Open Topics in Jupiter Imaging Science

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Outline

1. Jupiter Imaging Milestones
2. Future Planned Missions
3. Imaging Science Topics for Future Missions

Three Jupiter Science Themes

A: Dynamics and Circulation

- Dynamics of Jupiter's weather layer
- Thermodynamics of atmospheric phenomena
- Quantify the roles of wave propagation and atmospheric coupling
- Investigate auroral structure and energy transport
- Understand the interrelationships of the ionosphere & thermosphere

B: Composition and Chemistry

- Determine the bulk elemental abundances
- Measure the three-dimensional distribution of stratospheric hydrocarbons and their long-term variability
- Study localized and non-equilibrium composition
- Understand the importance of moist convection in meteorology, cloud formation, and chemistry

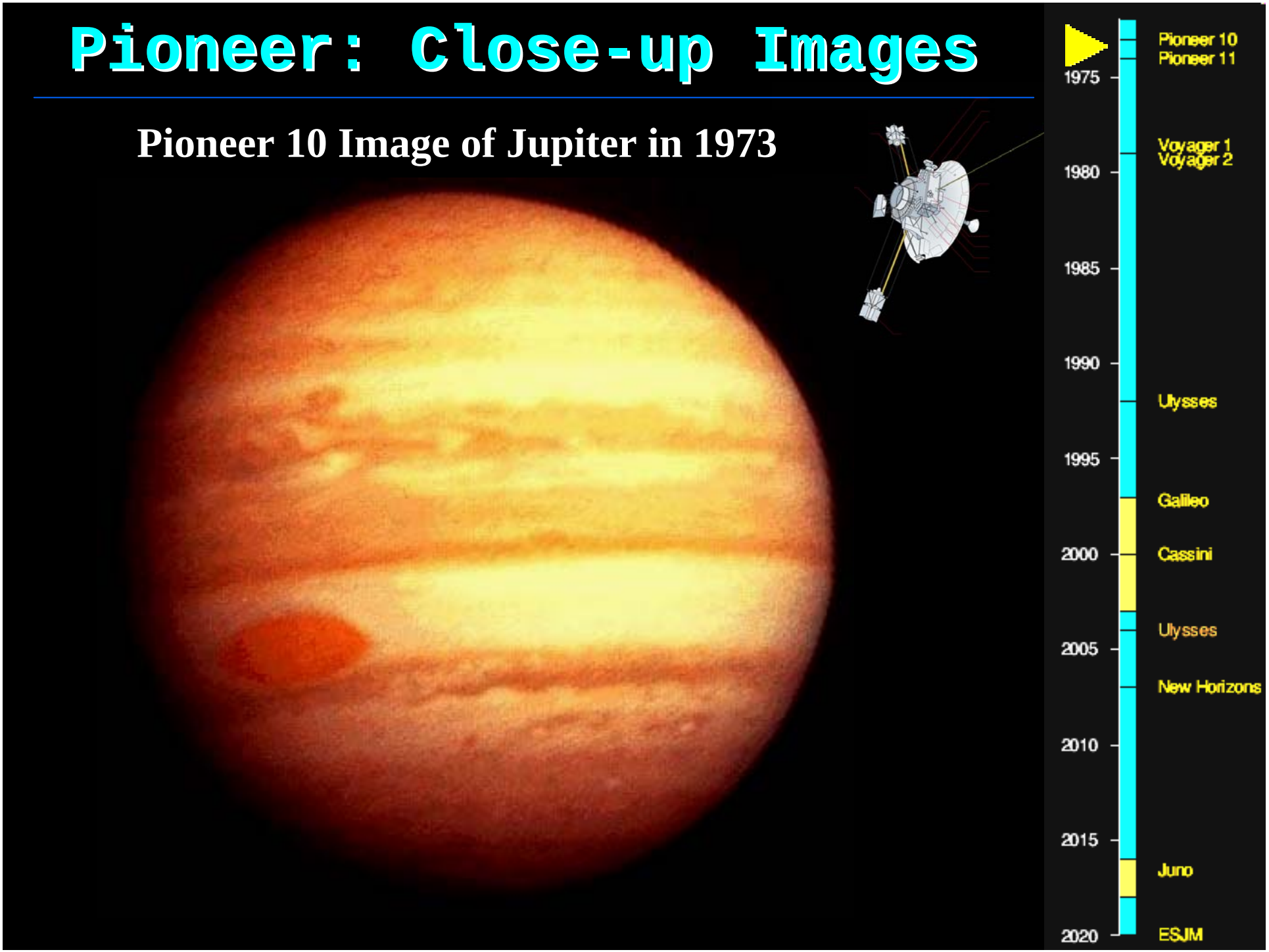
C: Atmospheric Structure

- Determine the 3-D structure of Jupiter's upper troposphere and stratosphere
- Explore atmospheric structure deep below the clouds
- Determine coupling (waves, eddies, etc.) between different atmospheric regimes.

