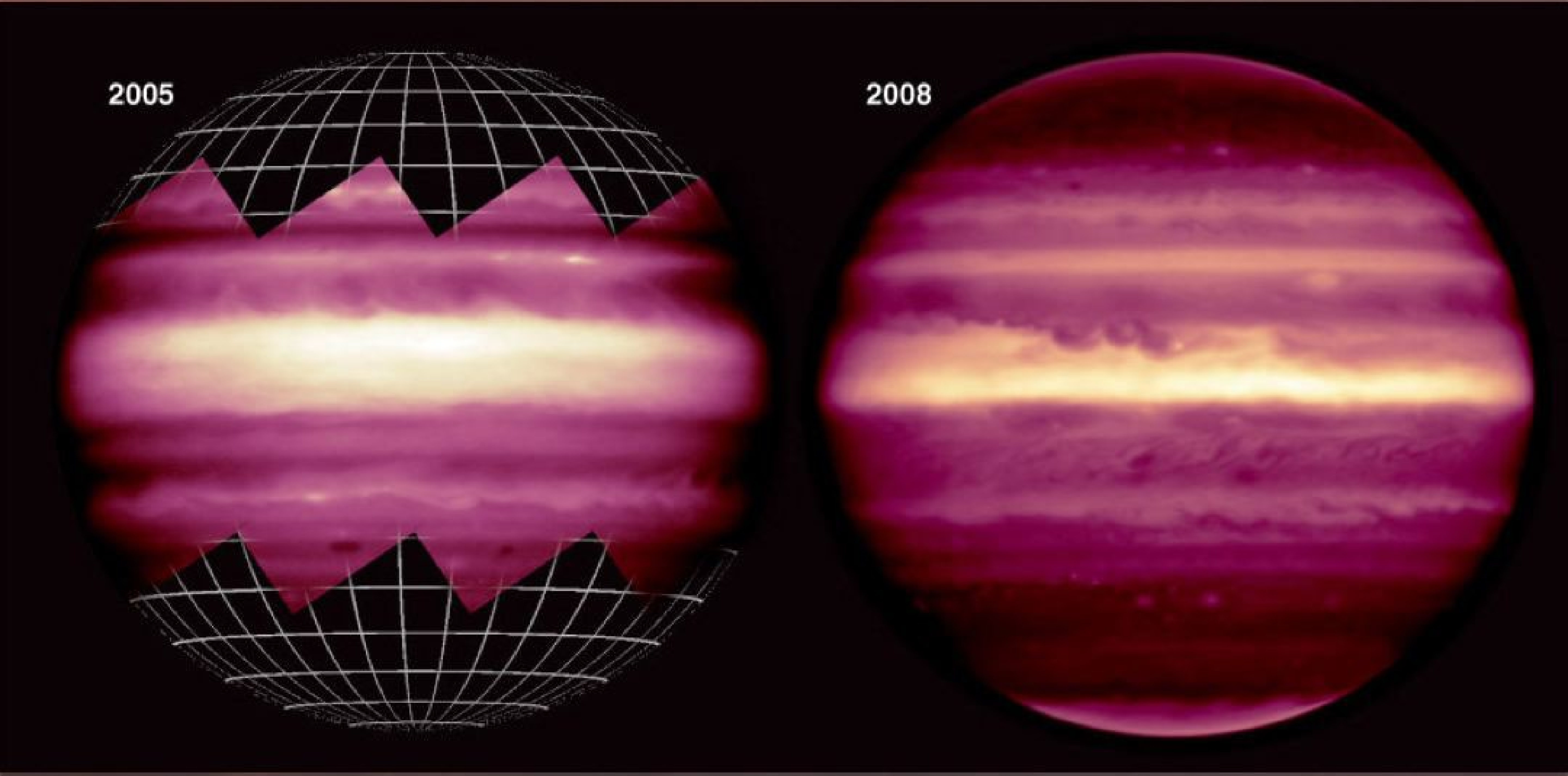
- original image reversed
- is Jupiter rotating the other way ??
- no, the haze has shifted !!



MAD (2008)

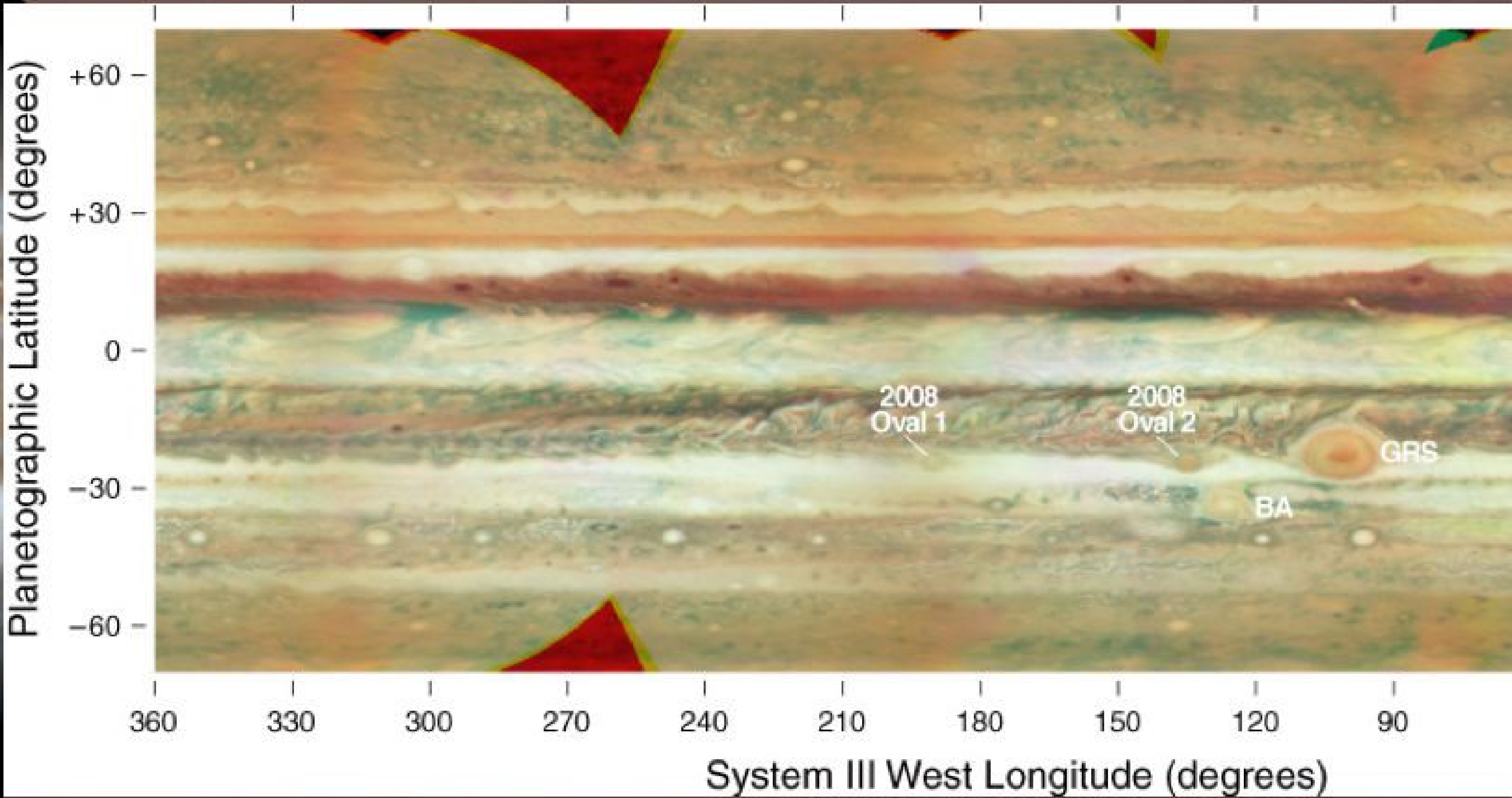
- deprojected into latitude-longitude space
- 3 wavelengths reprojected onto spheroid
- color/contrast enhancement (but no sharpening/deconvolution) by S. Tordo

Equatorial haze shift



Wong et al. (2008 DPS)

