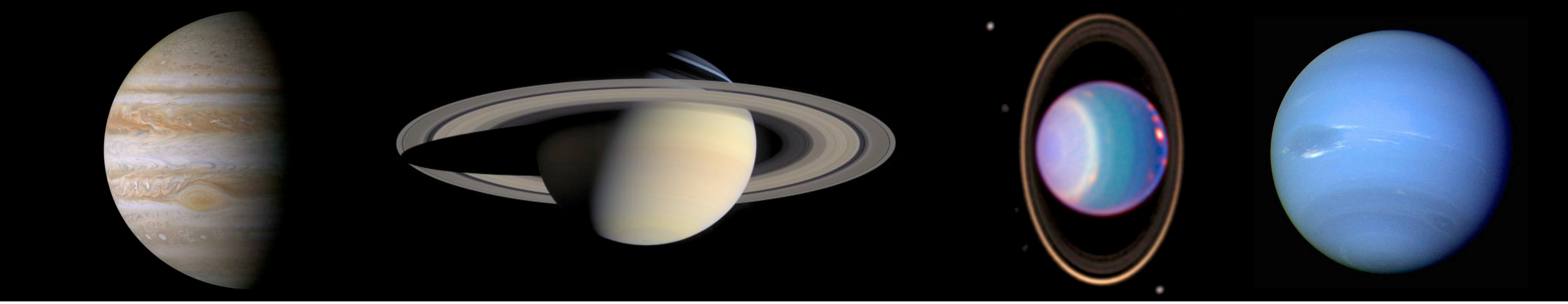
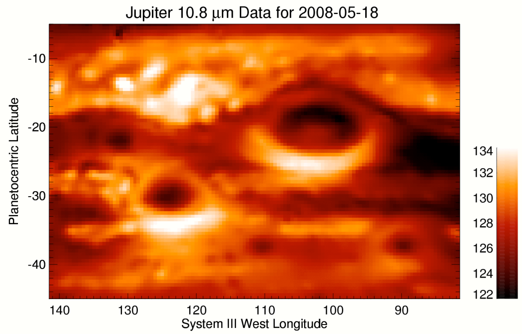
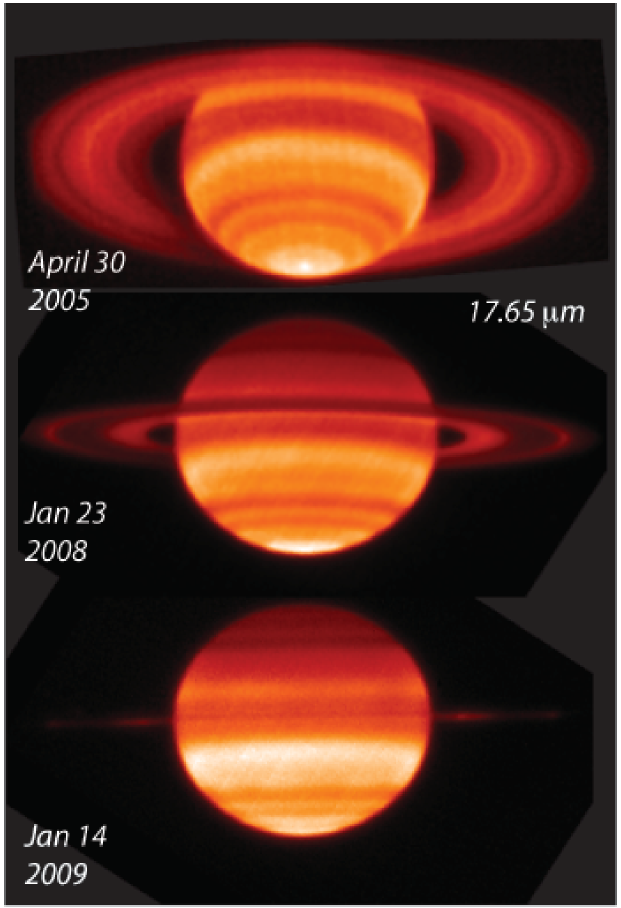


Time-Variable Atmospheric Phenomena in the Outer Solar System using Subaru/COMICS and Gemini/TReCS





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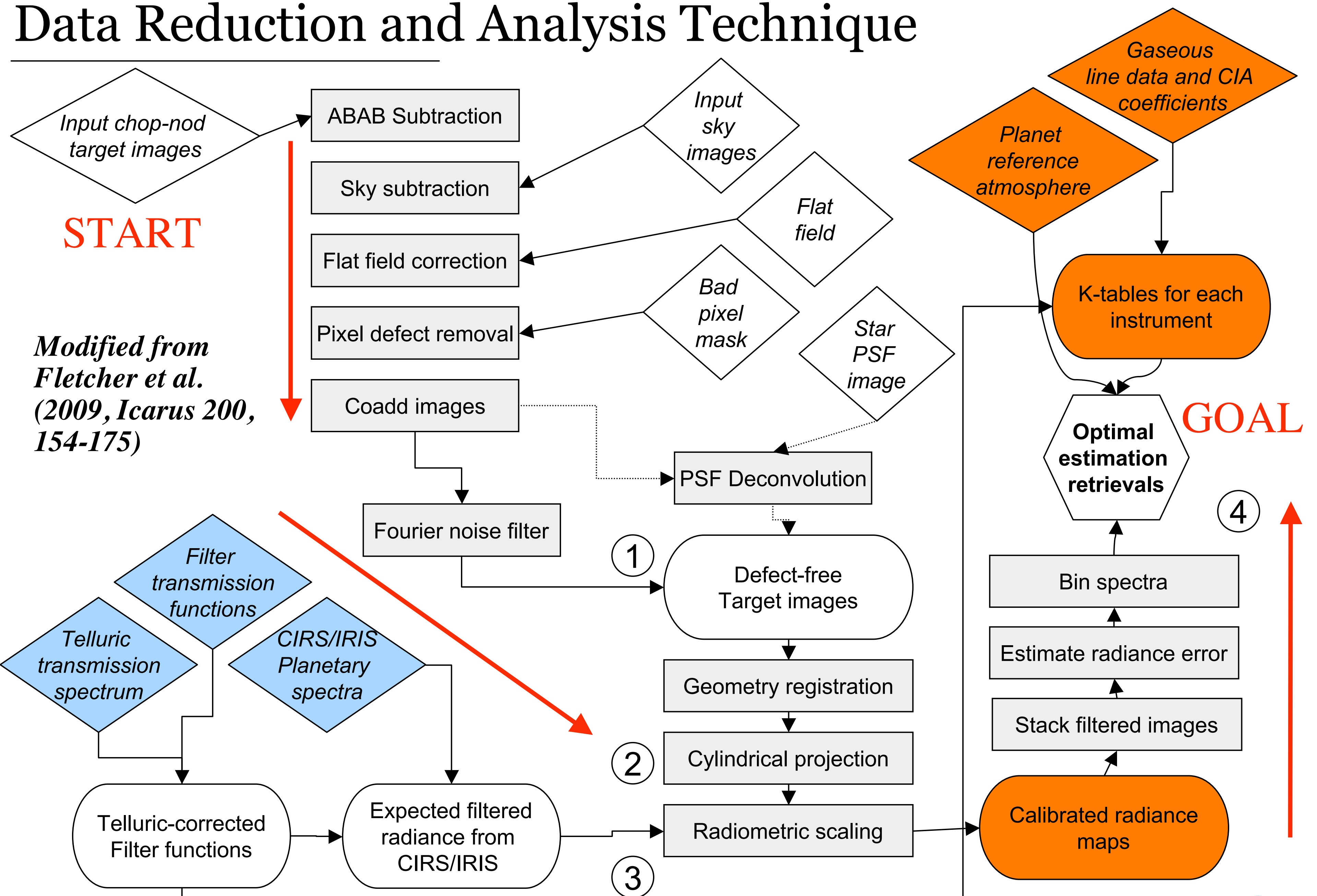
G.S. Orton (JPL), P. Yanamandra-Fisher (JPL), B.M. Fisher (JPL), P.G.J. Irwin (University of Oxford), P.D. Parrish (University of Edinburgh), T. Fujiyoshi (Subaru), T. Fuse (Subaru), T. Hayward (Gemini Observatory), J. De Buizer (NASA/Ames)

Introduction

- Spacecraft provided incredible snapshots:
  - Voyager imaging and spectroscopy revealed composition, chemistry and dynamics for the first time.
  - Galileo permitted a new understanding of Jupiter, but the low data rate restricted science capabilities.
- To really understand complex atmospheres we must study ***temporal phenomena - change…***
  - Require long-lifetime missions (**Cassini**), or continual monitoring from **ground-based observatories**.
  - Comparisons between the gas giants reveal their different responses to seasons, convective instabilities, etc.
- **This talk will highlight changing phenomena on the four gas giants.**

