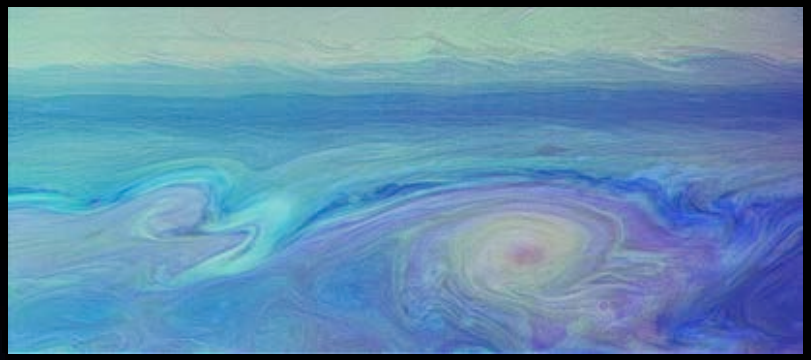
SEASONAL STORMS ON SATURN: NEW VIEWS FROM CASSINI



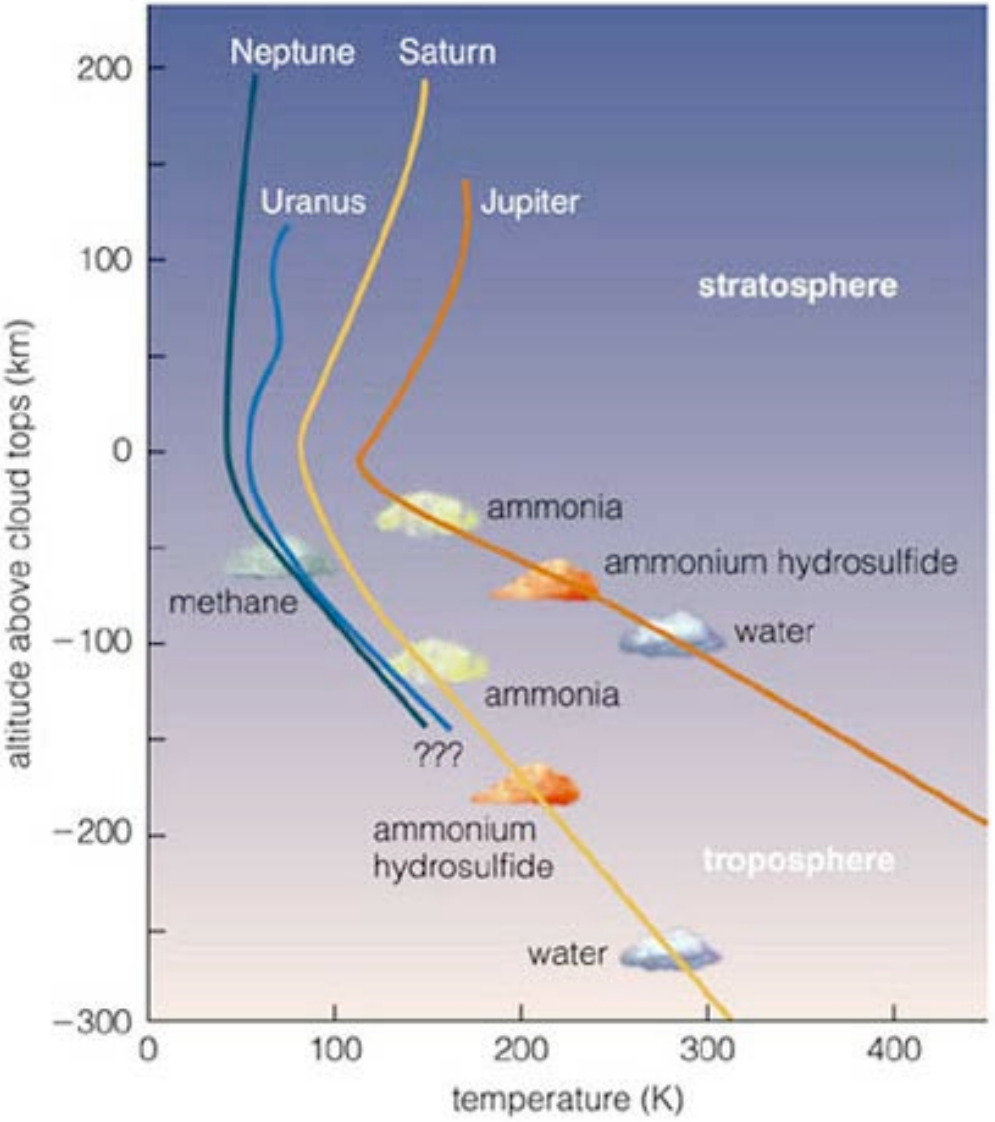
UNIVERSITY OF OXFORD

Leigh N. Fletcher

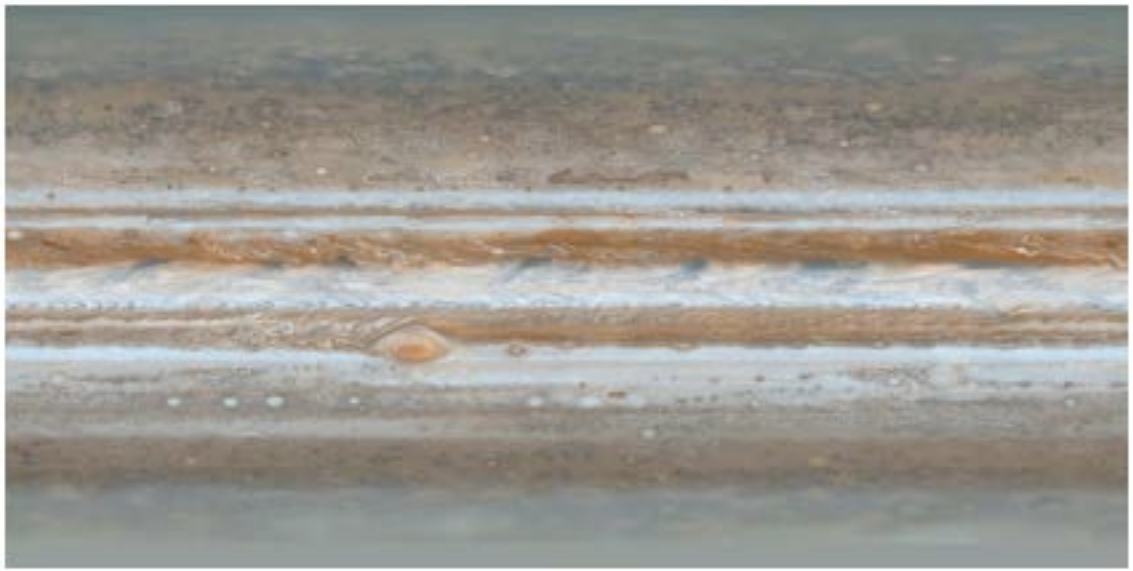
CHARM May 31, 2011

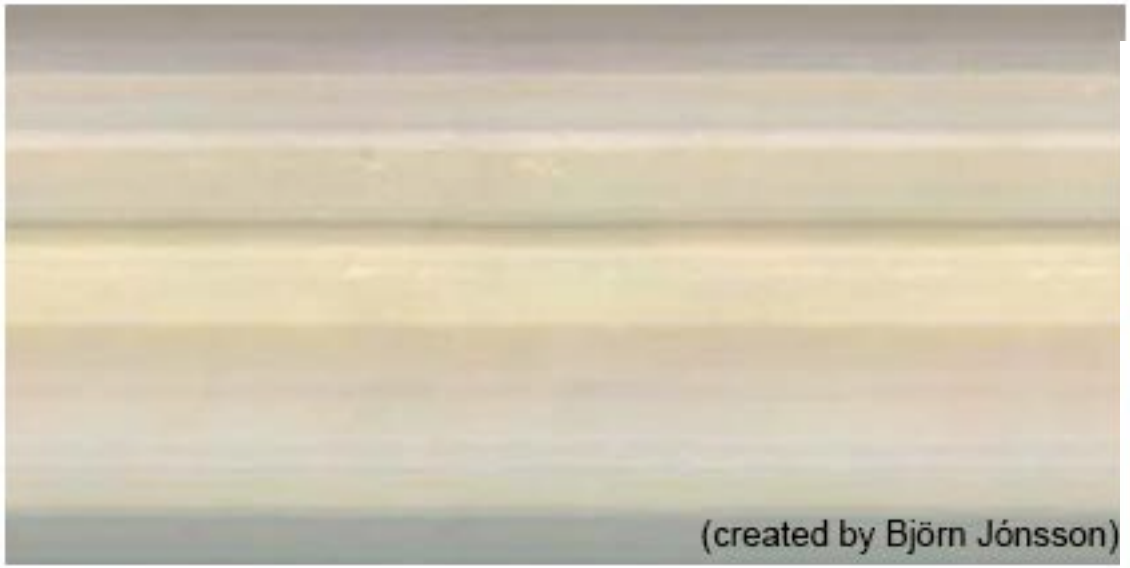
Probing the Giant Planet Depths

- Saturn's dynamic weather is shrouded by a **serene layer** of hazes.
- Remote sensing **struggles to penetrate** the thick cloud decks.
- Time-evolution of processes (storms, plumes, seasons) allow us to infer & model **deep atmospheric structure**.
- Long-distance storm chasing pushes astronomical phenomena into the realm of **meteorology and geophysics**.

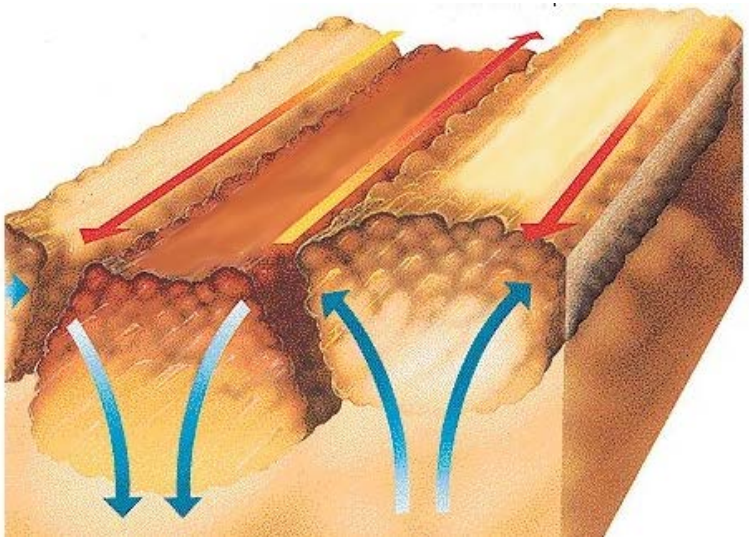


Less Dynamic, or Just Hidden?