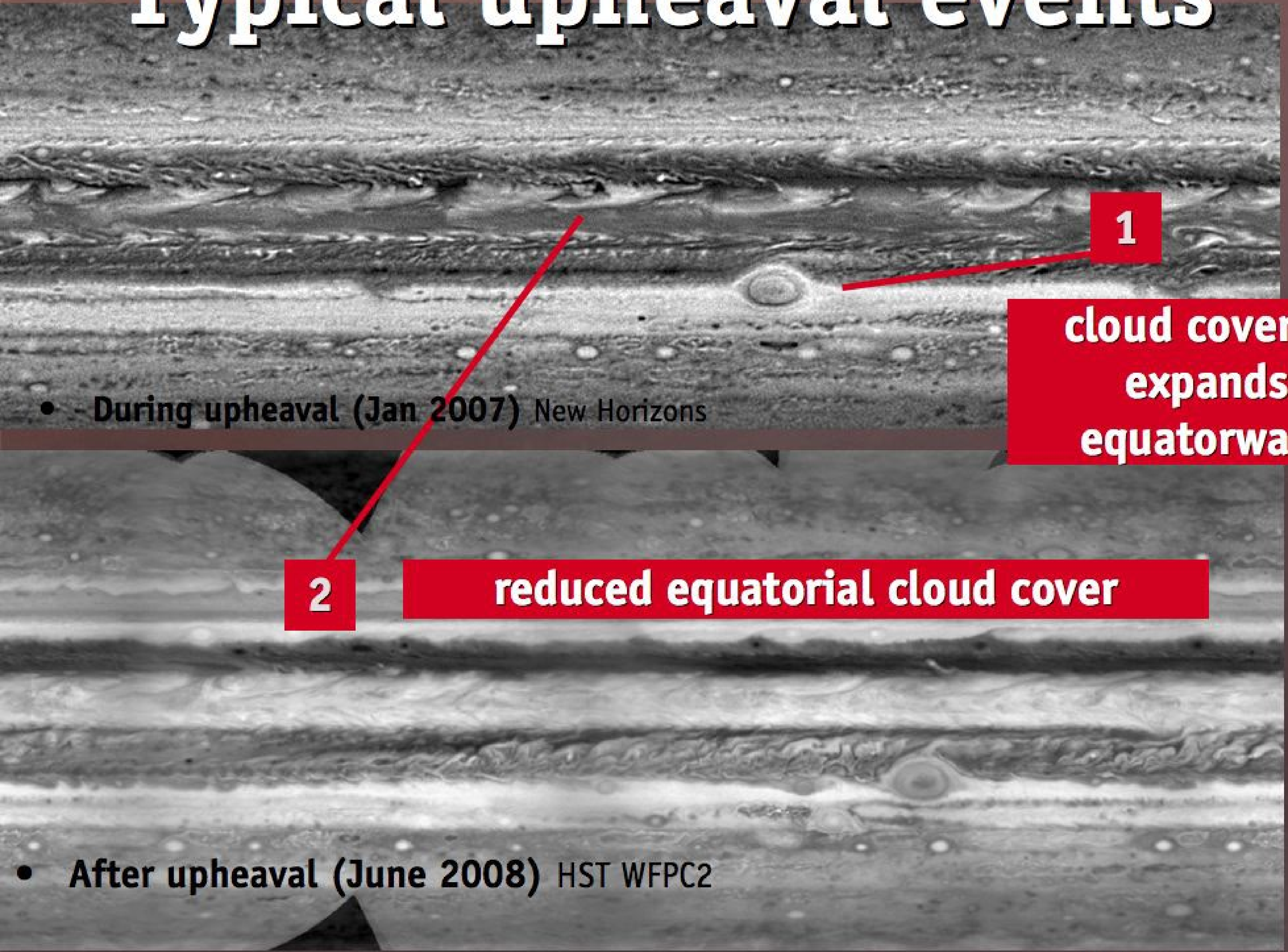
Global upheavals



- **During upheaval (Feb 2007)**
- **After upheaval (June 2008)**

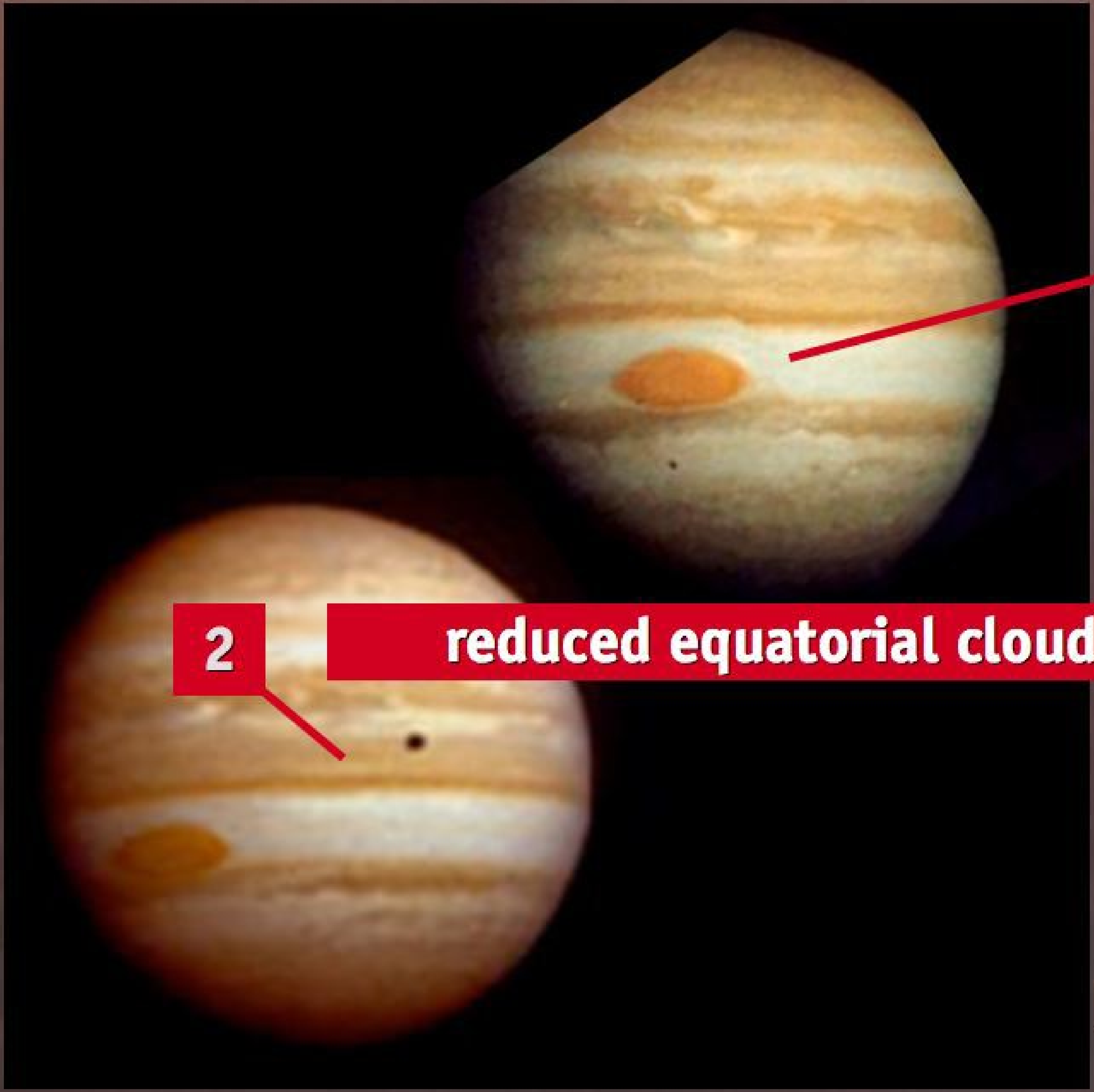
HST WFPC2

Typical upheaval events



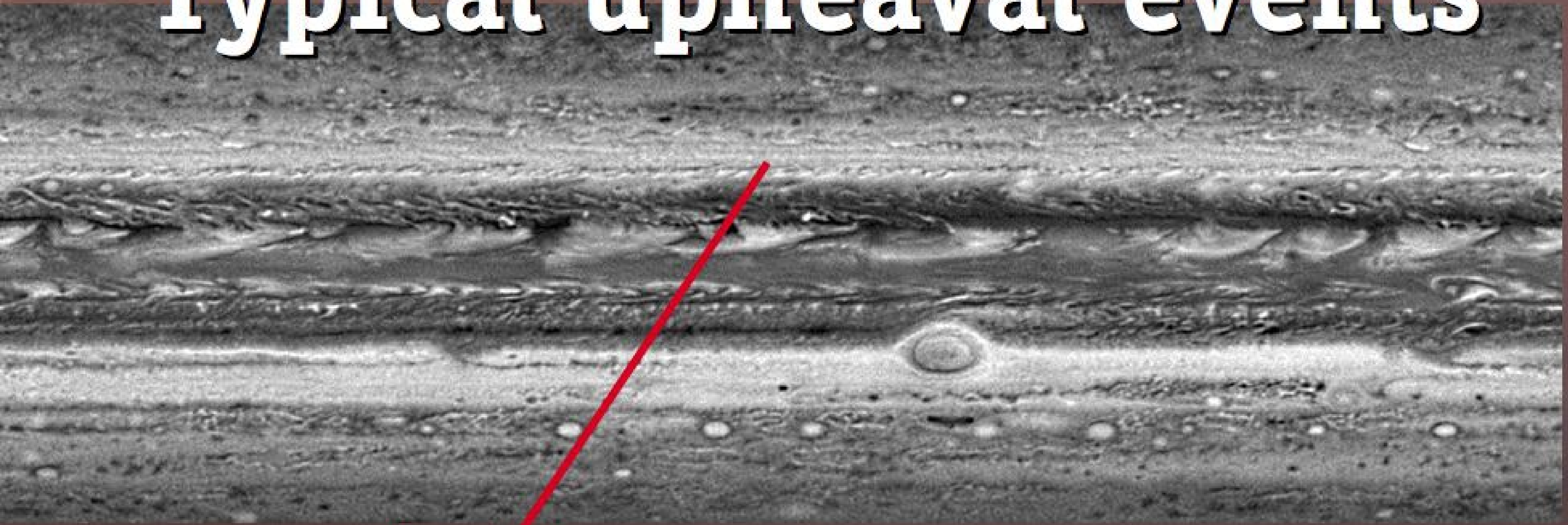
- During upheaval (Jan 2007) New Horizons
- After upheaval (June 2008) HST WFPC2

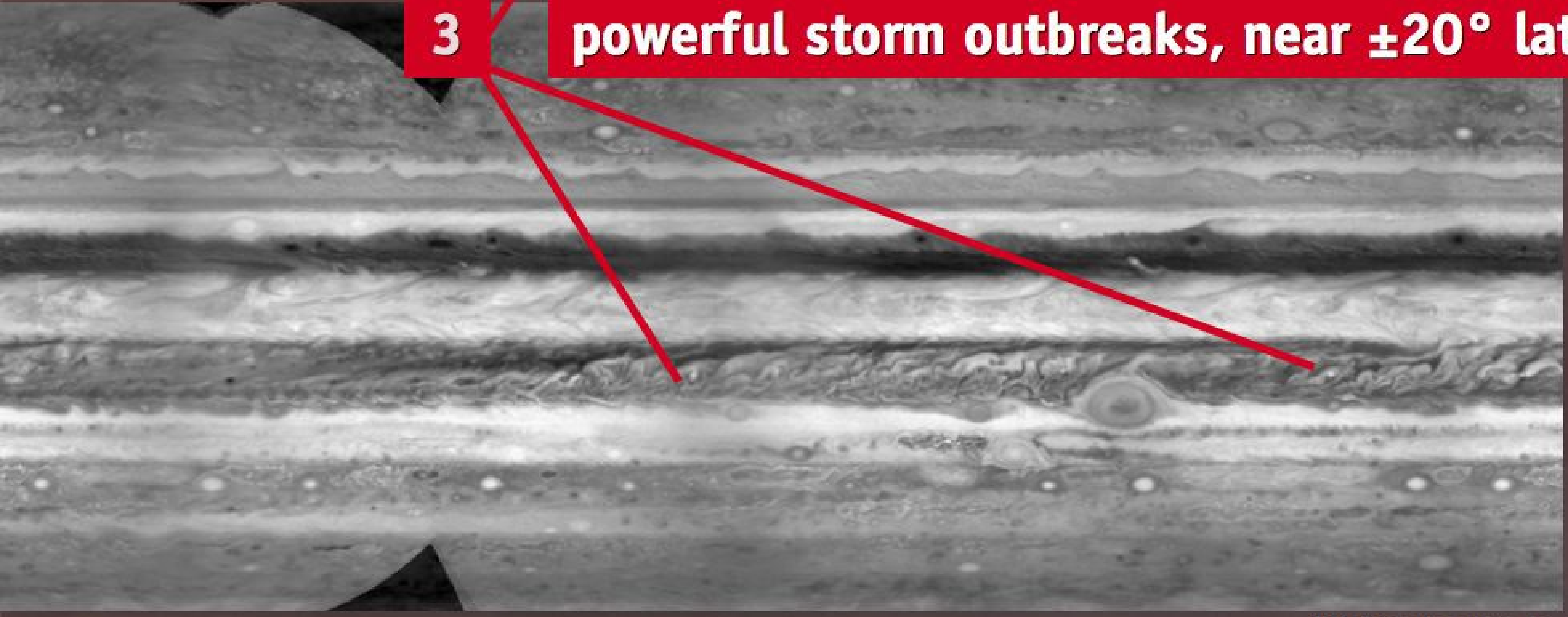
Typical upheaval events



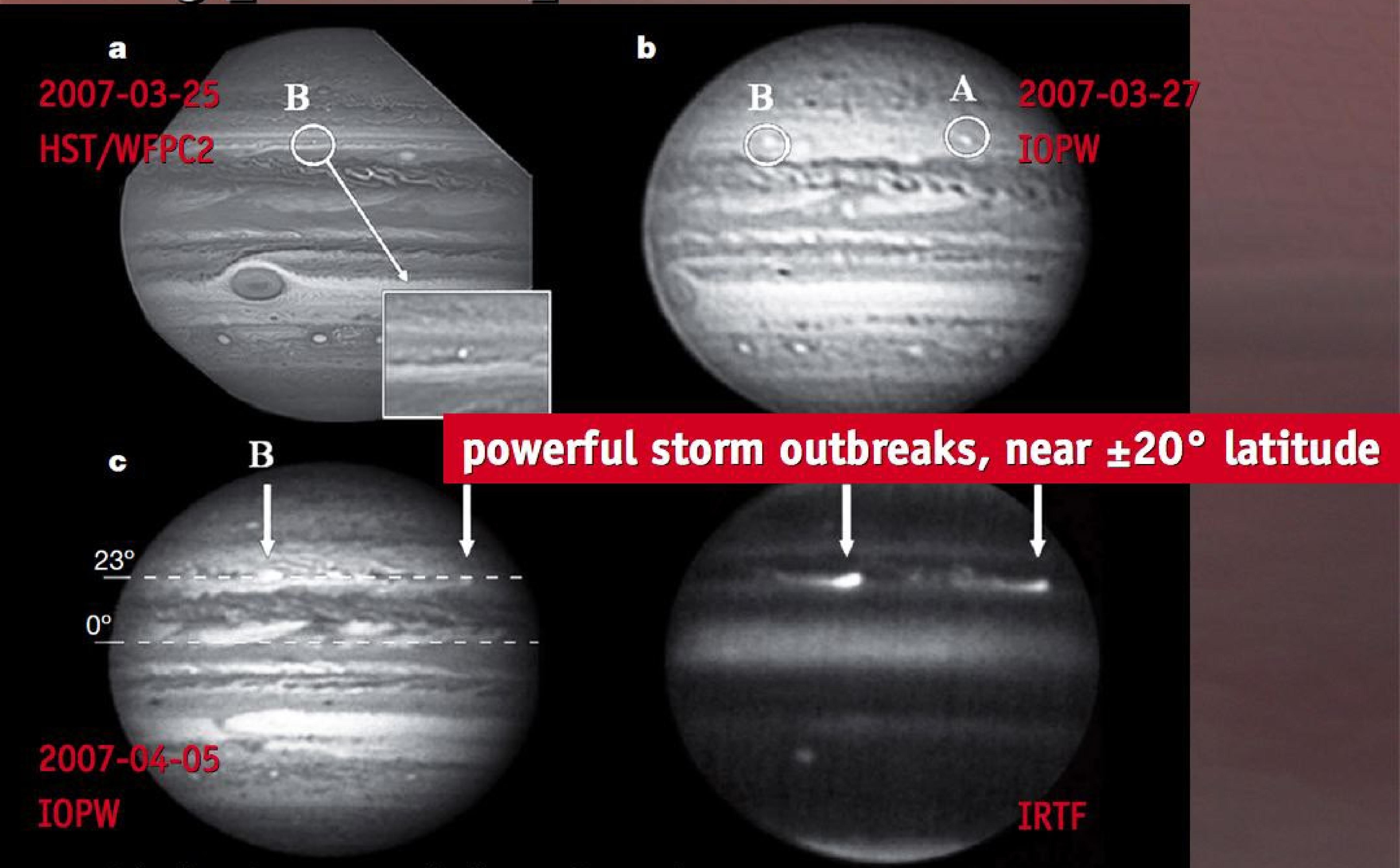
Pioneer 10 & 11, 1973-4

Typical upheaval events



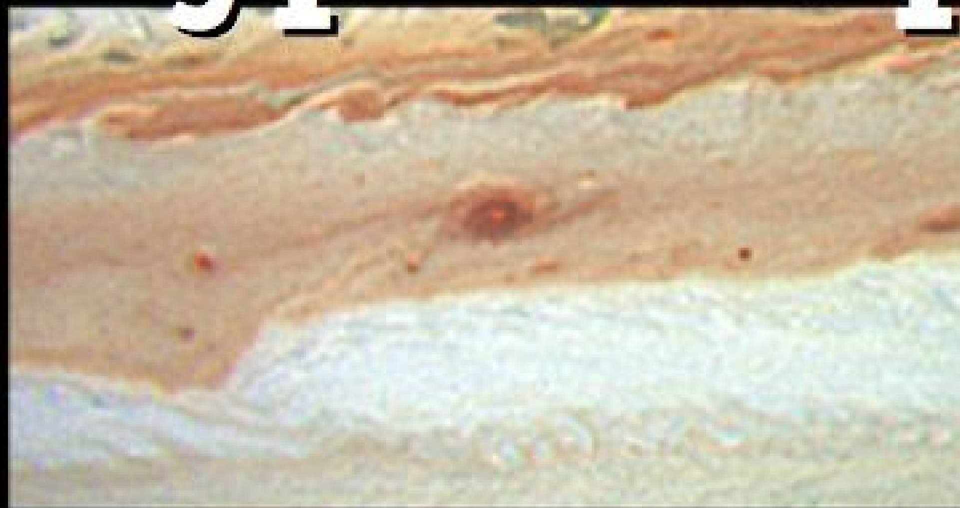


Typical upheaval events



Sánchez-Lavega et al. (2008 Nature)

Typical upheaval events



May 11, 2007 HST Image

May 17, 2007

May 22, 2007

June 1, 2007

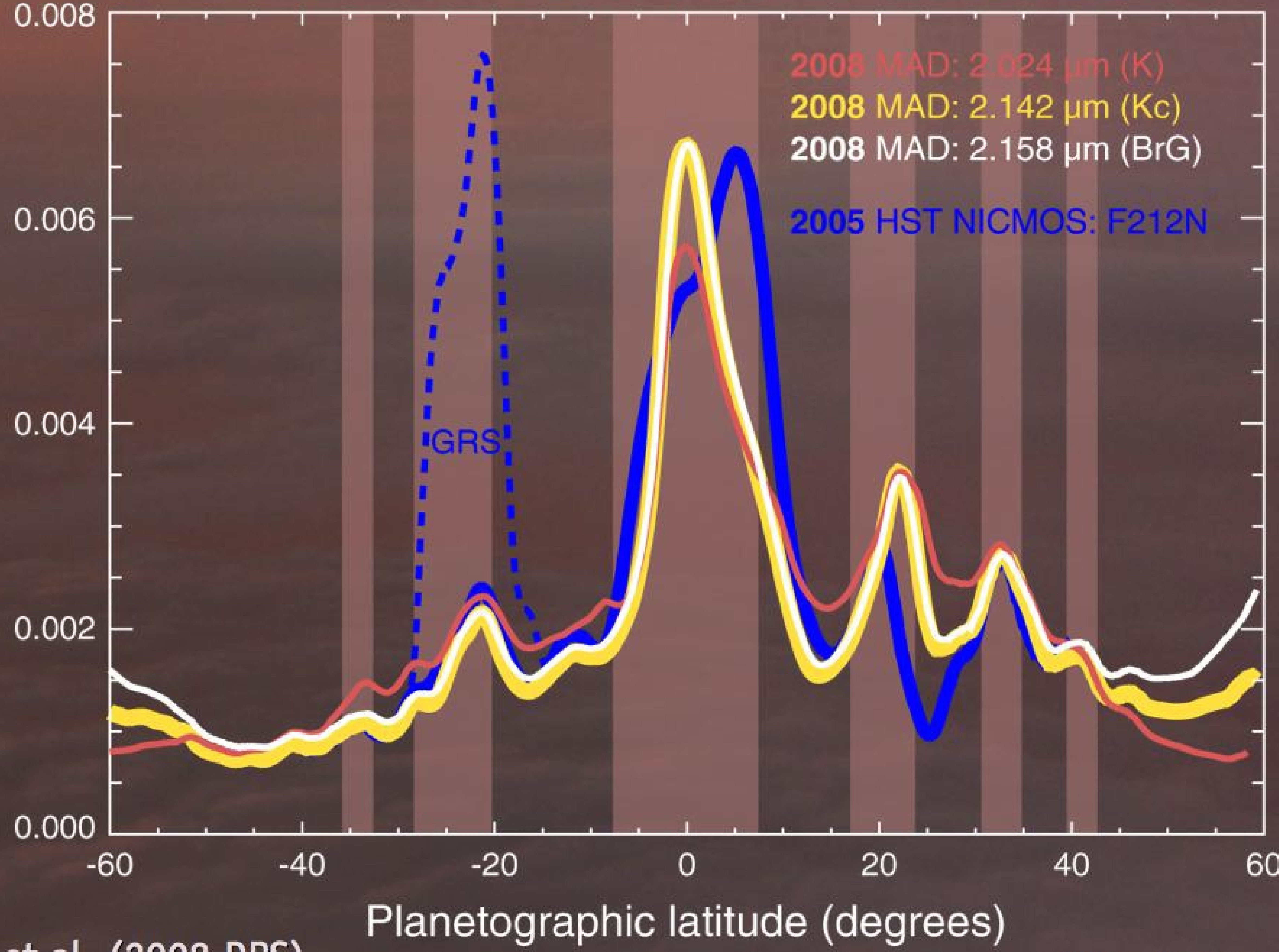
powerful storm outbreaks, near ±20° latitude