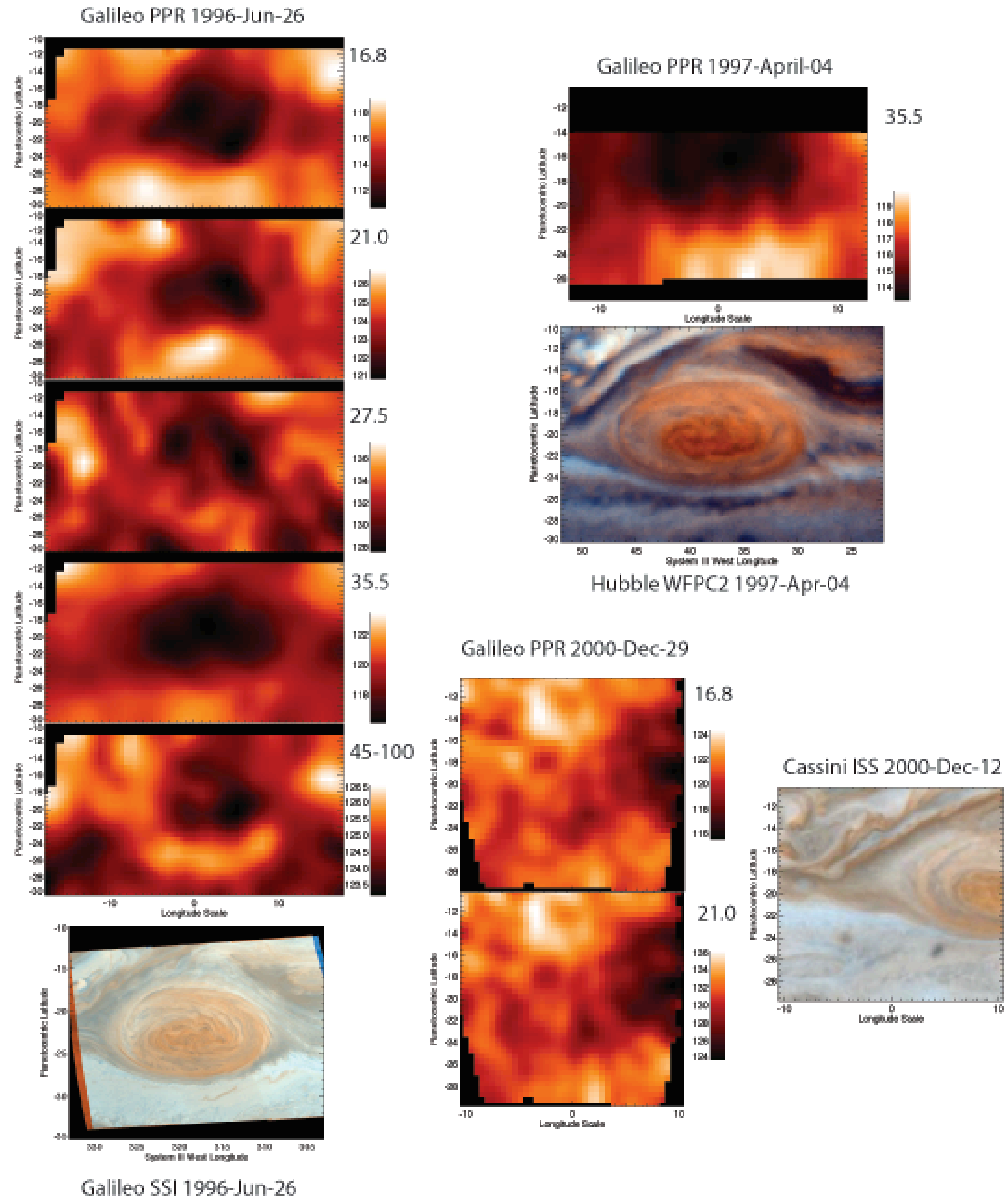
Data Reduction and Analysis Technique

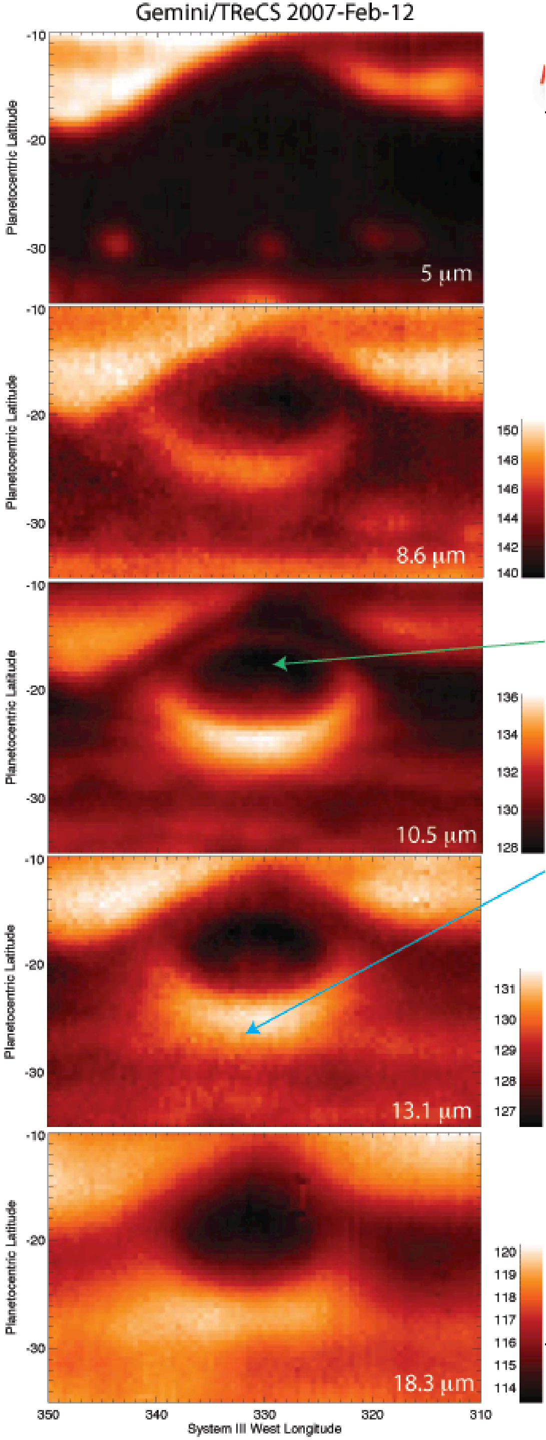


Modified from Fletcher et al. (2009, Icarus 200, 154-175)

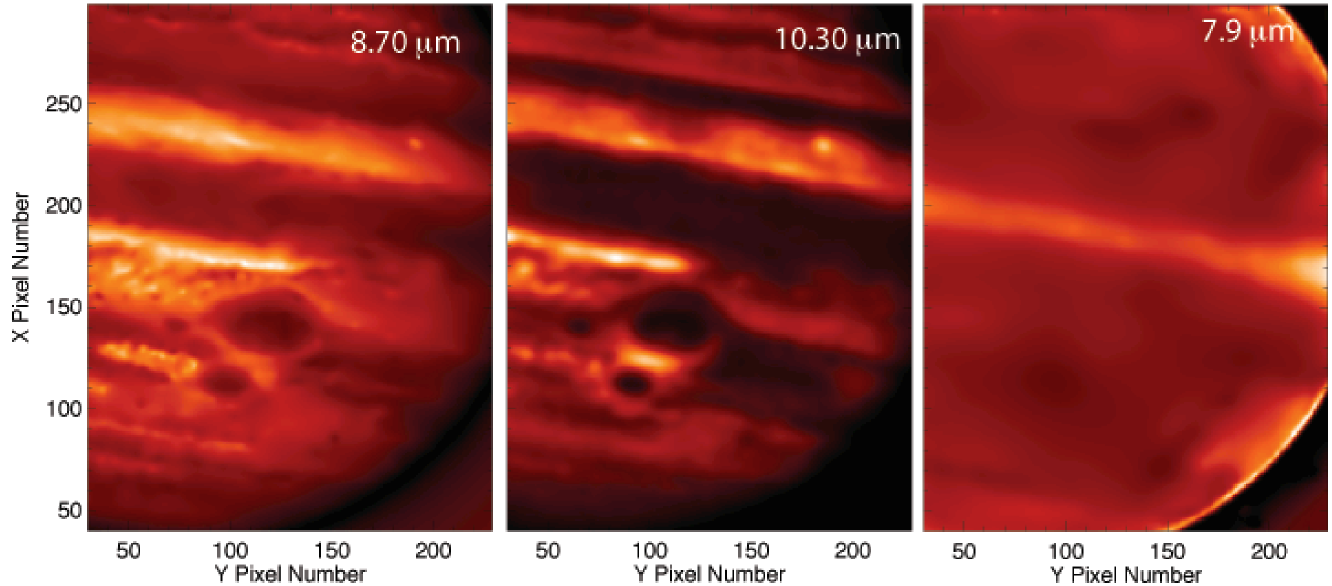
Jupiter: Great Red Spot and Oval BA 木星

- Thermal infrared imaging of Jupiter's giant anticyclonic storm systems:
  - Galileo limited by low telemetry rate, stuck filter wheel.
- Hard to compare low-resolution thermal images with high-resolution Galileo/HST visible images.
- Subaru/Gemini superb spatial resolution permits proper comparisons for the first time.