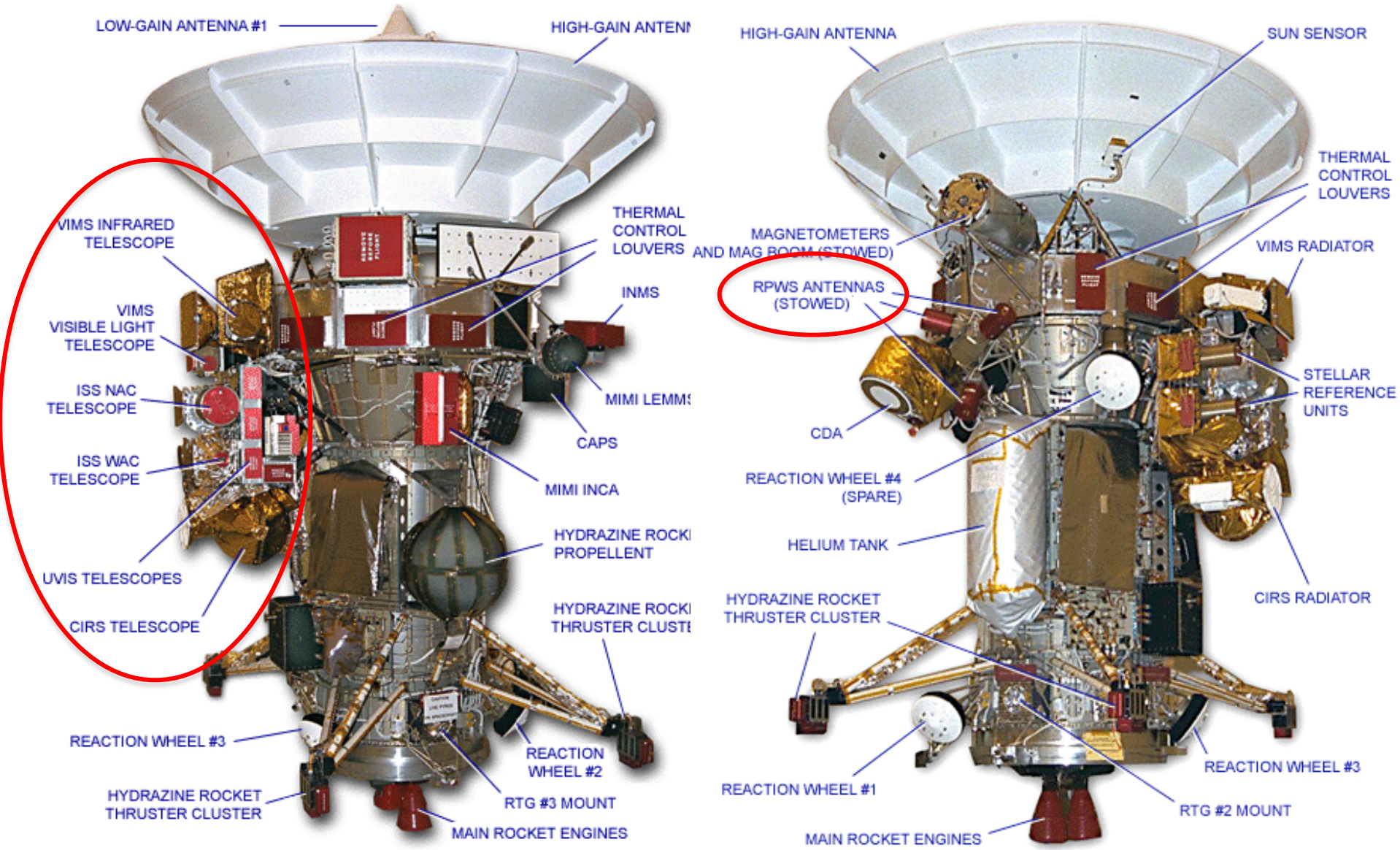




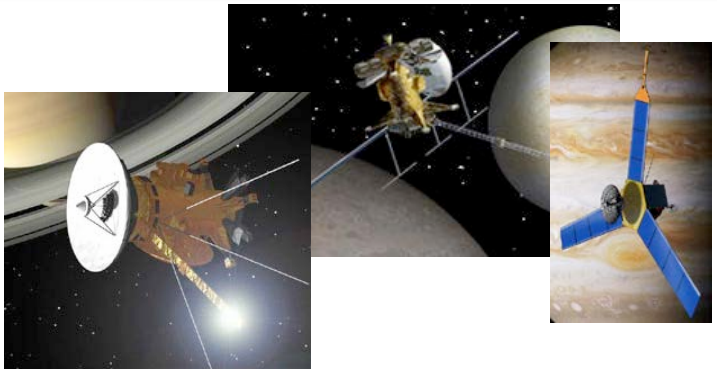
- Jupiter's thinner hazes make it a paradise for meteorologists.
- Saturn appears more placid, but potential for spectacular storms lurks beneath the clouds.

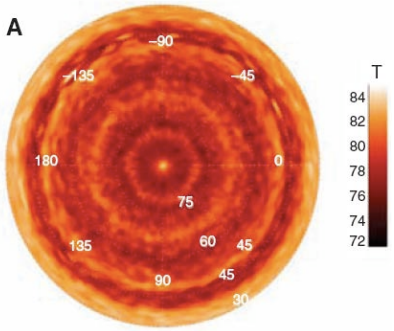


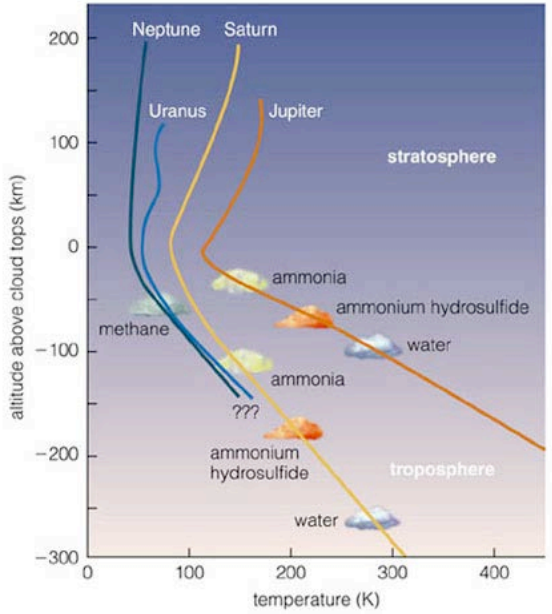
Cassini's Storm-Chasing Toolkit



Techniques







Spectra (near-IR to Microwave)

Imaging (Near-IR, Mid-IR)