Jupiter themes are cross-disciplinary for 'big picture' science

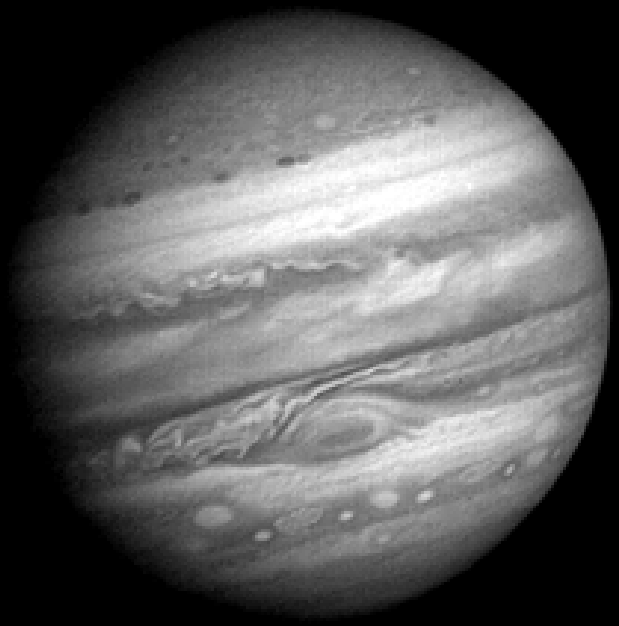
Pioneer: Close-up Images

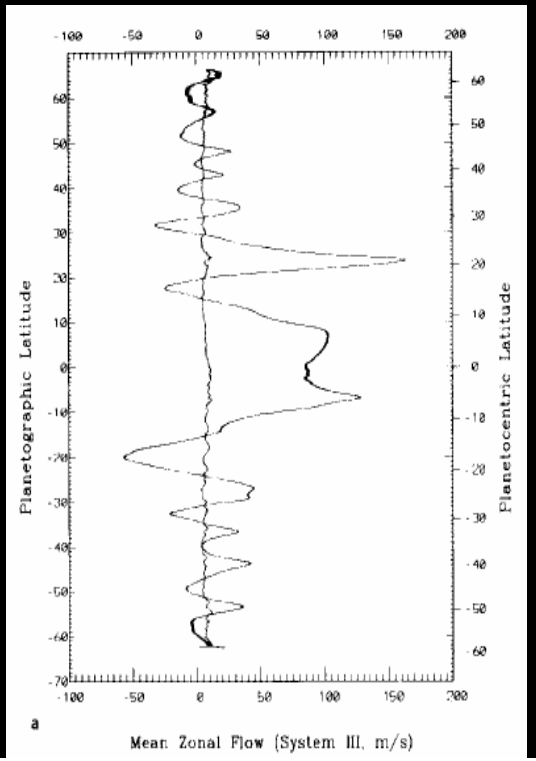
Pioneer 10 Image of Jupiter in 1973

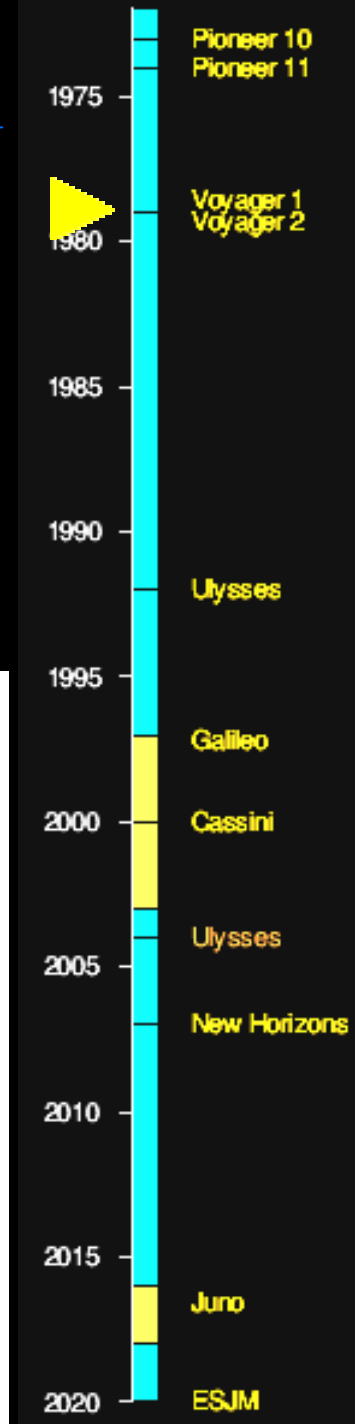


Voyager: Winds

Voyager 1 Approach Movie (1979)

