TMT Solar System ISDT: Giant planet atmospheres at high spatial resolution

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TMT SCIENCE FORUM, 2014 JULY TUCSON AZ

Decadal survey questions

TABLE 3.1 The Key Questions and Planetary Destinations to Address Them

Crosscutting Themes	Priority Questions	Key Bodie
Building new worlds	1. What were the initial stages, conditions and processes of solar system formation and the nature of the interstellar matter that was incorporated?	Comets, A (see Chapt
	2. How did the giant planets and their satellite systems accrete, and is there evidence that they migrated to new orbital positions?	Enceladus, Saturn, Ur Titan, ring
	3. What governed the accretion, supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres, and what roles did bombardment by large projectiles play?	Mars, the comets (se
Planetary habitats	4. What were the primordial sources of organic matter, and where does organic synthesis continue today?	Comets, as uraniaun s Titan (see

Decadal survey questions

Workings of solar systems	7. How do the giant planets serve as laboratories to understand Earth, the solar system, and extrasolar planetary systems?	Jupiter, N
	8. What solar system bodies endanger Earth's biosphere, and what mechanisms shield it?	Near-Eart (see Chap
	9. Can understanding the roles of physics, chemistry, geology, and dynamics in driving planetary atmospheres and climates lead to a better understanding of climate change on Earth?	Mars, Jup Venus (se
	10. How have the myriad chemical and physical processes that shaped the solar system operated, interacted, and evolved over time?	All solar (see Chap

Specific giant planet atmosphere objectives: CIRCULATION

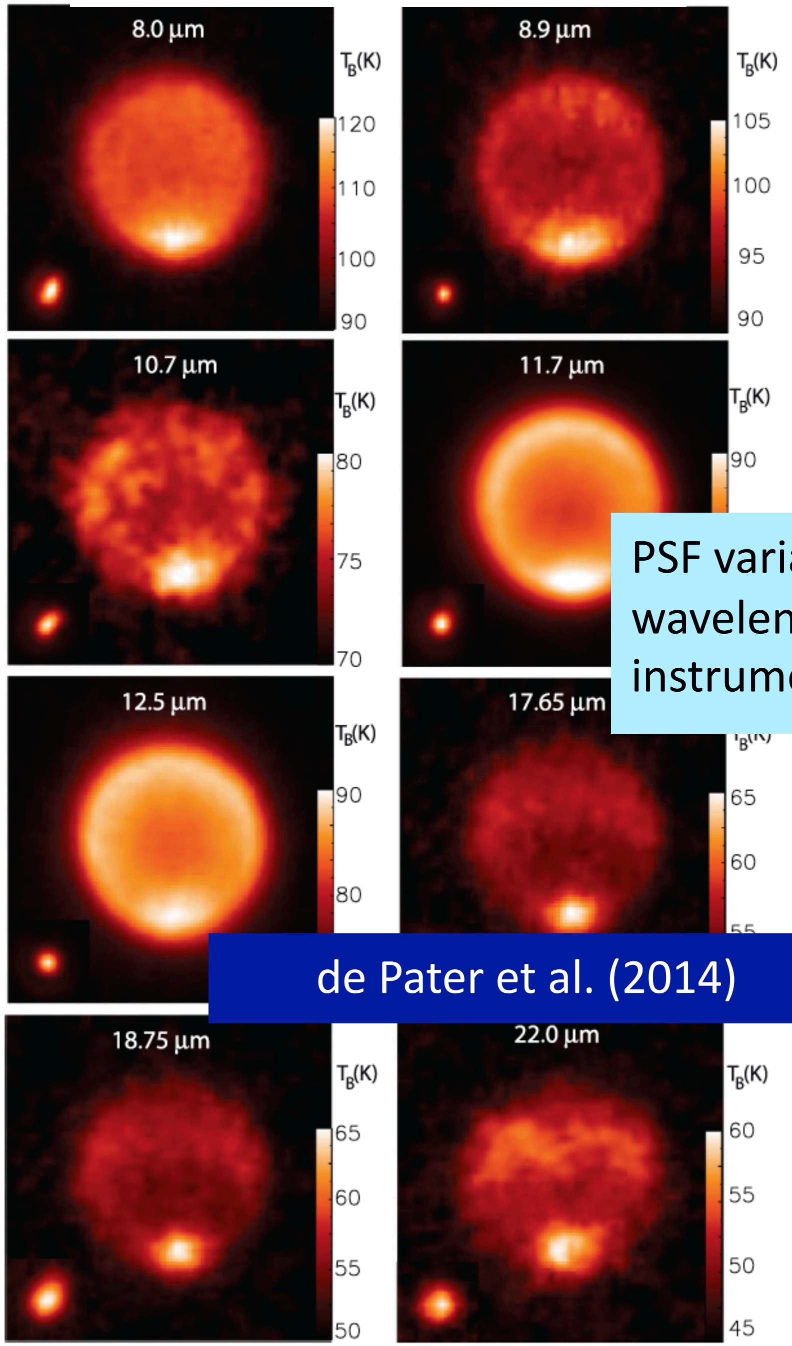
- Determine the distributions of dynamical tracers, and how they change
  - temperature
  - disequilibrium species like CO and PH_3
  - condensable volatiles
- Relate the histories of thermal evolution of the giant planets to the array of diverse exoplanets
- Identify chemical and physical processes that affect dynamical tracers
  - cloud processes
  - haze aerosols
  - stratification

Specific giant planet atmosphere objectives: VARIABILITY

- Study dynamic processes over a wide range of timescales
  - short (days–months): impacts, superstorms
  - medium (months–years): vortex origins, zonal cloud and haze shifts
  - long (multi-year): trends in cloud activity, seasonal responses (12–164 years)

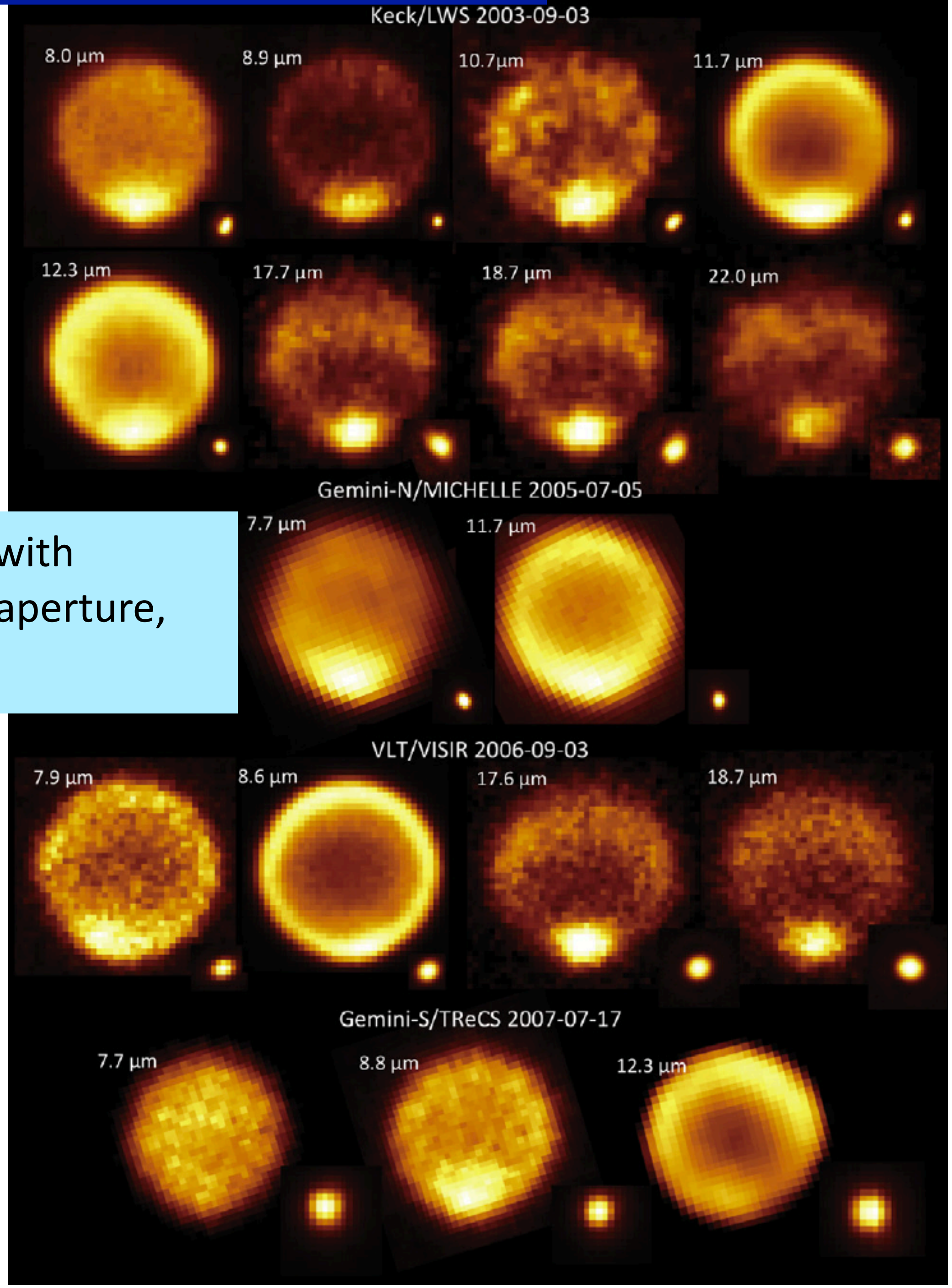
- David Silva: we need coherent reusable datasets
- Key programs can satisfy this goal
  - precedents with research reusing NASA spacecraft data (PDS), HST archive, etc.
  - need well-designed observation pattern and useful cadences
  - continuity with prior work
  - anchors baseline for new high spatial resolution era

Neptune MIR



de Pater et al. (2014)

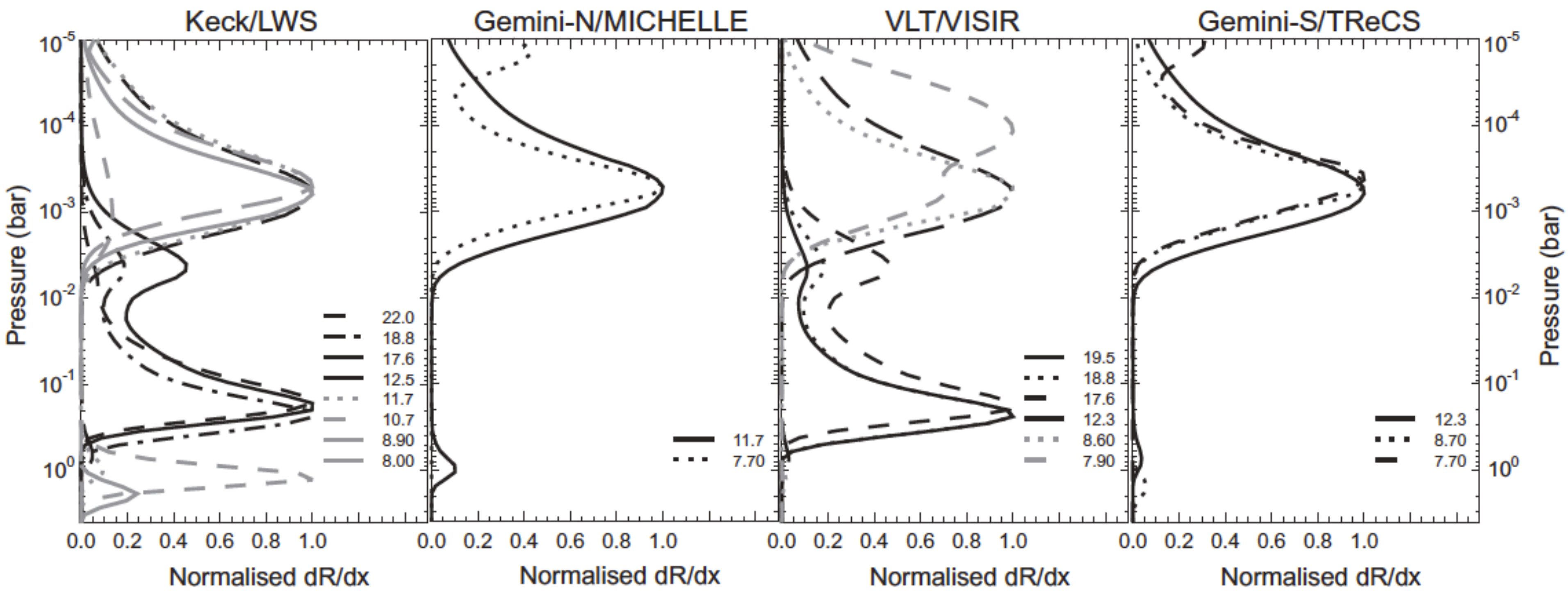
Fletcher et al. (2014)



PSF variable with wavelength, aperture, instrument...