Radiative Transfer Forward Models

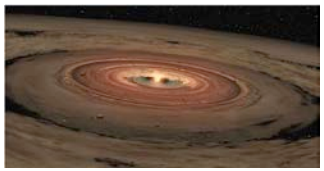
Optimal Estimation Retrievals

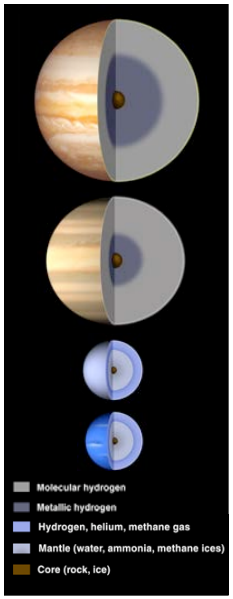
Weather & Dynamics

Composition & Chemistry

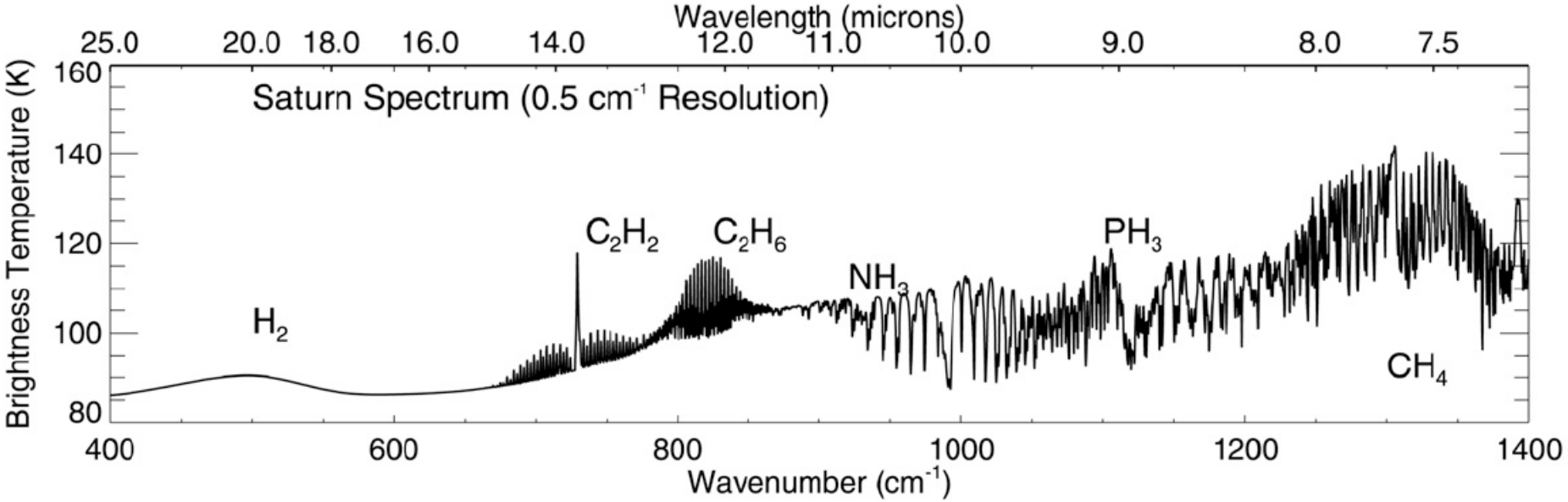
Origins & Formation

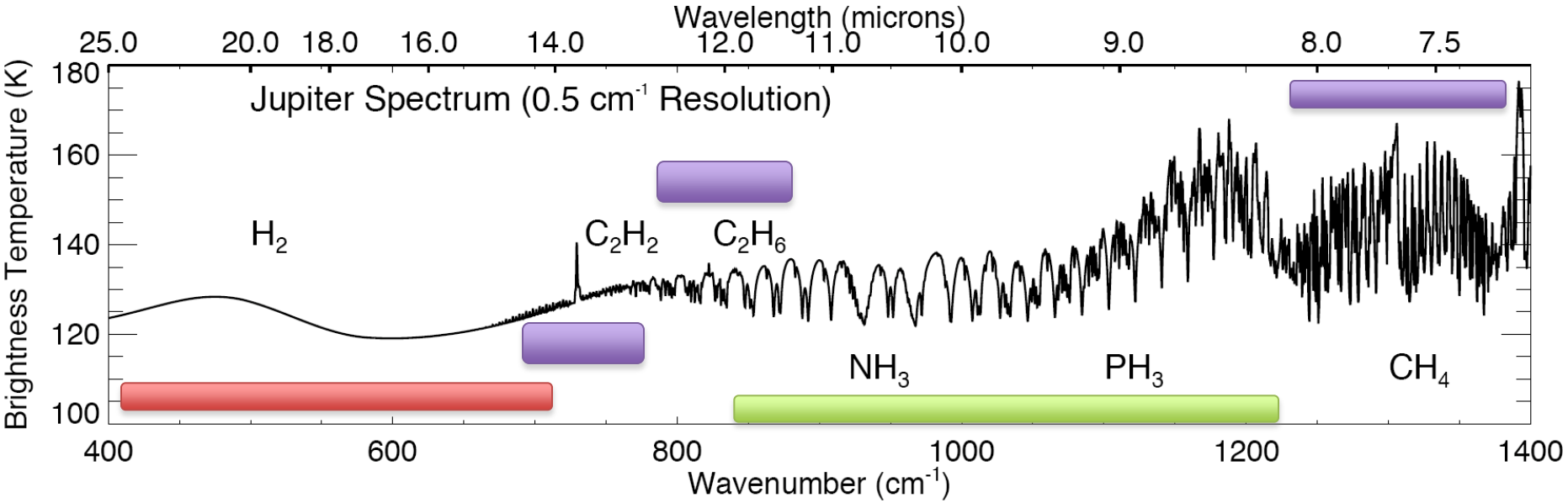
Clouds &Volatiles





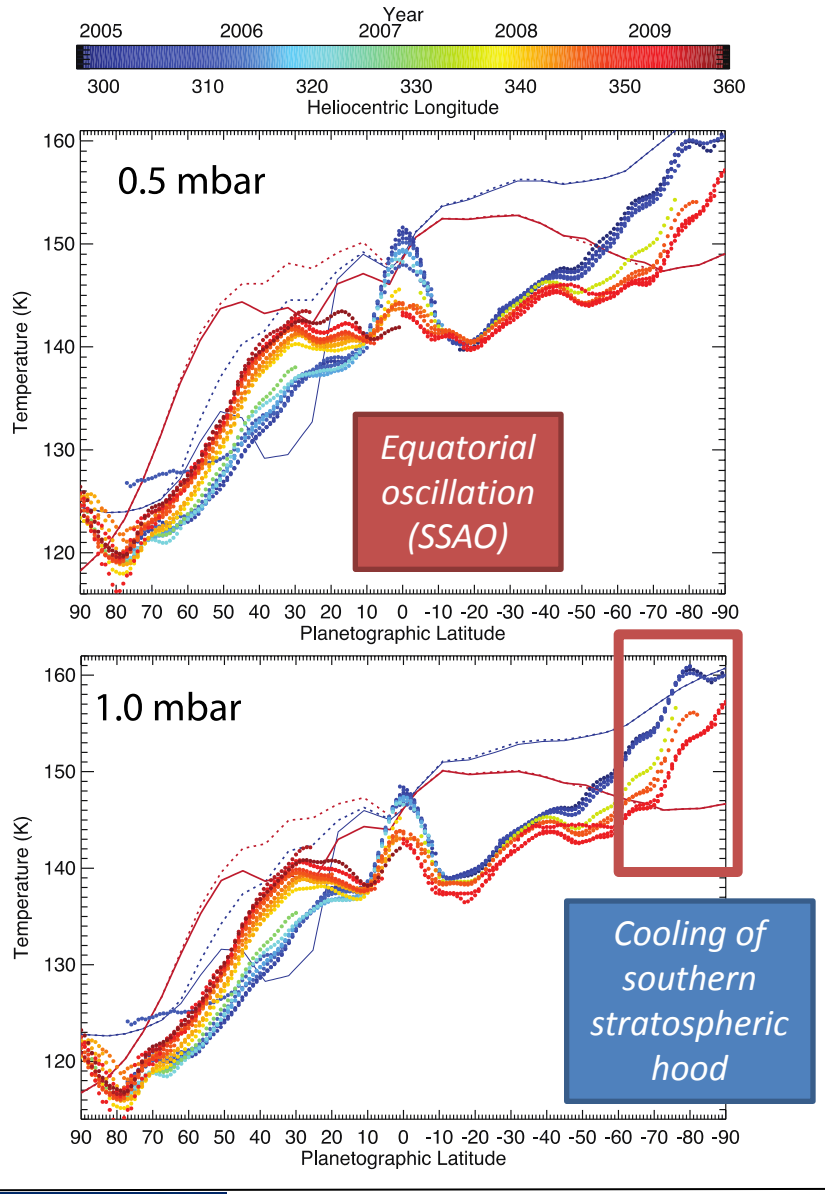
CIRS Spectra of Giant Planets

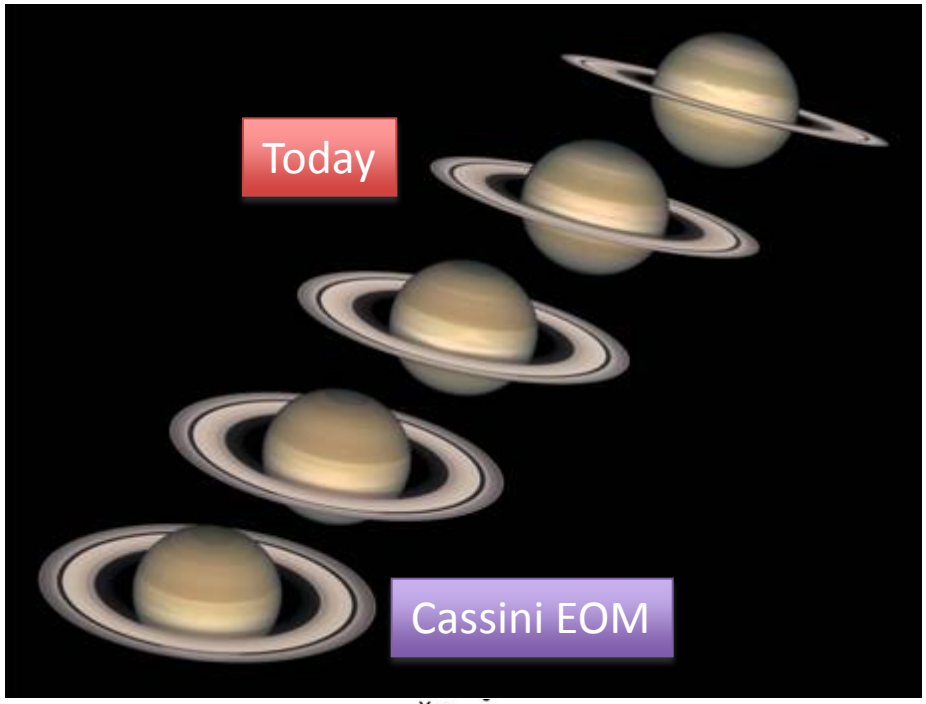


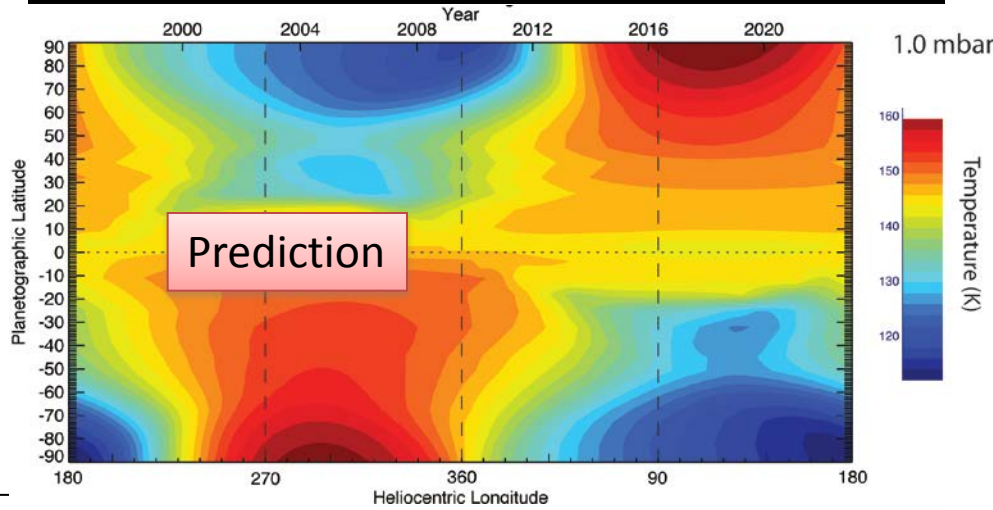


- **Saturn Today**: 6+ years climate database (northern winter to spring).
- **New findings**:
  - Polar vortices
  - Long-lived hexagons
  - Seasonal changes
  - Lightning flashes
  - Jet pumping
  - …and many more.
- Slow seasonal evolution was spectacularly disrupted by a powerful storm still raging today…

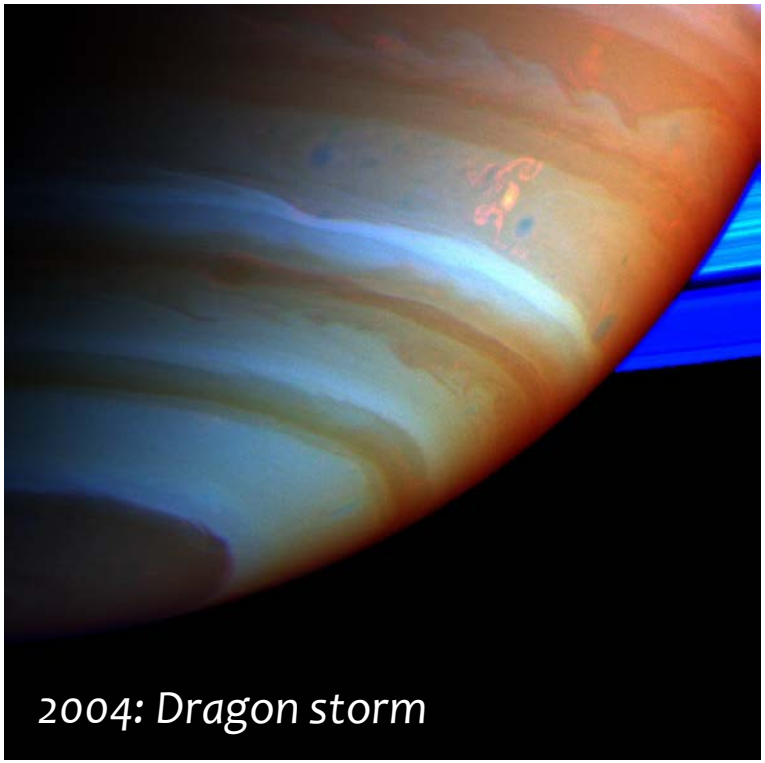
Saturn Typically Evolves Slowly…



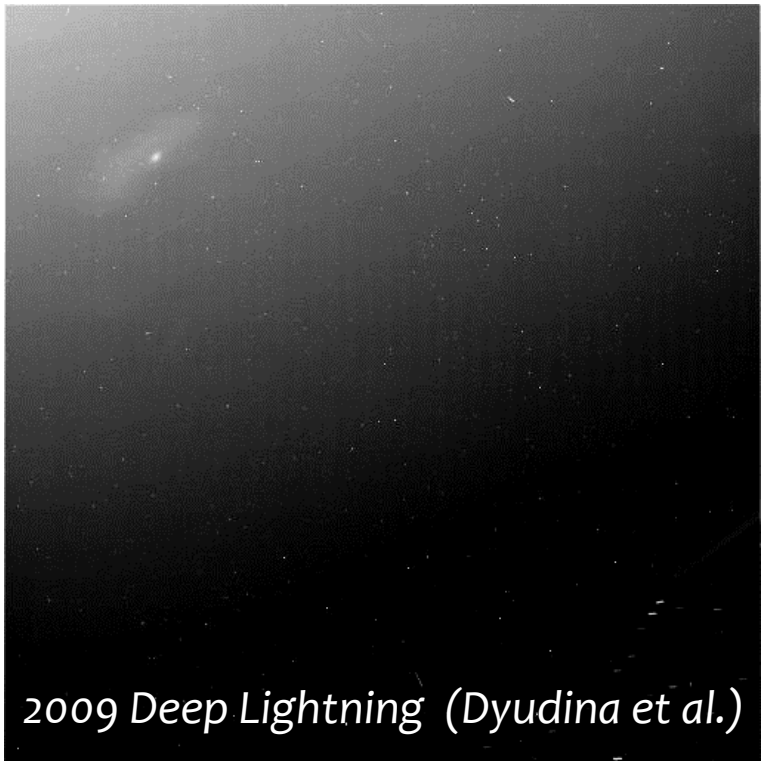




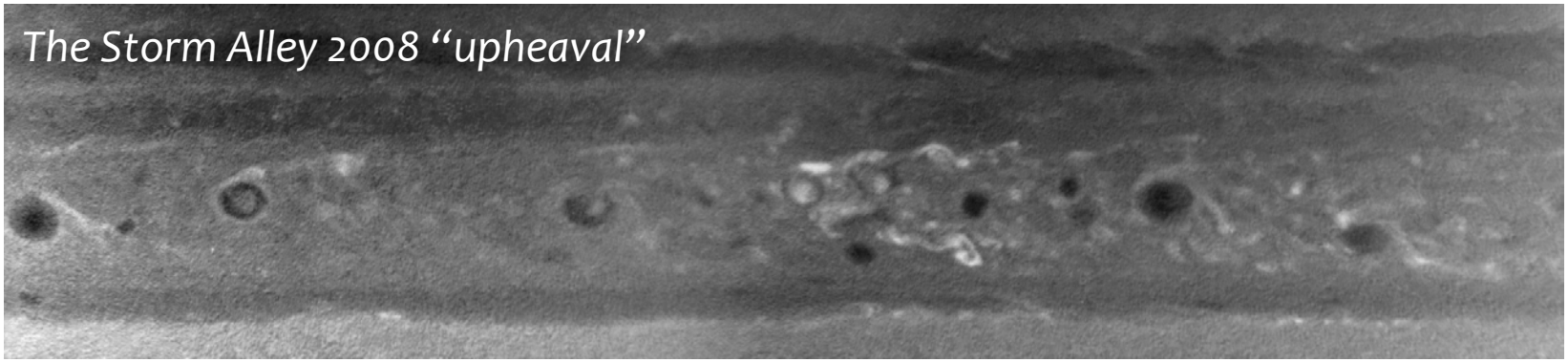
Convective storms (days-weeks) sometimes occur:



2004: Dragon storm



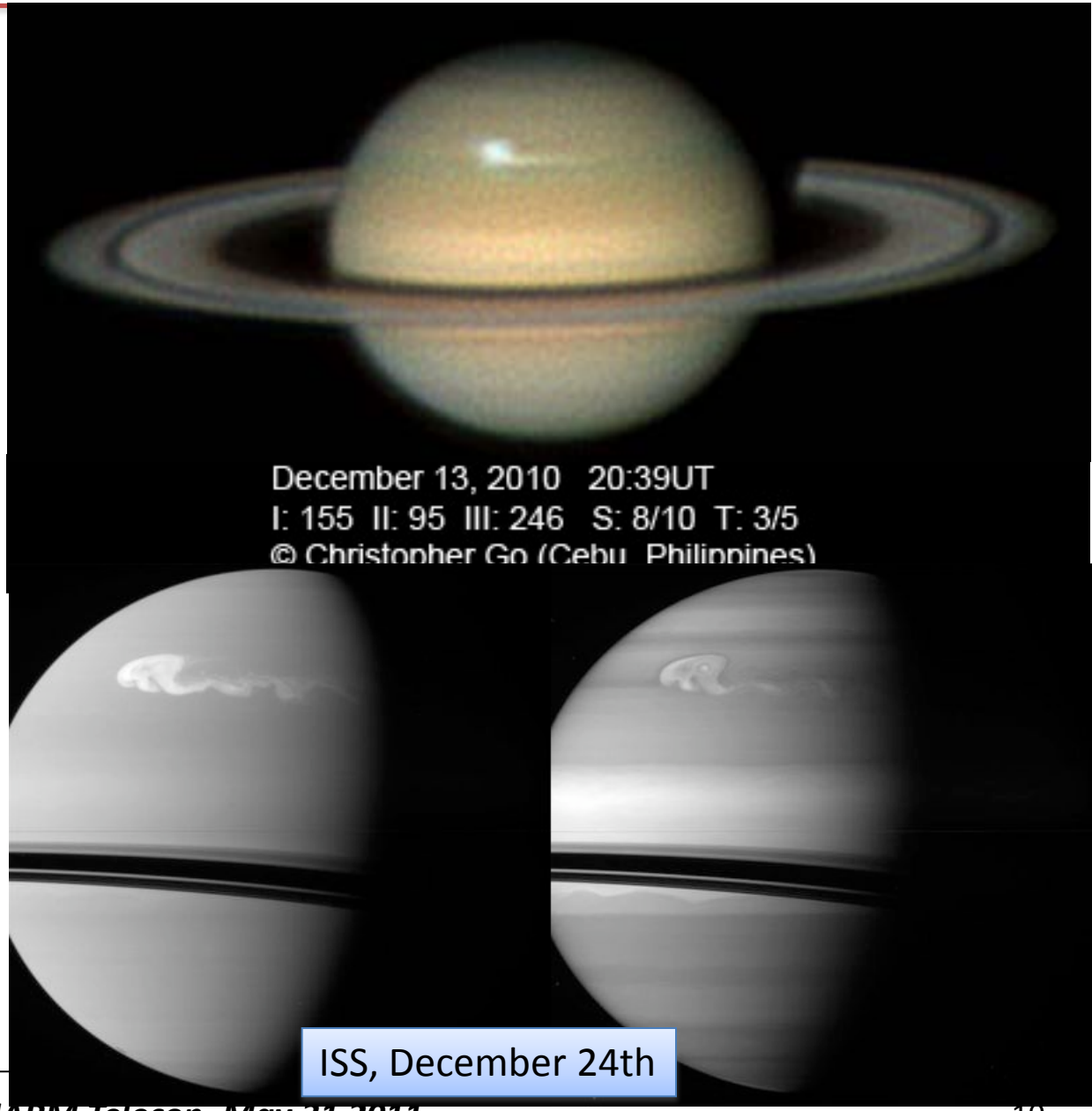
2009 Deep Lightning (Dyudina et al.)



The Storm Alley 2008 "upheaval"

Birth of a New Storm: December 2010

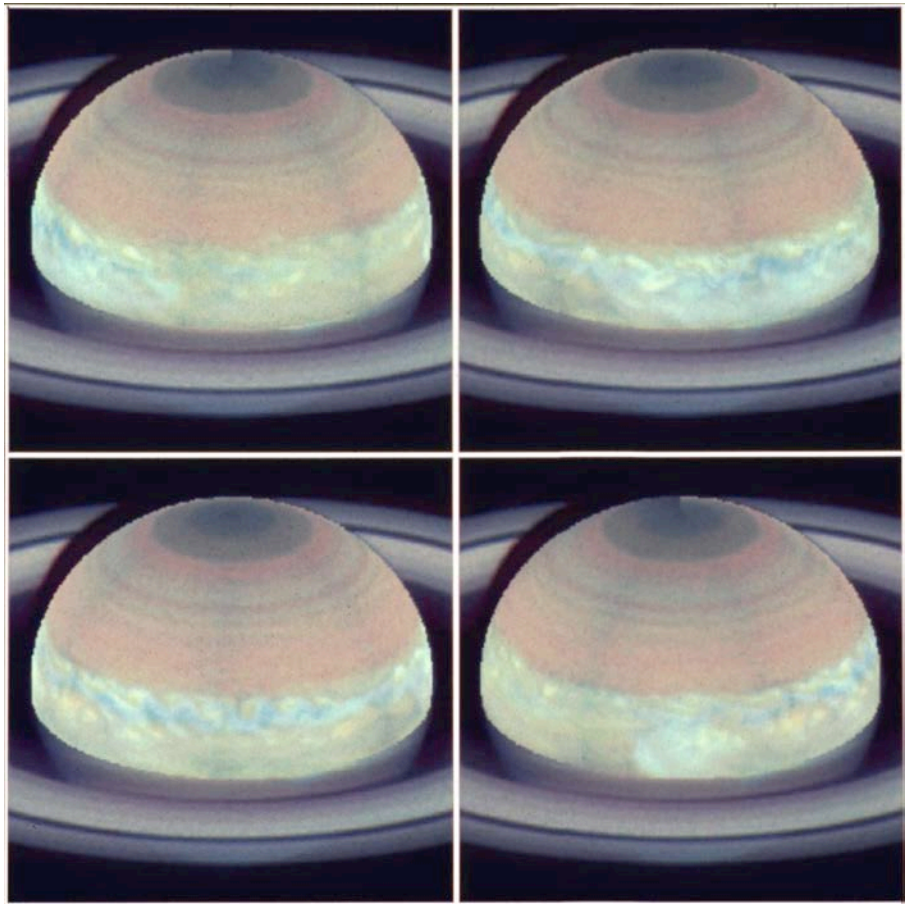
- Cassini/RPWS detected strong emissions indicative of a powerful thunderstorm on December 5th.
- ISS and amateur images showed small white spot on this date.
- Storm core moved westward, with a tail expanding to the east observed from December 12th onwards.
- Motion of the storm core and the tail consistent with prevailing zonal flows:
  - Eastward at 32 and 47N;
  - Westward at 39N.



ISS, December 24th

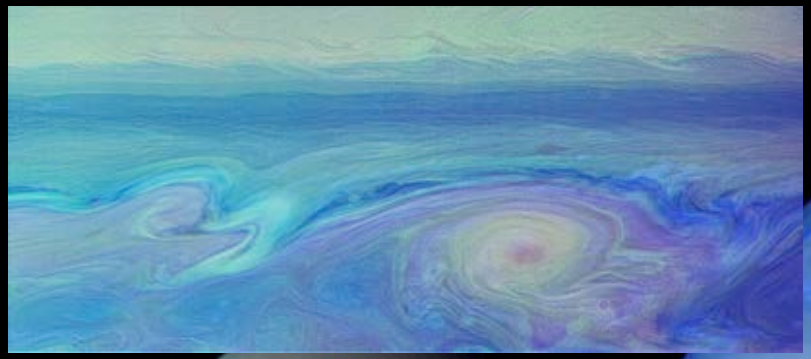
Significance of the Storm

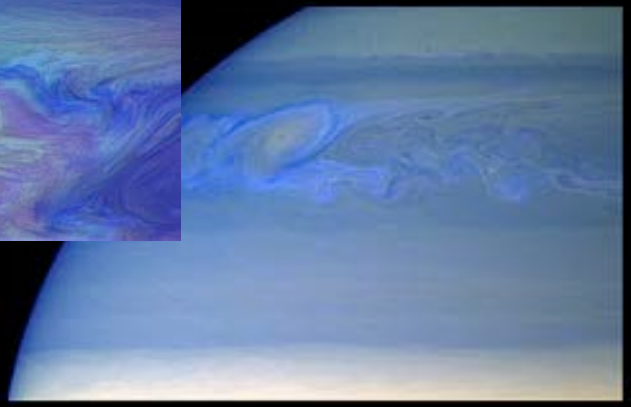
- Storm expanded to be planetary-scale, largest event in 20 years.
- Only **the sixth planet-wide disturbance** observed on Saturn.
- Usually after **northern summer** solstice, but this storm is early – northern spring!
  - We're lucky Cassini was still there to observe it.
- **Northern mid-latitudes** in 1903, 1960 and 2010, but **equator** in 1876, 1933 and 1990
- Never observed during southern summer.

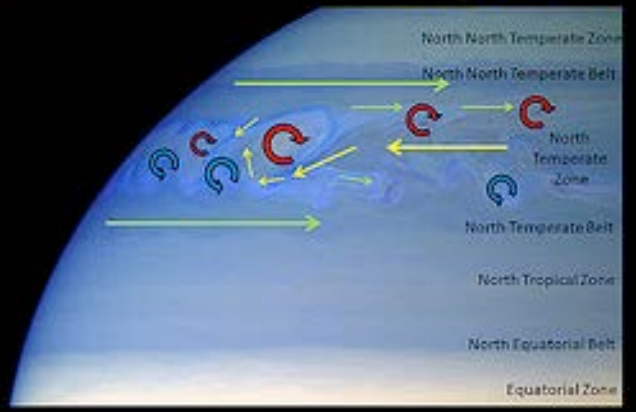


Equatorial storm observed by Hubble in 1990

Mature ‘Serpent Storm’ January 2011





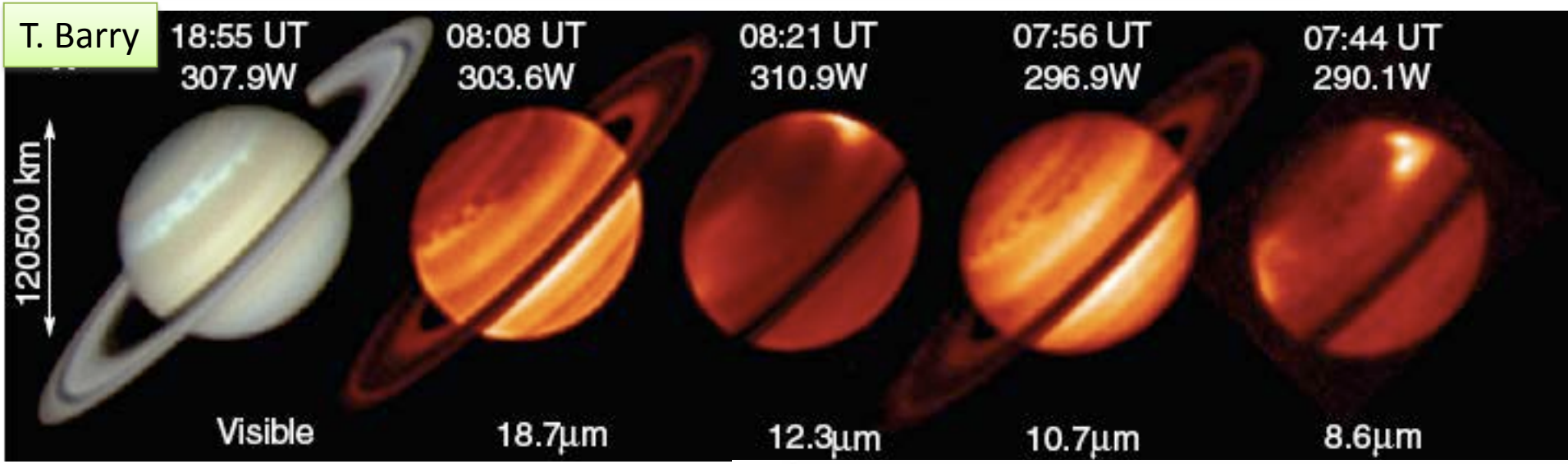


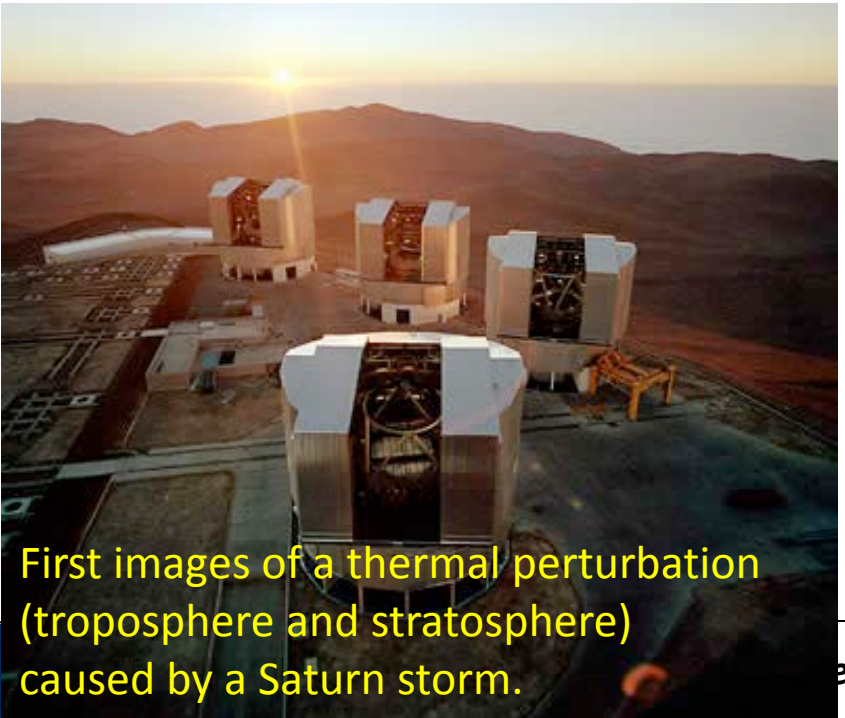
Composite assembled from Cassini raw images January 12, 2011