June 13, 2007

July 2, 2007

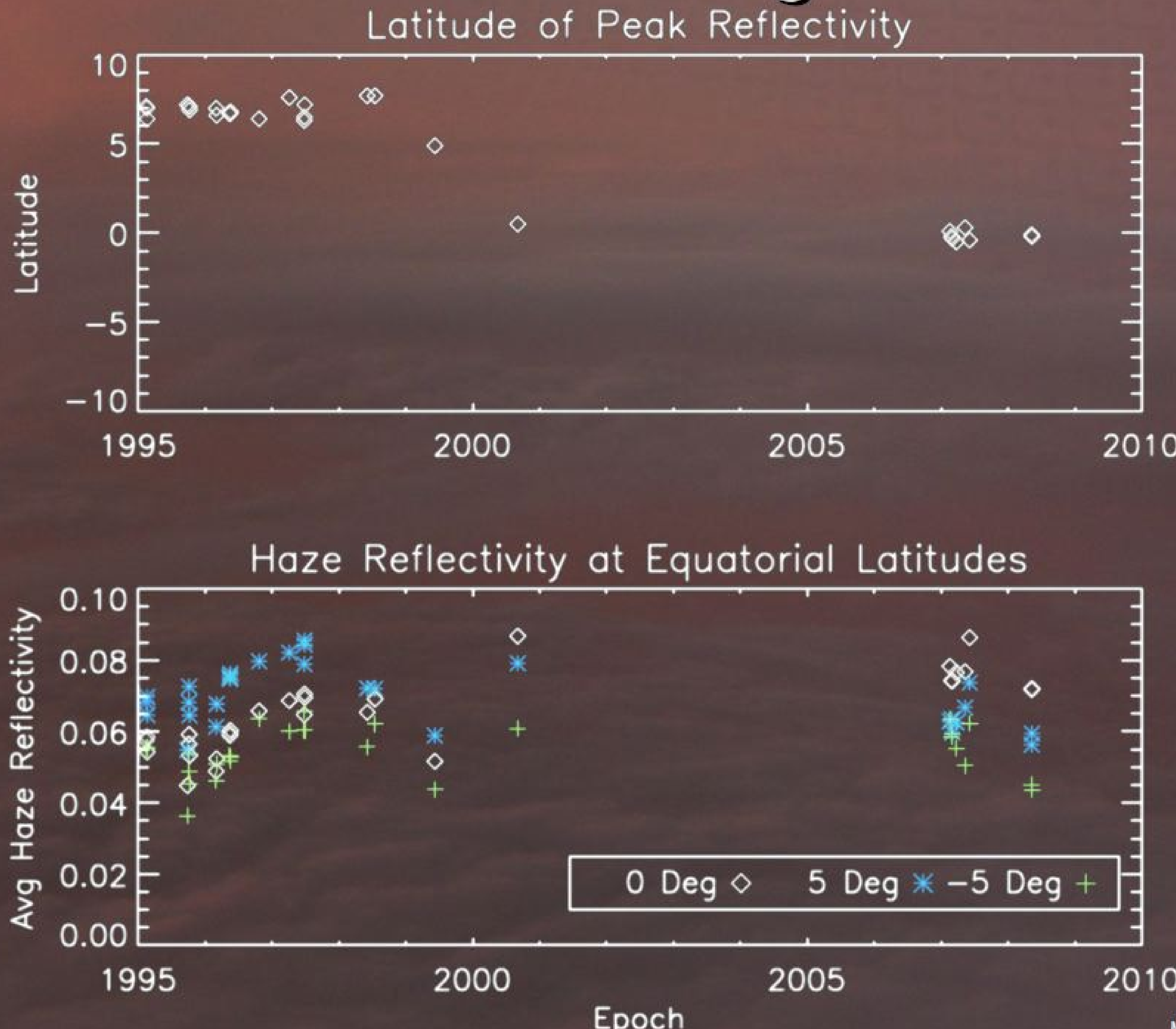
Go et al. (2008 DPS)

Shifted haze distribution



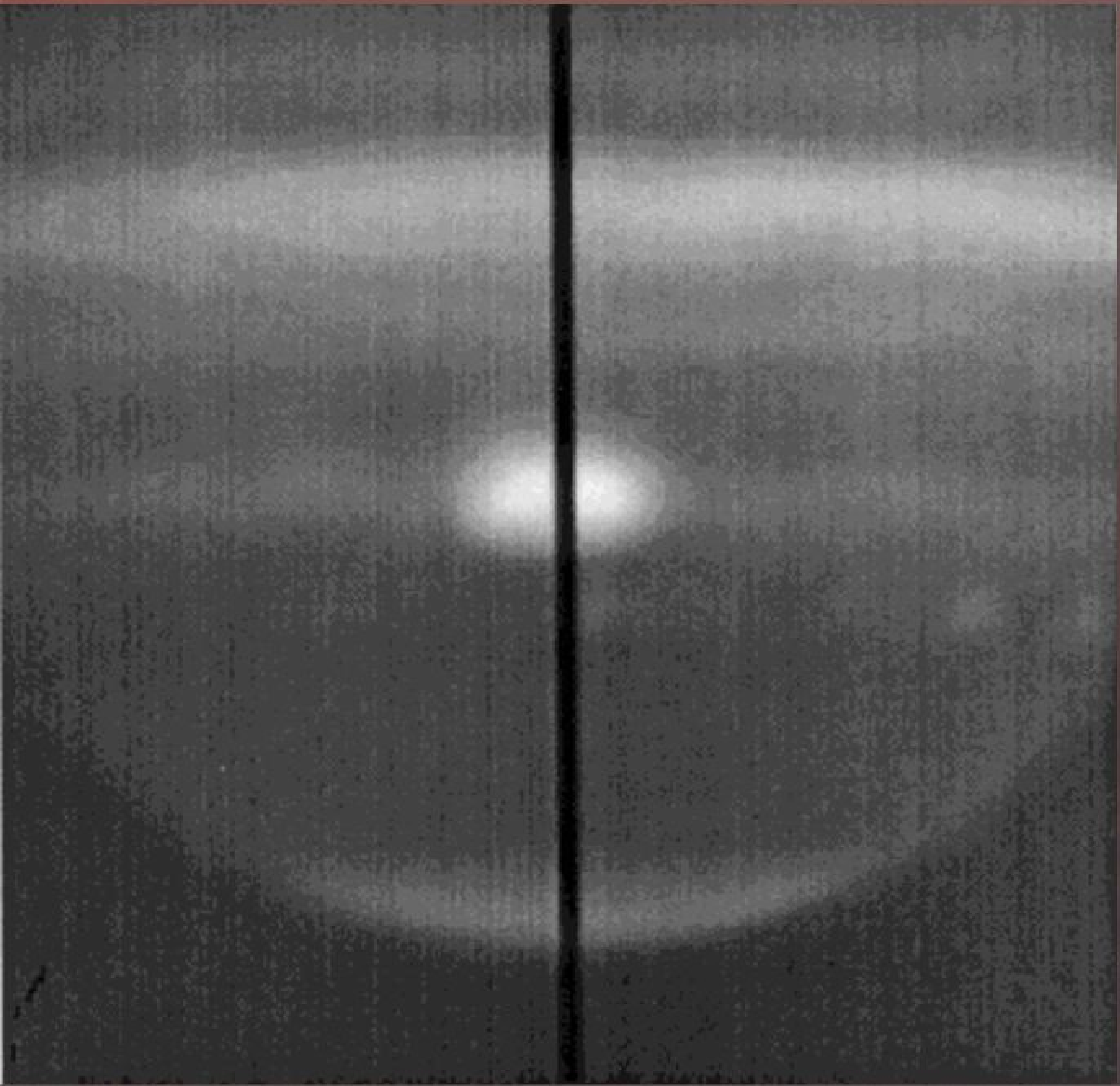
Wong et al. (2008 DPS)

Haze variability



Lii et al. (2009, in preparation)

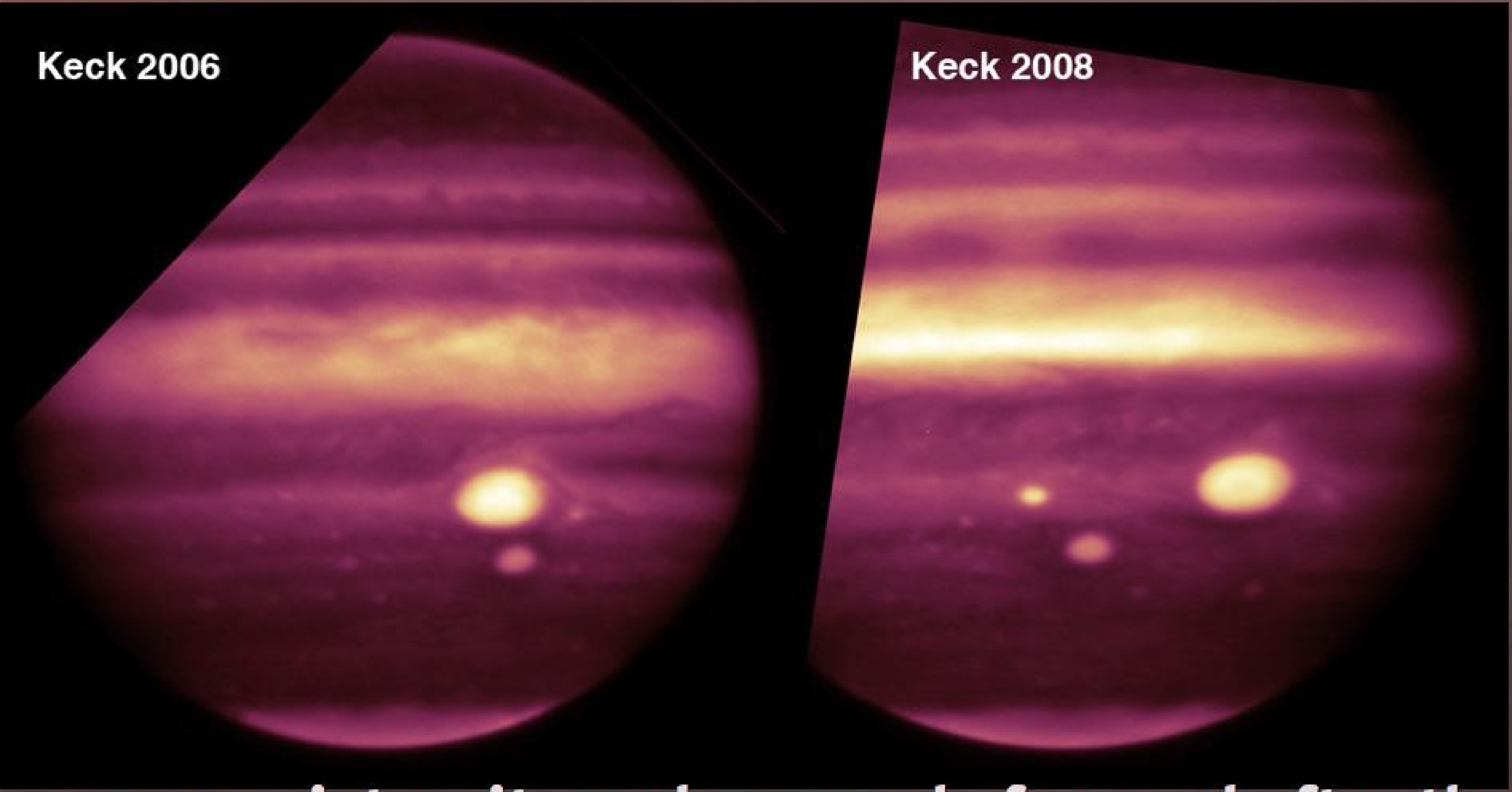
AO needed !!



Banfield et al. (1998)

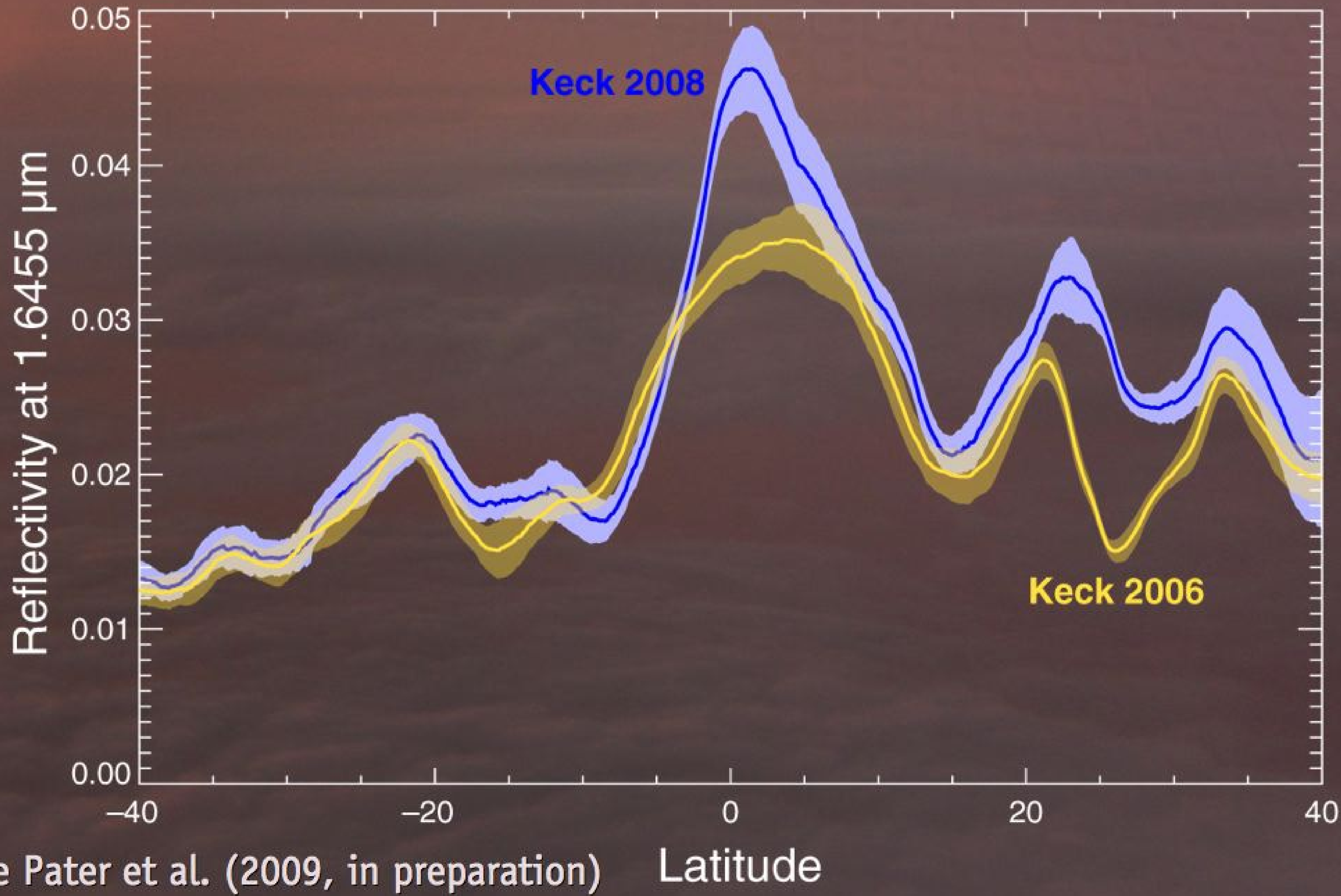
- K-band spectroscopy
- seeing-limited data
- 5-m Palomar telescope
- haze structure poorly resolved