Neptune MIR

contribution functions show altitude response at each wavelength



Fletcher et al. (2014)

Neptune NIR

Gemini North
AO with Triton NGS
resolution 0.15"–0.25"

144 P.G.J. Irwin et al. / Icarus 216 (2011) 141–158

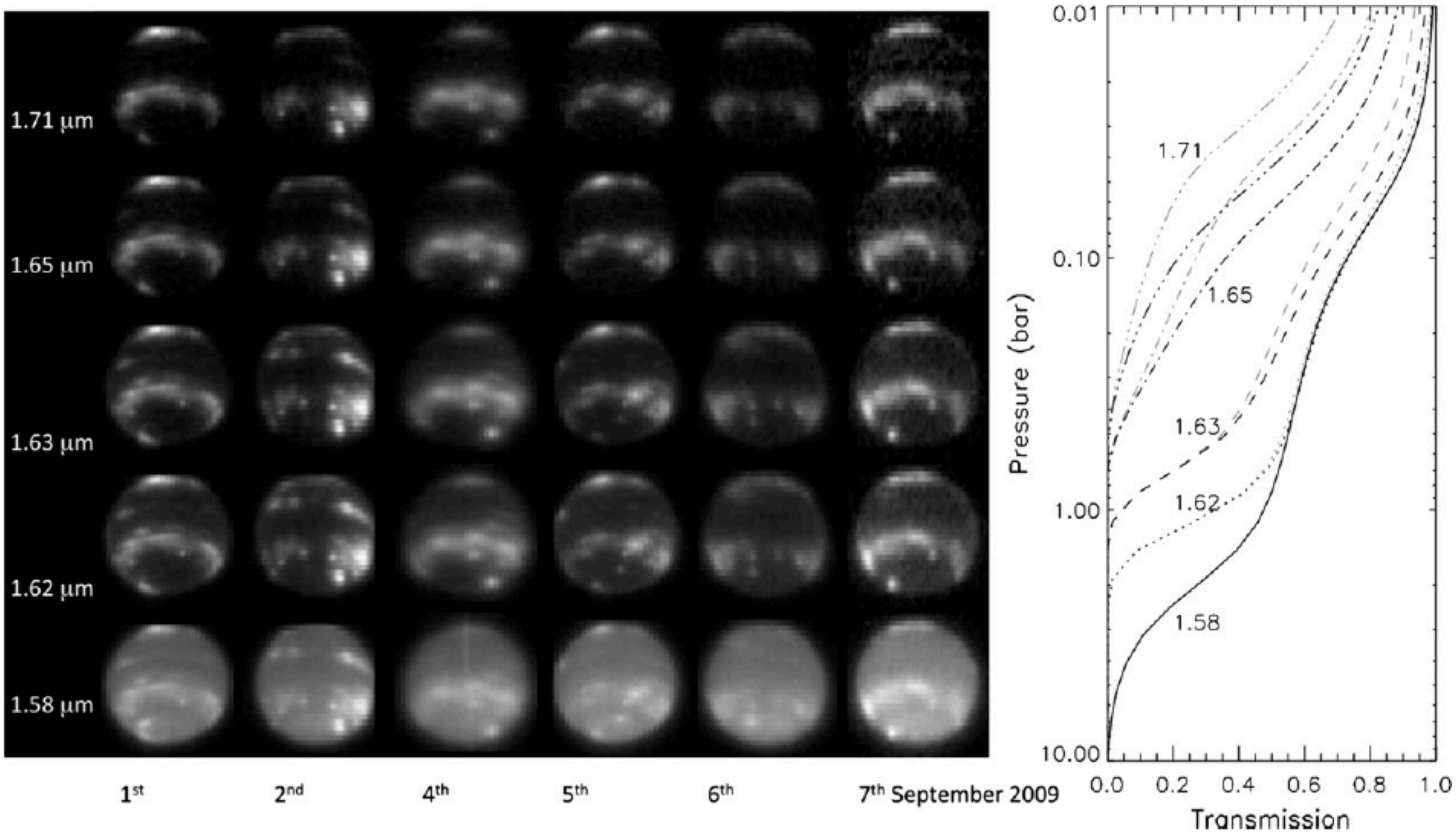
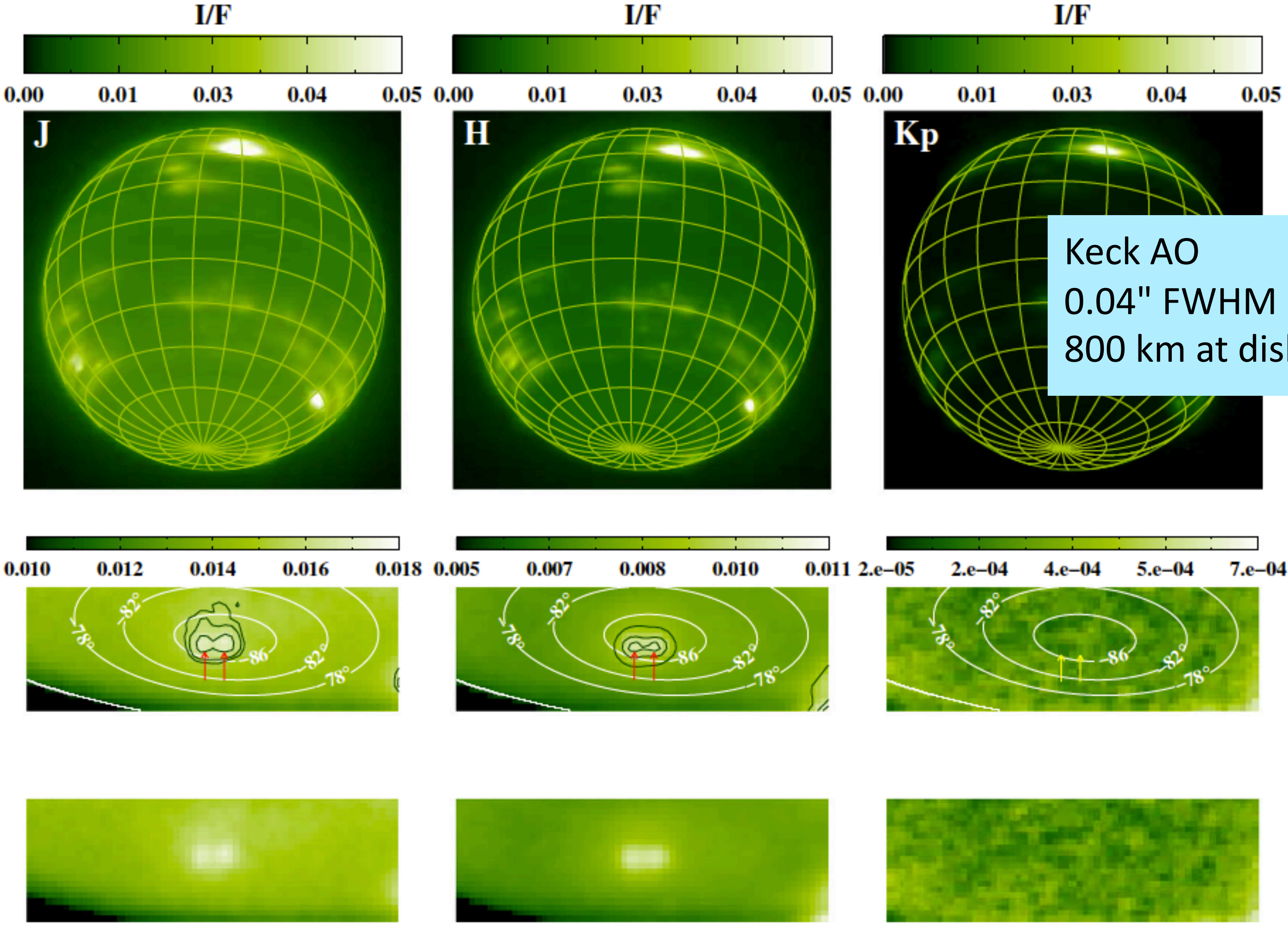


Fig. 2. Gemini/NIFS observations (left panel) for September 1st, 2nd, 4th, 5th, 6th, and 7th plotted at a number of different wavelengths sounding to deeper and deeper levels in Neptune' atmosphere (1.71, 1.65, 1.63, 1.62, 1.58 μm). The transmission curves (from and to space for nadir viewing) for these wavelengths are plotted in the right hand panel using different linestyles and for two different values of the stratospheric methane abundance of 3.5×10^{-4} (black) and 1.5×10^{-3} (light grey). As can be seen the transmission decreases more rapidly with pressure for the higher stratospheric methane abundance case for wavelengths of strong methane absorption.

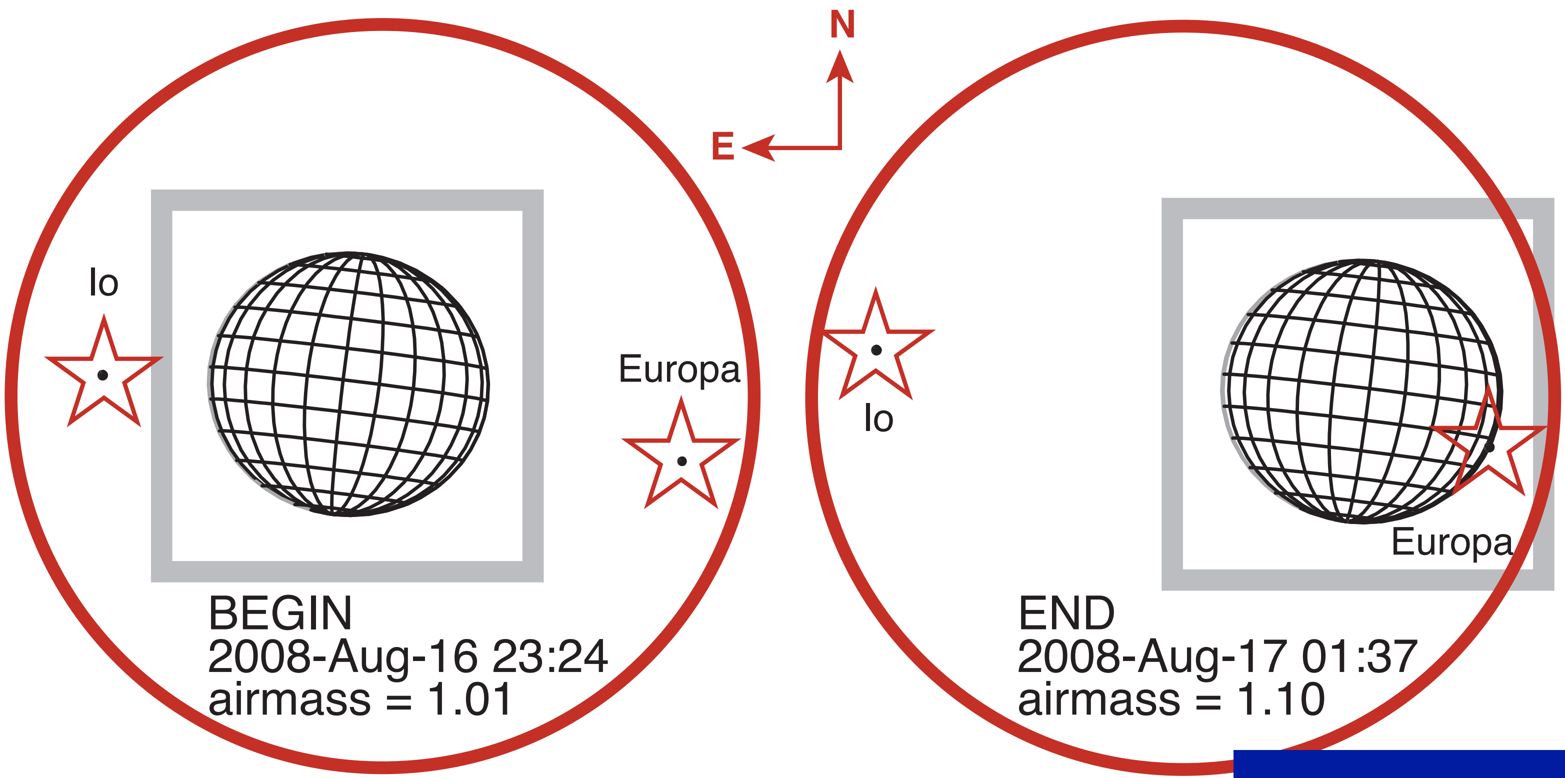
Neptune NIR

Luszcz-Cook et al. (2010)