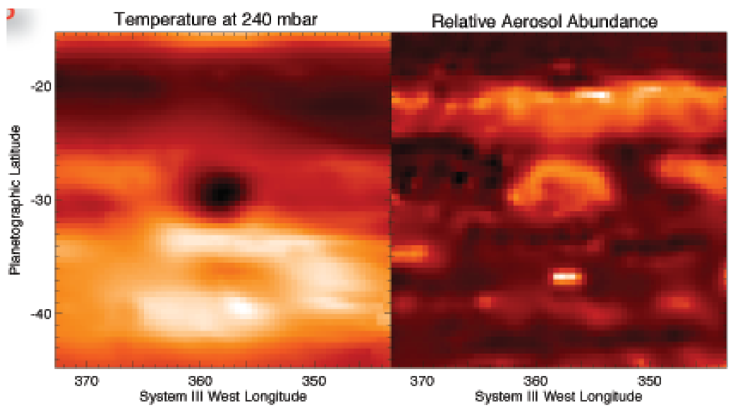
Jupiter from COMICS and TReCS



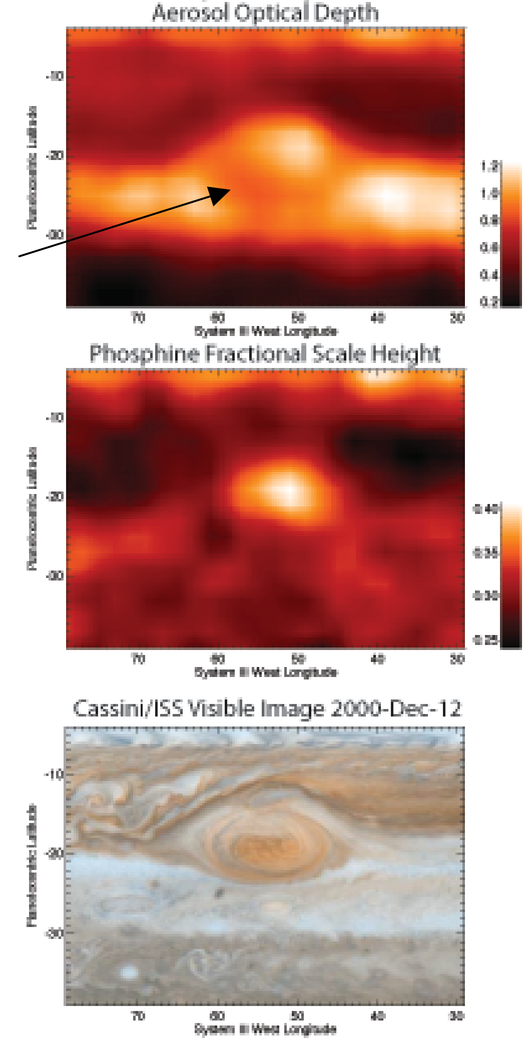
COMICS images acquired as the Great Red Spot, Oval BA and a newly-formed Little Red Spot interacted on June 24th 2008.

- First detection of **inhomogeneous thermal structure** within the GRS.
- Changing morphology of warm southern periphery with depth, perturbations by passing storms.
- Observe interactions with smaller anticyclones, changing temperature of turbulent wake region.
- But we can do more with Optimal Estimation Retrievals…

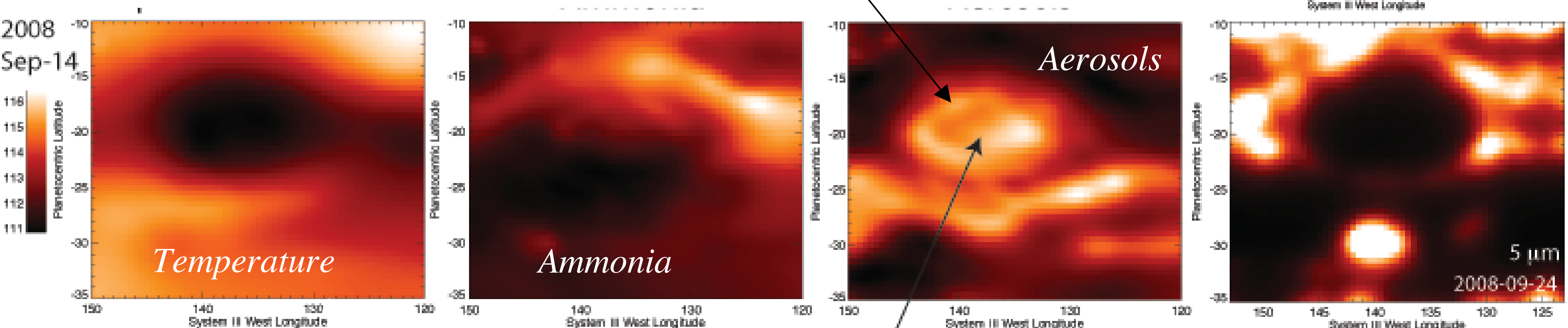
Retrievals of Atmospheric Properties



Cassini/CIRS retrievals from full spectra are consistent with filtered imaging results.

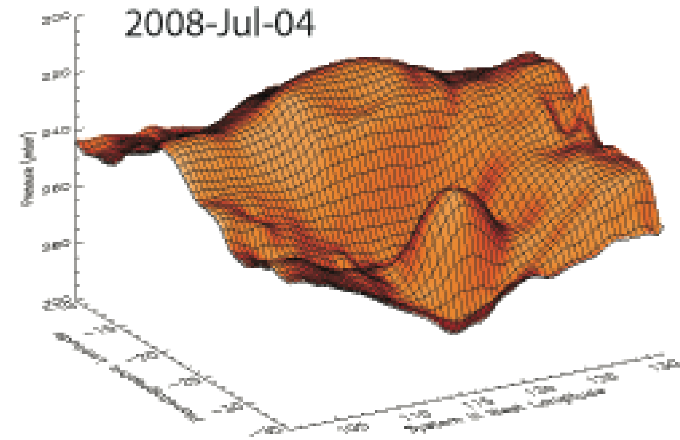


- Stack images to form a low-resolution spectral cube to retrieve:
  - (a) atmospheric temperatures; (b) ammonia distribution; (c) aerosol opacity; and (d) para-hydrogen.
- GRS and BA have similar properties:
  - Upwelling cold cores lofting aerosols to high altitudes.