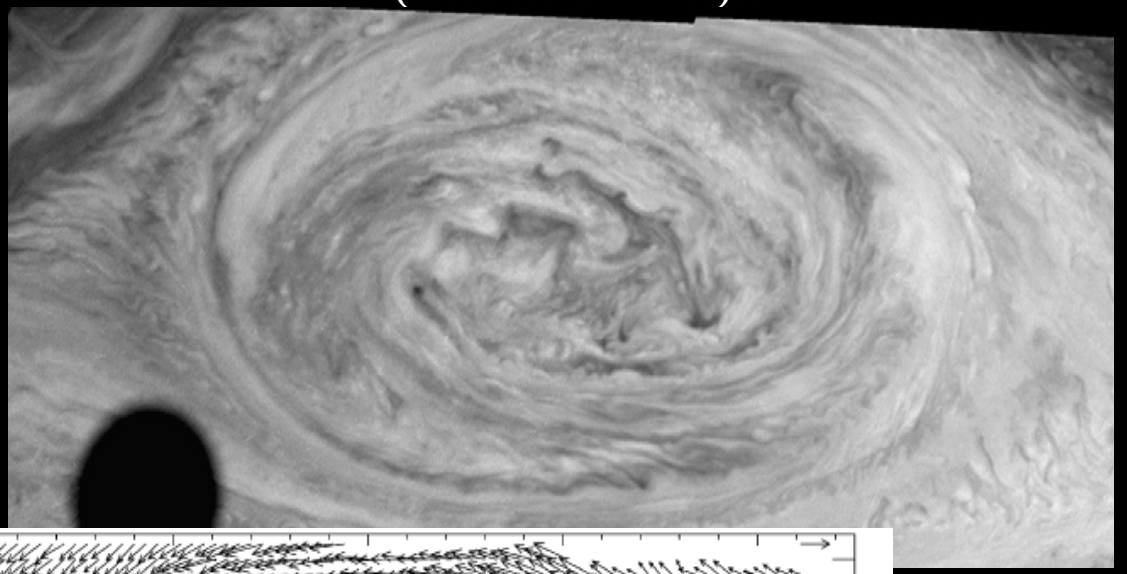


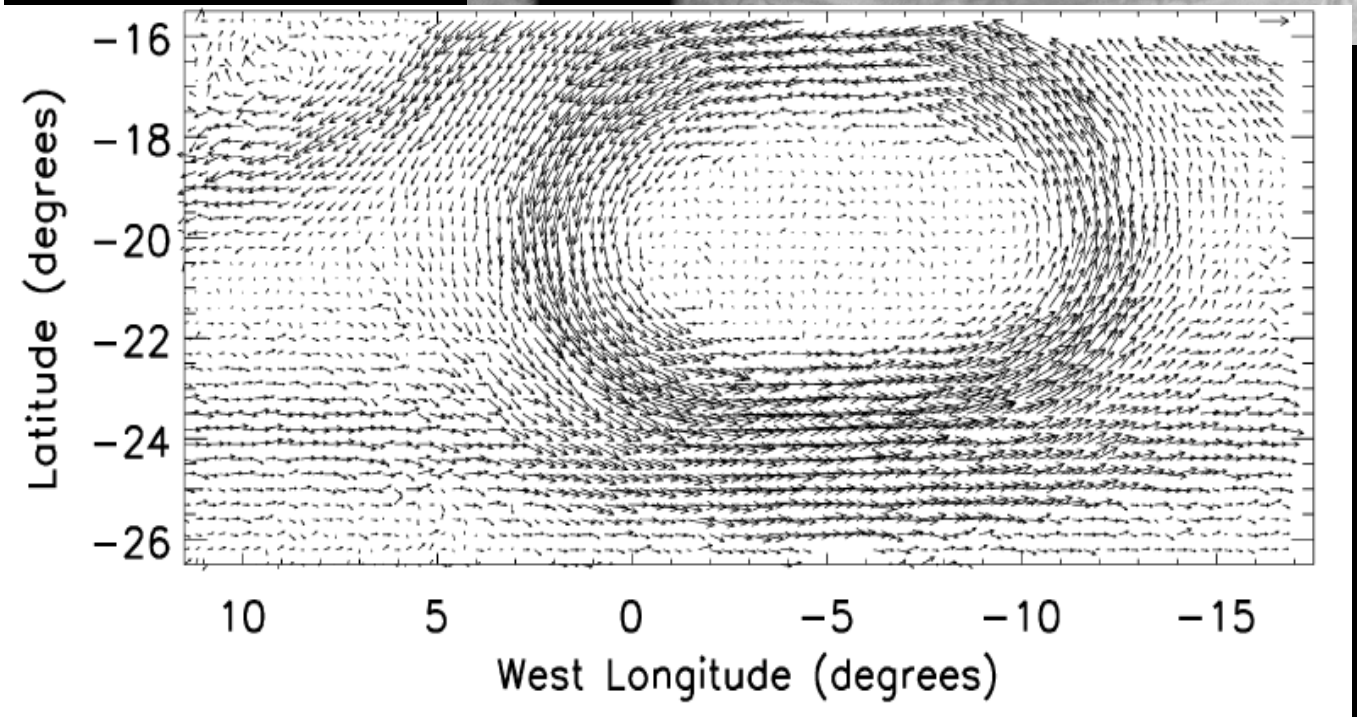


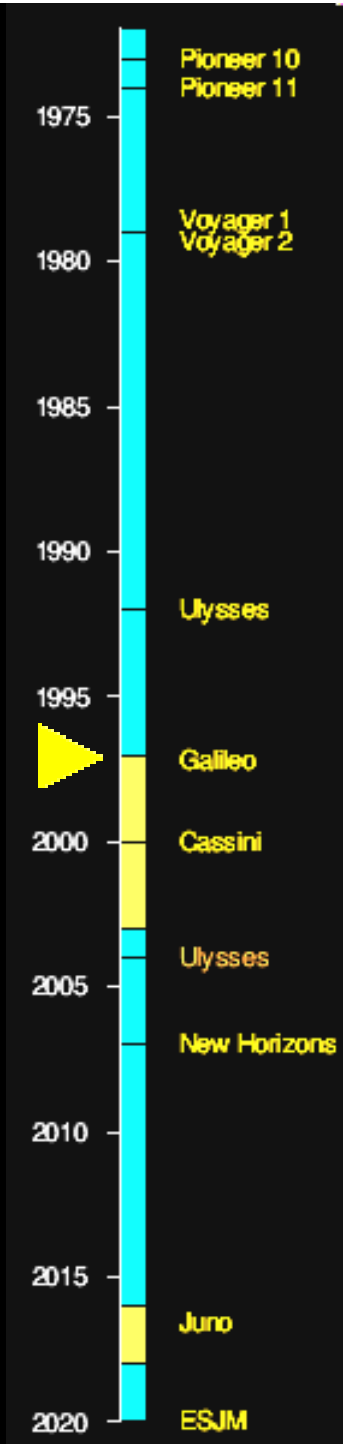


Galileo: Hi-Res Wind Fields

Galileo Wind Field Measurement of GRS (Choi et al. 2007)