Keck NGS AO (1.65 µm)



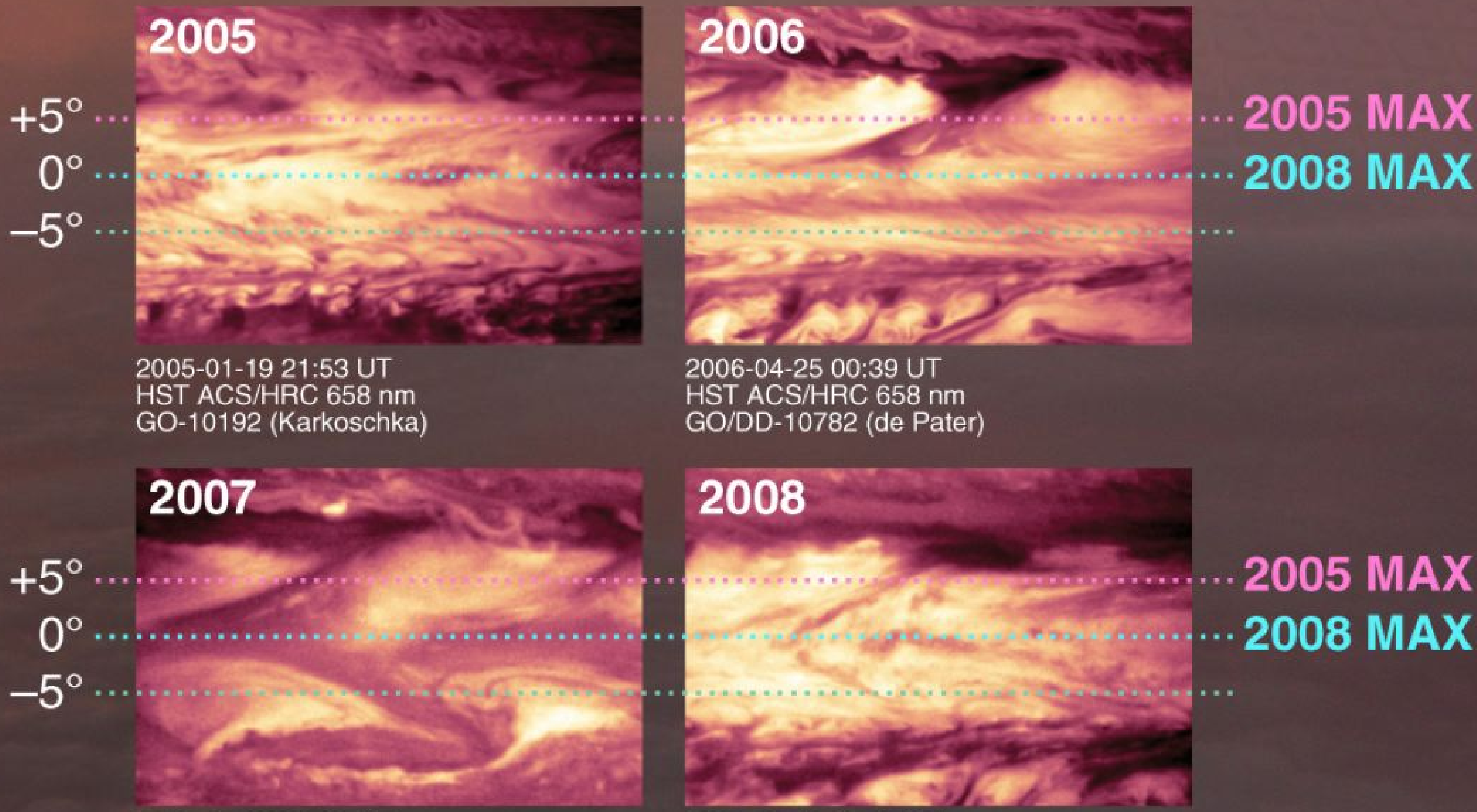
- same intensity scale
- clear changes at 23°N and near equator
- before and after the 2006/2007 global upheaval

Shifted haze distribution



de Pater et al. (2009, in preparation)

Equatorial CLOUD variation



2005-01-19 21:53 UT
HST ACS/HRC 658 nm
GO-10192 (Karkoschka)

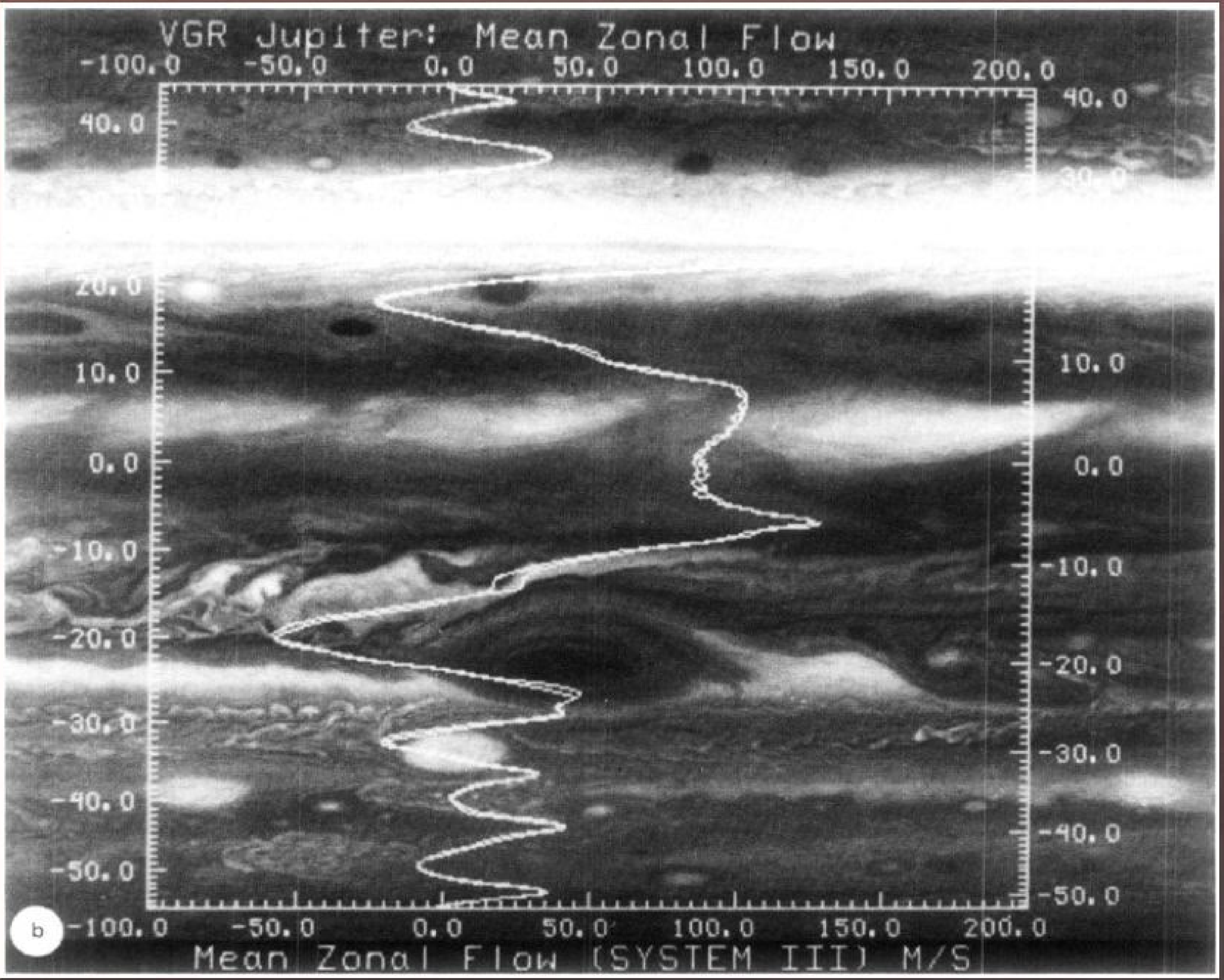
2006-04-25 00:39 UT
HST ACS/HRC 658 nm
GO/DD-10782 (de Pater)

2007-03-08 04:08 UT
HST WFPC2 673 nm
GO/DD-10782 (de Pater)

2008-05-10 11:50 UT
HST WFPC2 673 nm
GO-11102 (de Pater)

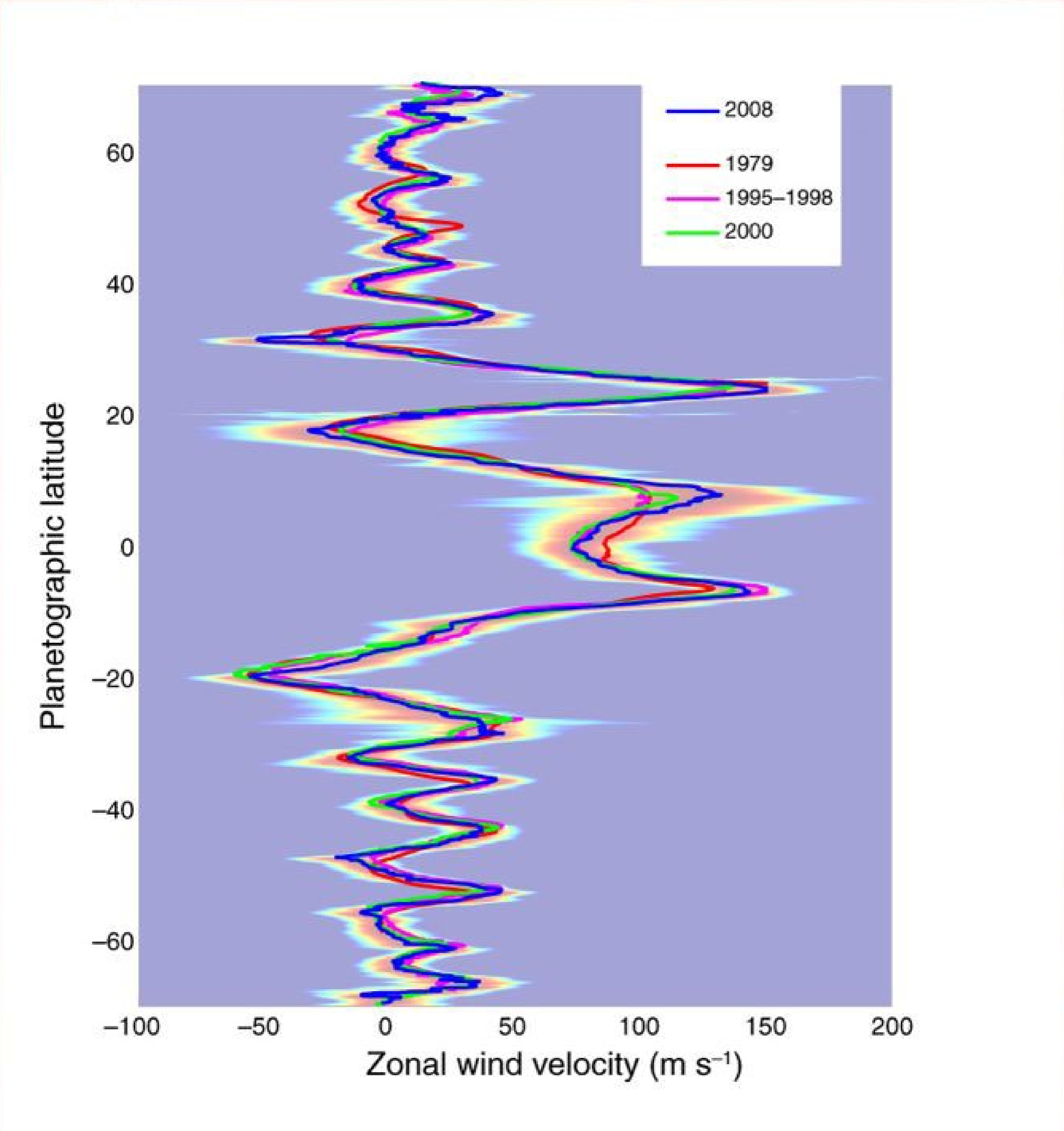
Wong et al. (2008 DPS)

Zonal winds and clouds



Limaye (1986 Icarus)

Equatorial WIND variation

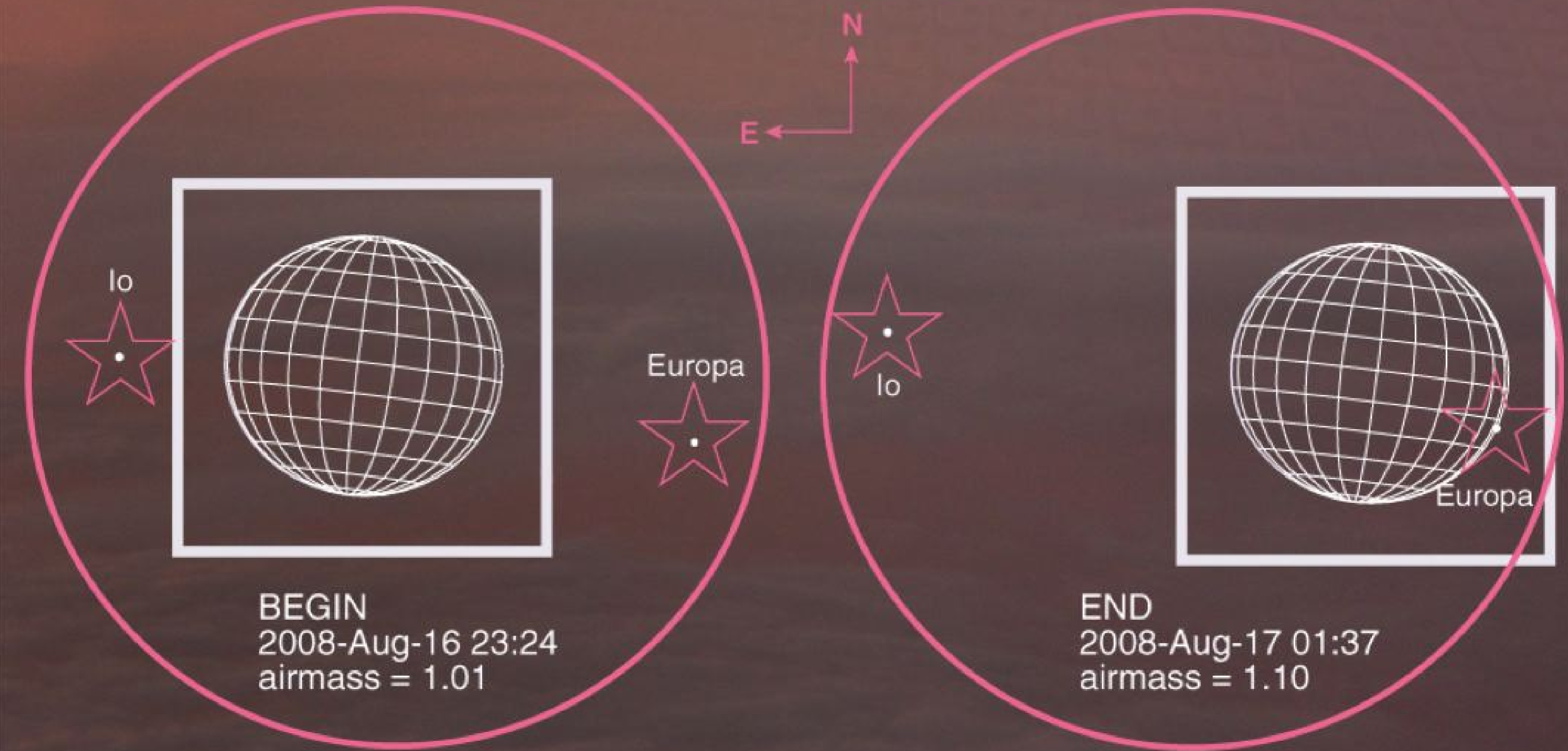


Asay-Davis et al. (in preparation)