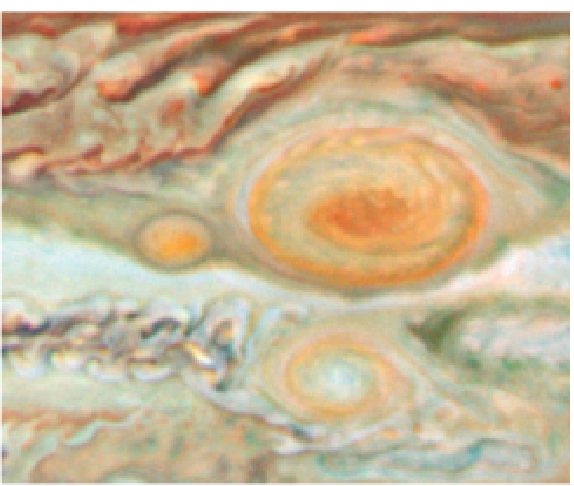
Tracing Atmospheric Dynamics

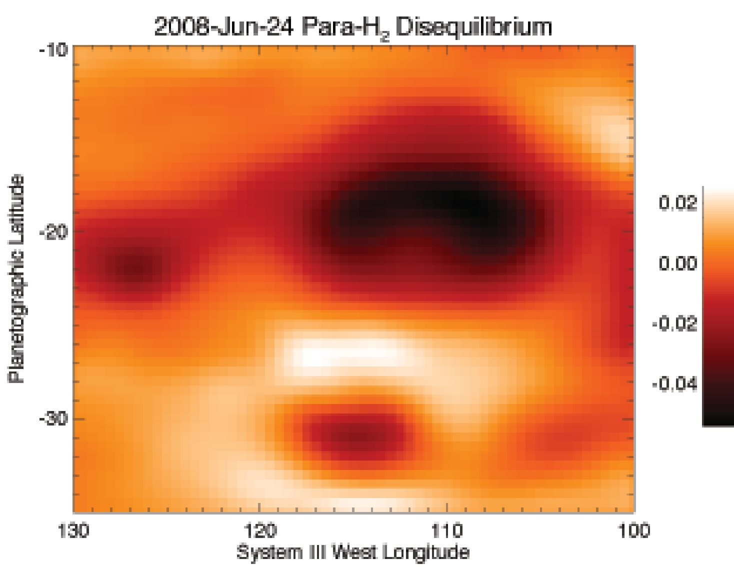
- First ground-based determination (COMICS) of ortho/para-hydrogen ratio within Jupiter's storms:
  - Dark (sub-equilibrium) indicated upwelling.
  - Bright (super-equilibrium) indicates subsidence.
- All storm have upwelling cores, GRS has possible subsidence in the warm centre associated with the deepest red colouration.



Pressure in an isentropic surface indicates upwelling storms reach lower pressures/higher altitudes.

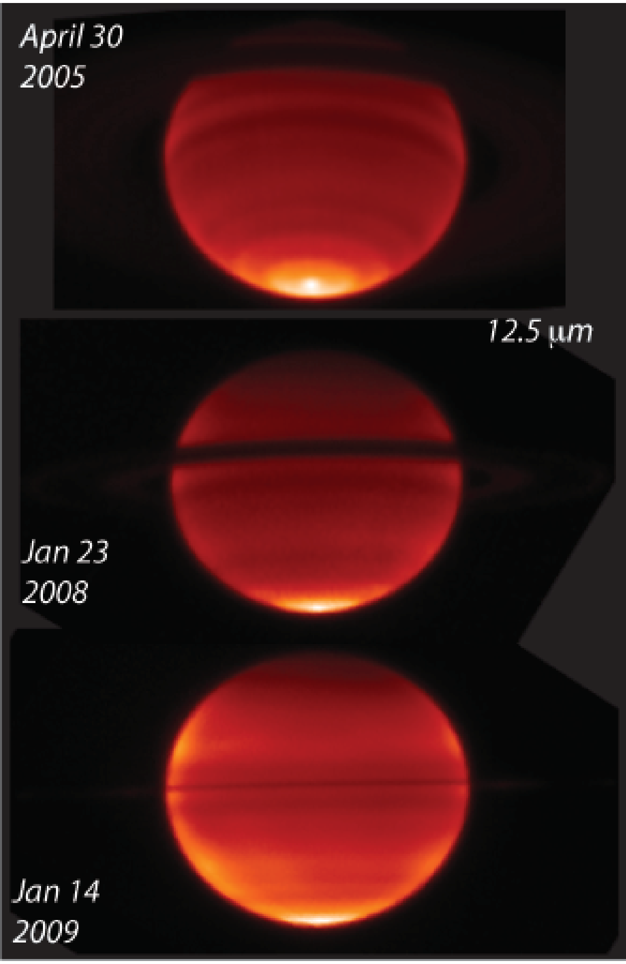
Hubble June 28th



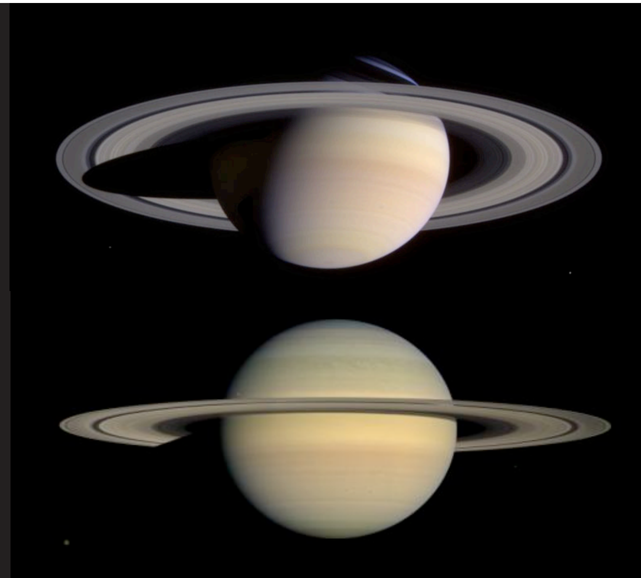


Jupiter results submitted to Icarus (Fletcher et al., 2009)

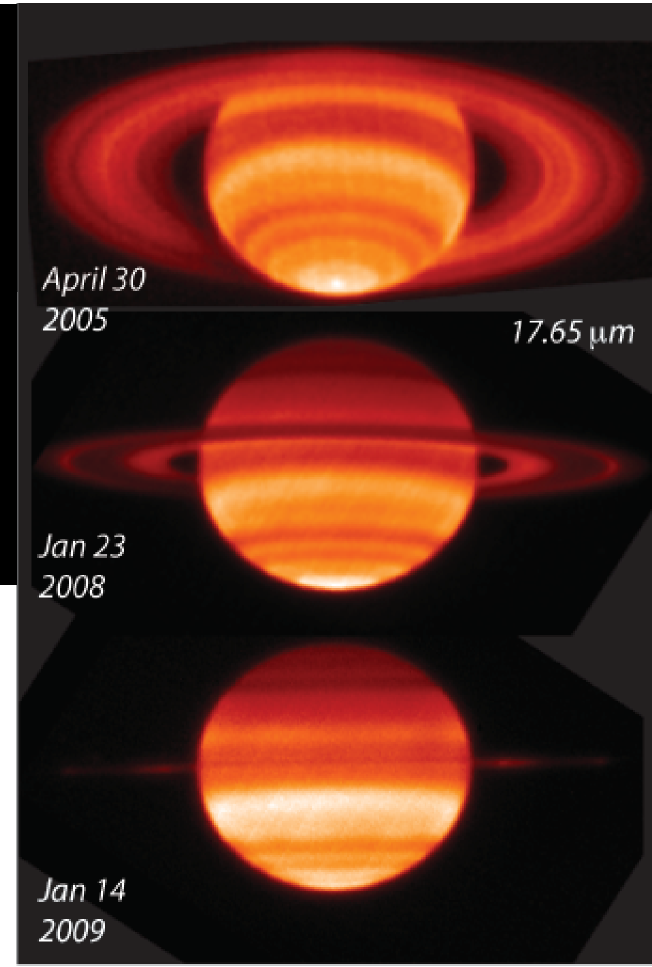
Saturn: Seasonal Changes 土星



Warm stratospheric vortex at the summer pole.



Saturn’s orbital obliquity of 26 degrees causes large seasonal variations in insolation. Between April 2005 and January 2009 we track the closing of the ring angle as southern summer progresses to autumn (the equinox is August 2009).



Belt/zone structure and hemispheric asymmetry in troposphere.