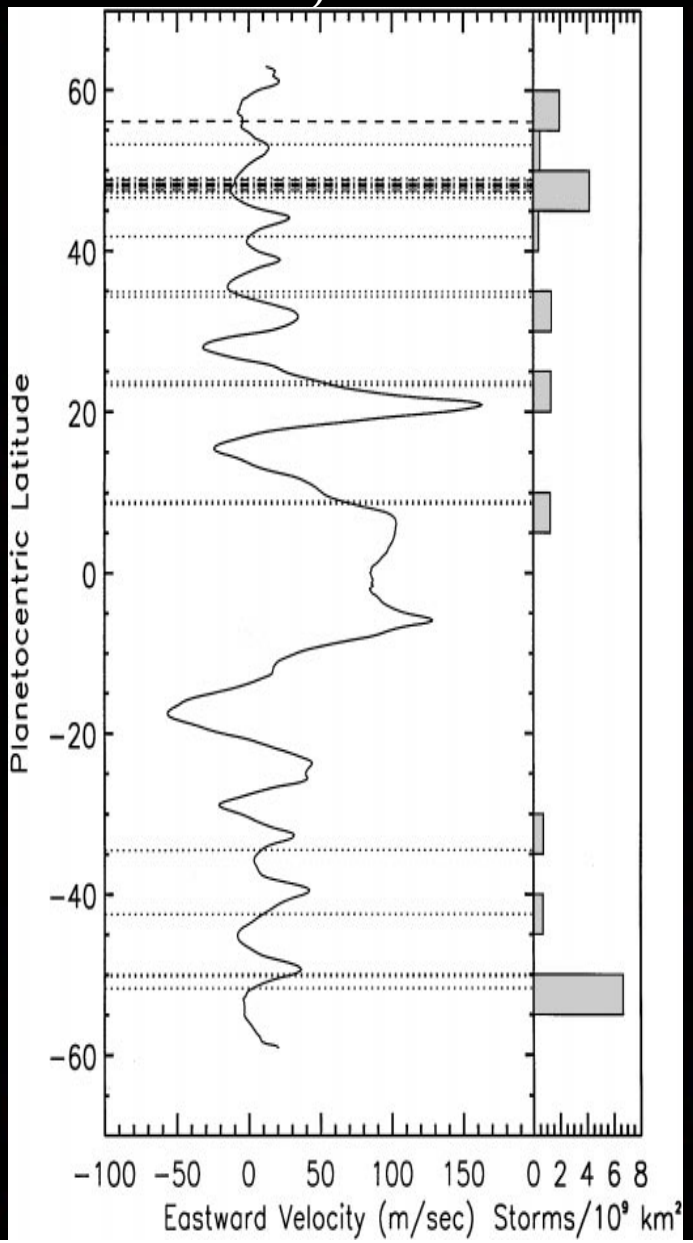


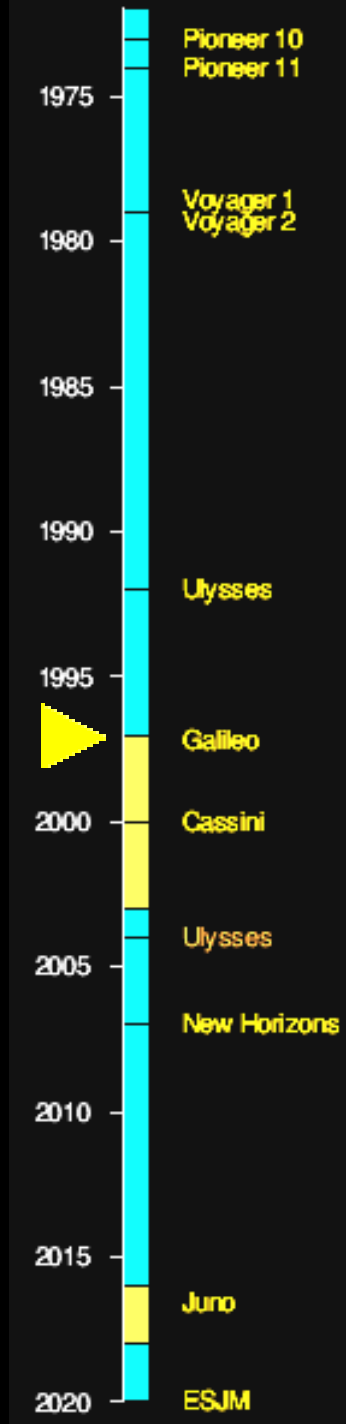




Galileo: Lightning

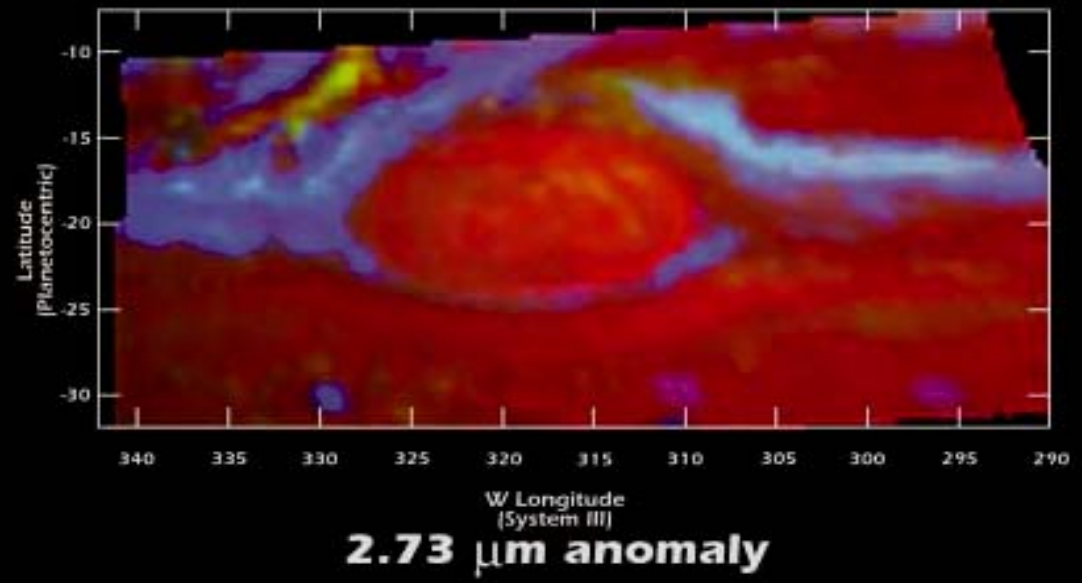
Galileo Observation of Lightning Flashes (Little et al. 1999)