(annotated version)

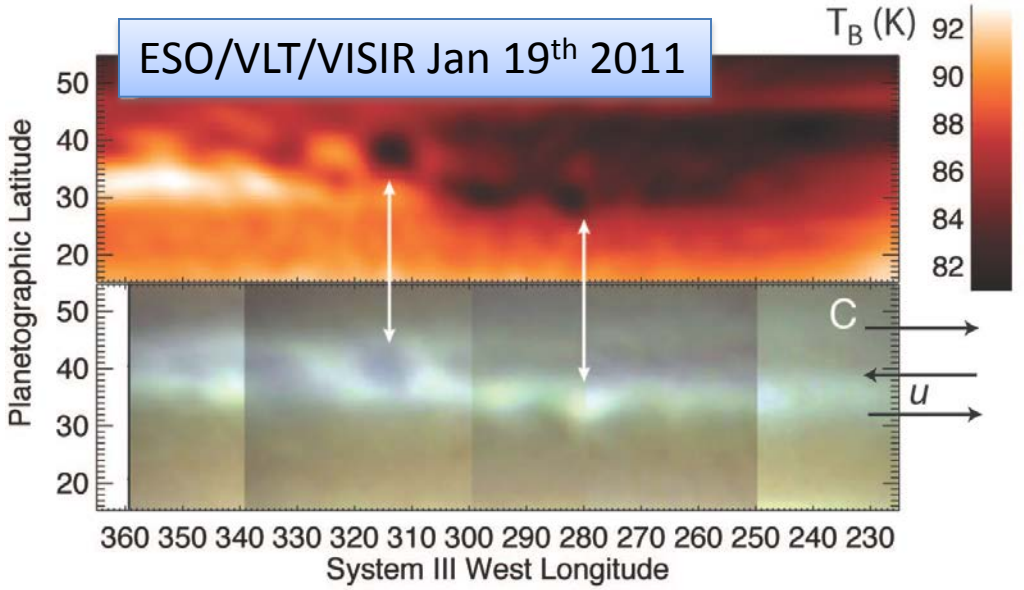
Cassini/ISS Images compiled by Mike Malaska

Thermal Imaging during the Mature Phase

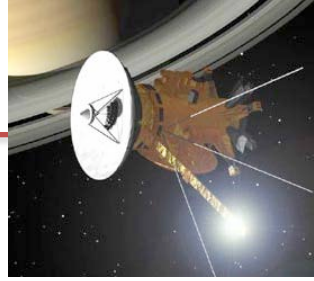




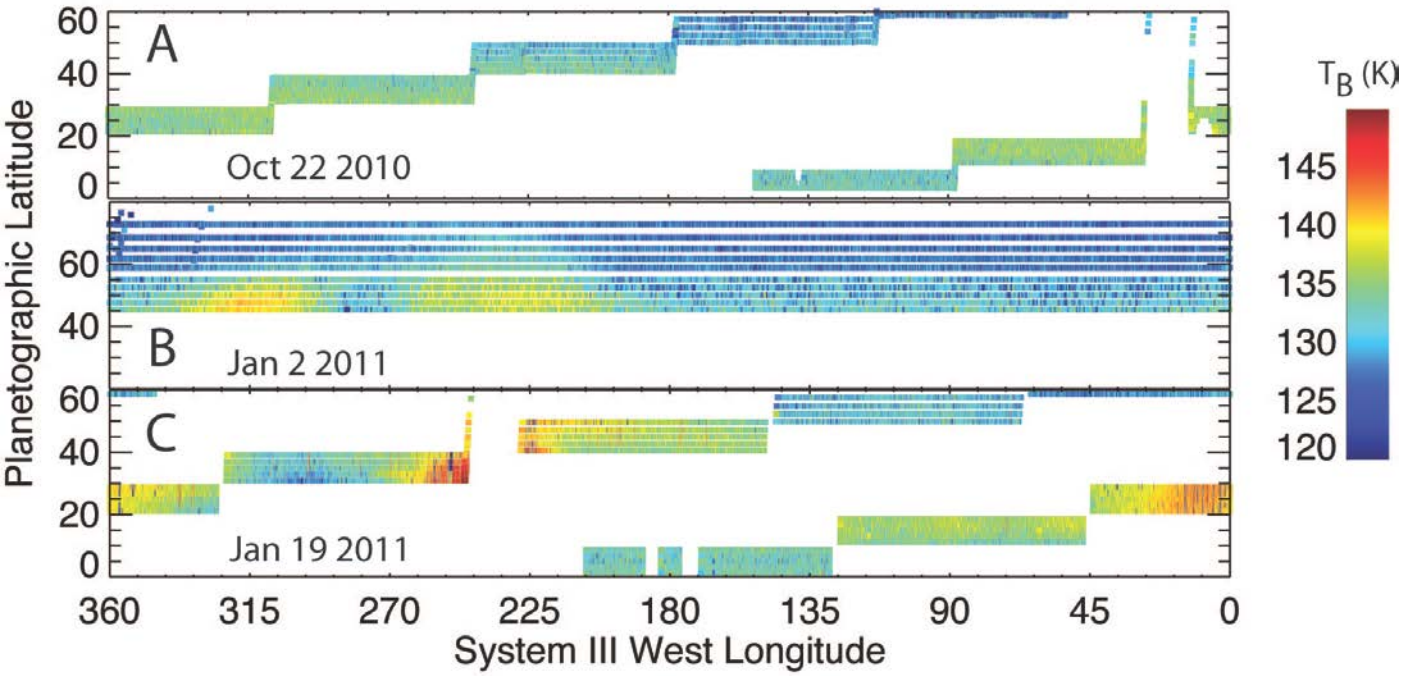
First images of a thermal perturbation (troposphere and stratosphere) caused by a Saturn storm.



Cassini/CIRS Spectroscopy 7-500 µm



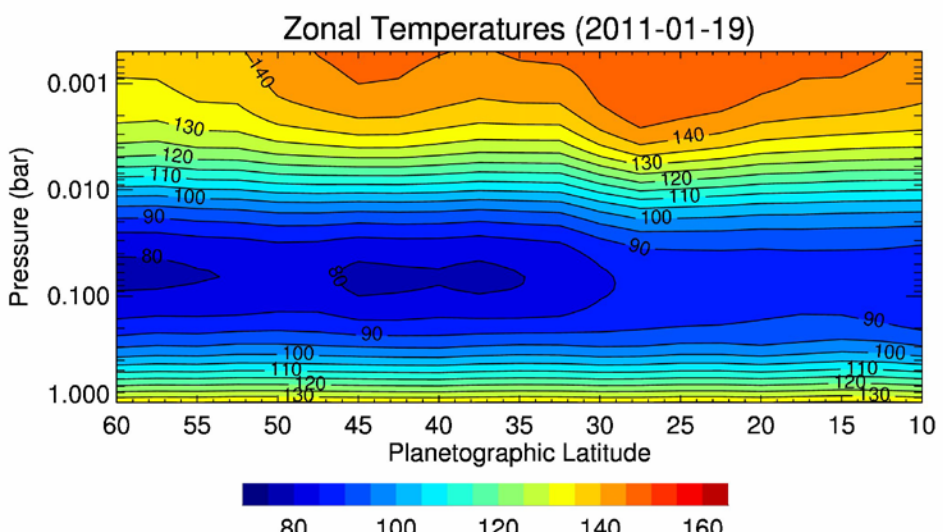
7.7 µm Stratospheric emission

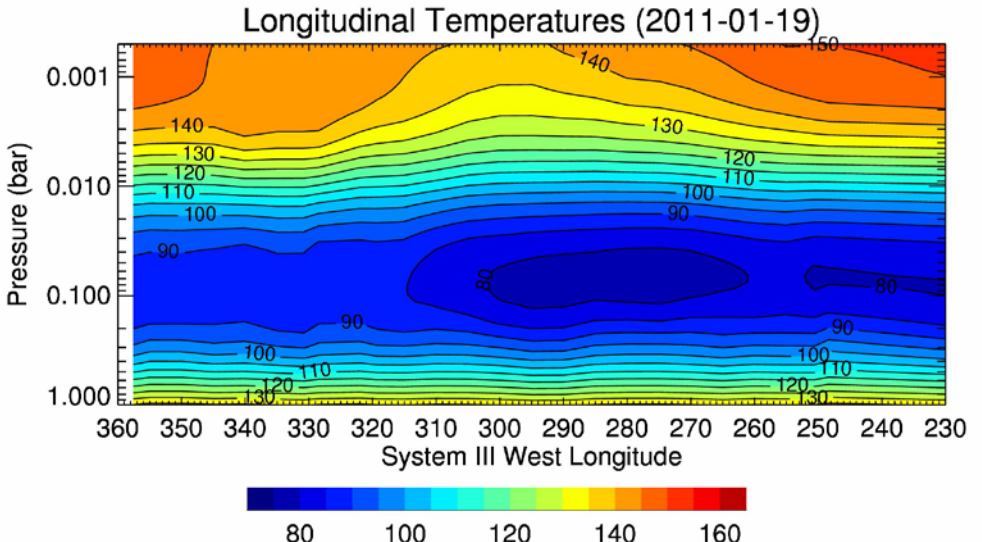


A: before the onset of the disturbance, 2.5 cm^{-1} scan

B: sit-and-stare technique, 0.5 cm^{-1} resolution, showing stratospheric perturbations