Keck AO
0.04" FWHM on cal star
800 km at disk center

MAD observing geometry



Wong et al. (2008)
arxiv.org/abs/0810.3703

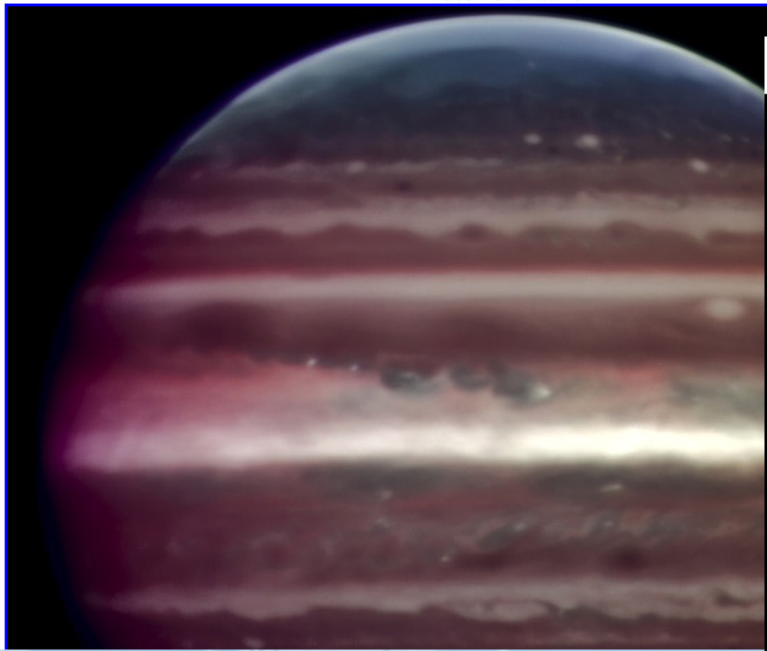
MAD WFS 2' field of regard
camera 1' FOV

compare with NFIRAOS:
2' field of regard?
high definition region (30") spans most of Jupiter disk
IRIS imager 32" wide, need to tile

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

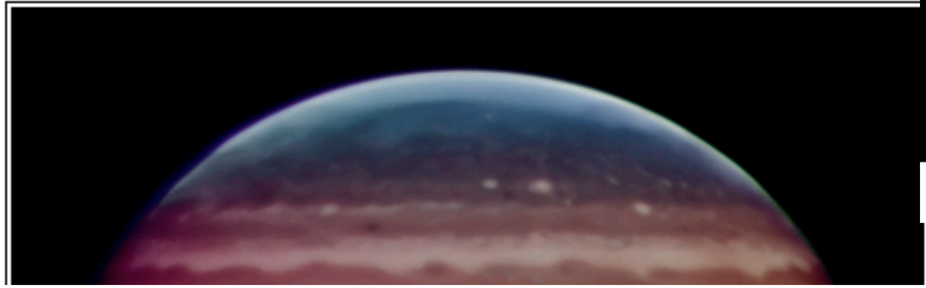


NATIONAL GEOGRAPHI

REPORTING YOUR WORLD DAIL

MAIN ANIMAL NEWS ANCIENT WORLD ENVIRONMENT NEWS CULTURES NEWS SPA

NEW JUPITER IMAGE: Sharpest View Ever From Earth



back scatter

Adapting adaptive optics

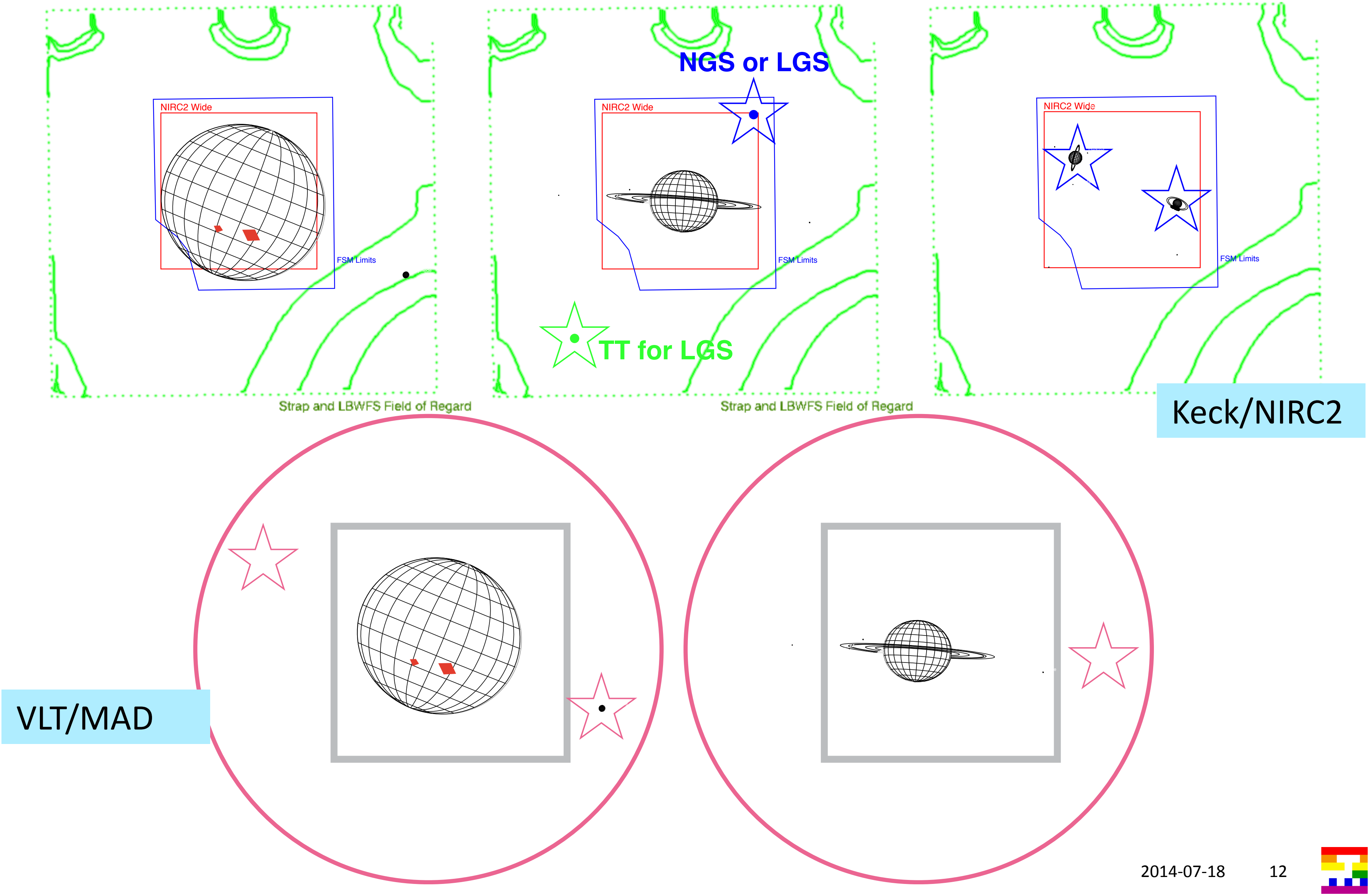
For the past 20 years, adaptive optics techniques have provided ground-based astronomers with space-quality images. With rapid, real-time analysis of the time-varying spread of light from a star or other point source (termed a guide star), a computer-controlled deformable mirror corrects for the distortion 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.

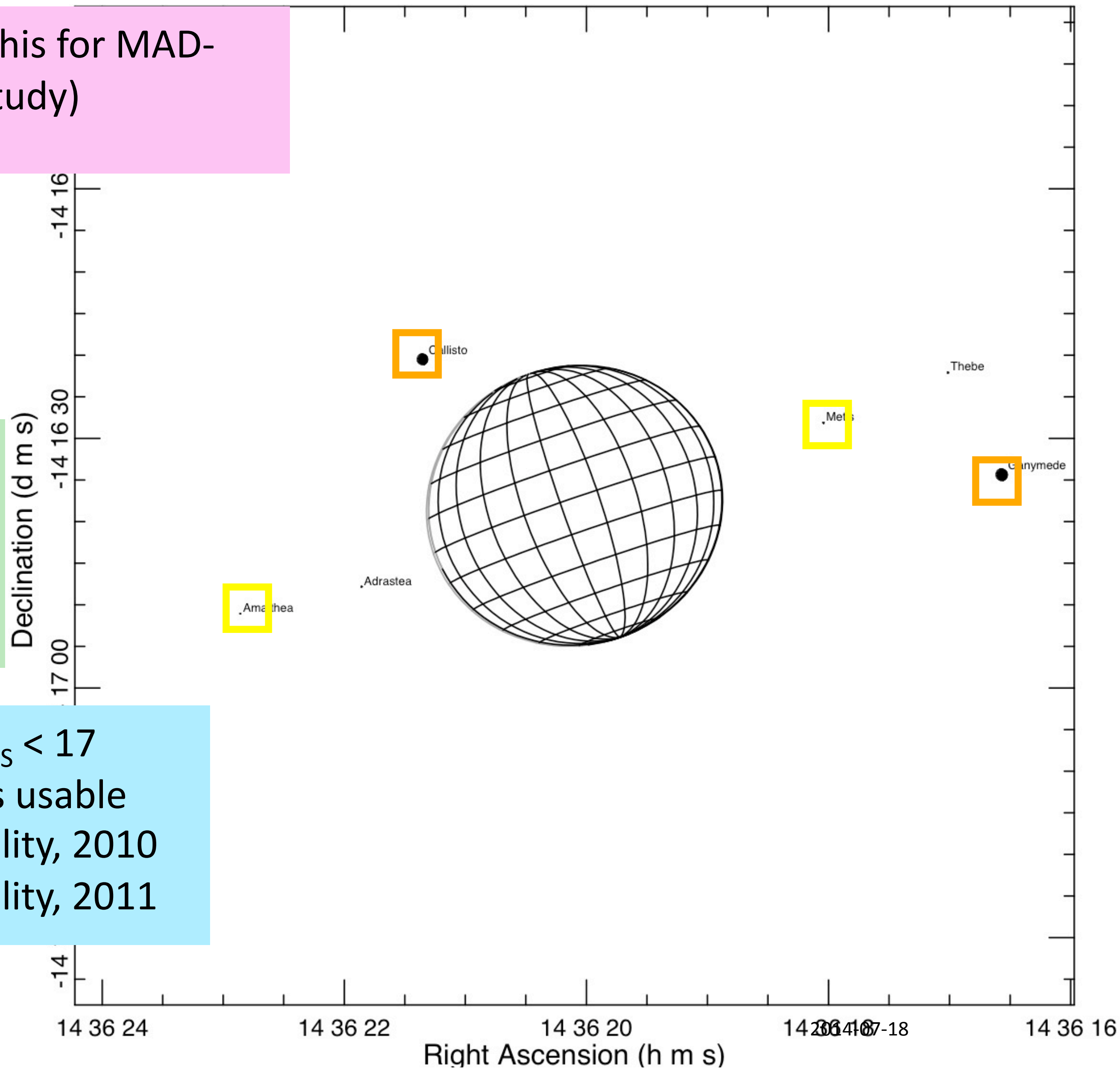
NATIONAL GEOGRAPHIC

Outer solar system



Jupiter MCAO configuration example

(from Franck Marchis for MAD-MAX instrument study)