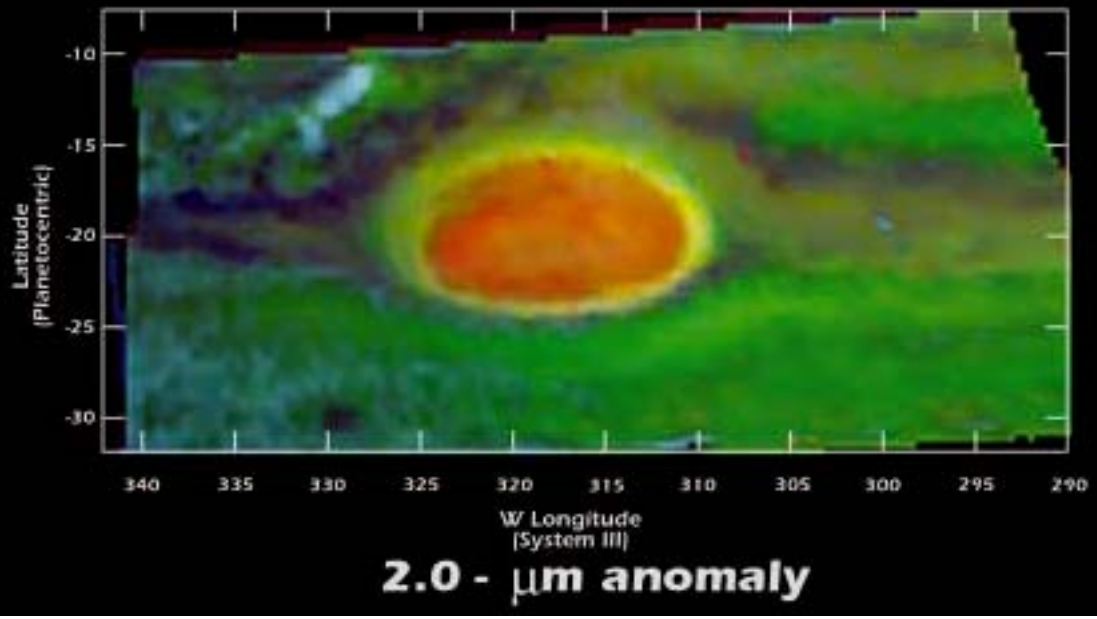


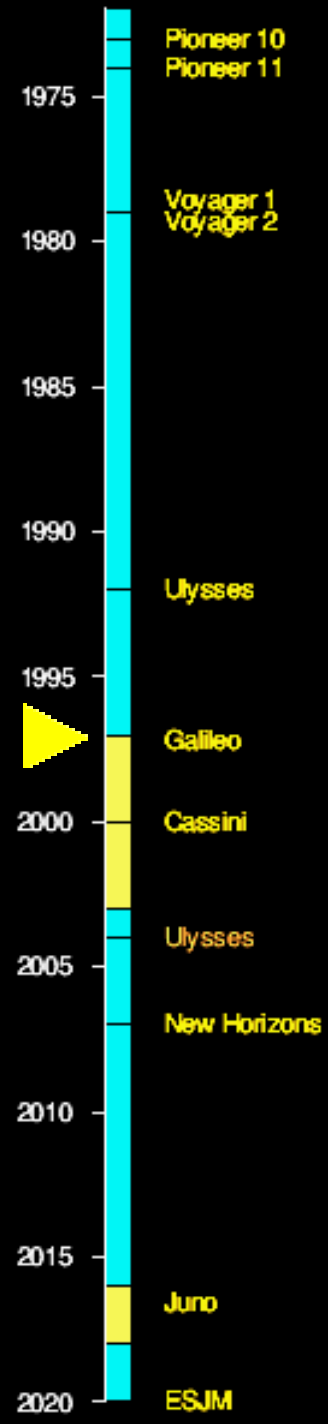


Cloud Composition & Vertical Structures

Galileo NIMS Observation of Fresh Ammonia Ice Clouds (Baines et al. 2002)