C: mature phase of the storm, 2.5 cm^{-1} scan

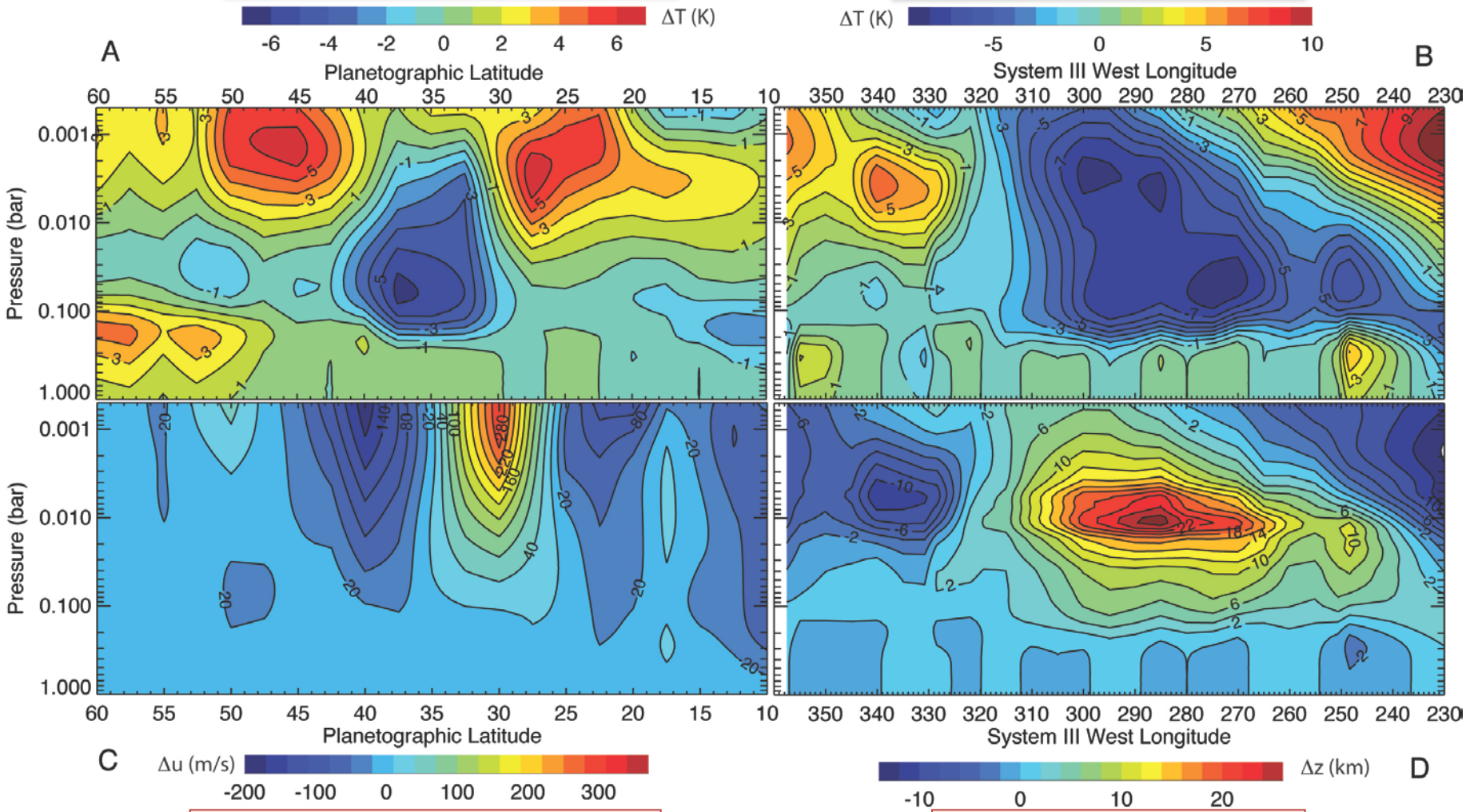




Storm-Induced Temperature Changes

North-South Temperatures

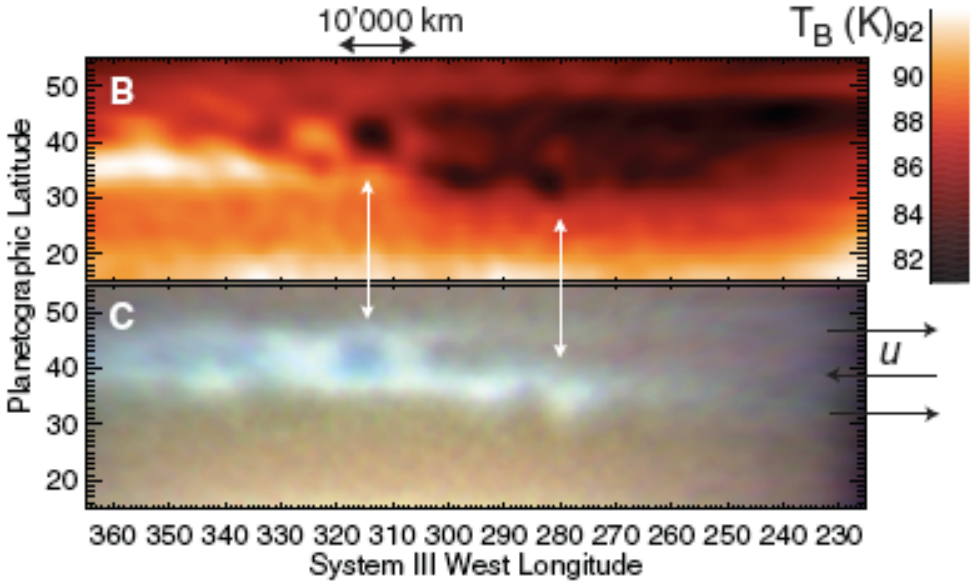
East-West Temperatures

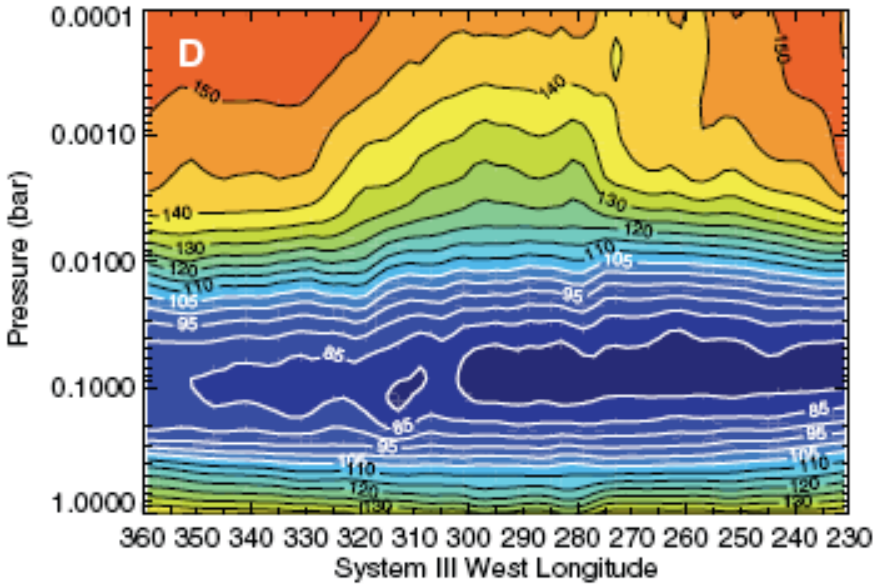


Acceleration of Zonal Winds

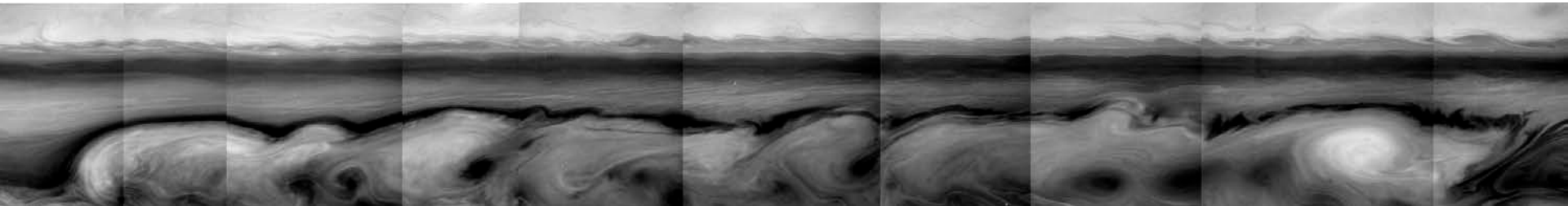
Vertical Displacement

Temperature Contrasts affect Winds



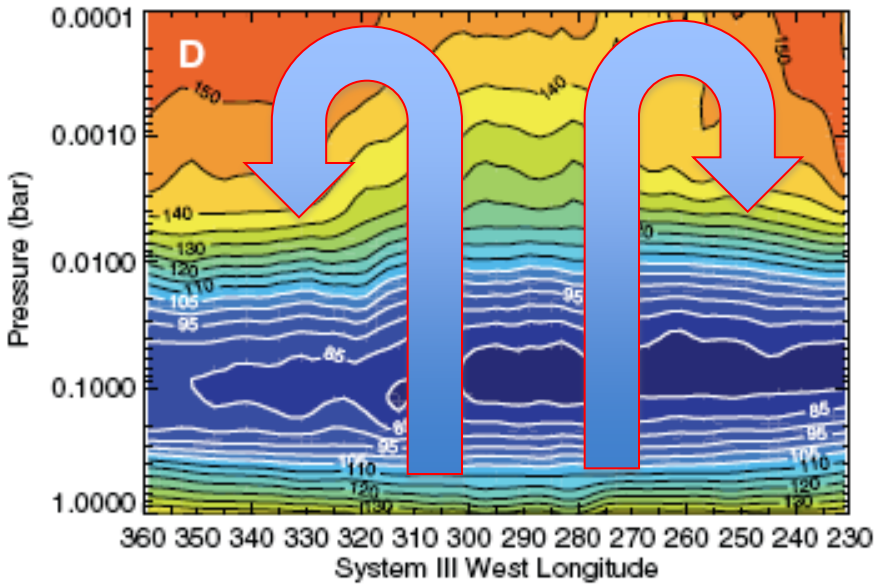


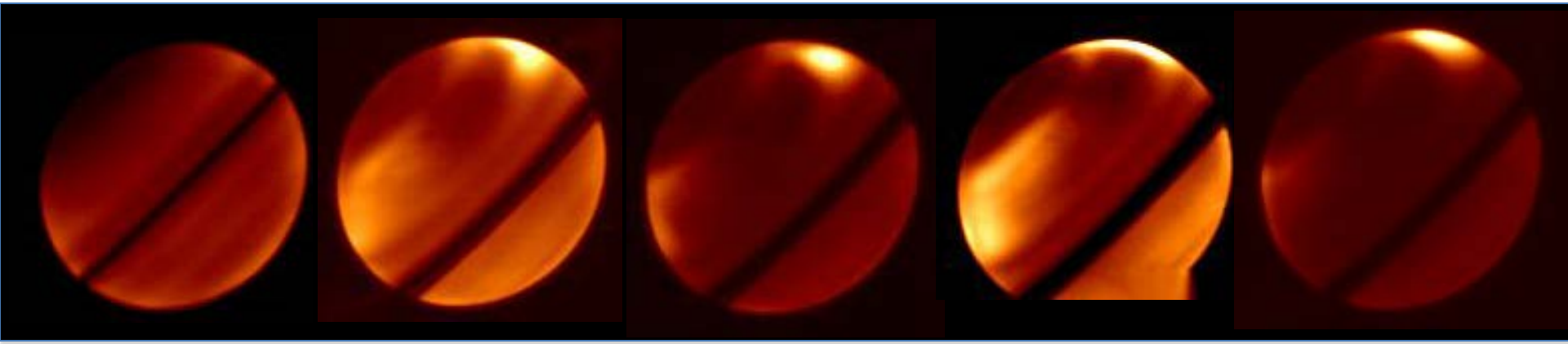
- Thermal contrasts are related to the shear on the winds.
- Storm has created temperature contrasts causing jet streams to meander, form closed vortices.
- New oval has formed, cold vortex in the flow, boundary between east and west of the disturbance.