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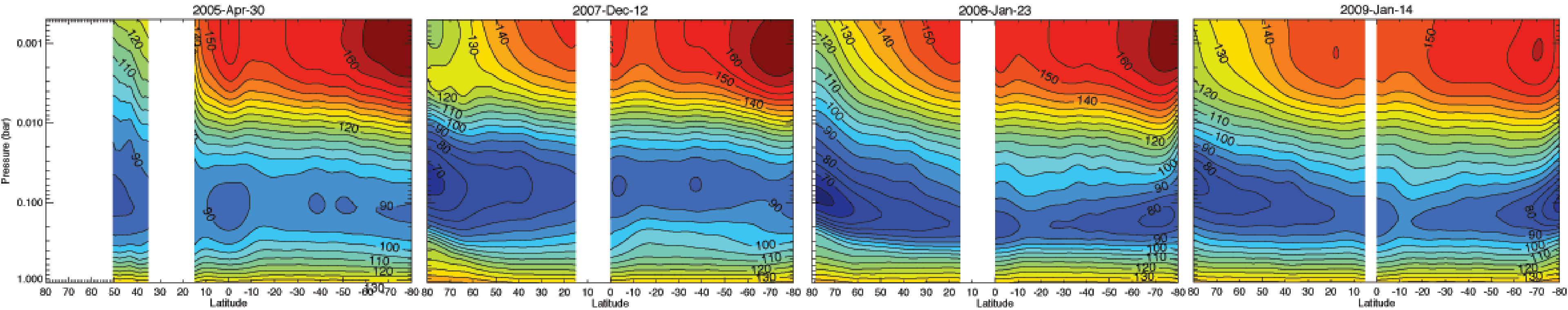
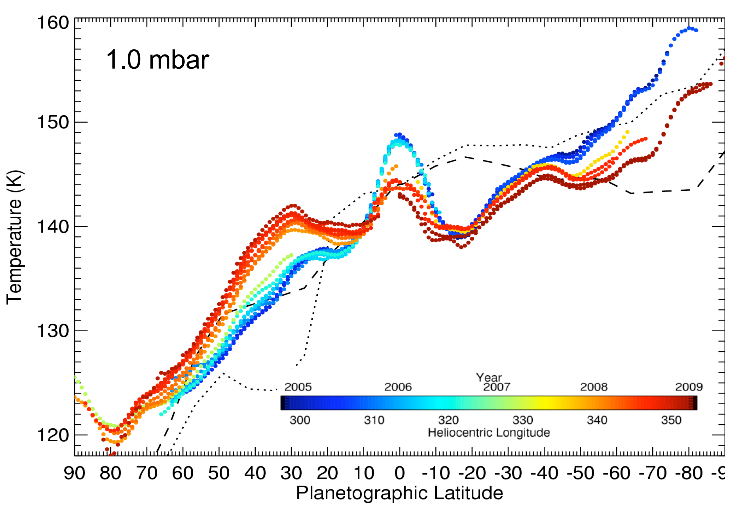
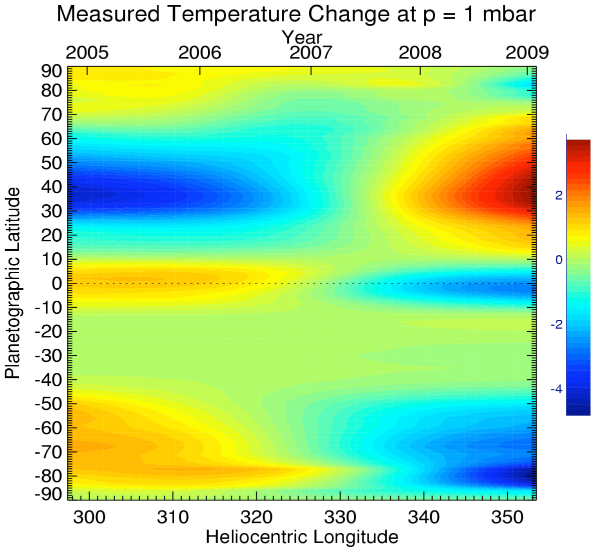
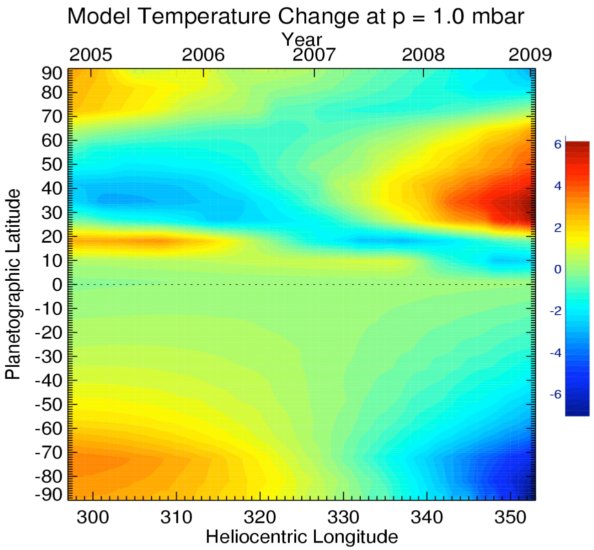
Saturn Temperature Retrievals



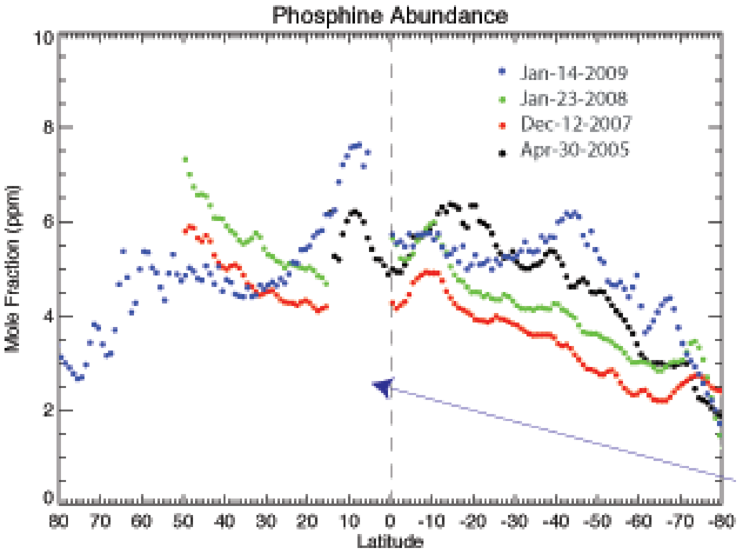
- Comparing COMICS T(p) retrievals from 17-25 um and 7-12 um filters with Cassini results:
  - General cooling of northern mid-latitudes, cooling in south.
  - Cooling of south polar vortex, equatorial structure associated with Semi-Annual Oscillation.
  - Measurements consistent with radiative-climate model of Greathouse et al.