Science summary

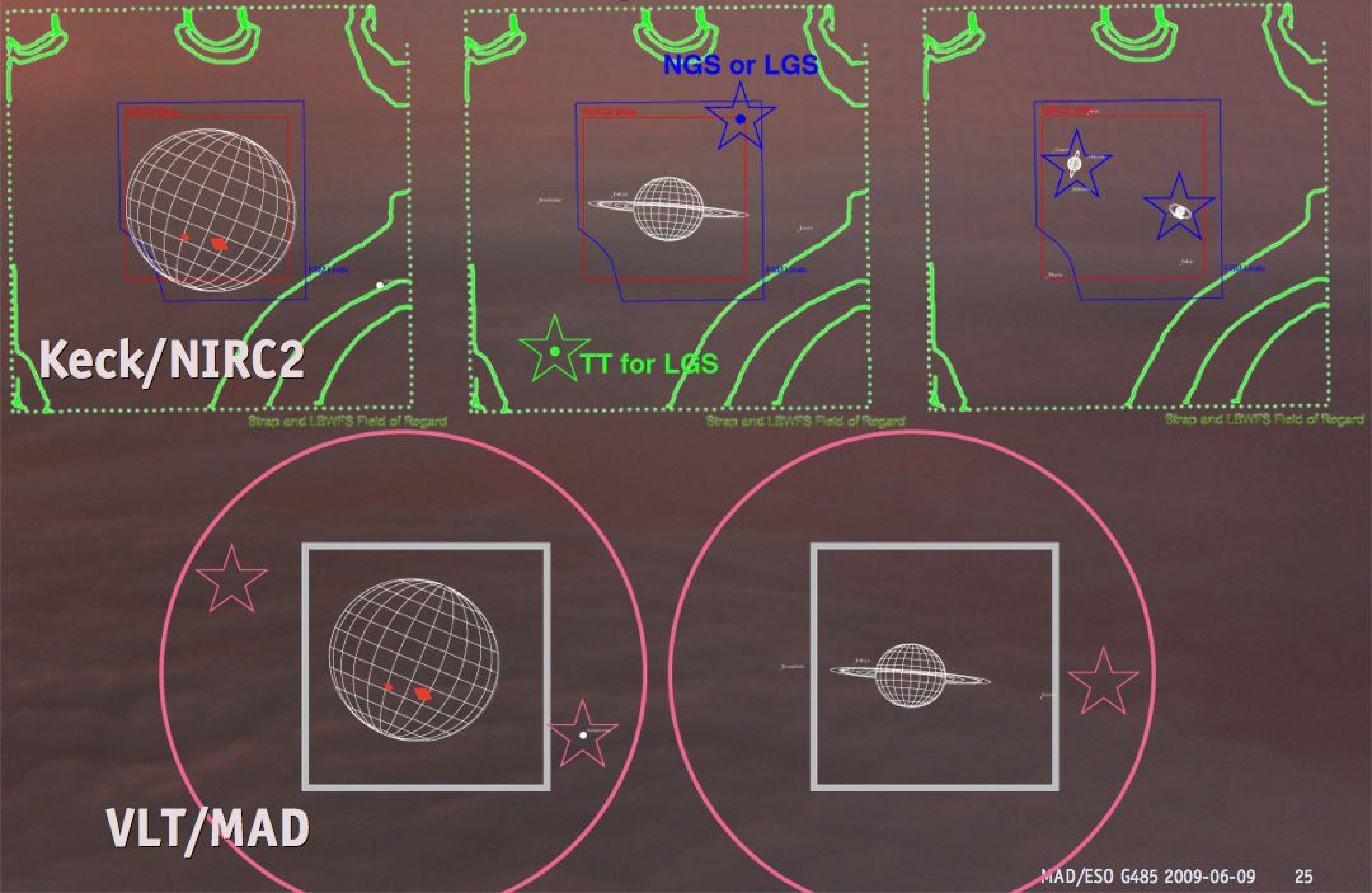
- Latitude of peak haze reflectivity shifted south
- Possible explanations:
  - upheaval related
  - cloud lofting source variation
  - temperature/NH_3 gas supply variation
  - controlled by zonal winds
- MAD opened a new area of time-domain solar system science
- Time variability is an important constraint for investigating the origin of the haze
- Global upheavals an active area of research

MAD observing geometry

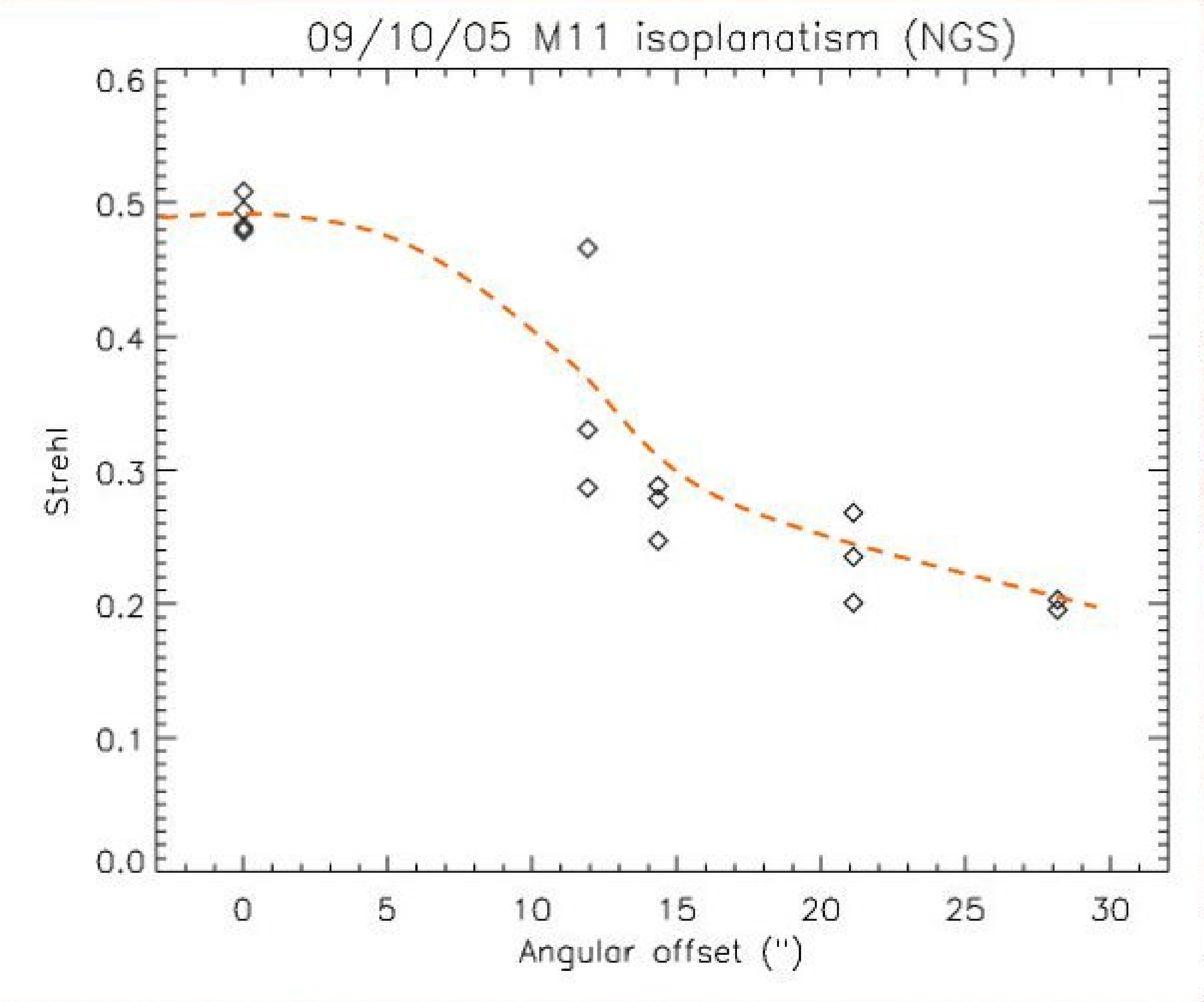


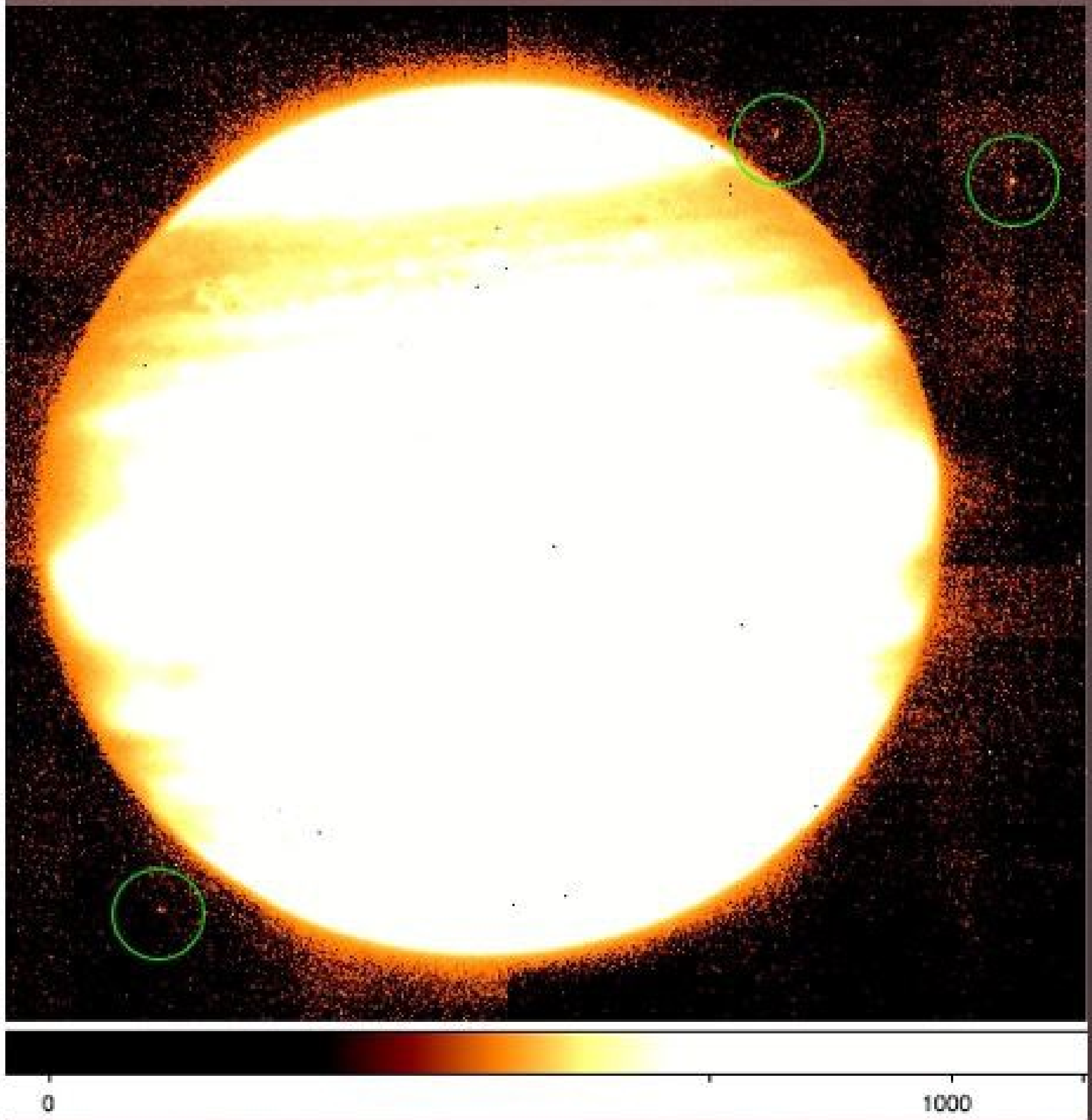
- WFS 2′ field of regard
- camera 1′ FOV