Saturn's Stratospheric Beacons

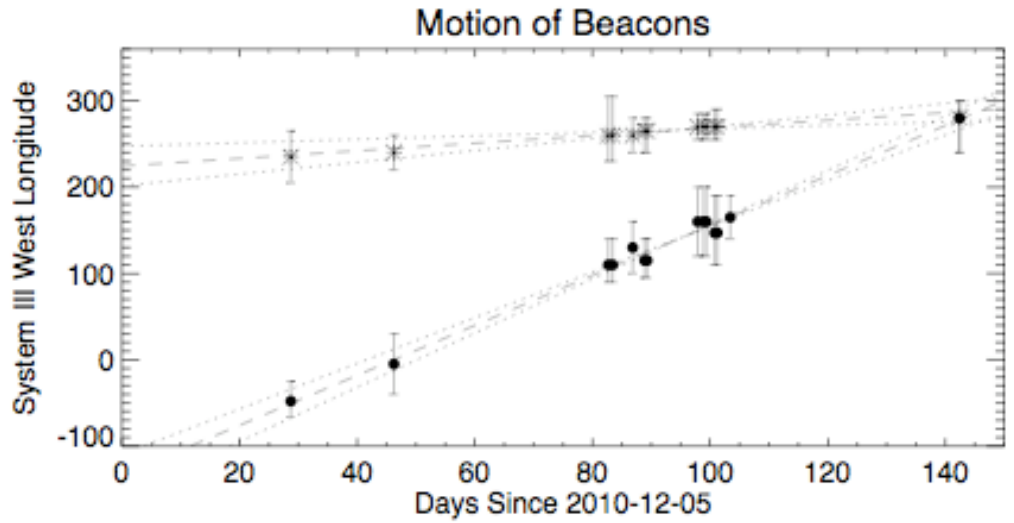
- Huge **stratospheric perturbations** completely unexpected, reversed Saturn's springtime warming trend.
- Saturn's bright `beacon' **dominates emission.**
- 16-K stratospheric **perturbation largest observed to date.**

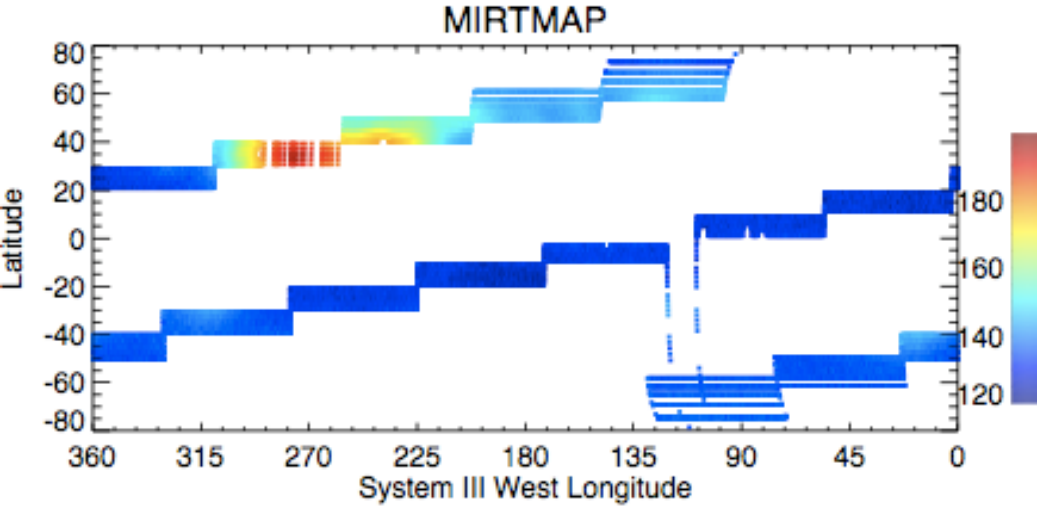


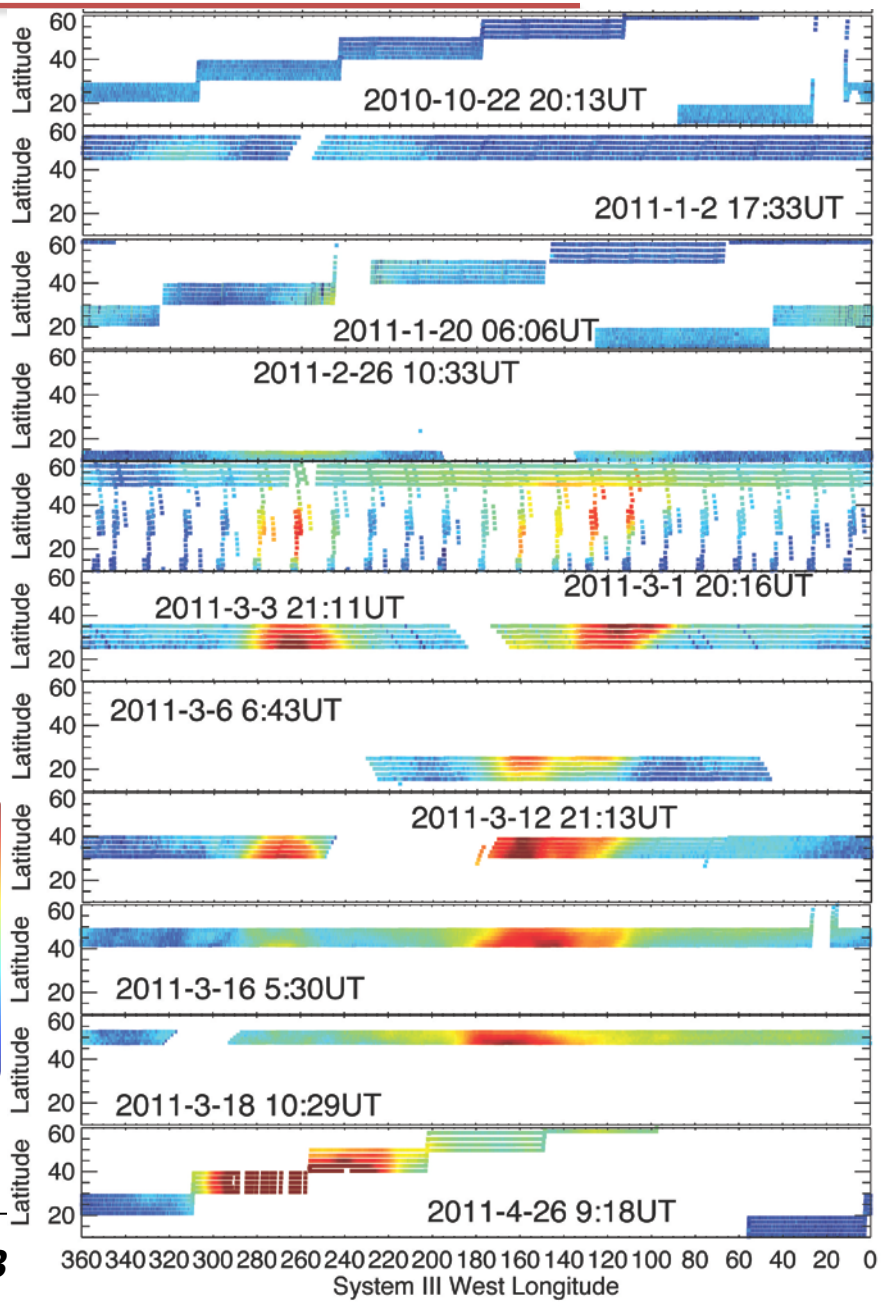


March 21 2010 | Jan 19 2011 | Jan 27 2011 | Jan 31 2011 | Feb 8 2011

Beacon Chasing from Cassini/CIRS



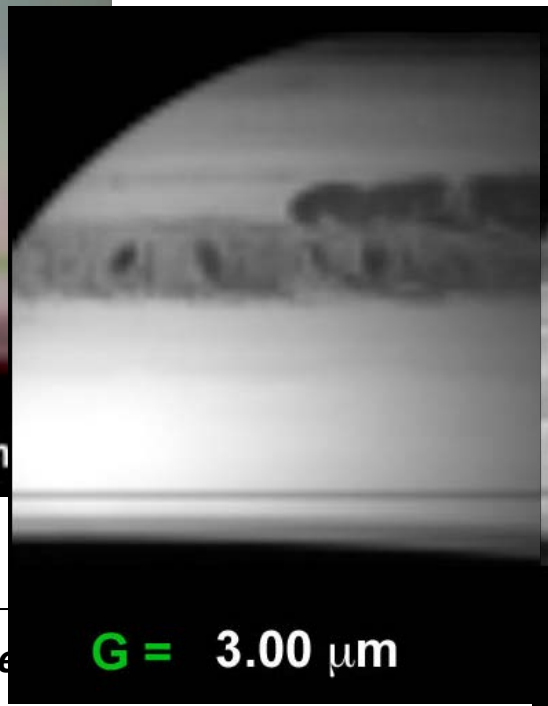


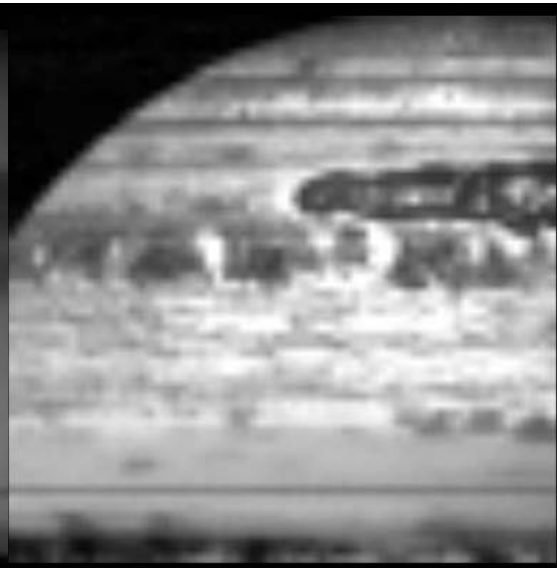


Reflected Sunlight: Signs of Upwelling

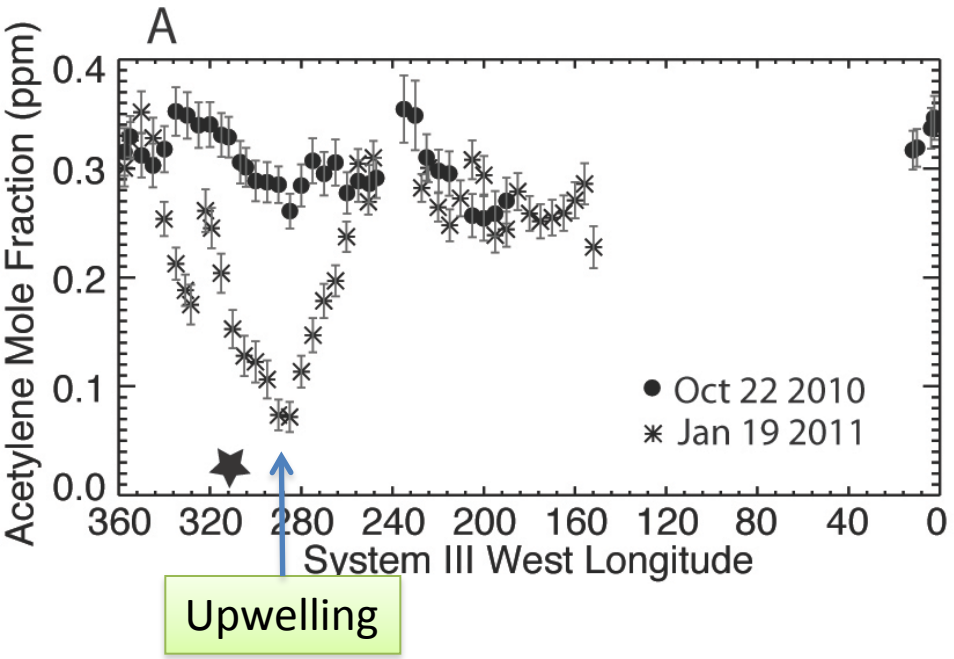
- Cassini/VIMS reflected sunlight images, February 24th.
- Red: 4.08 μm Continuum Reflectivity: Large particle scattering
- Green: 0.90 μm High alt. clouds
- Blue: 2.73 μm NH3 absorption
- Dark at 5 μm (thick clouds), absorbing at 3 μm (N-H materials)

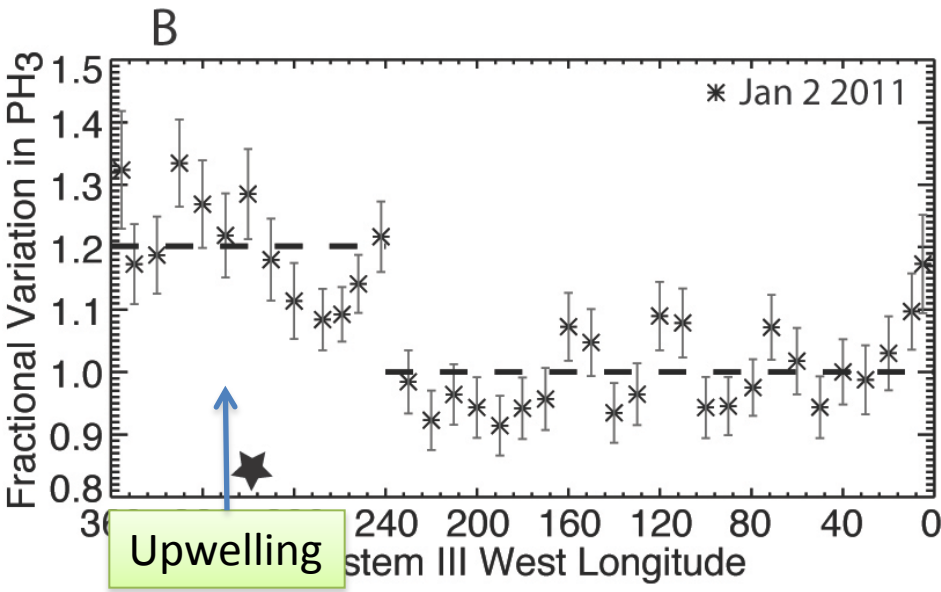
Yellow storm = large red/green signal. Combination of (1) ammonia ice comprised of (2) large particles indicates extremely powerful convective storm.