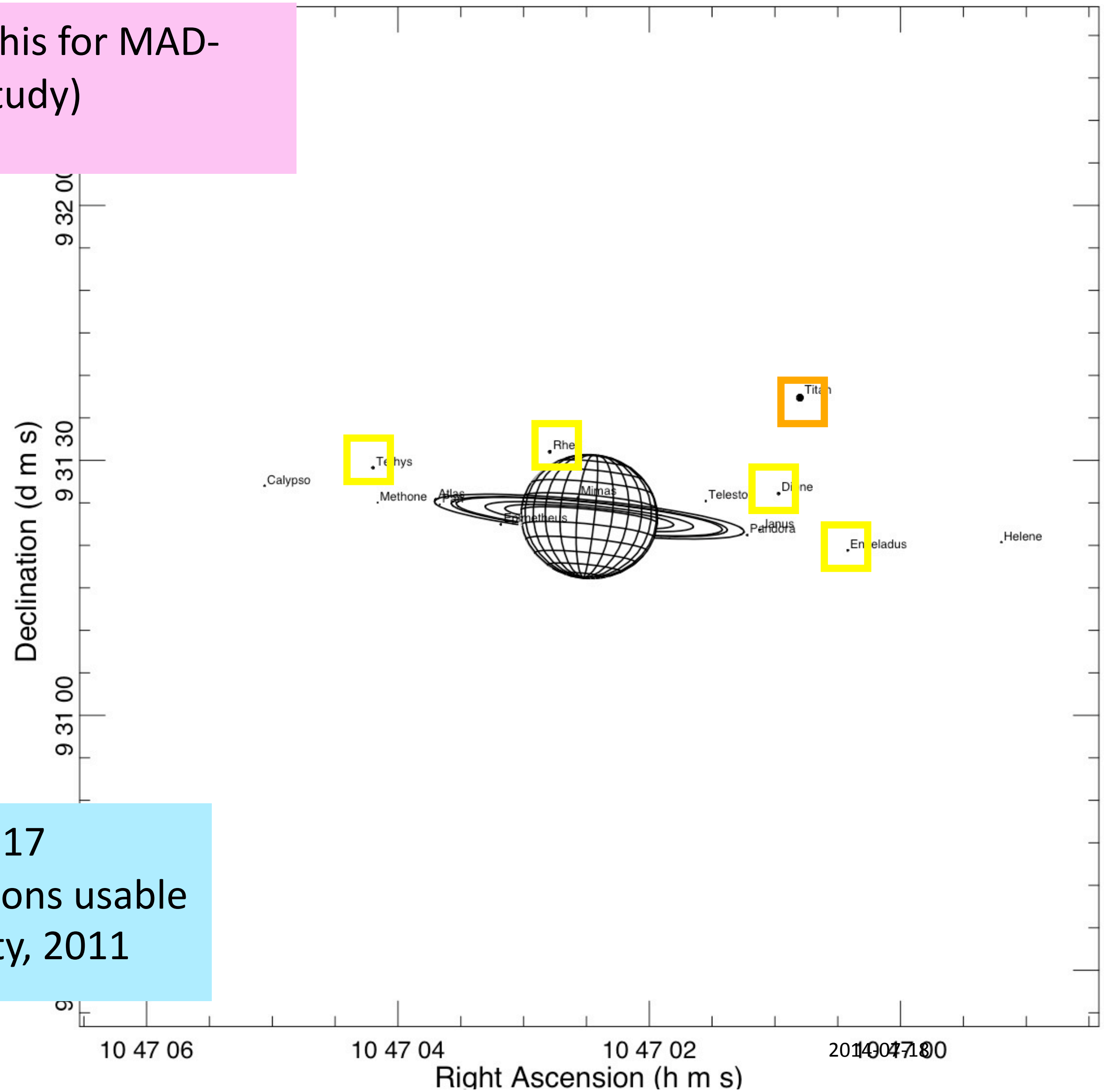


MAD: $V_{NGS} < 12$
only 4 Jovian moons usable
2.1% observability, 2010
2.4% observability, 2011

MAD MAX: $V_{NGS} < 17$
8 Jovian moons usable
8.5% observability, 2010
9.1% observability, 2011

Saturn MCAO configuration example

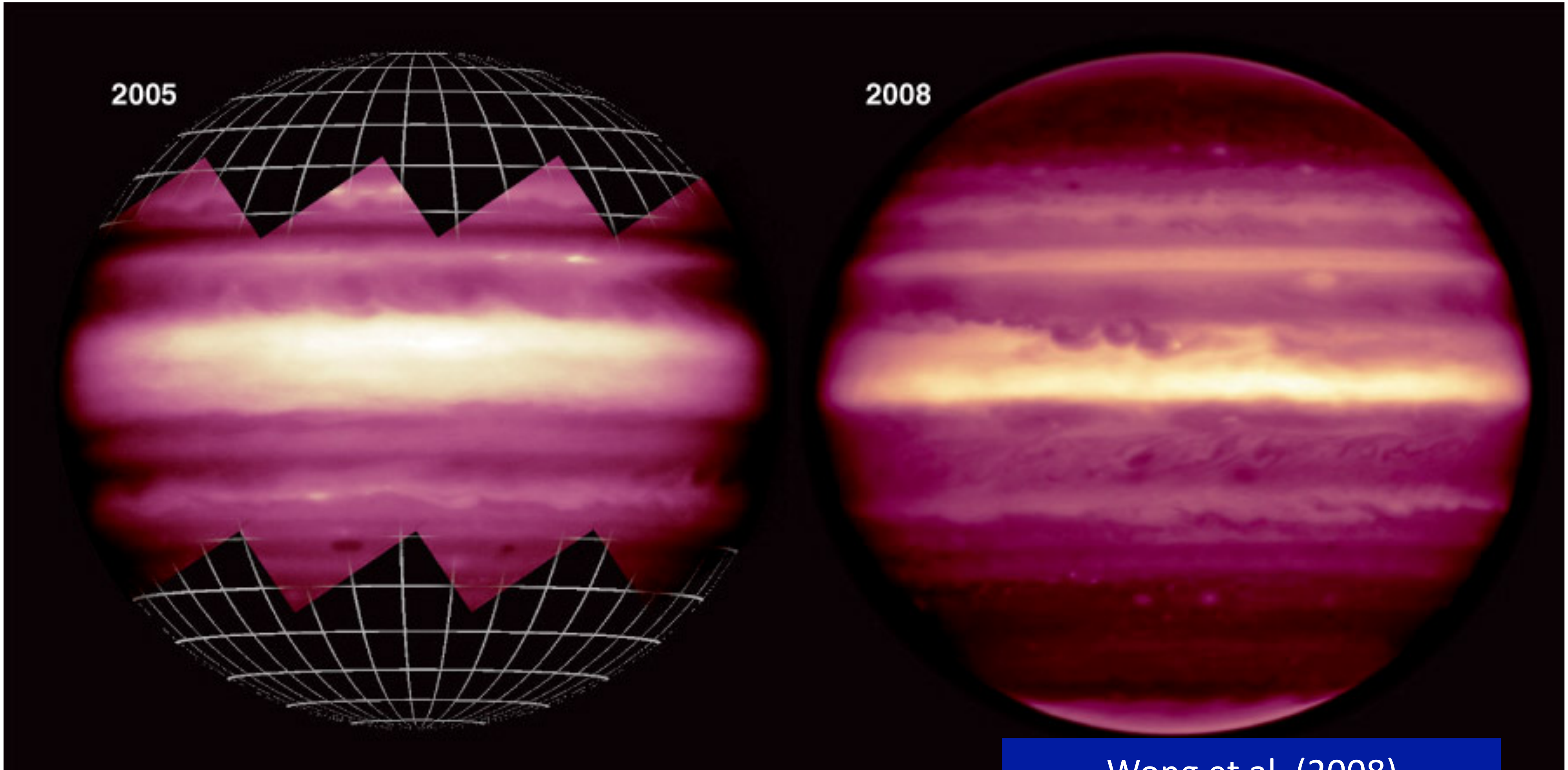
(from Franck Marchis for MAD-MAX instrument study)



MAD: $V_{NGS} < 12$
6 Kronian moons usable
88.5% observability, 2011

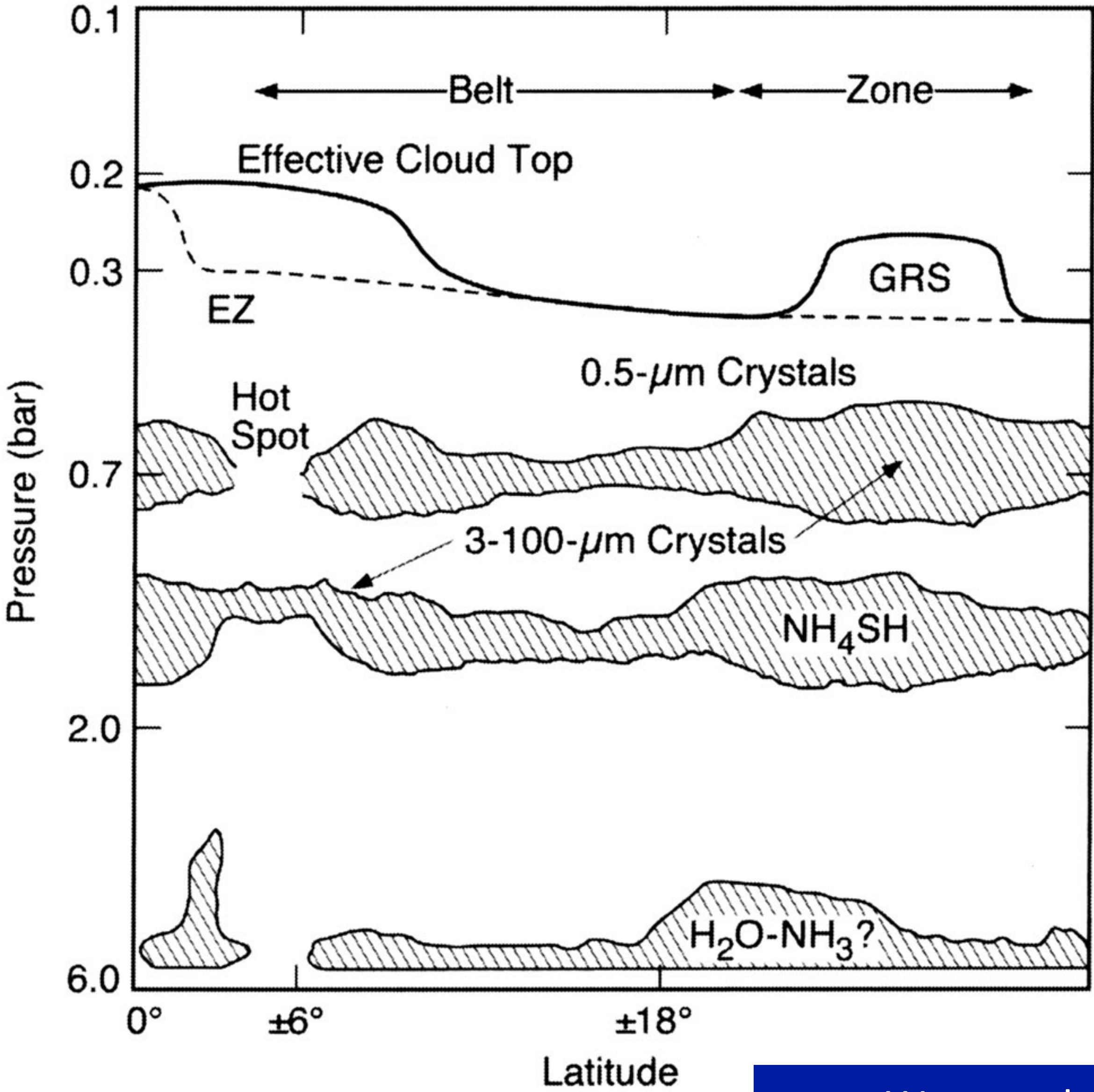
MAD MAX: $V_{NGS} < 17$
5–7 additional moons usable
97.0% observability, 2011