Outer solar system



SCAO vs MCAO



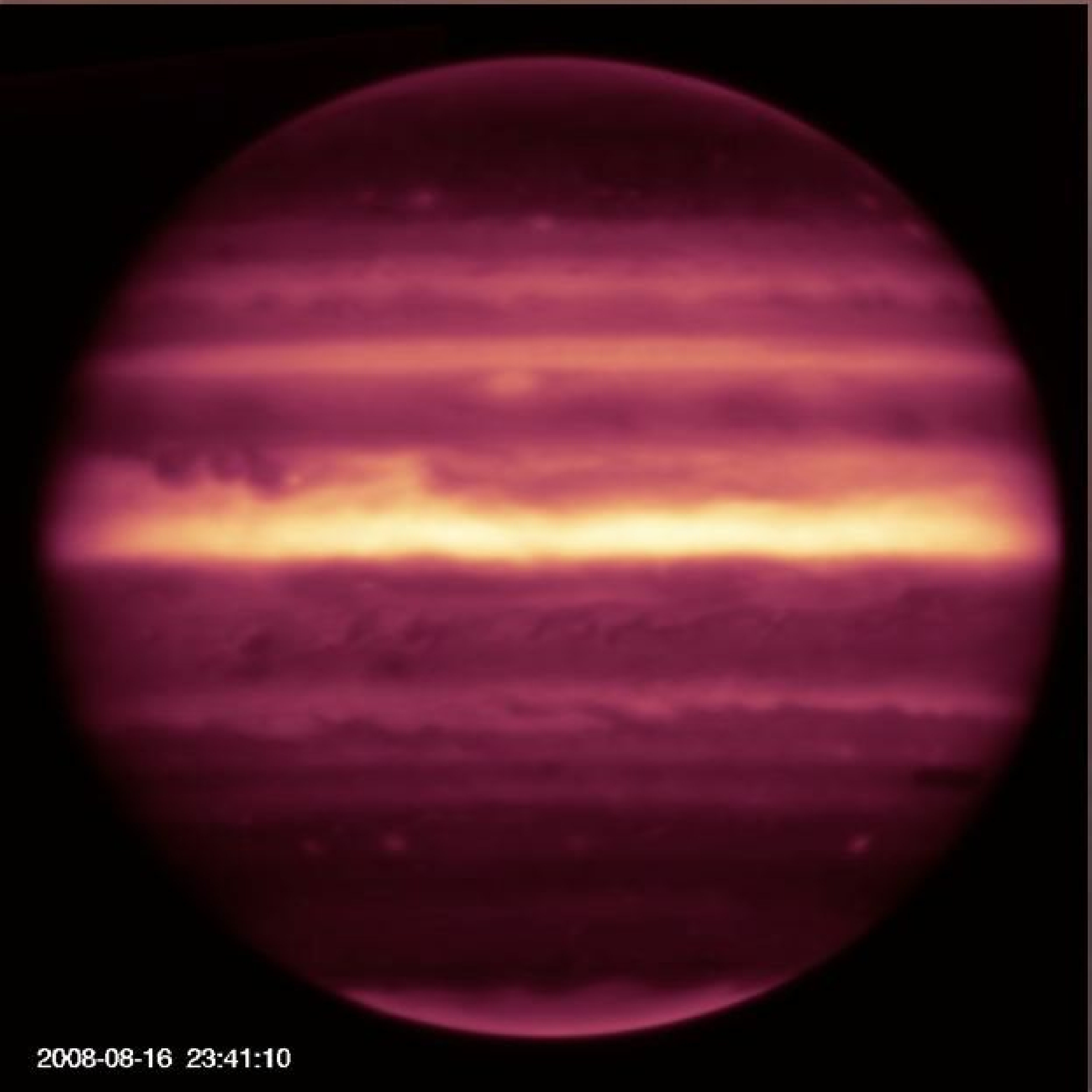


Le Mignant (2008) Keck AO workshop

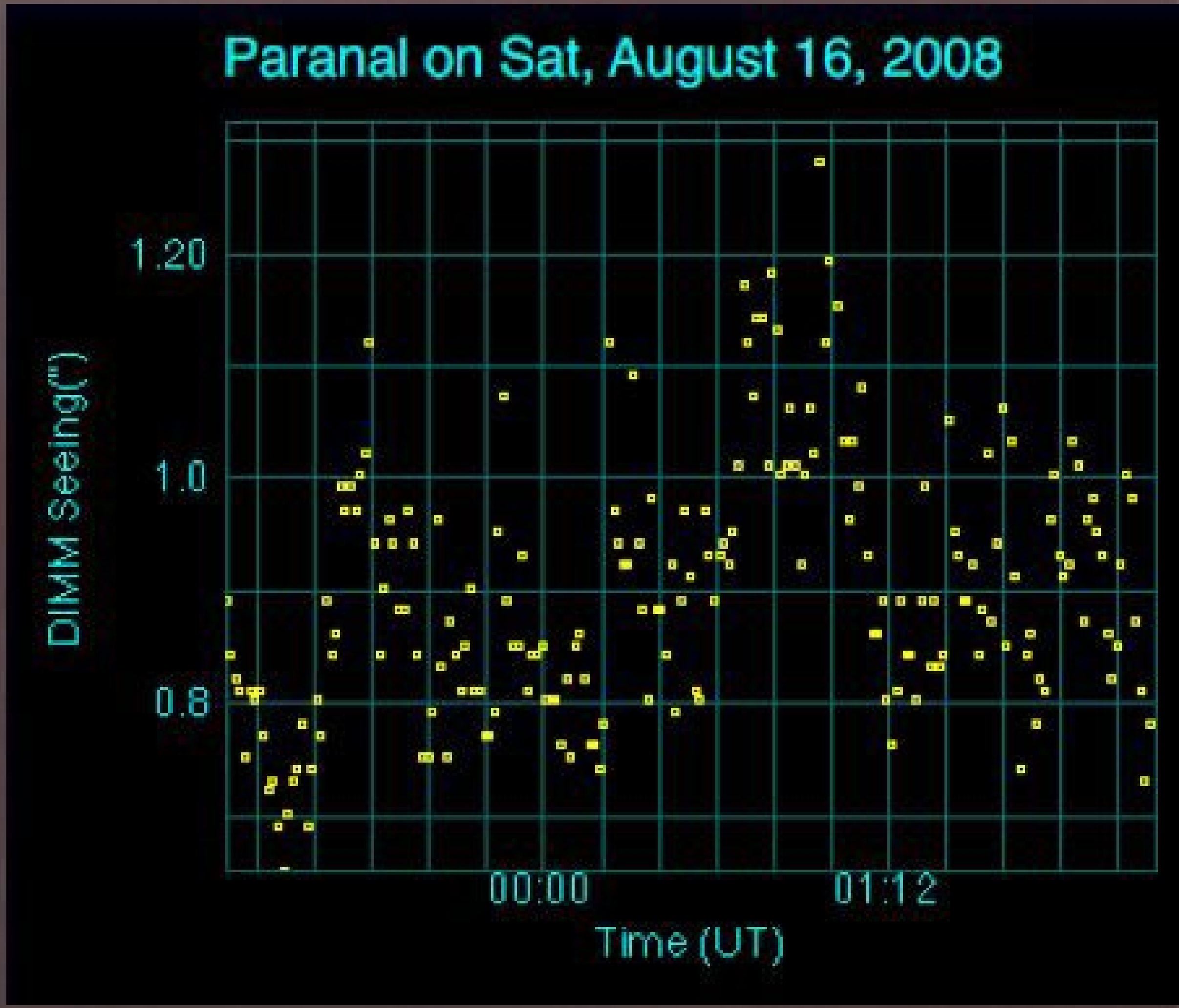
- **0.090±0.004" FWHM from background stars**

Image quality variation

Movie composed of ~80 K-band images

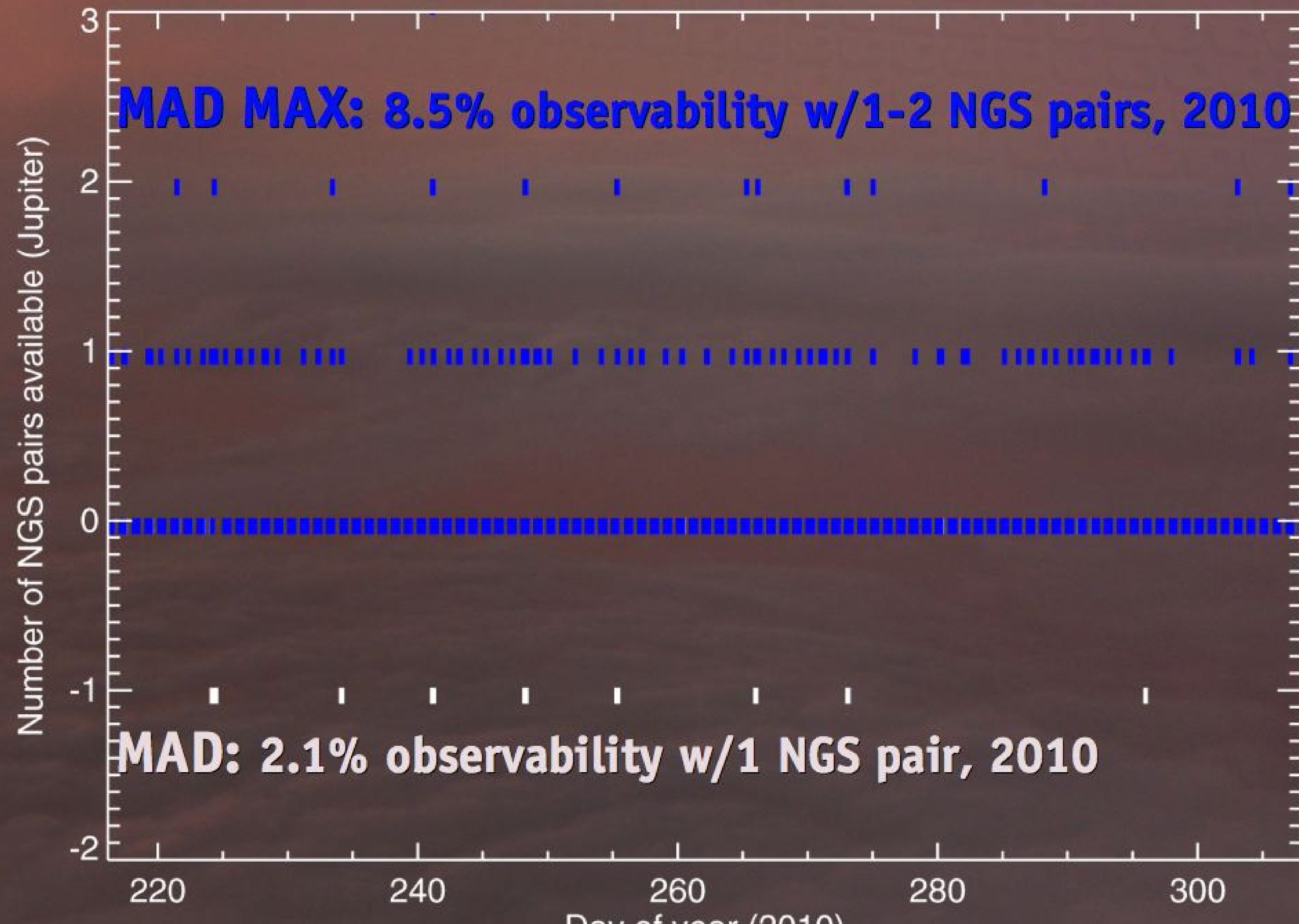


DIMM seeing monitor



very variable seeing (0.9"±0.2)
-> variable correction

Jupiter with MAD MAX



Observing requirements

- planet near opposition (maximize spatial resolution)
- at night
- airmass < ~2

- POSITION: two moons within 2′ of target, not eclipsed or occulted, on opposite sides
- BRIGHTNESS: moons must be bright enough (V<12 MAD; V<17 MAD MAX)
- RELATIVE MOTION: co-moving moons (tolerance is approx. 5″ / hour)

Jupiter with MAD MAX

- MAD: $V_{NGS} < 12$
  - only 4 Jovian moons usable
  - 2.1% observability, 2010
  - 2.4% observability, 2011
- MAD MAX: $V_{NGS} < 17$
  - 8 Jovian moons usable
  - 8.5% observability, 2010
  - 9.1% observability, 2011

Name	semi-major (km)	angular distance arcsec	V
Metis	127700	44	17.3
Amalthea	181400	**62**	**13.9**
Thebe	221890	**76**	**15.5**
Io	421700	144	5
Europa	671000	229	5.2
Ganymede	1070400	365	4.5
Callisto	1882709	643	5.6
Himalia	11451970	3909	**14.6**
Elara	11778034	4020	**16.6**
Pasiphae	23307318	7956	17.1

Limited brightness

Orange: current
Yellow: new
Green: marginal

Saturn with MAD MAX

- MAD: $V_{NGS} < 12$
  - 6 Kronian moons usable
  - 88.5% observability, 2011
- MAD MAX: $V_{NGS} < 17$
  - 5–7 additional moons usable
  - 97.0% observability, 2011

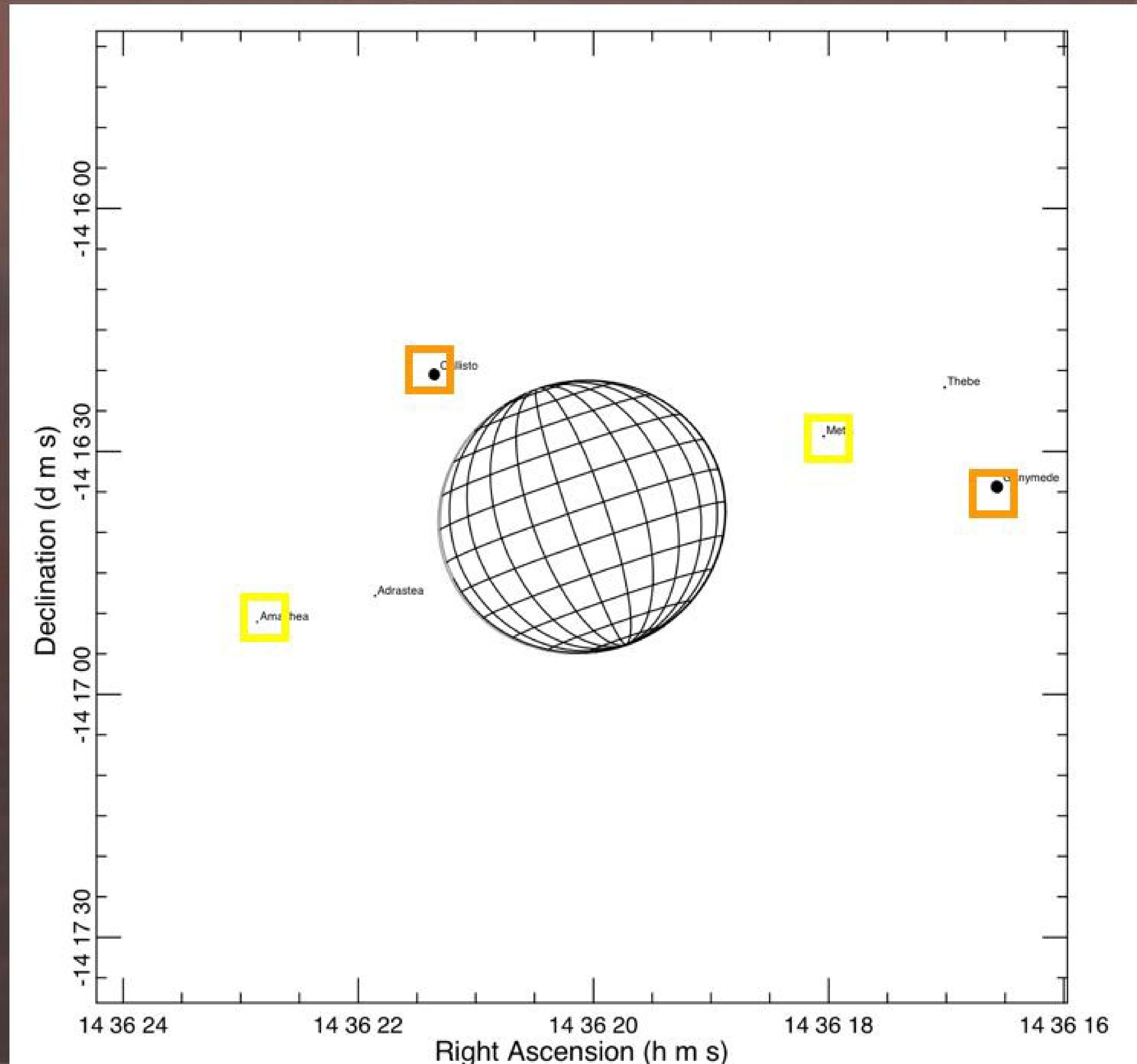
Name	D (km)	semi-major (km)	angular d arcsec	V
Prometheus	119	139400	23	15.7
Pandora	103	141720	23	16.4
Epimetheus	113	151422	24	15.6
Janus	193	151472	24	14.4
Mimas	415	185404	30	12.8
Enceladus	513	237950	38	11.7
Tethys	1081	294619	48	10.2
Dione	1128	377396	61	10.3
Rhea	1529	527108	85	9.6
Titan	5151	1221930	197	8.3
Hyperion	360	1481010	239	14.3
Iapetus	1472	3560820	575	11
Phoebe	230	12869700	2078	16.3