Chemical Signatures: Tracers of Motion



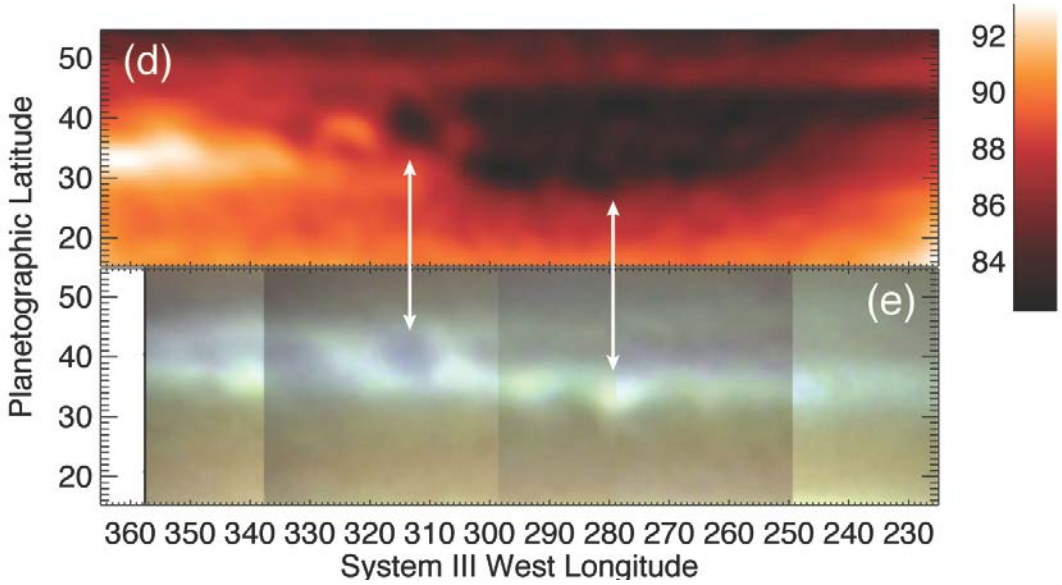


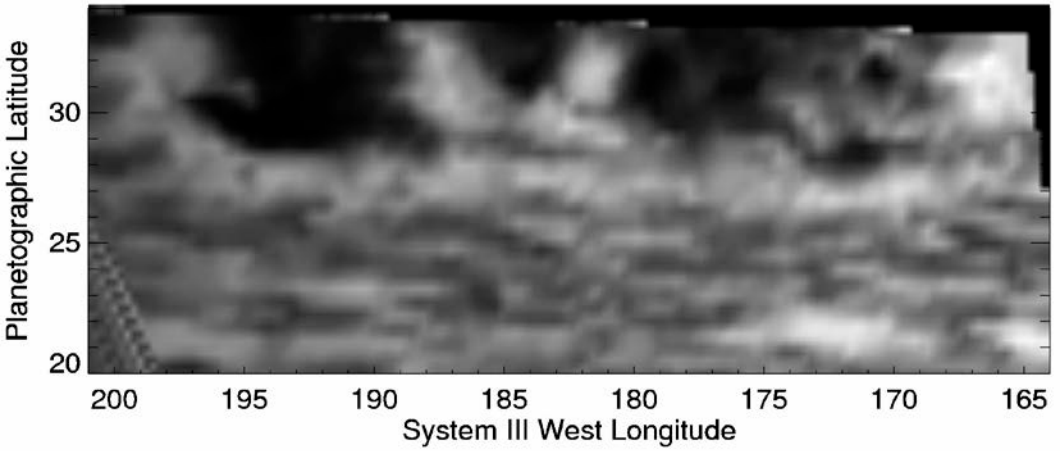
Zonal variation of C_2H_2: abundance minimum caused by upwelled parcels of air acetylene-depleted gas over the storm.

Zonal variation of PH_3: phosphine was elevated by ~20% over the head of the storm and its easterly branches.

Wave Motion in Southern 'Tail'

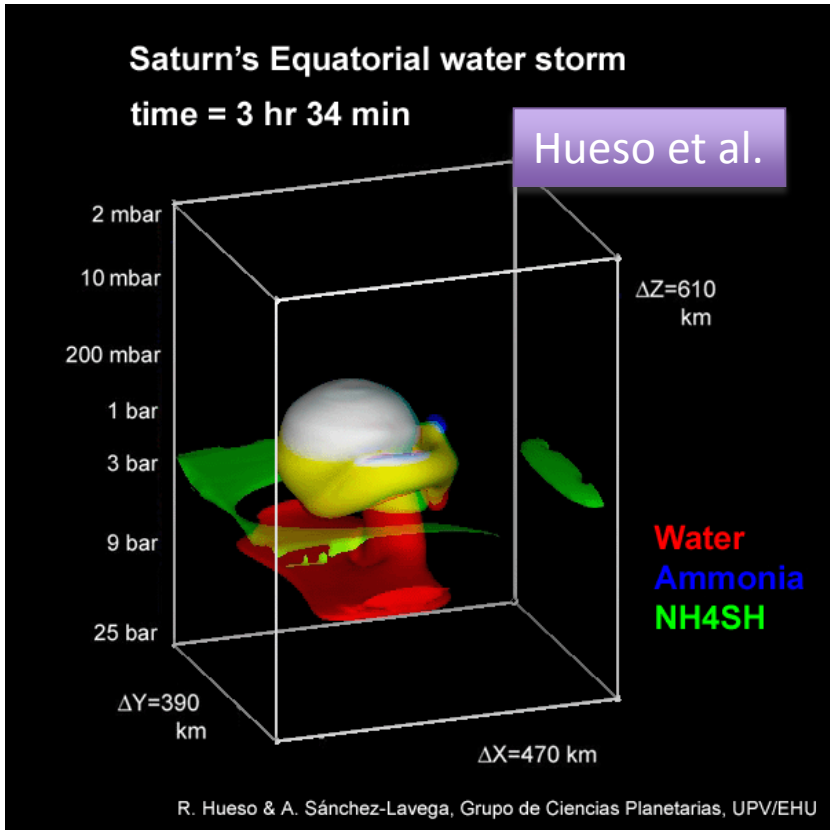
- Undulating structures along the southern tail separated by 15^{o} longitude (12000 km)
- Produces a series of white spots (condensation clouds) in cool wave troughs.
- Cassini/VIMS observed opaque clouds with the sam separation on January 9th.
  - 4.5-5.2 µm thermal emissio from 1-3 bar level.
- Dark regions depleted in NH3, elevated in PH3 – upwelling and condensatio
- Storm head now interacting with wave tail.





Vertical Structure of the Storm

1. Upwelling plume, possibly from **water cloud ~200-300 km below visible clouds**. Becomes a sustained updraft.
2. Rising plume **dredges N-H species** to condense in upper troposphere – fresh ices.
3. Adiabatic expansion **cools storm regions**, temperature contrasts **modify winds**.
4. East-west winds **shear the storm** in longitude.
5. Tropospheric storm radiates waves, **perturbs stratosphere** ~300 km above cloud-tops.
6. **Stratospheric beacons** (subsiding airmasses, adiabatic heating) flank central upwelling.

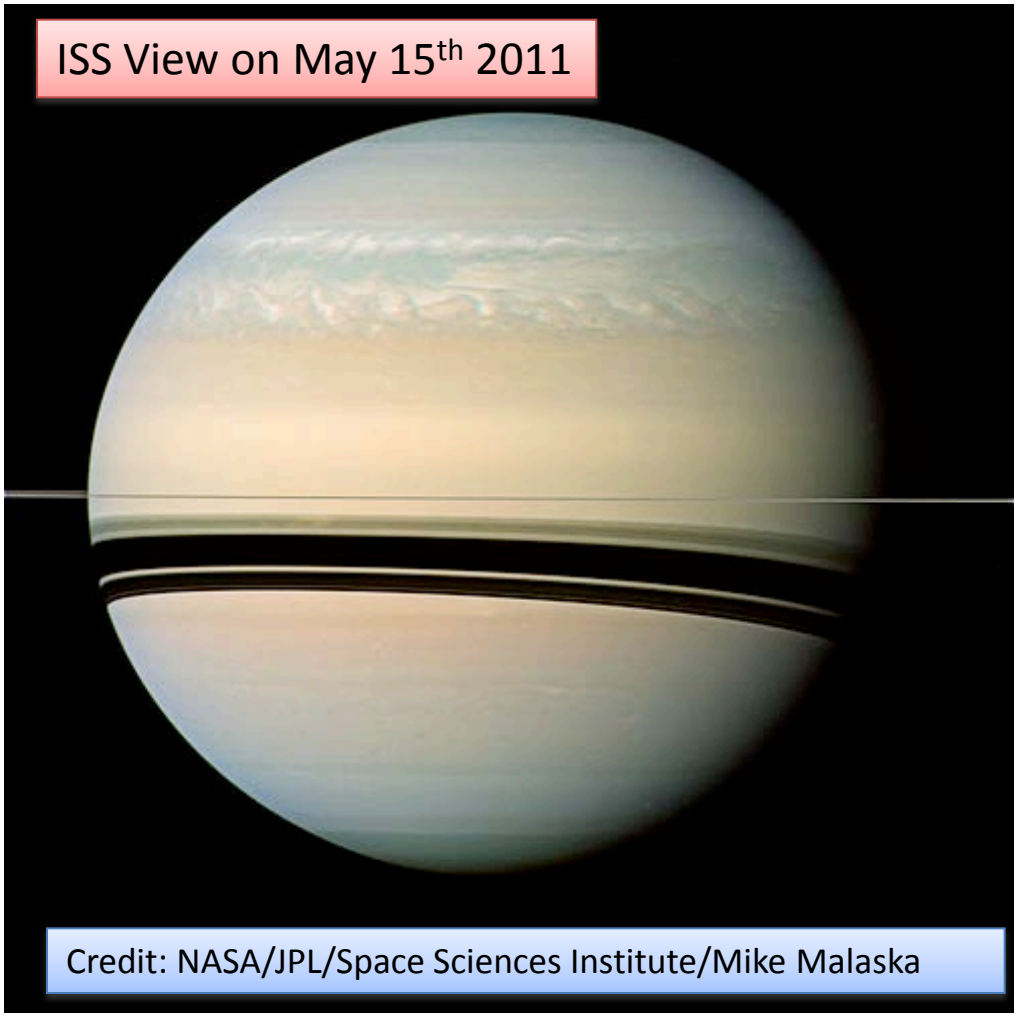


Many Questions…?????

- Why Now?
  - Something unique about this point in the seasonal cycle (springtime), between equinox and solstice?
  - Never observed in the autumn/winter hemisphere.
- Why Here?
  - Why northern mid-latitudes in 1903, 1960 and 2010, but equator in 1876, 1933 and 1990?
  - Never observed in the southern hemisphere?
  - Westward jets may be more susceptible to instabilities (e.g., Read et al., 2009).
- How?
  - What conditions have changed to allow such a large atmospheric perturbation from the convective plume (seasonal effects should be irrelevant at depth).

Story isn't over yet…

- Storm is **still raging** in the troposphere, beacons are still present in the stratosphere.
- Cassini, amateurs and ground-based observers are **continuing to monitor**.
- Could have a substantial effect on atmospheric structure for some time to come.
- Modelling of disturbance and inferences about deep clouds are beginning….



Conclusions

- **Spectacular springtime storm** is being tracked by Cassini and ground-based observatories.
- Vertical structure from troposphere to stratosphere from **thermal-infrared and reflected sunlight.**
- Allow us to study the deeper workings of Saturn's weather layer **beneath the serene veil.**
- Saturn is just as active as Jupiter, but seasons modulate plume eruptions into the upper atmosphere.

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Cassini Raw Images

Saturn's great northern storm, 2011 Feb.26: closeups from Cassini

Top: first rotation. Bottom: second (next?) rotation.

Cassini ISS raw images from NASA/JPL/Space Sciences Inst., compiled by John Rogers. North up.