Equatorial haze shift



Wong et al. (2008)
arxiv.org/abs/0810.3703

Observed cloud structure

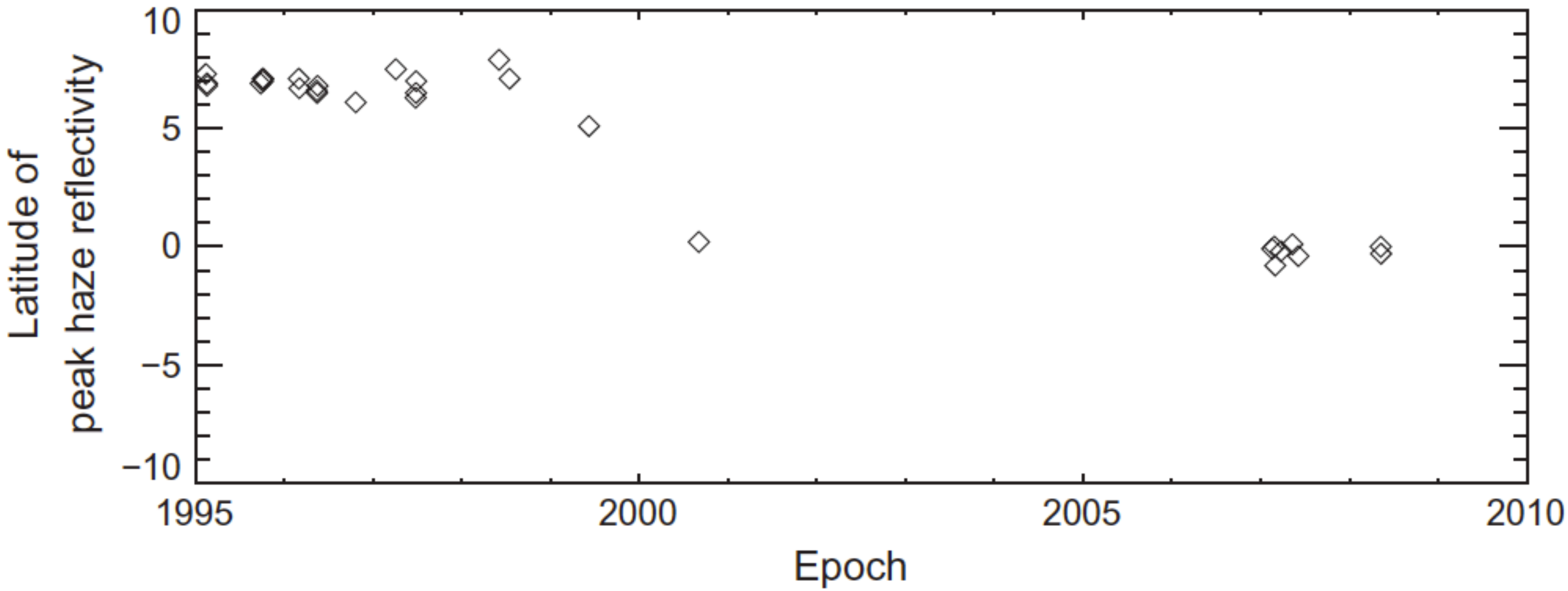


cartoon based on a review of a large colletion of observations

top lines indicate top of haze in northern (dashed) and southern (solid) hemispheres

West et al. (2004)

Haze variability

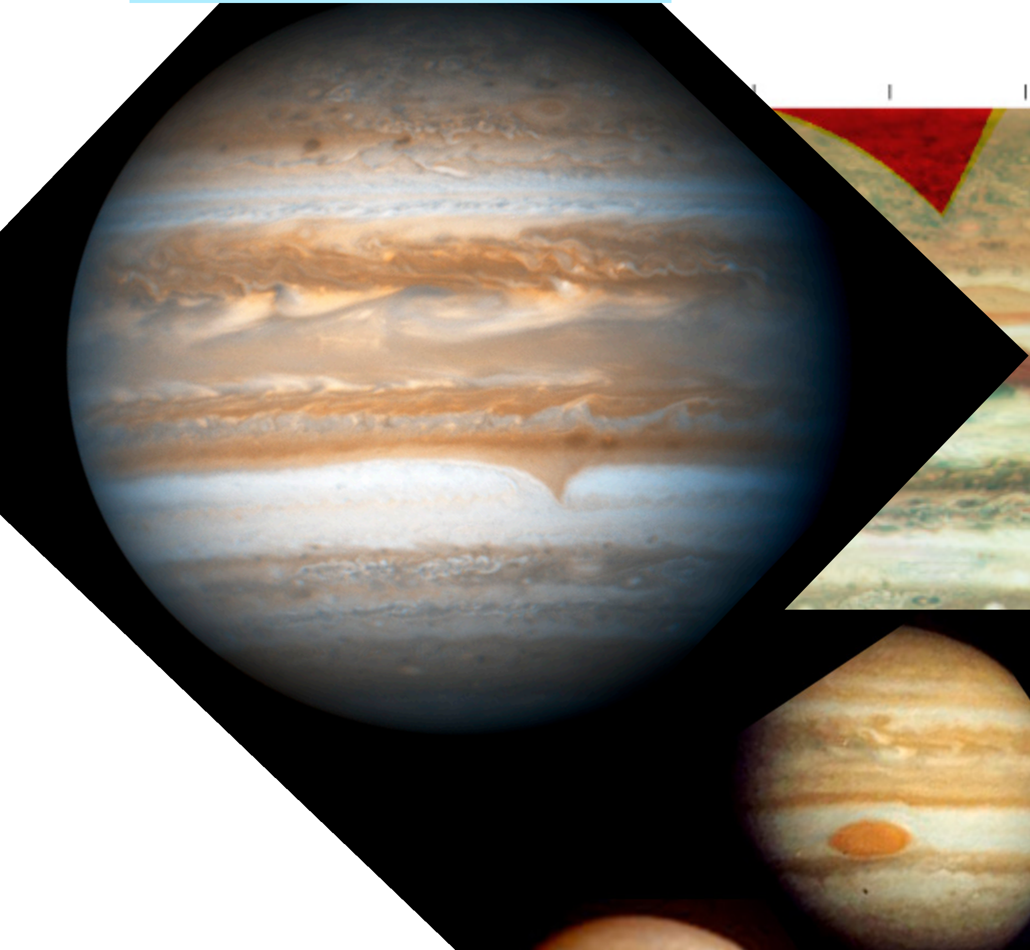


Lii et al. (2010)

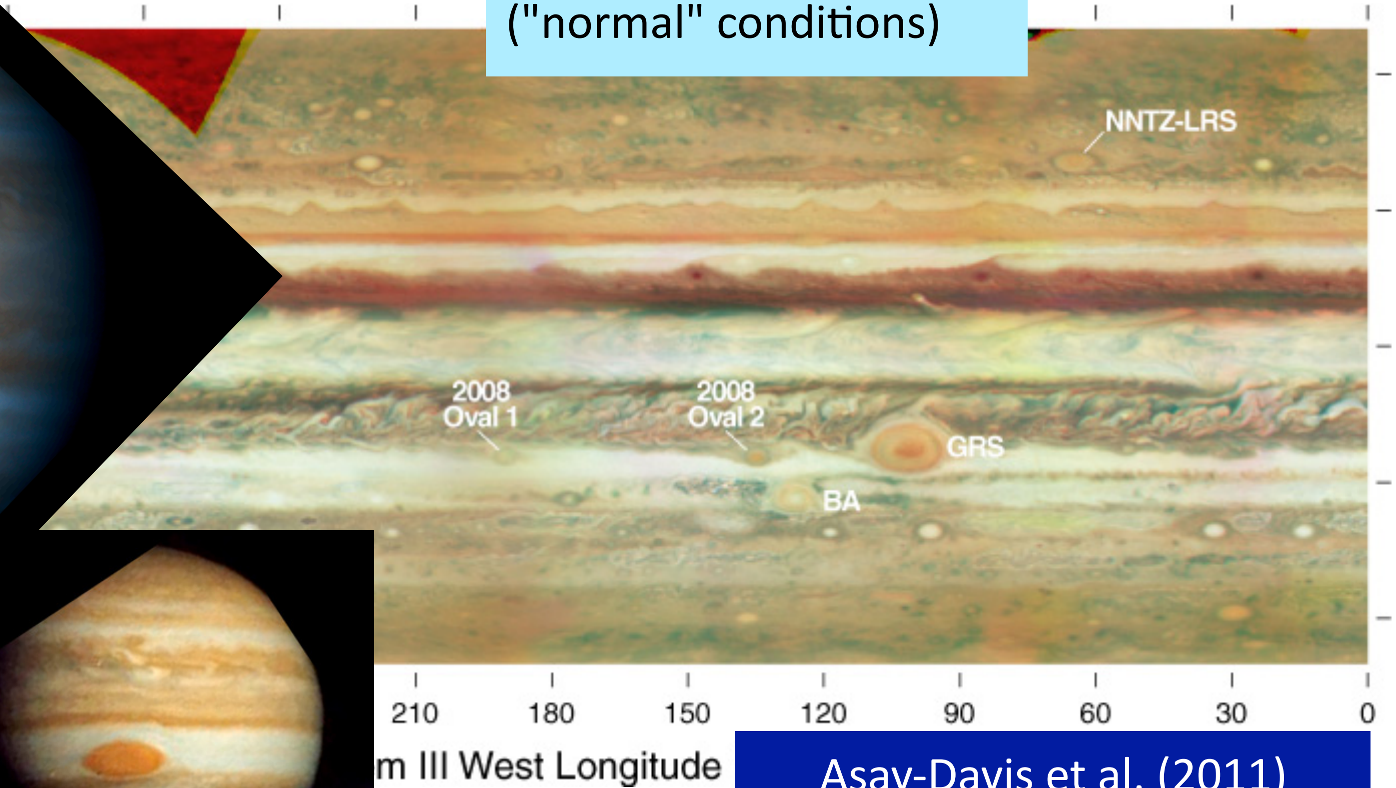
HST/WFPC2 data: value of coherent reusable datasets

Cloud variability

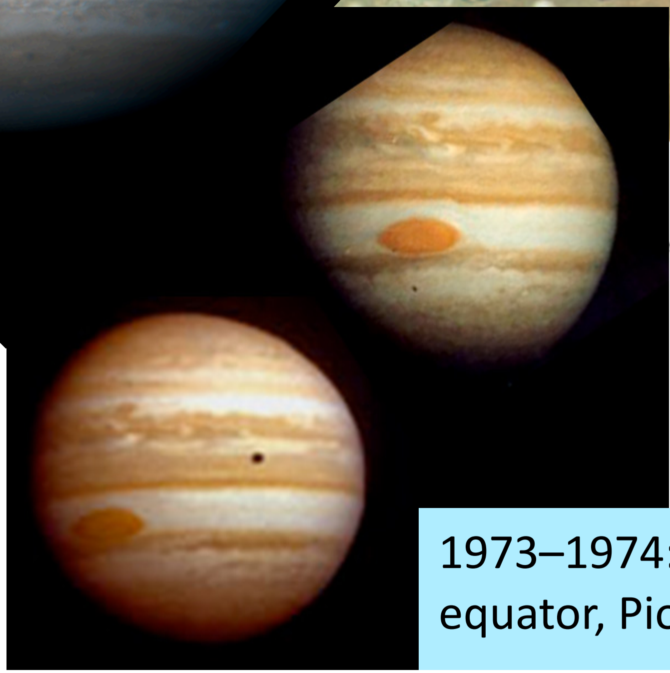
2007: dark equator (global upheaval conditions)



2008: bright equator ("normal" conditions)