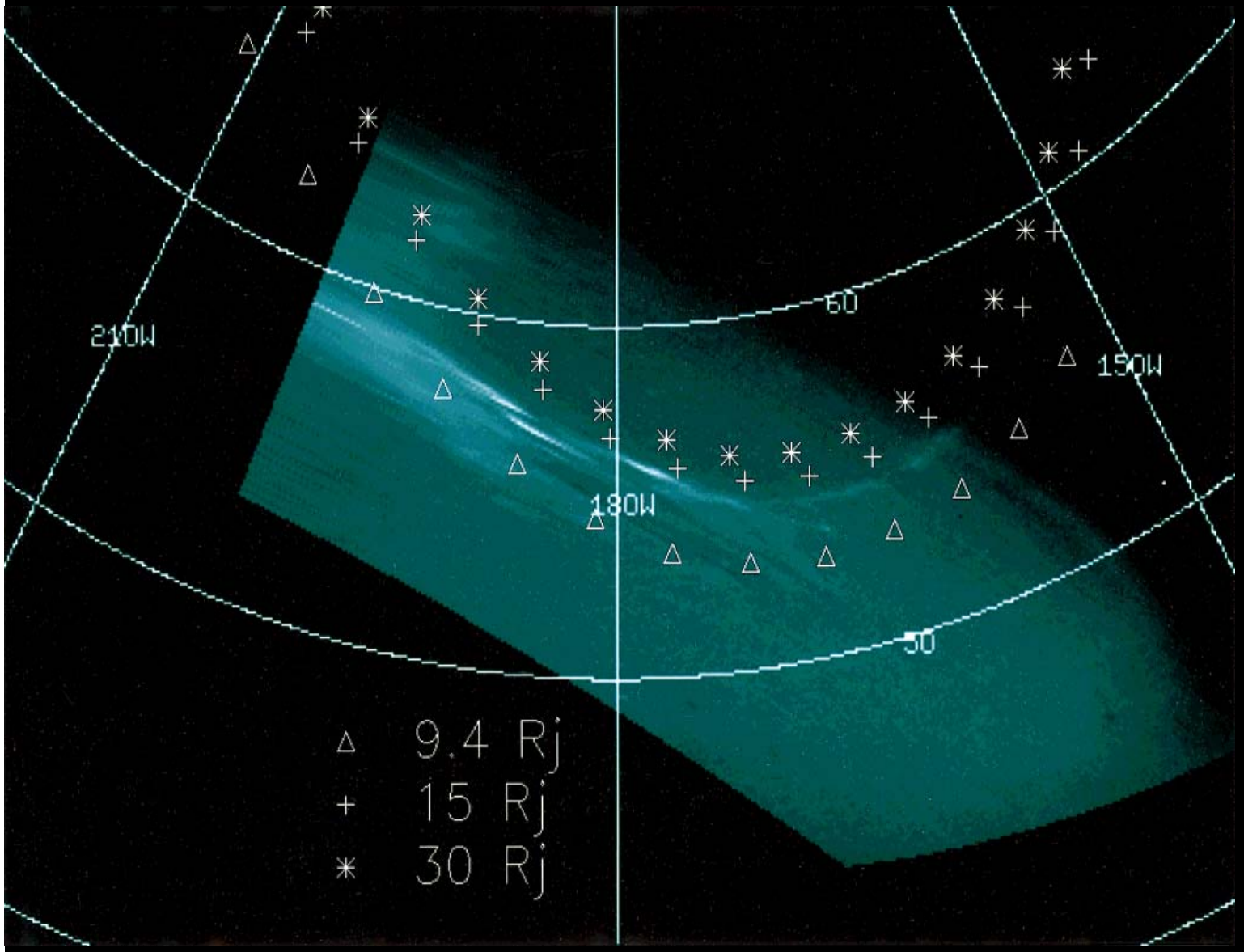


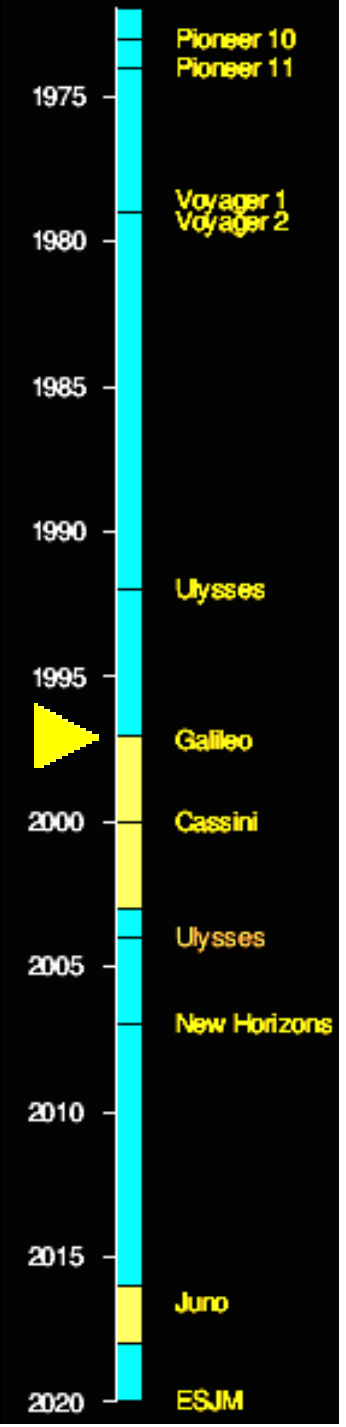




Aurora

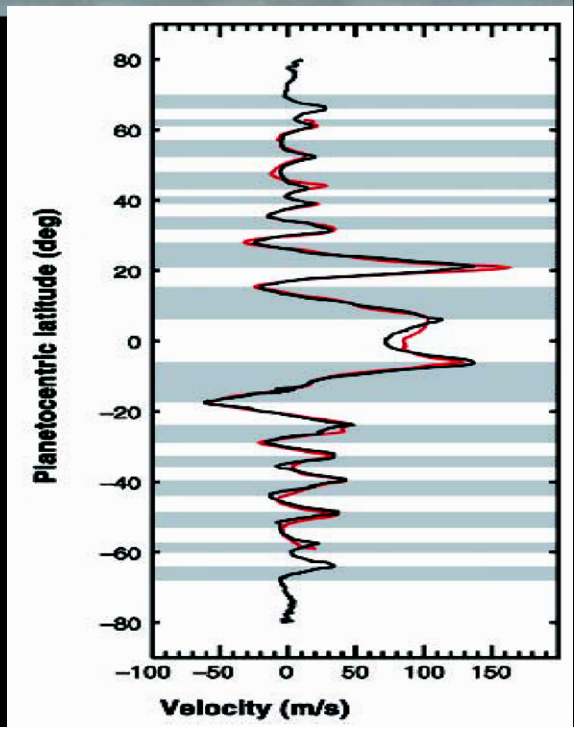
Galileo Observation of Northern Aurora (Ingersoll et al. 1998)