Too close to rings

Orange: current
Yellow: new
Green: marginal

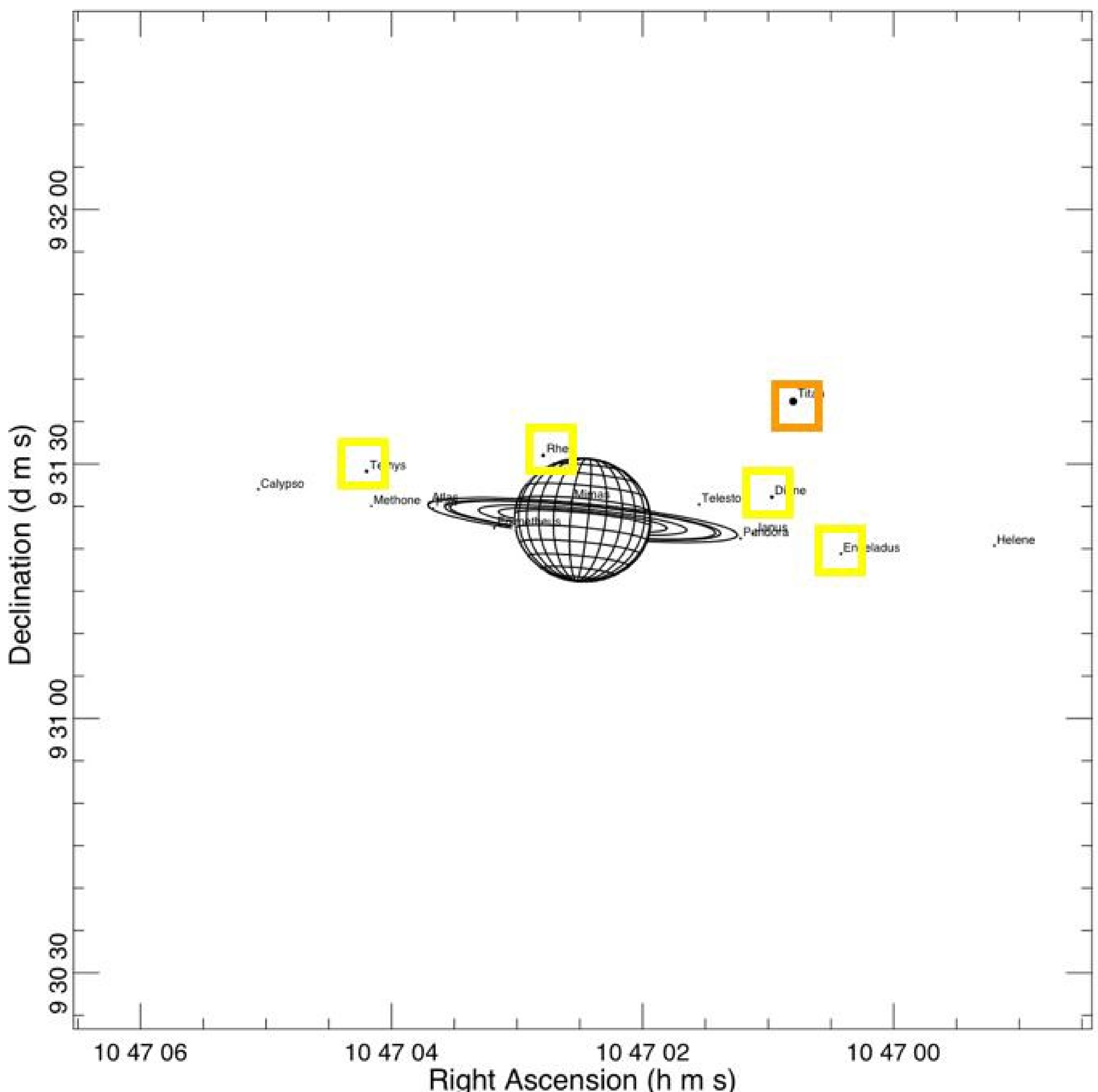
Jupiter configuration example

120”



Saturn configuration example

120”

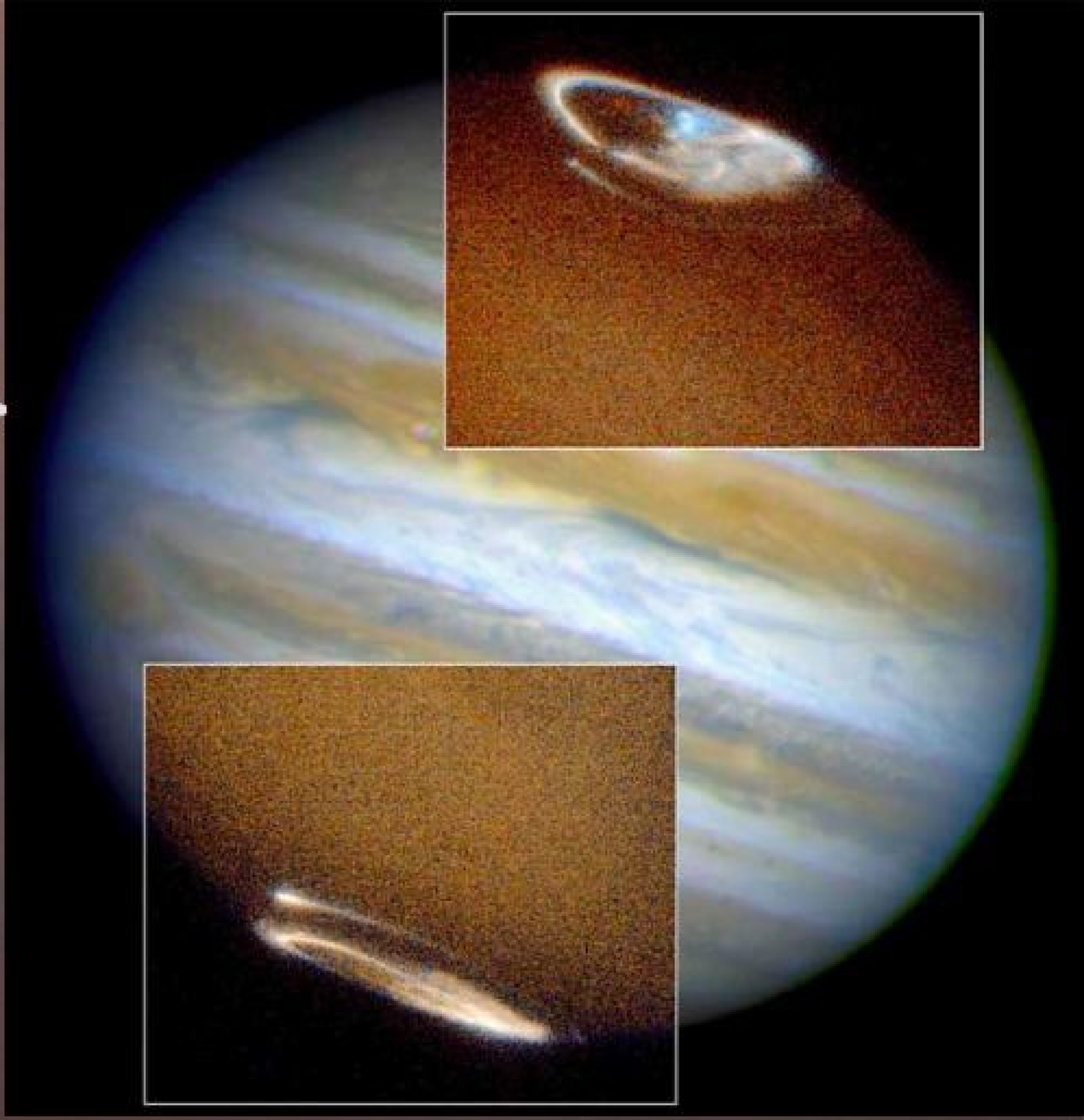


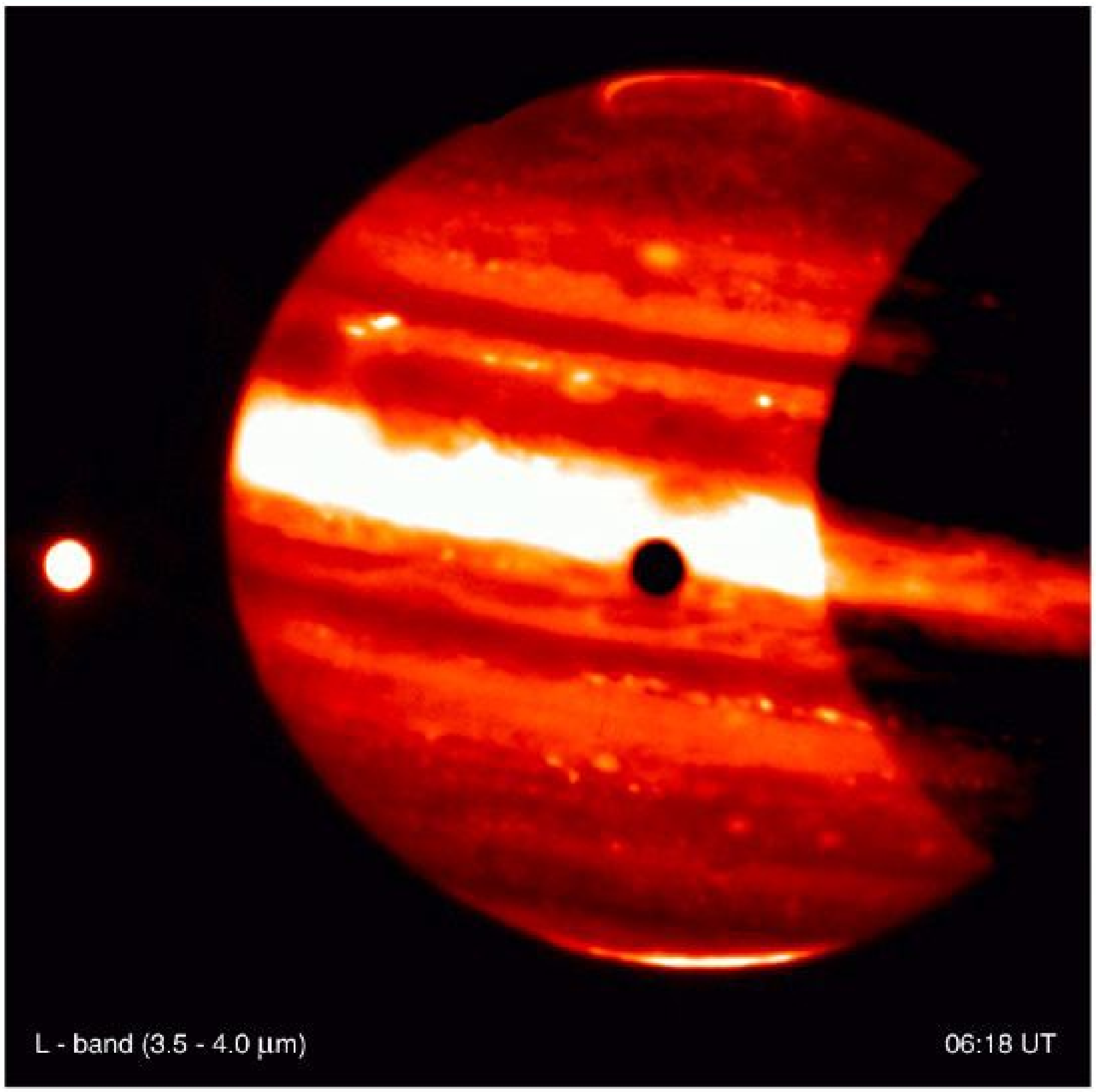
Jupiter/Saturn science with MAD MAX *and beyond*

- Imaging in NIR (1-2.5 µm):
  - cloud and haze vertical distributions
  - dynamics (cyclones, zonal winds, anticylcones at 1.6 µm)
  - convective events (evolution, energetics, statistics)
  - dusty rings (east-west asymmetry?)
- Spectroscopy:
  - composition and temperature measurements from deep ($p \leq 7$ bar) troposphere to stratosphere
  - much more accurate aerosol vertical distributions
- Imaging in thermal IR (3-5 µm):
  - dynamics below the level of the visible clouds
  - aurorae: interaction with satellites and solar wind (H_3^+ emission)
  - particle size, albedo, composition of the thin rings (L-band albedo upper limit only with Keck NGS AO)

Jupiter atmosphere and aurora

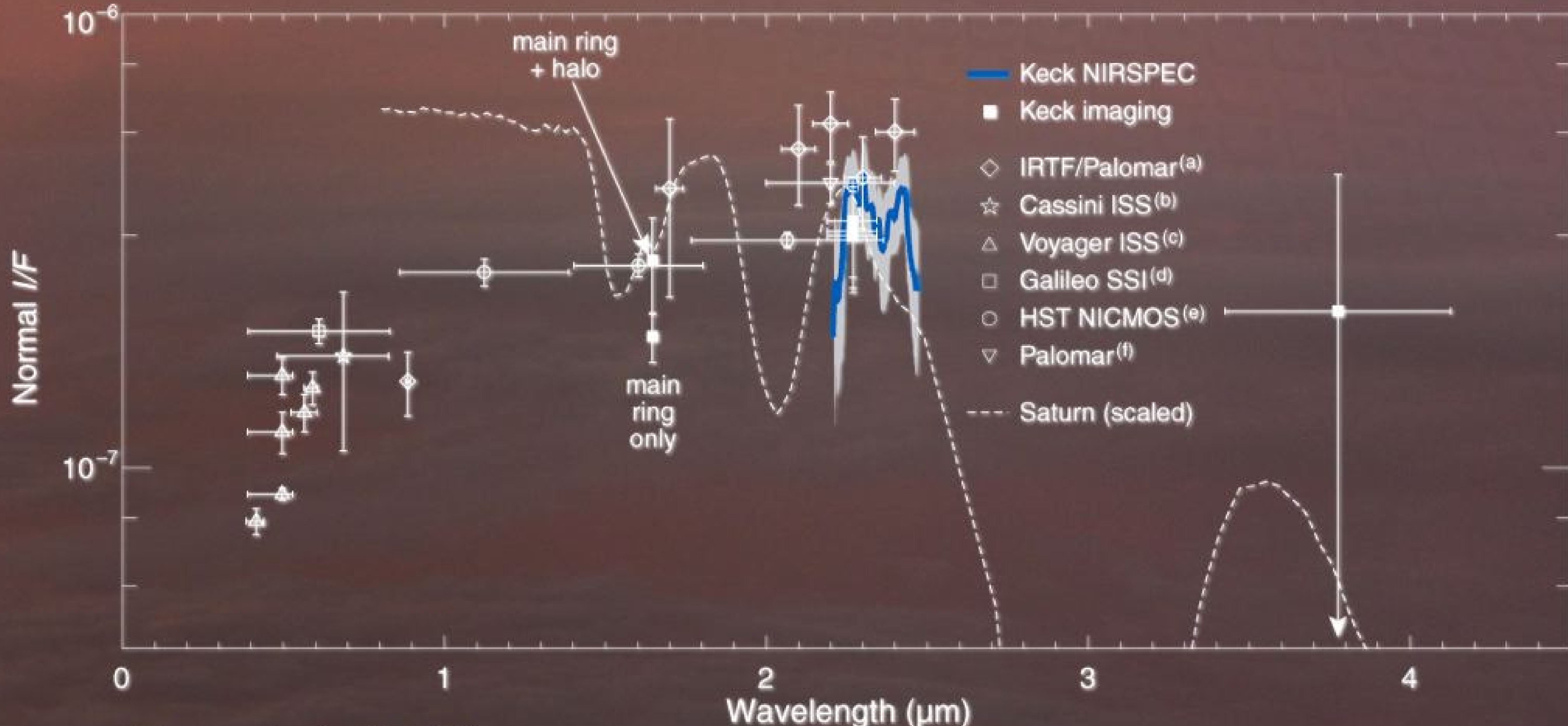
HST observations (0.06" in vis/UV) ->





<- VLT/ISAAC observations (0.8" in L band)