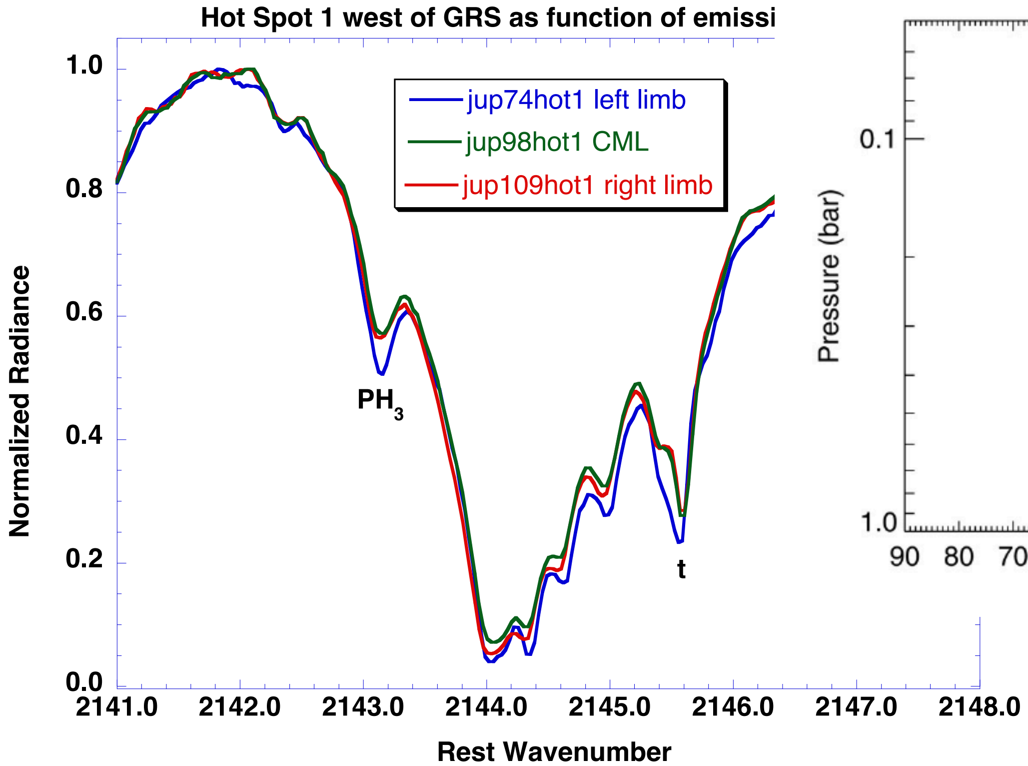
Asay-Davis et al. (2011)
HST/WFPC2 data

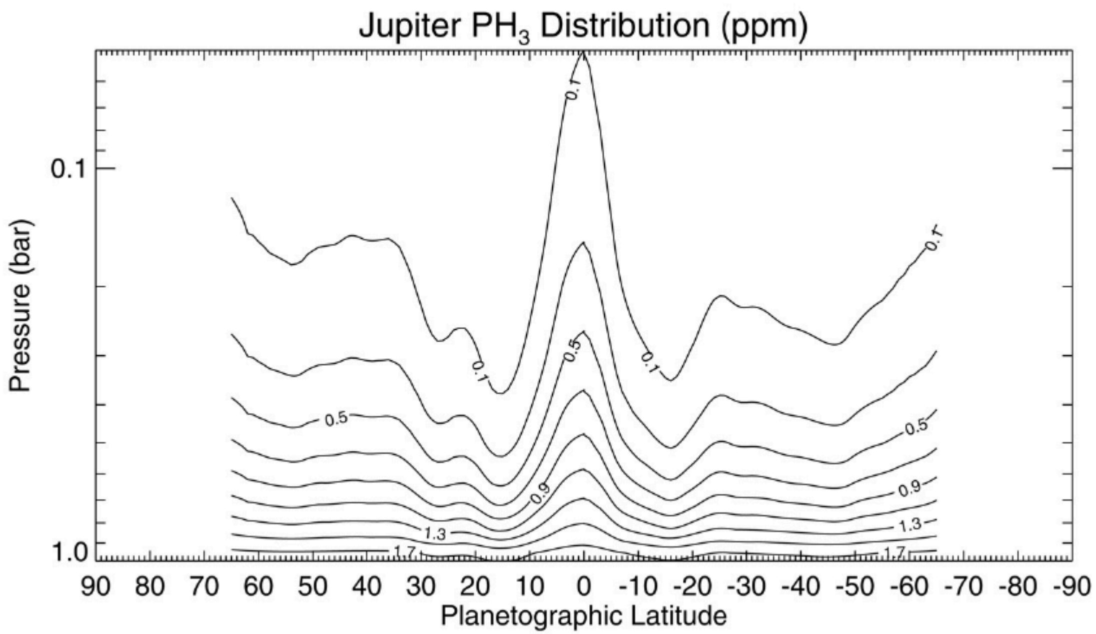


1973–1974: dark equator, Pioneer 10 & 11

PH_3 dynamical tracer

Fletcher et al. (2009)
(Cassini CIRS, N-band in IR)

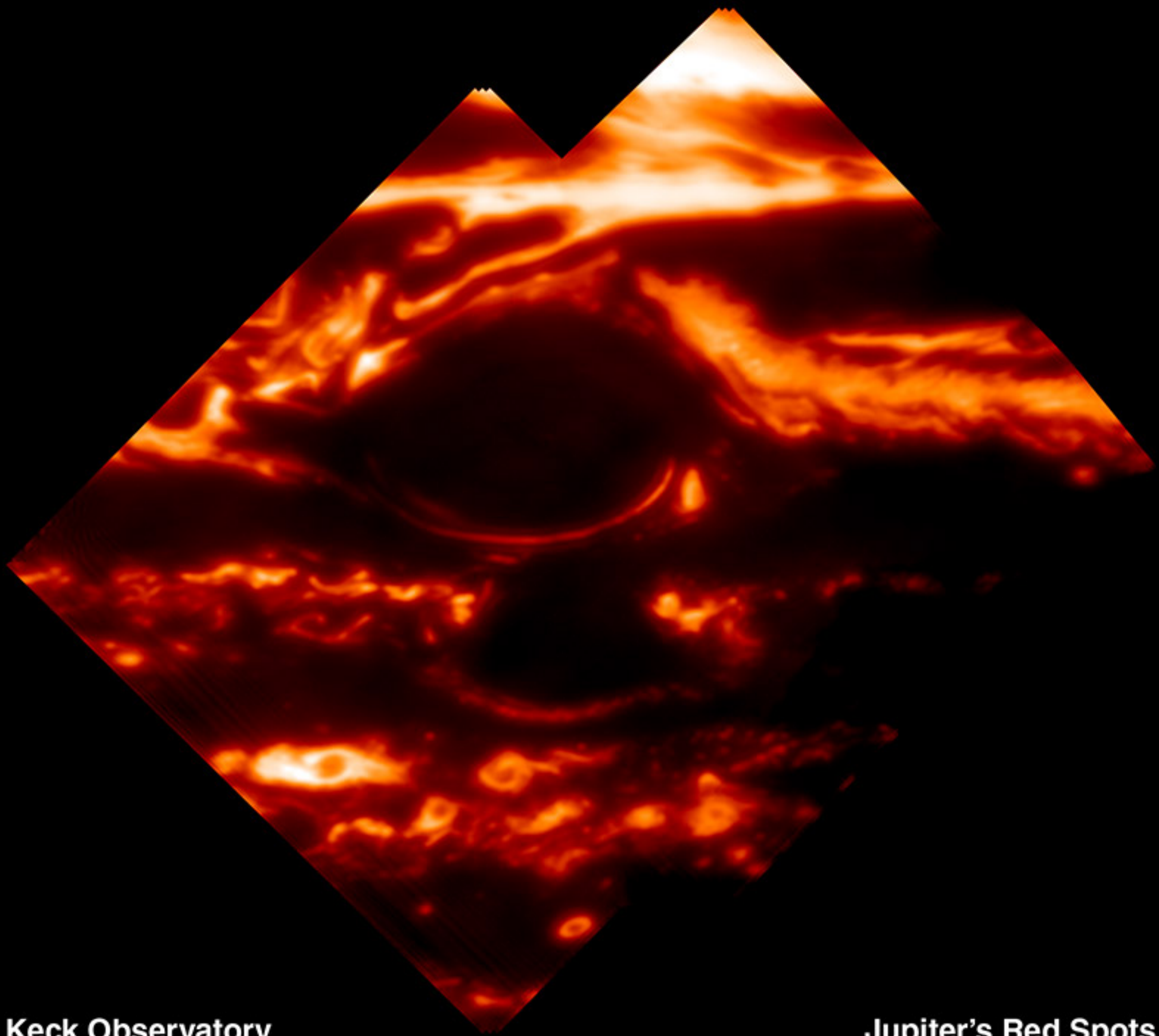




Bjoraker et al.(2013 DPS)
(Keck NIRSPEC, M-band)

- PH_3 in disequilibrium, so tracer of dynamics and connection to deeper interior
- enchancement at equator

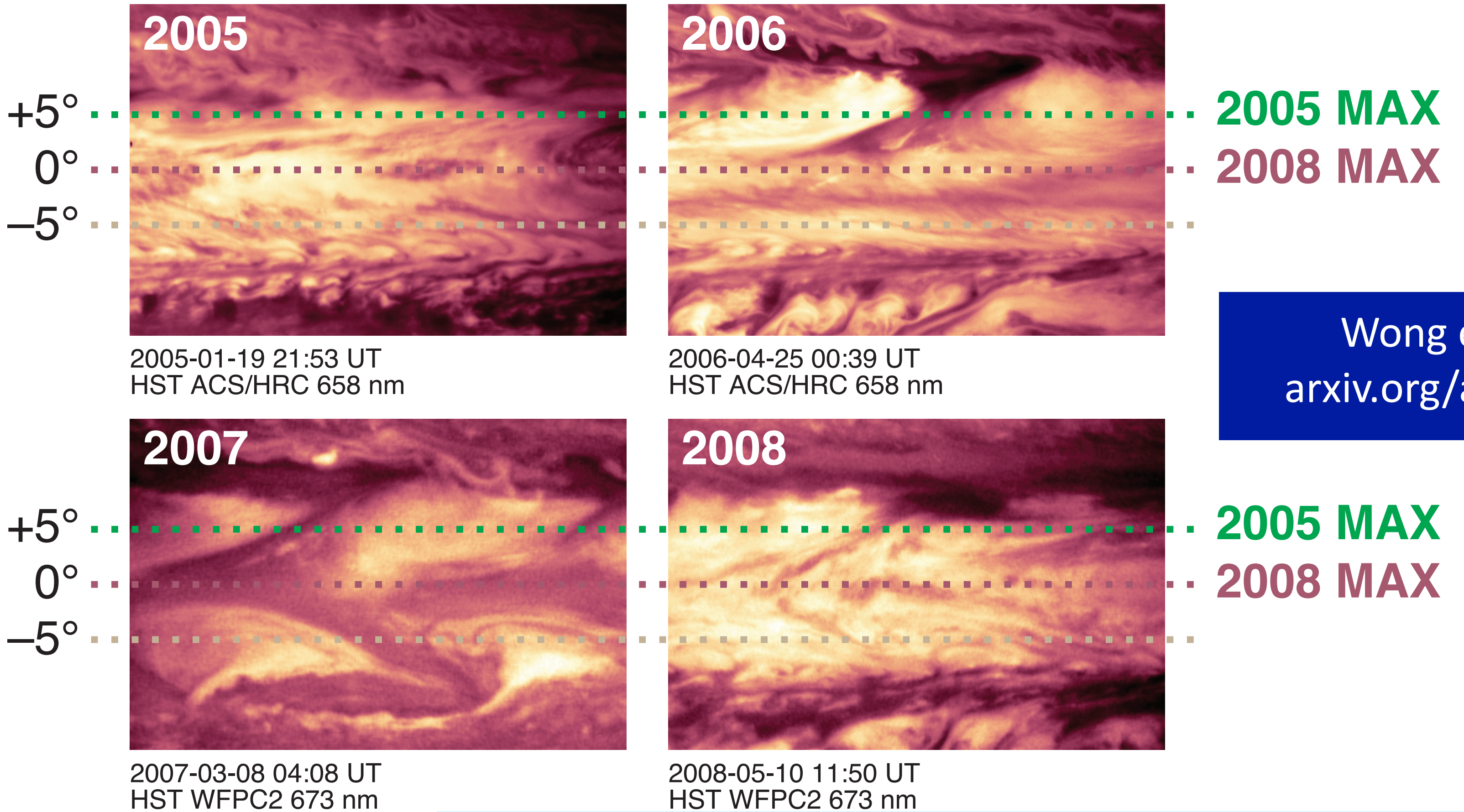
- but equatorial abundances zonally averaged for S/N
- use resolution and sensitivity of TMT to longitudinally resolve PH_3 abundances



Keck Observatory
NIRC2 LGS-AO
Imke de Pater, Mike Wong, Al Conrad

Jupiter's Red Spots
M-band thermal IR
21 July 2006 UT

Equatorial spatial/temporal variability



Wong et al. (2008)
arxiv.org/abs/0810.3703

- obvious variability
- obvious anisotropy: are these features connected to deep interior?