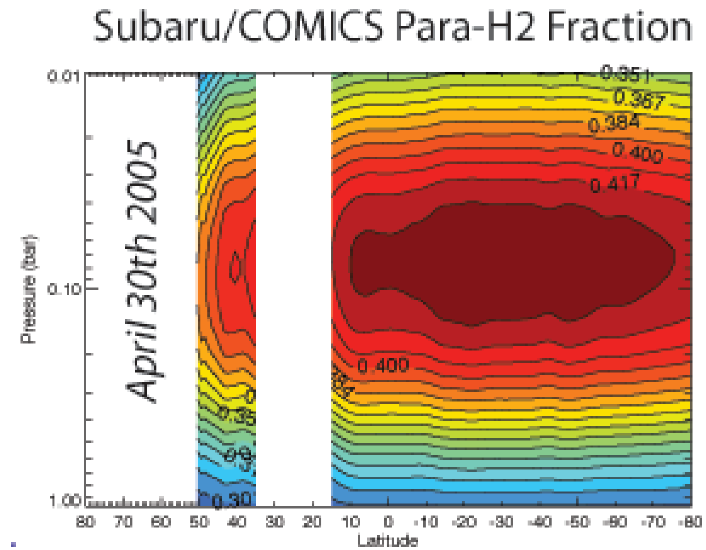


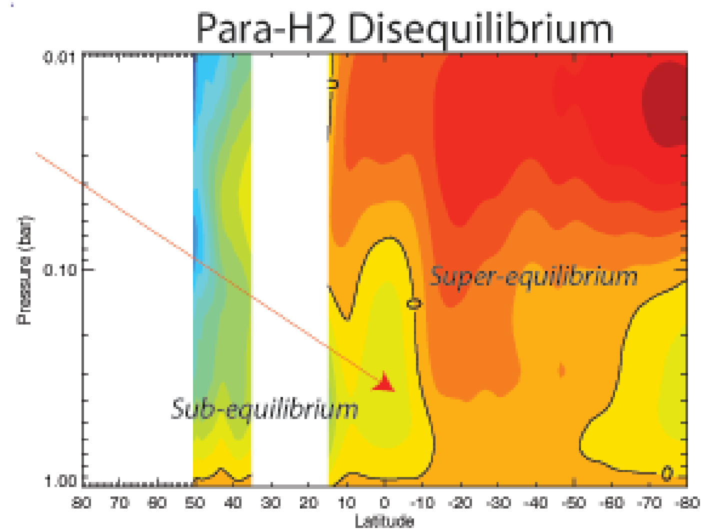




Saturn's Atmospheric Dynamics



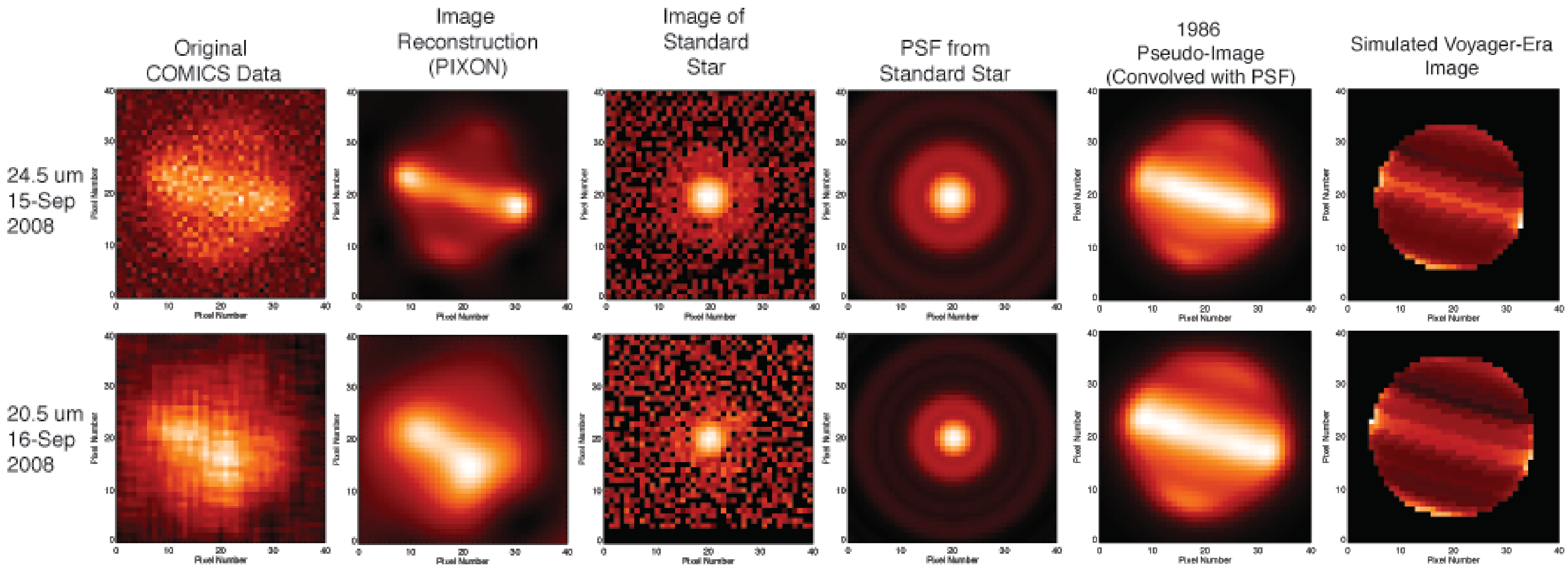


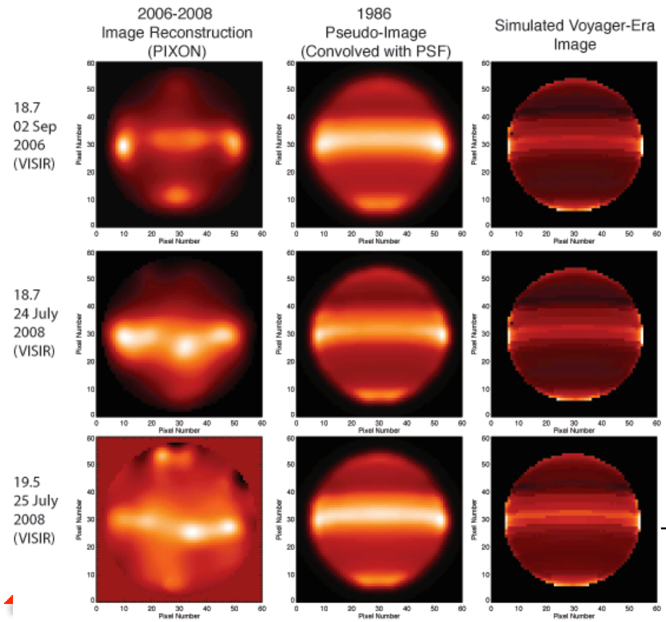


- Para-H_2 and PH_3 trace atmospheric motions.
- Elevated equatorial PH_3 and sub-equilibrium para-H_2 conditions suggest equatorial upwelling, consistent with Cassini (Fletcher et al., 2009, in press.).
- North-south para-H_2 asymmetry suggests a relation with aerosol opacity.

Saturn results are being prepared for publication (Yanamandra-Fisher et al.)

Uranus: Tropospheric Temperatures 天王星





- Uranus extreme seasonal insolation variations due to 98 deg. obliquity.
- Image reconstruction techniques to obtain an image from low-signal data.
- Comparison between Voyager-era pseudo-image and present day reveals **north polar cooling.**

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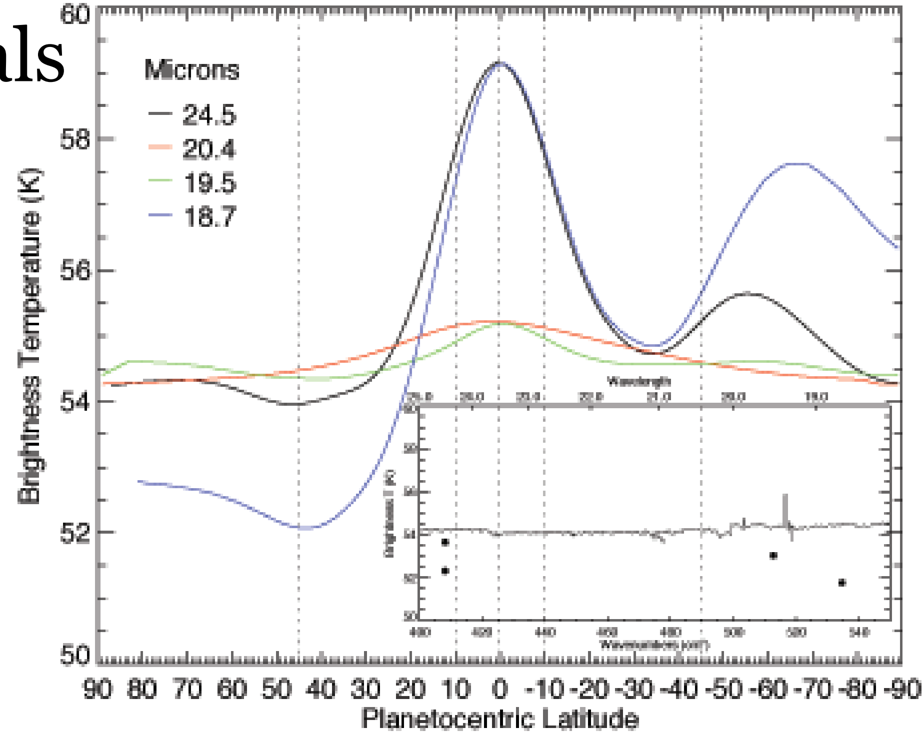
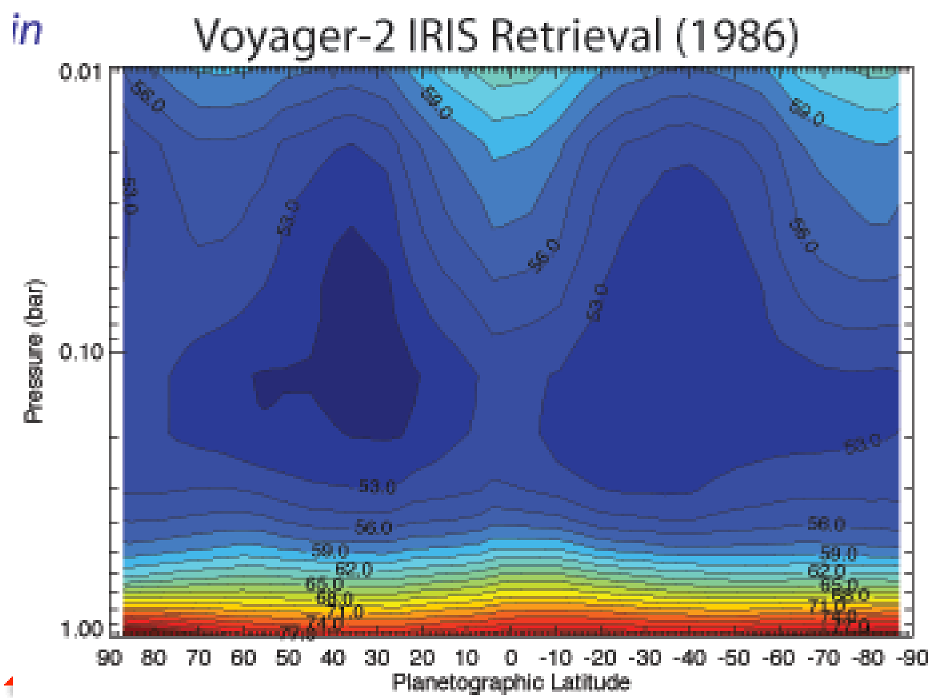
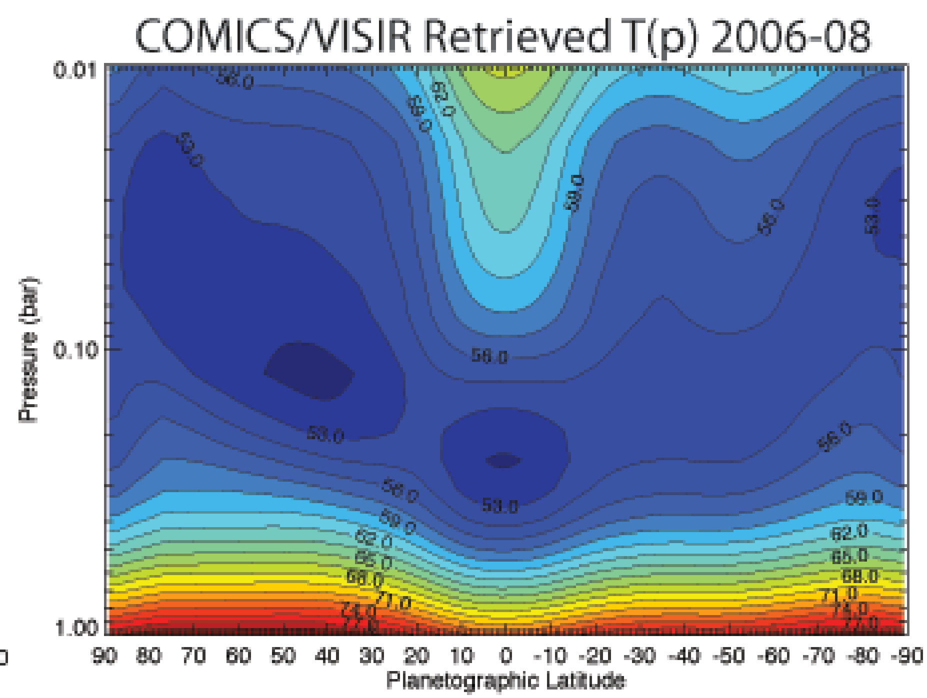
Uranus Temperature Retrievals