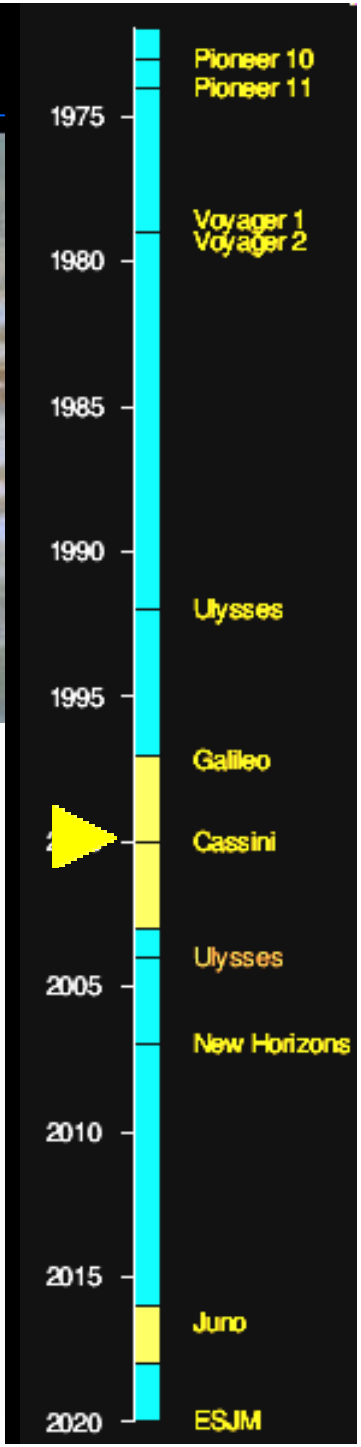




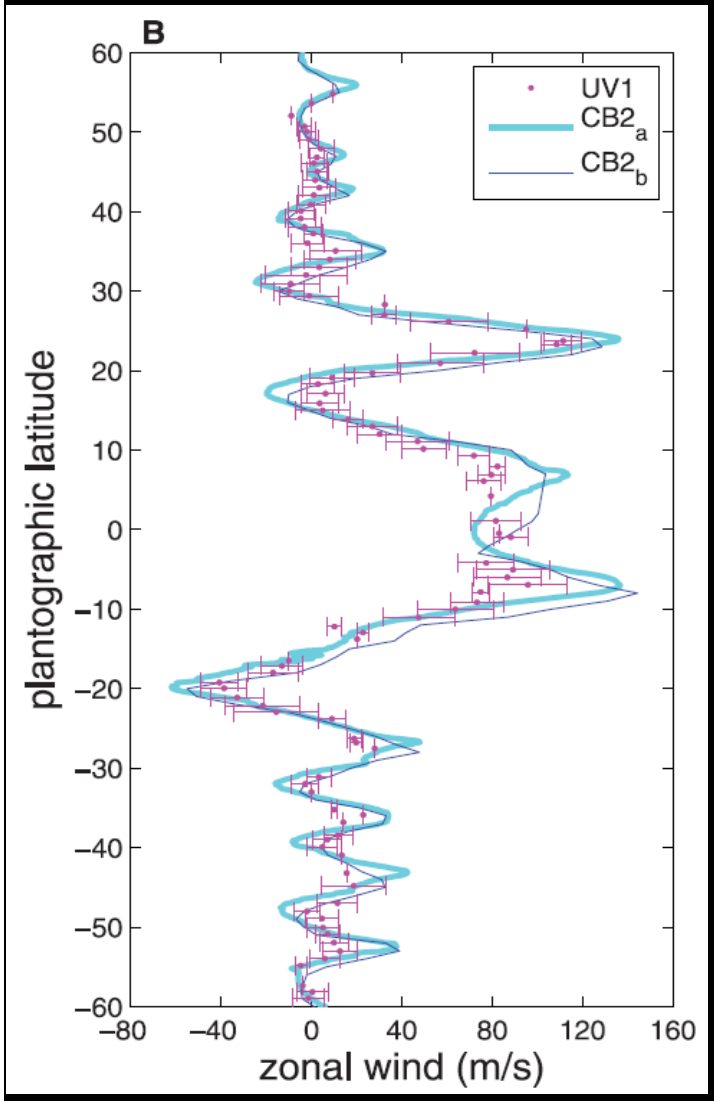
Cassini: Stable Zonal Jets

Right:
Red = Voyager in 1979 (Limaye, 1986),
Black = Cassini in 2000 (Porco, et al. 2003)