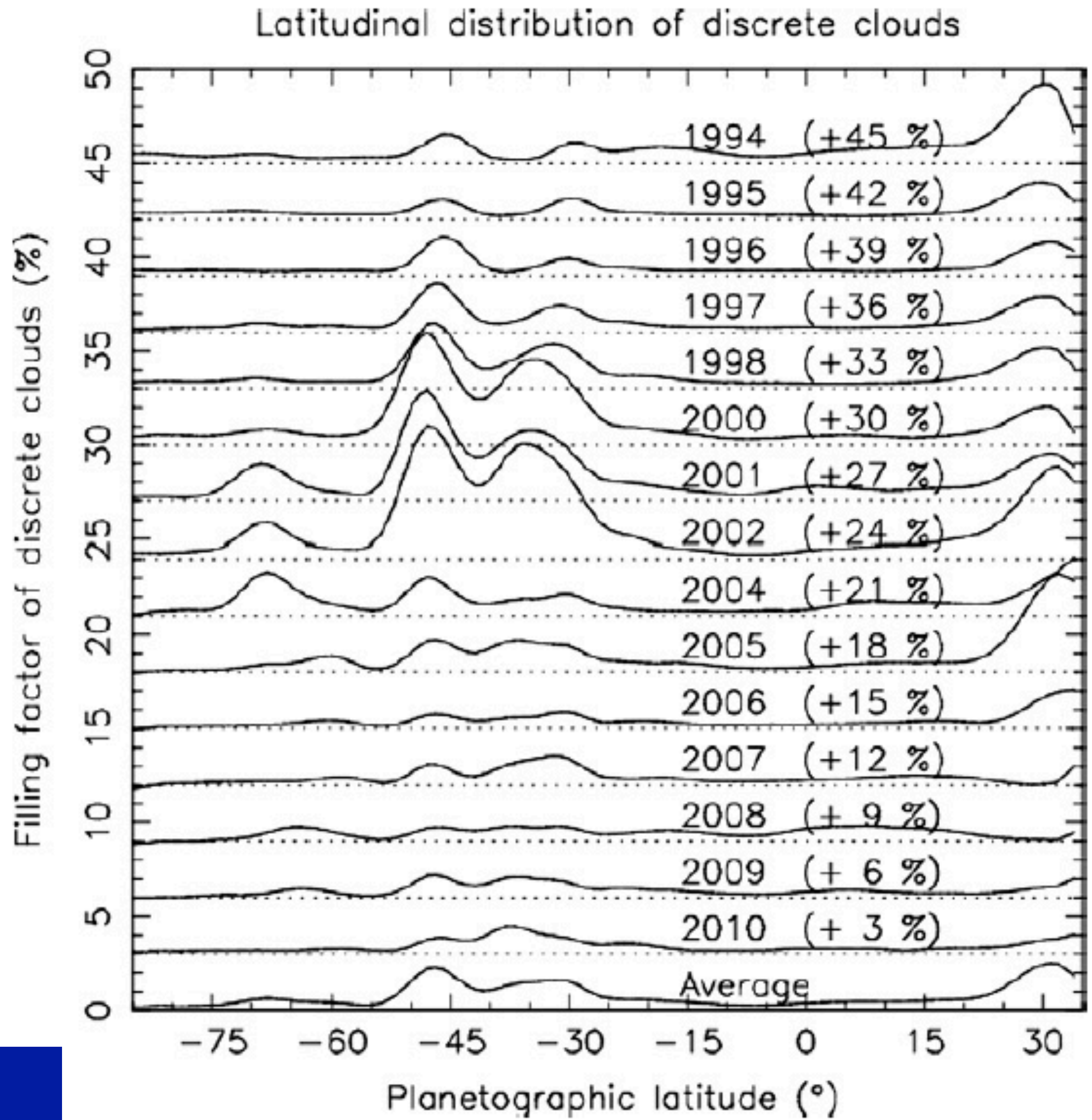
HST/WFPC2 data: value of coherent reusable datasets

Neptune: cloud distribution variability

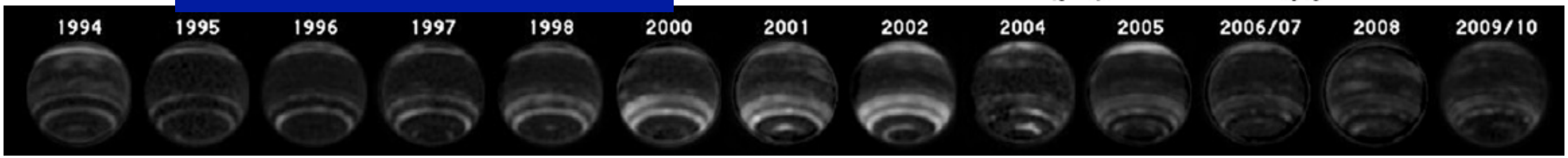
cloud distributions based on HST optical data

demonstrates value of coherent reusable datasets for archival research

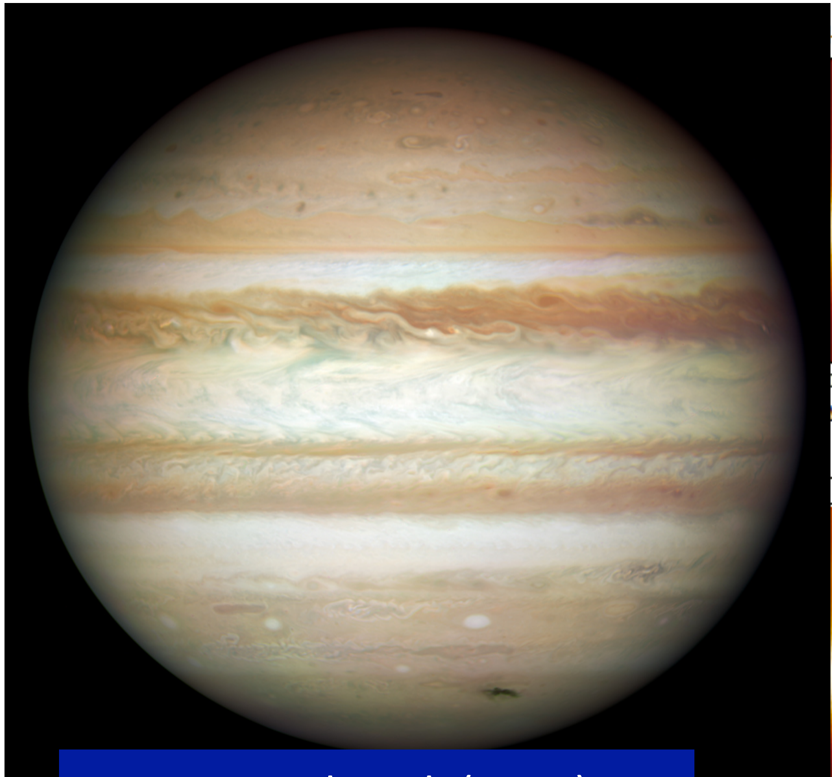
demonstrates value of long campaign durations, arguing for key program at TMT



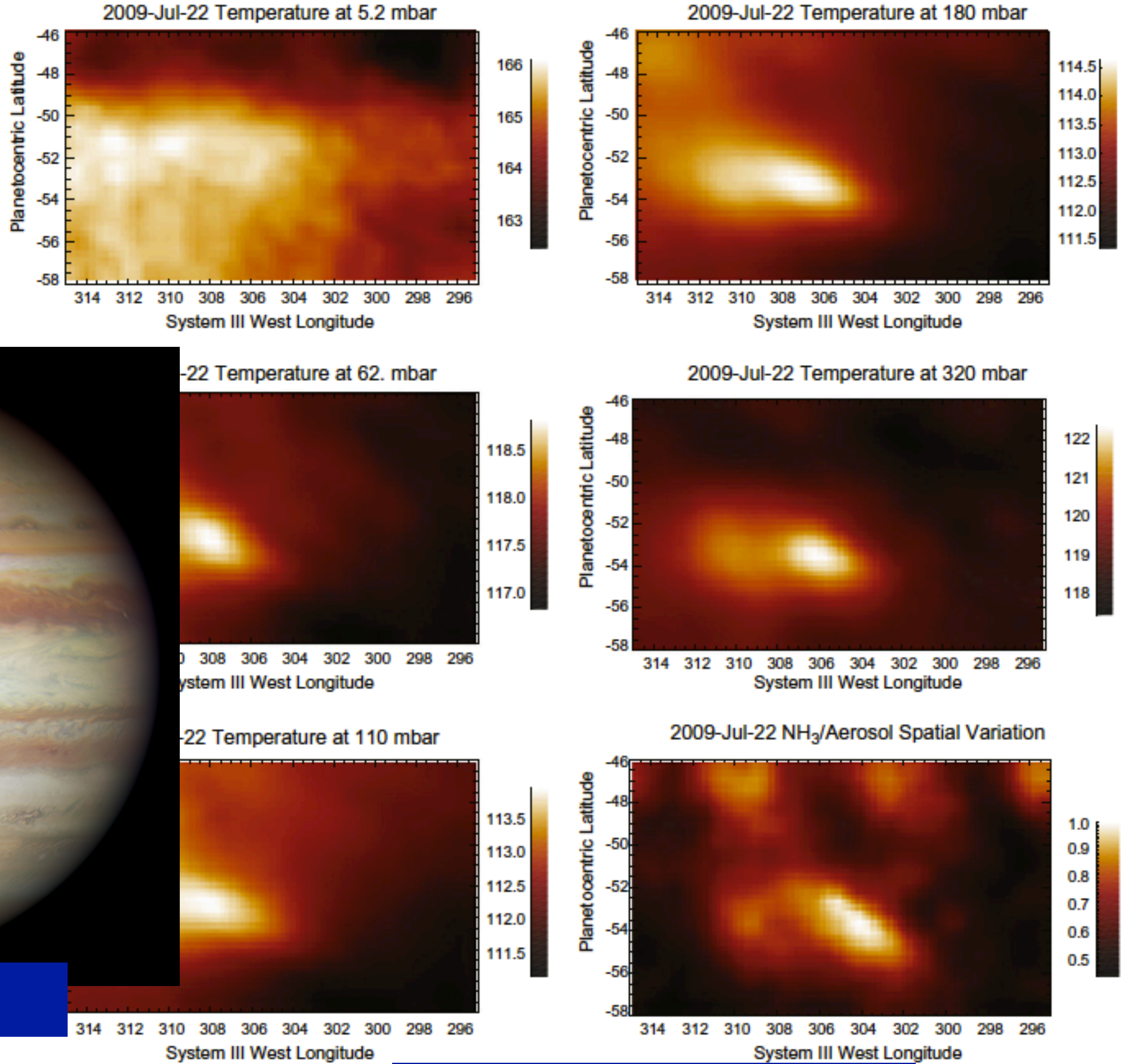
Karkoschka et al. (2011)



Impact (2009)



Hammel et al. (2010)