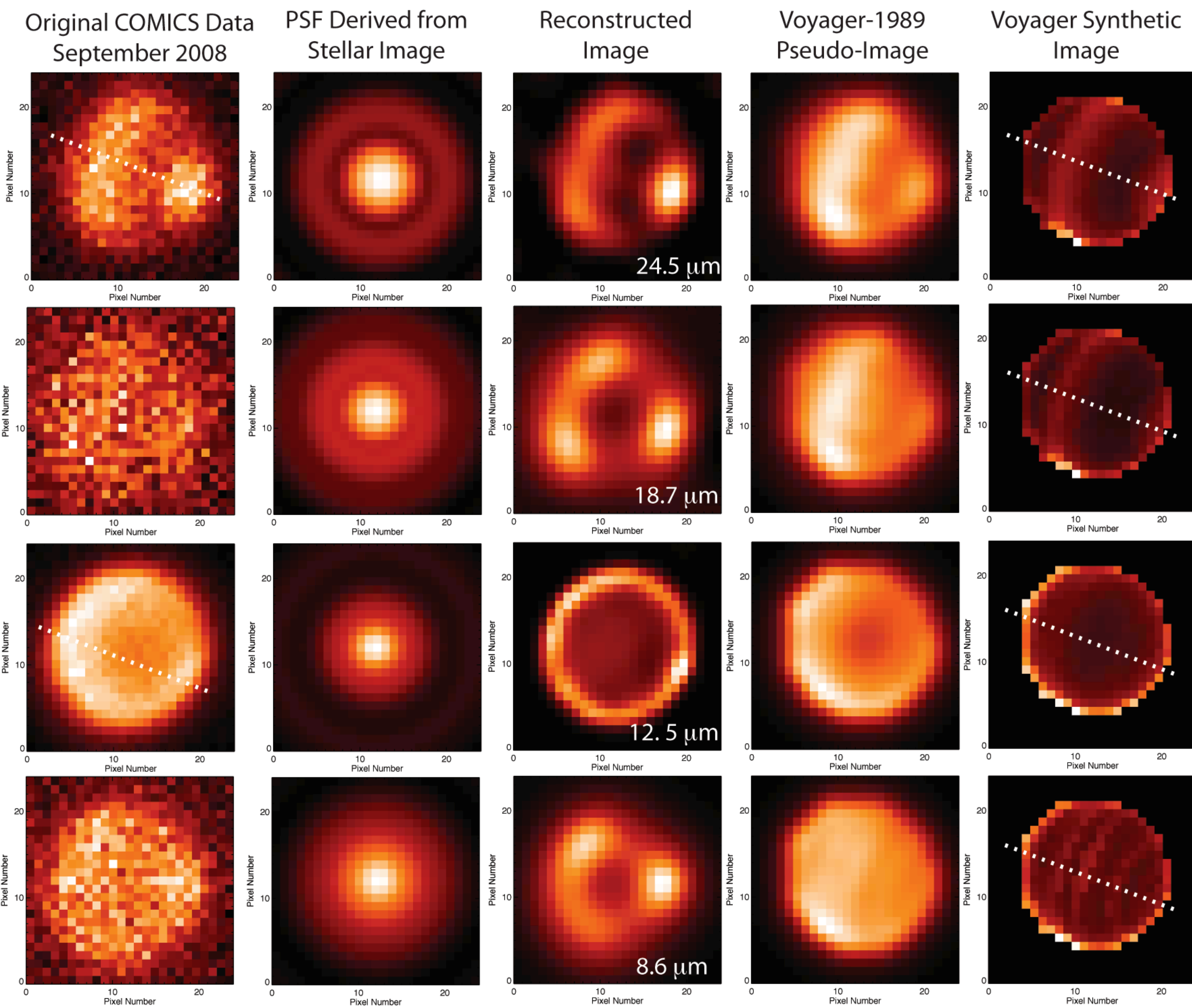
- Pseudo-images based on Voyager/IRIS temperature retrieval.
- Calibrate with (a) standard stars and (b) comparison to Spitzer/IRS observations.
- Combine all COMICS and VISIR observations of Uranus 2006-08 to form a low resolution spectral cube to derive T(p) structure.
- **Temperature asymmetry developed.**







Neptune: South Polar Hotspot 海王星



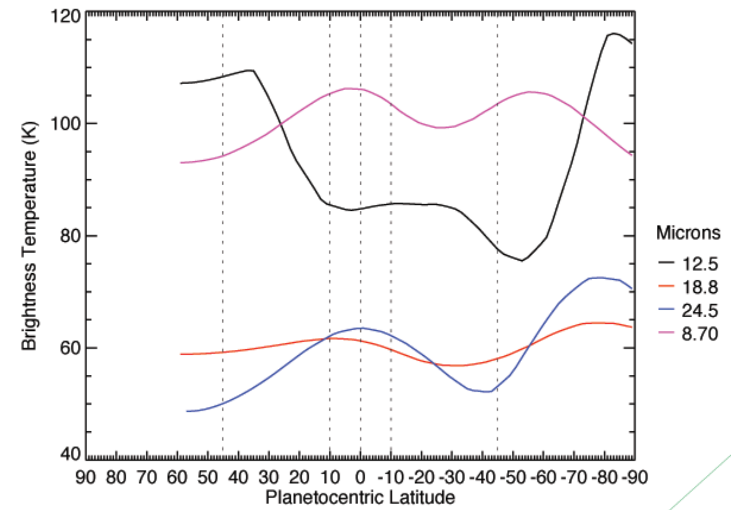
Using the same technique as Uranus:

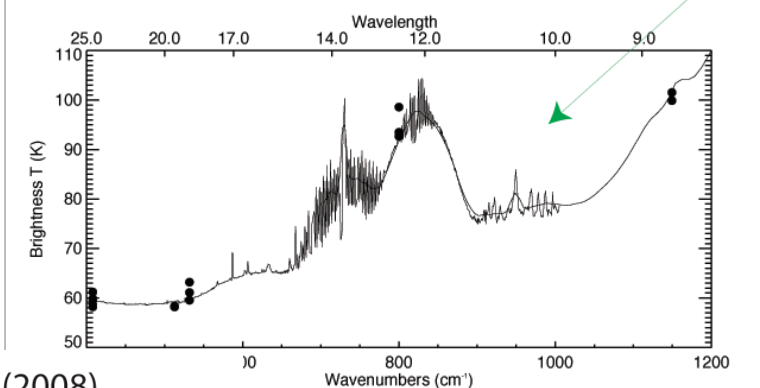
- PSF reconstruction.
- PIXON image.
- Voyager/IRIS Synthetic image comparison.