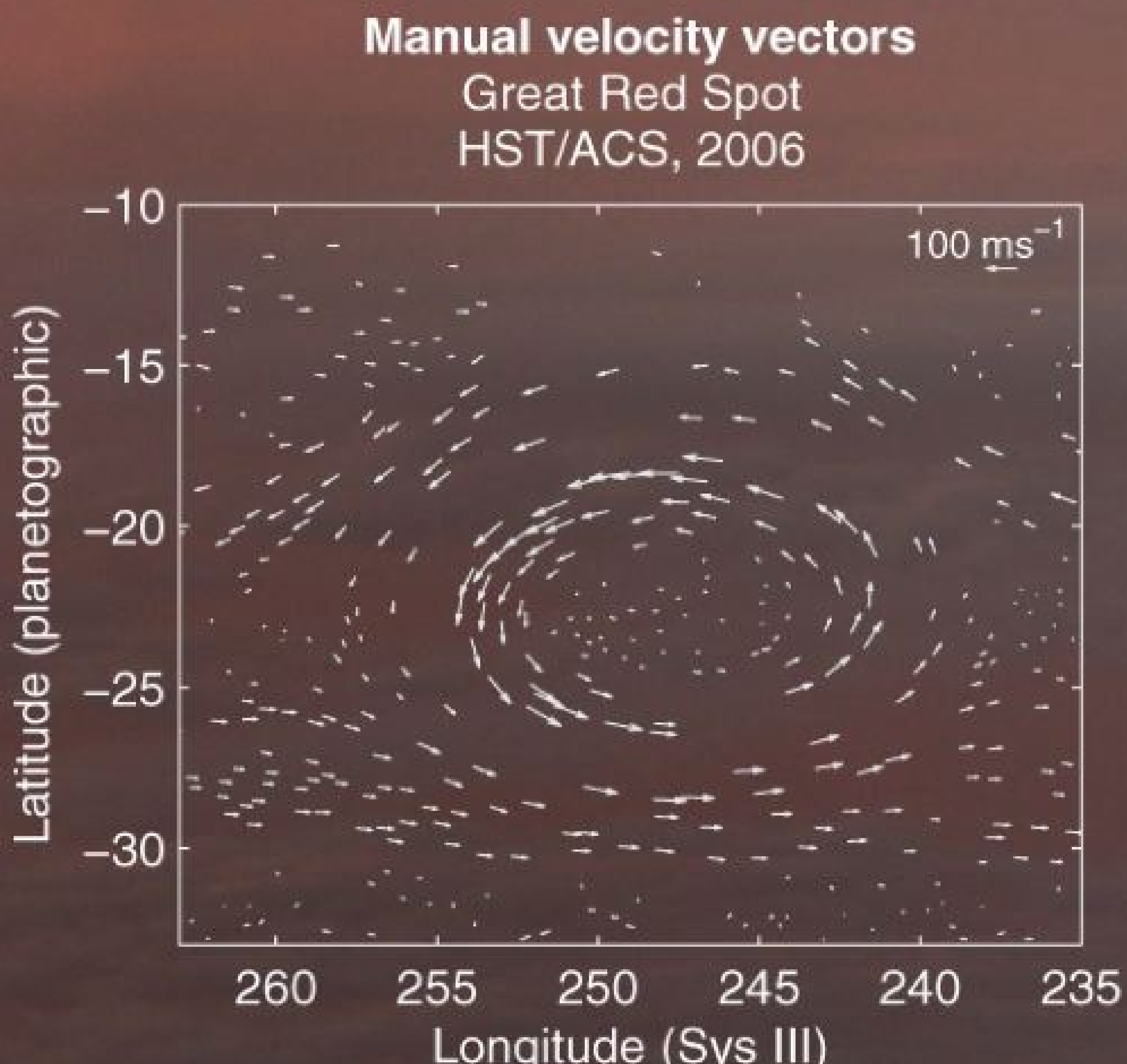
L-band ring imaging

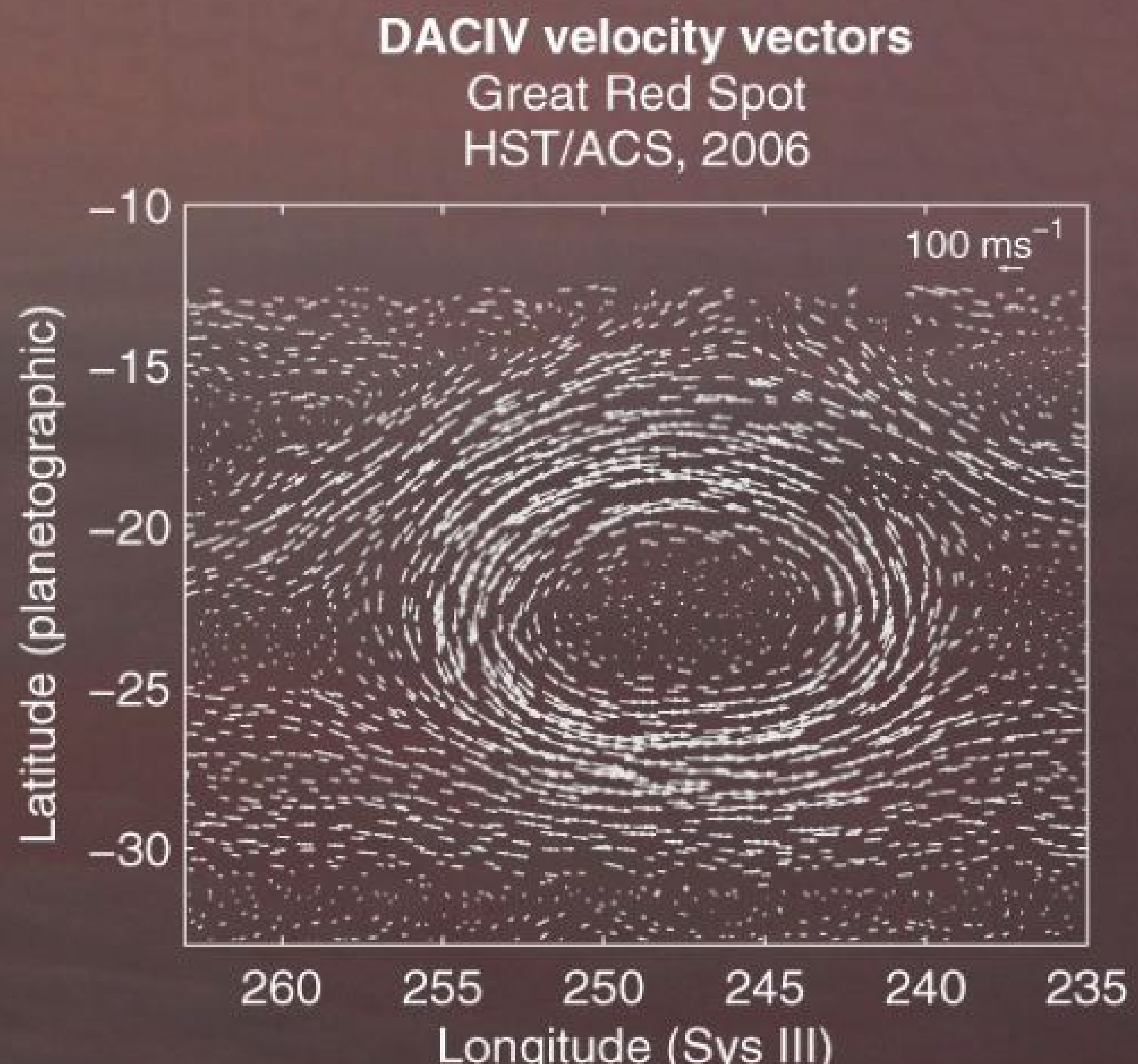


Wong et al. (2006)

- **composition: is there water?**
- **L-band upper limit only from Keck**
- **MAD MAX would give longer T_{int}**

Vortex velocity fields

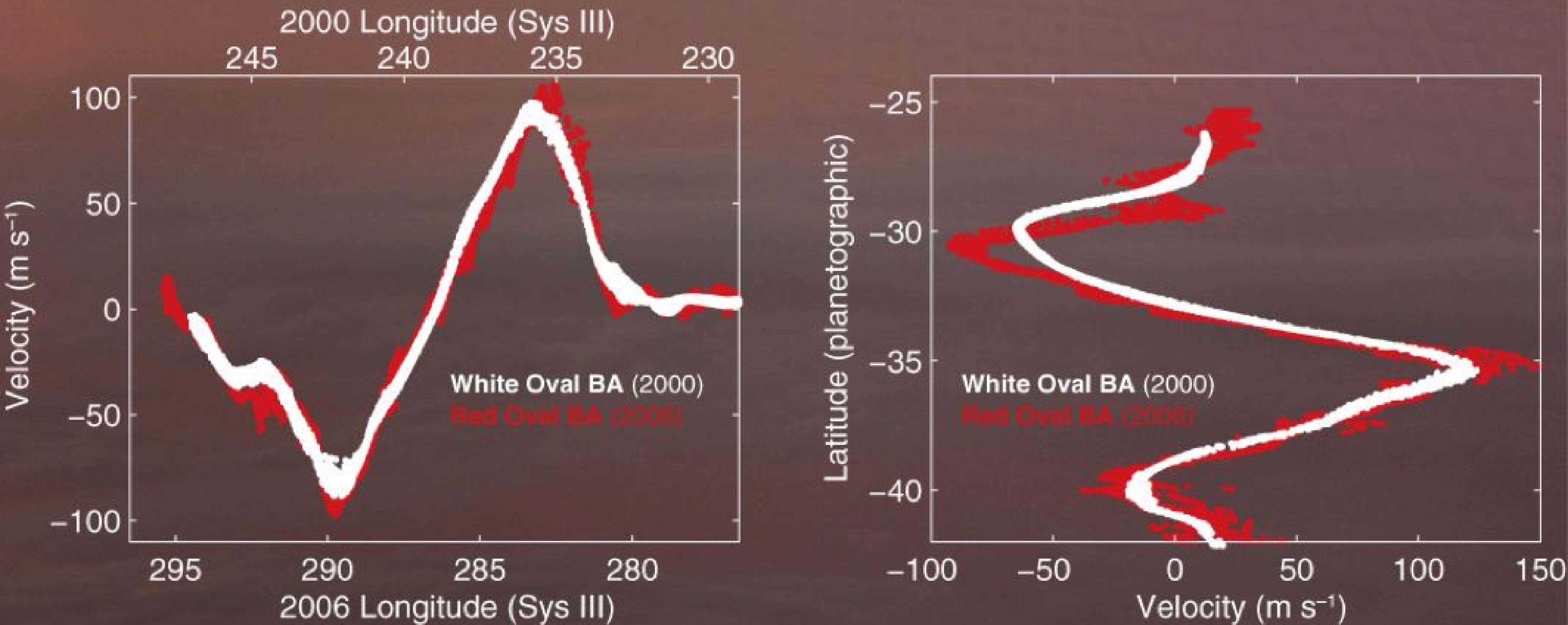




Asay-Davis et al. (2009, in press)

- **ACCIV gives much higher density of velocity vectors**

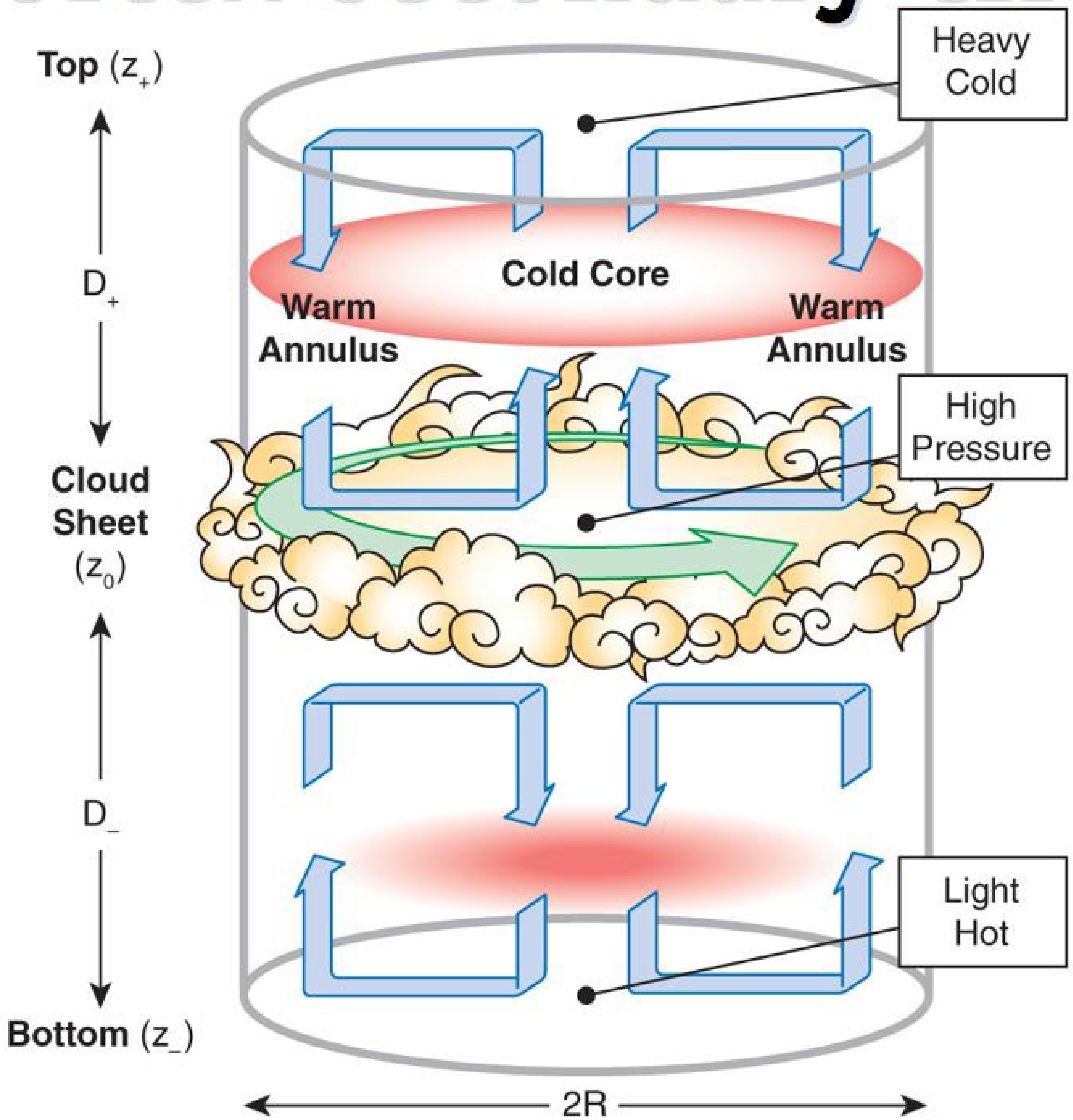
Oval BA velocity fields



Asay-Davis et al. (2009, in press)

- **2000 data effective resolution 270 km**
- **MAD 2008 data eff. resolution 280 km**

Vortex secondary circulation



Marcus et al. (2009, submitted)