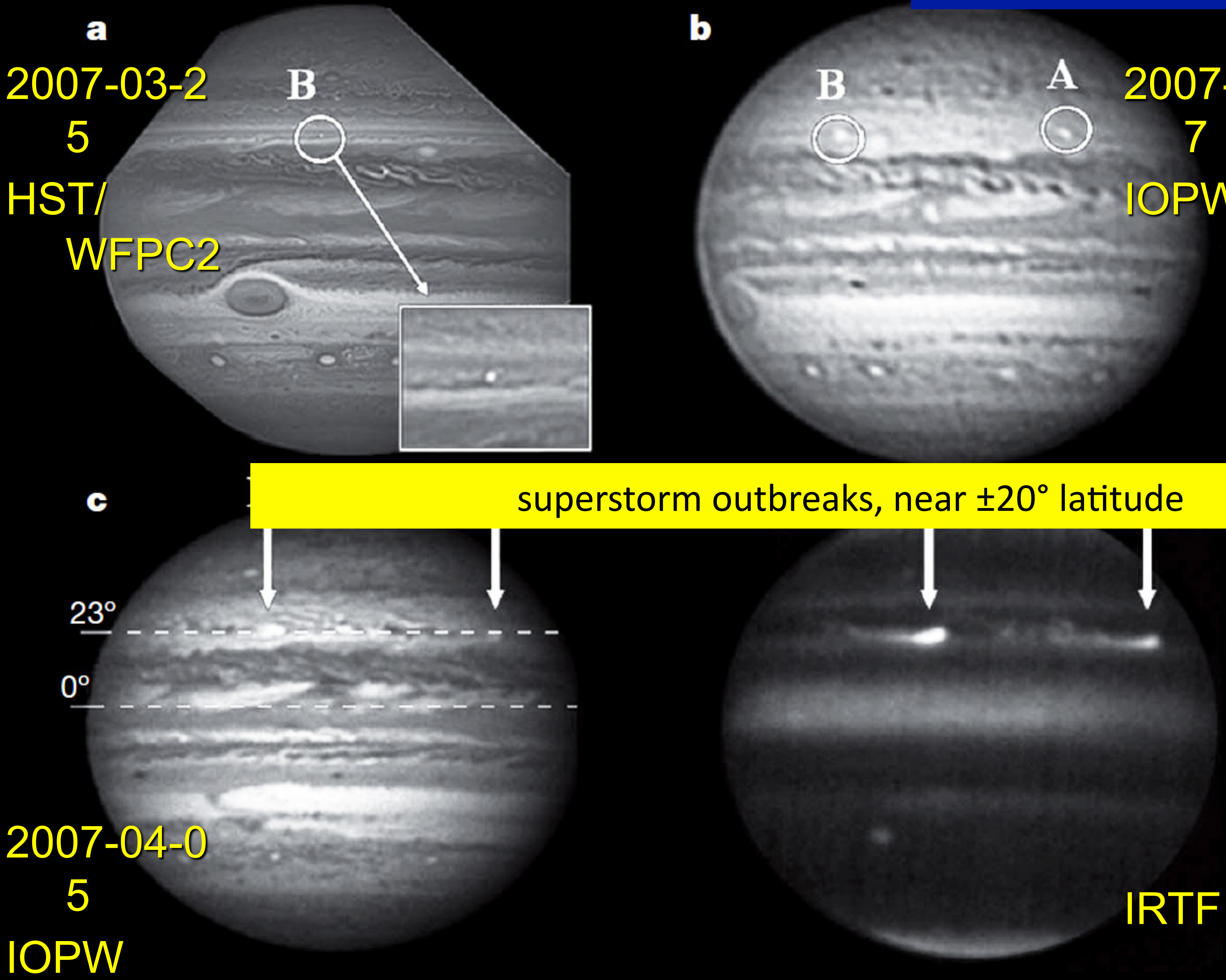


de Pater et al. (2010)

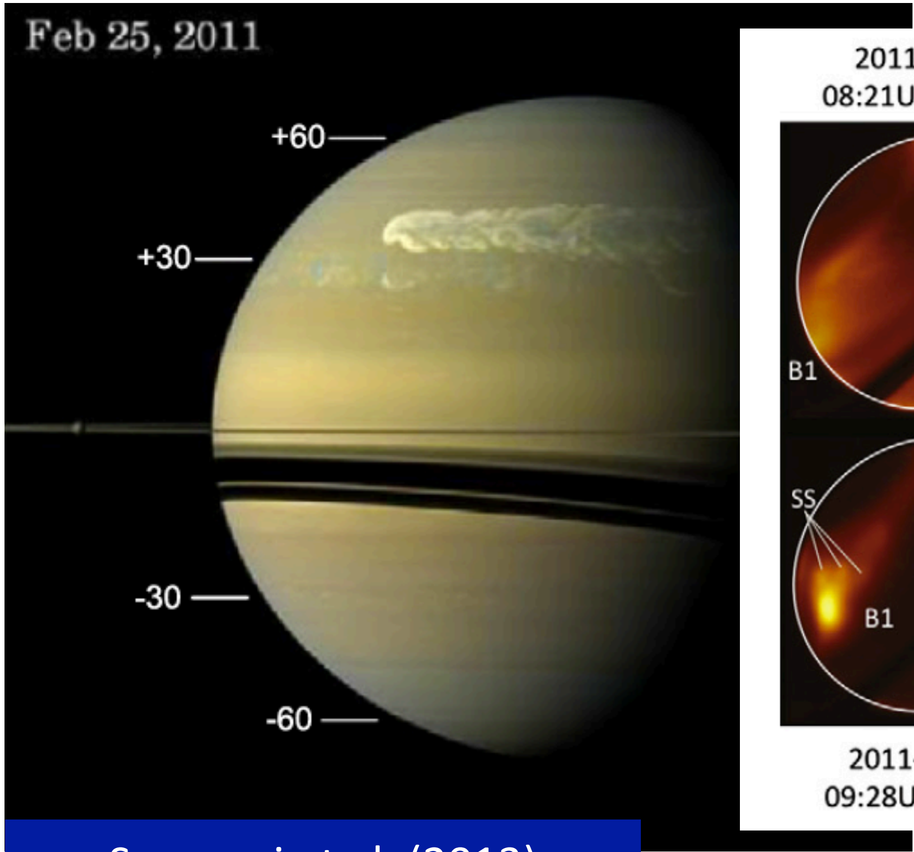
Gemini/MICHELLE
7.7–18.1 µm

Superstorms on Jupiter

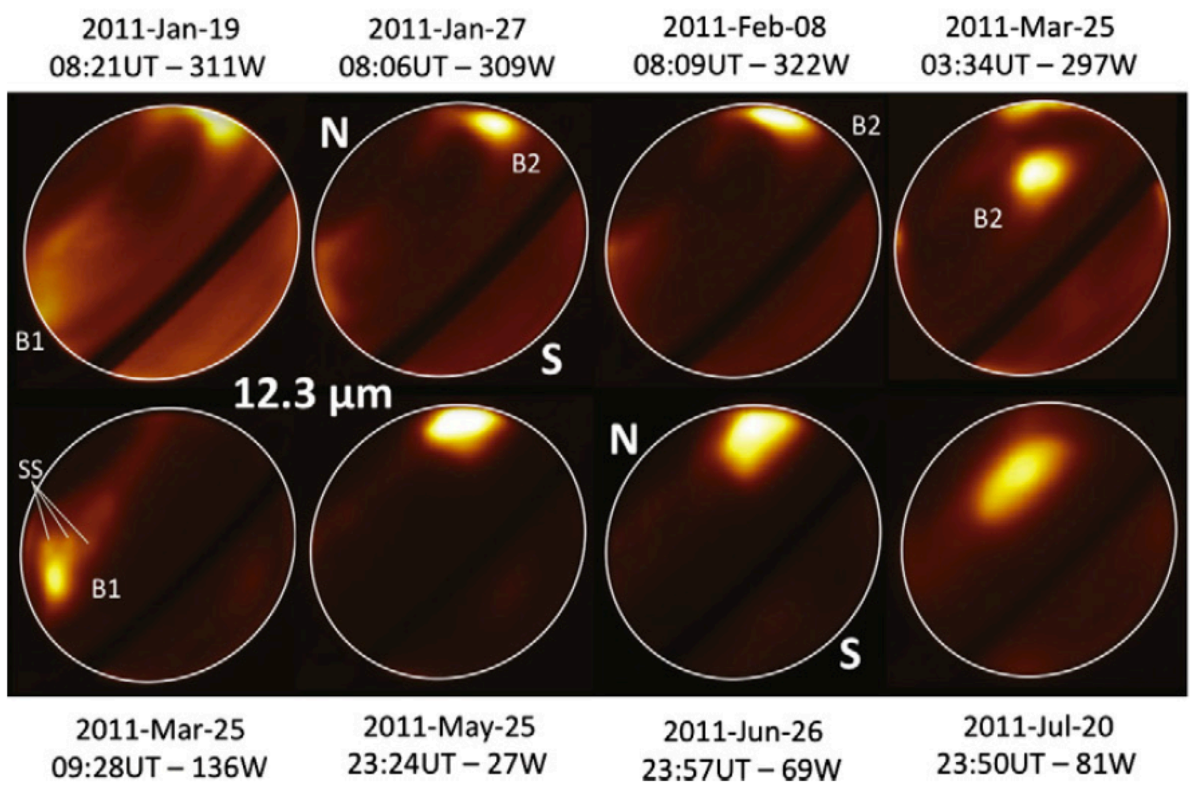
Sánchez-Lavega et al. (2008)



Saturn superstorm



Sayanagi et al. (2013)



Fletcher et al. (2012)

Specific giant planet atmosphere objectives

CIRCULATION

- Determine the distributions of dynamical tracers, and how they change
- Relate the histories of thermal evolution of the giant planets to the array of diverse exoplanets
- Identify chemical and physical processes that affect dynamical tracers

VARIABILITY

- Study dynamic processes over a wide range of timescales
- David Silva: we need coherent reusable datasets
- Key programs can satisfy this goal

Key program design considerations

- Cadence:
  - at least once per apparition for seasonal timescale campaigns
  - several snapshots throughout apparition for ice giant statistics
- Coherence:
  - maintain key program design for several years
- Imaging design for general usability
  - full disk in multiple filters
  - cover a range of latitudes, ideally global coverage (requires multiple visits over ~2 nights)
- Spectroscopic design for general usability
  - IRIS-IFS gets full disk at ice giants
  - select regions/features at Jupiter and Saturn (e.g., Great Red Spot if it's still there)

Solar system technical issues

INSTANT DEATH ---

- **Tracking:** Non-sidereal moving targets, while using sidereal guide stars
- **Brightness:** Short exposures for bright targets

VERY INCONVENIENT ---

- **Chop/nod throws:** Large enough to get a sky background away from a bright, extended target (prefer ≥ 30")
- **NFIRAOS WFS backgrounds:** Guide star backgrounds should be immune to nearby bright objects
- **PSF sampling:** Plate scale should critically sample PSF, because dithering is not feasible for some applications (rotating target, precise relative image navigation)

Telescope Requirements for SS Small Bodies

- 1. Need to ensure capability for non-sidereal GUIDING (not just tracking). Rates can range from < 1 arc sec/hr (typical of KBOs), to several 100 arc sec / hr for Near Earth Objects (and NASA in particular may be interested in characterizing potentially hazardous objects that come close to Earth)
- 2. The Adaptive Optics system needs to be able to handle moving targets too.
- 3. For moving objects there is a need to fully integrate with national archives of orbital elements - so that standard names (asteroid numbers, comet designations, satellite, planet names) can be entered, and the ephemeris can be calculated by the operating system for the time of the observation, and the rates for the guide probe can be uploaded.

Critical instruments for Key small body science

1. High resolution optical spectrograph — for getting isotope ratios in comets (R ~ 60,000-80,000)

- 2. High resolution near IR spectrograph - for parent organic volatiles (R ~ 20,000)

Possible Key Project
- synergy with TMT/JWST/ALMA - Understanding Origin of Volatiles for Habitable Worlds

- - isotope measurements (D/H, 18O/17O/16O, 15N/14N) as tracers of disk processes
- - $H_2O/CO/CO_2$ ratios
- - Direct measurement of volatiles in outer asteroid belt
- Dynamics models make specific predictions where the volatiles originated from that arrived at Earth. Several models make different testable predictions of distance (which is equivalent to Temperature in the disk).
- Disk chemical models make predictions of different chemical gradients for isotopes as a function of Temperature/distance.
- We can measure chemistry / isotopes in small bodies that can integrate these models addressing how to build habitable worlds.