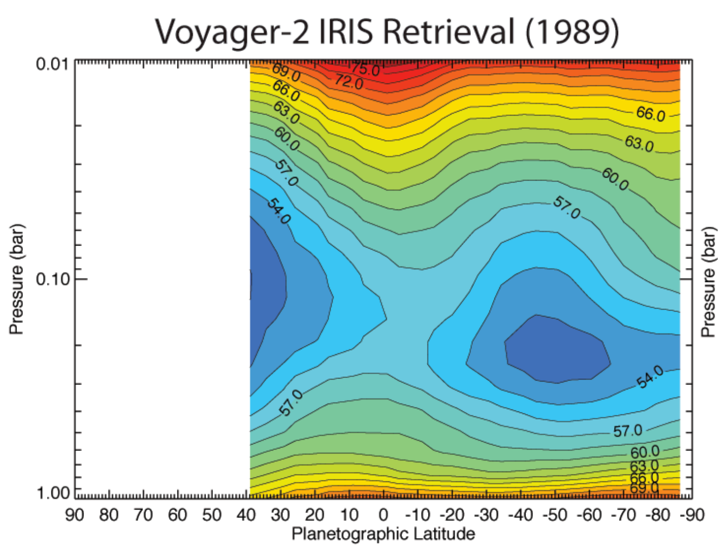
Revealed the hot south pole (VISIR data, September 2006, Orton et al., 2007).

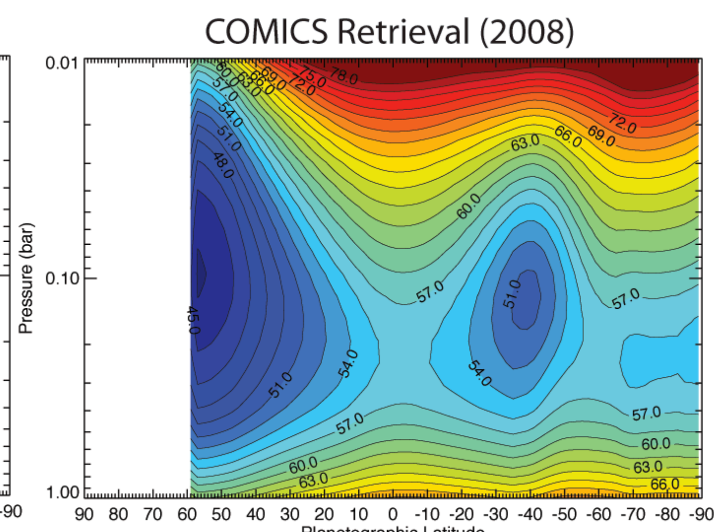
Neptune Temperature Retrievals

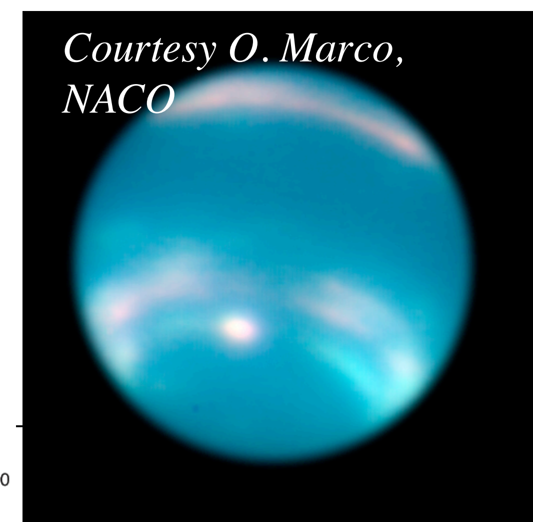
- The 12.5 micron filter provides stratospheric sensitivity via ethane emission (see comparison to Spitzer/IRS spectra). Voyager was not sensitive to the stratosphere.
- Tropospheric temperatures have similar morphologies in COMICS and Voyager retrievals demonstrating the capabilities for ground-based thermal monitoring.
- Cold temperatures = upwelling. Band of discrete cloud features observed in the visible/near-IR



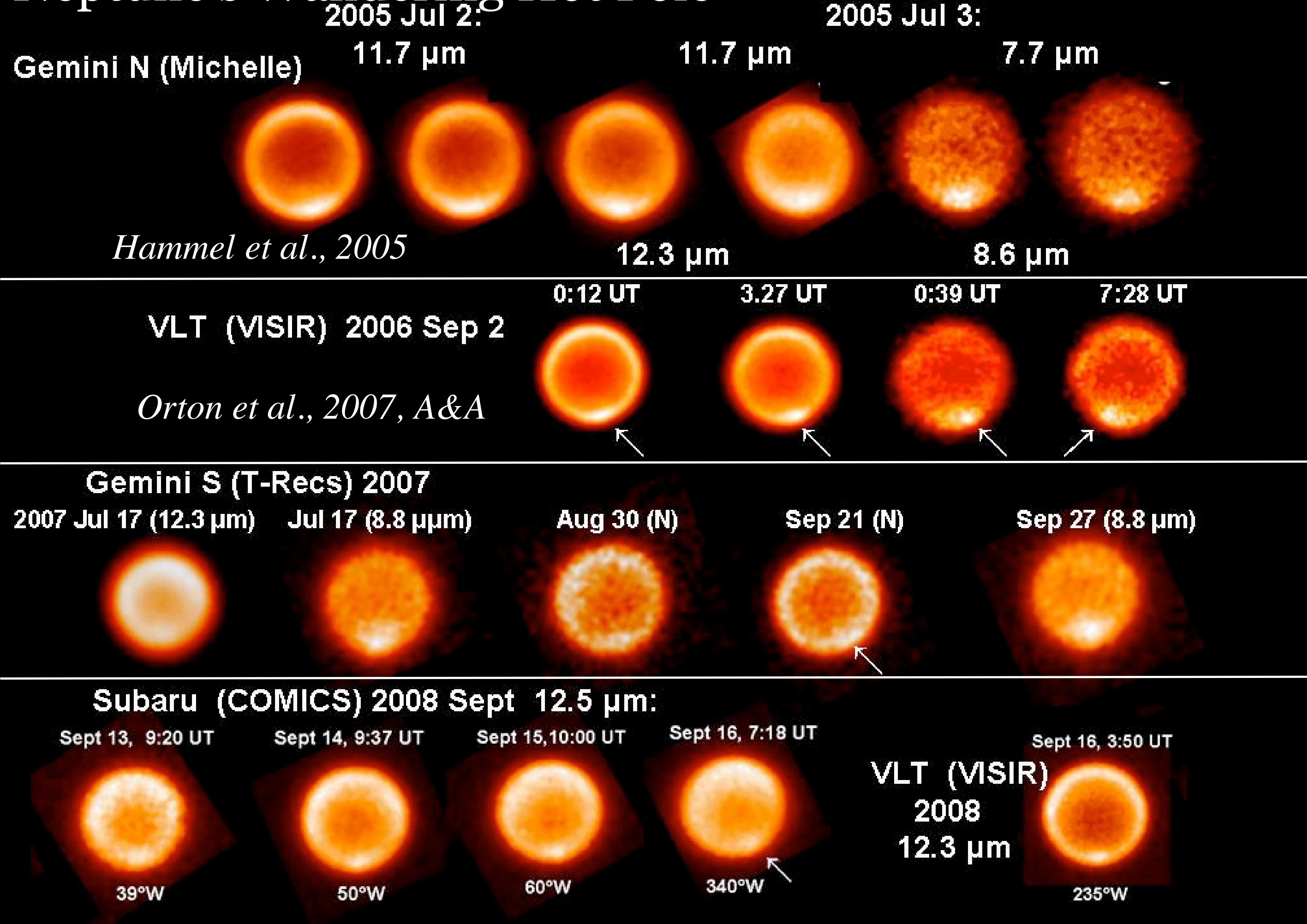








Neptune's Wandering Hot Pole



Conclusions

- "Snapshots" of the planets provide a lot of information about the atmosphere, but ***monitoring change*** (both in discrete features and seasonal effects) improves our **understanding of the gas giants**.
  - **Jupiter:** interactions between storm systems elucidates three-dimensional structure and thermochemical changes.
  - **Saturn and Uranus:** Different responses to seasonal insolation because of different composition.
  - **Uranus and Neptune:** Temperature monitoring from the ground for the first time since Voyager.
  - **Neptune:** Wandering hot polar vortex is not seen elsewhere on the giant planets.
- Key advances from using 8-m telescopes for outer solar system studies can support and surpass spacecraft missions.