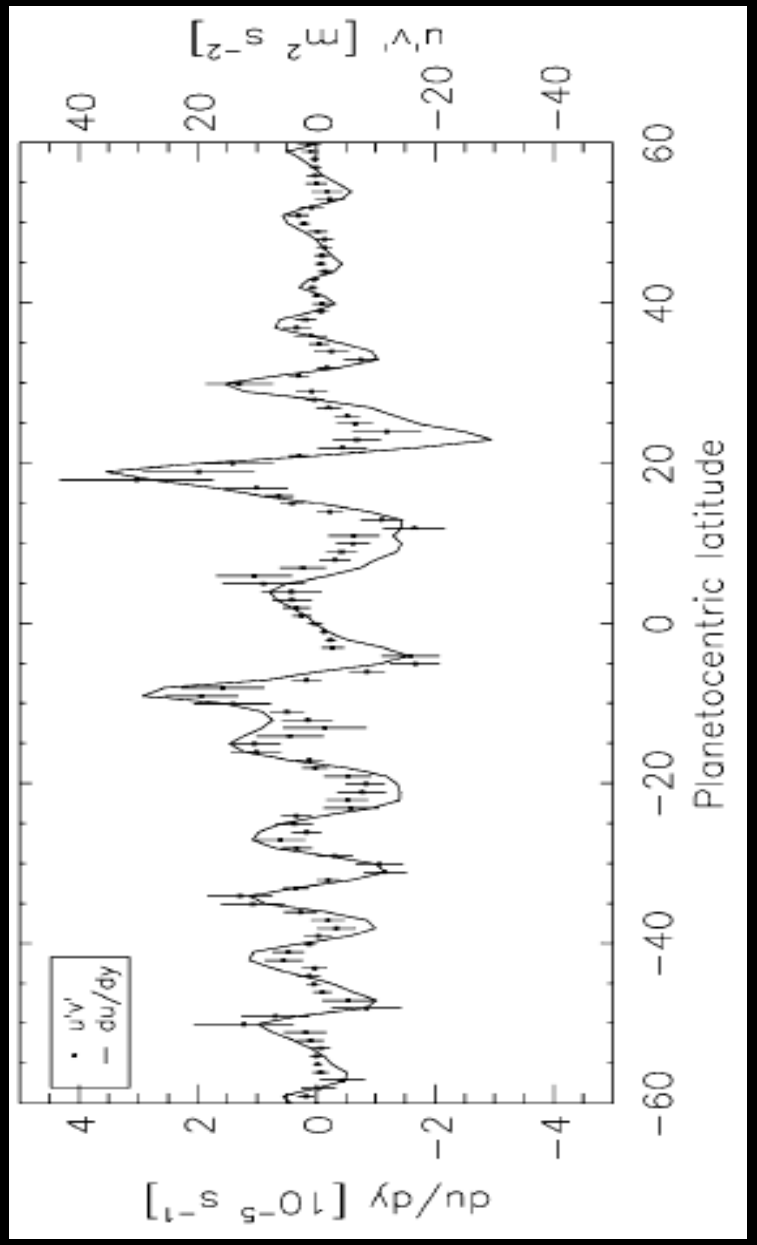




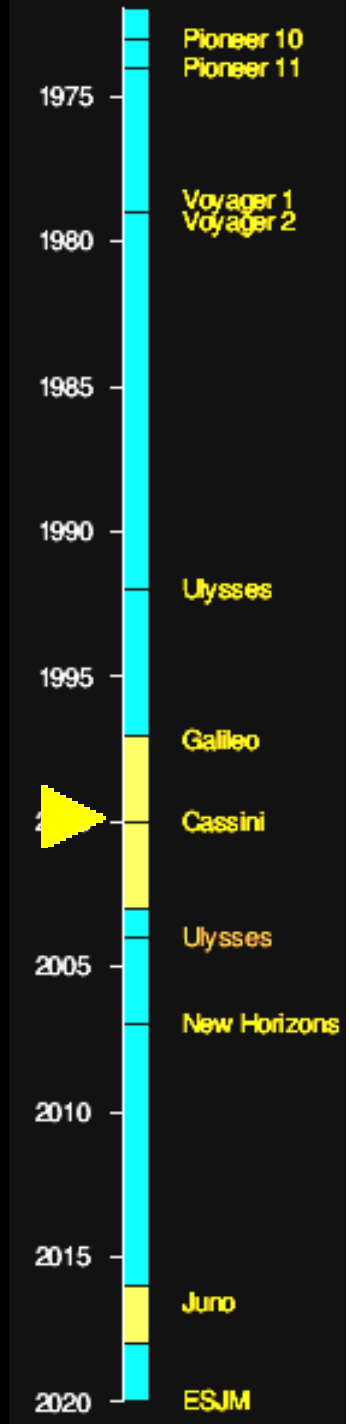
Vertical Shear, Eddy Momentum Flux



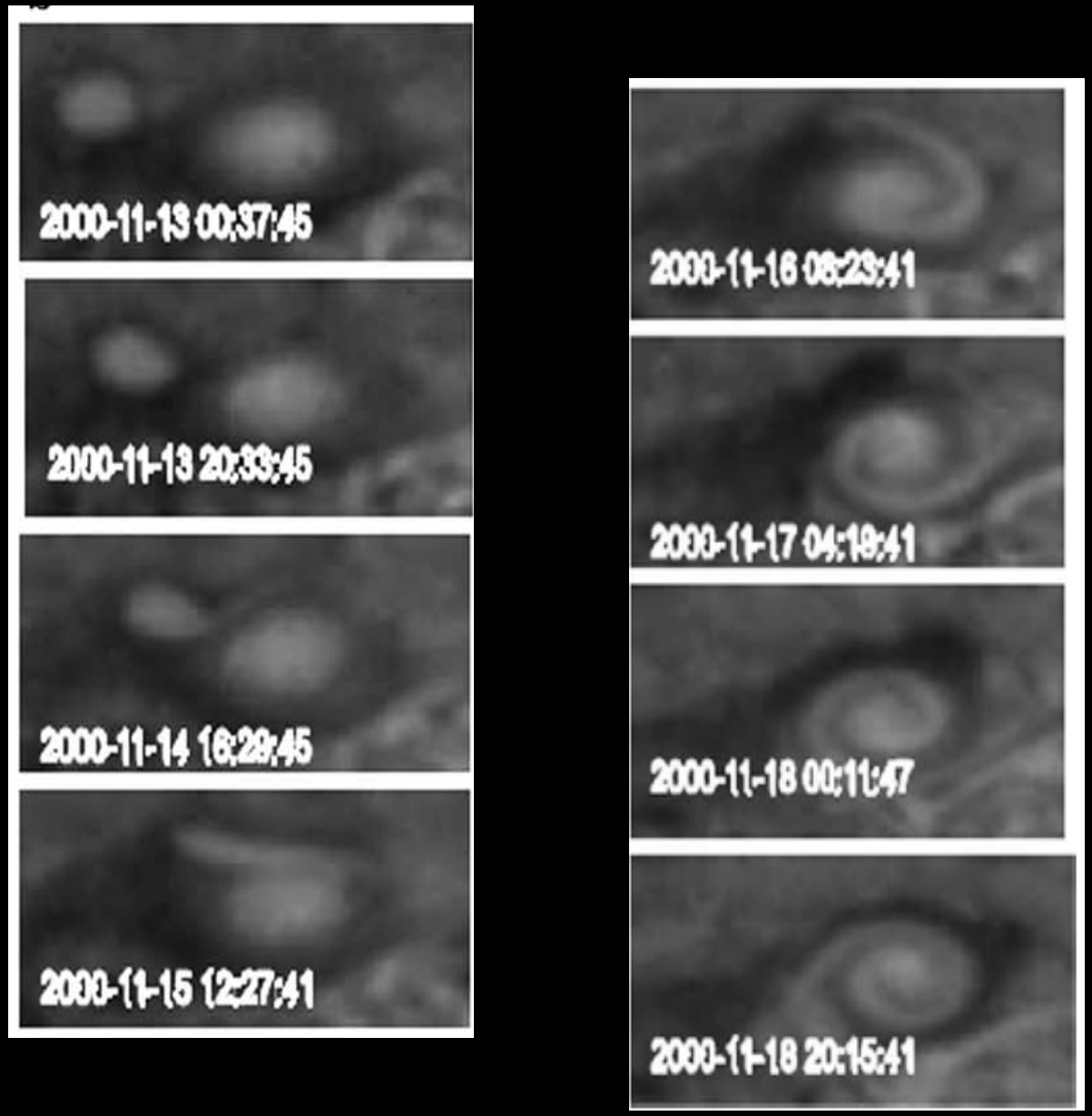
Vertical Shear (Li et al. 2006)



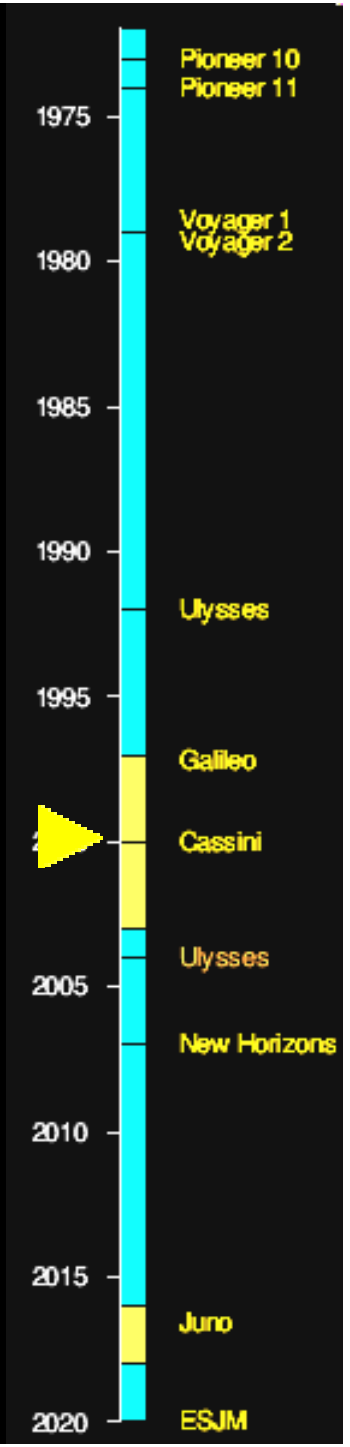
Eddy Momentum Flux (Salyk et al. 2007)



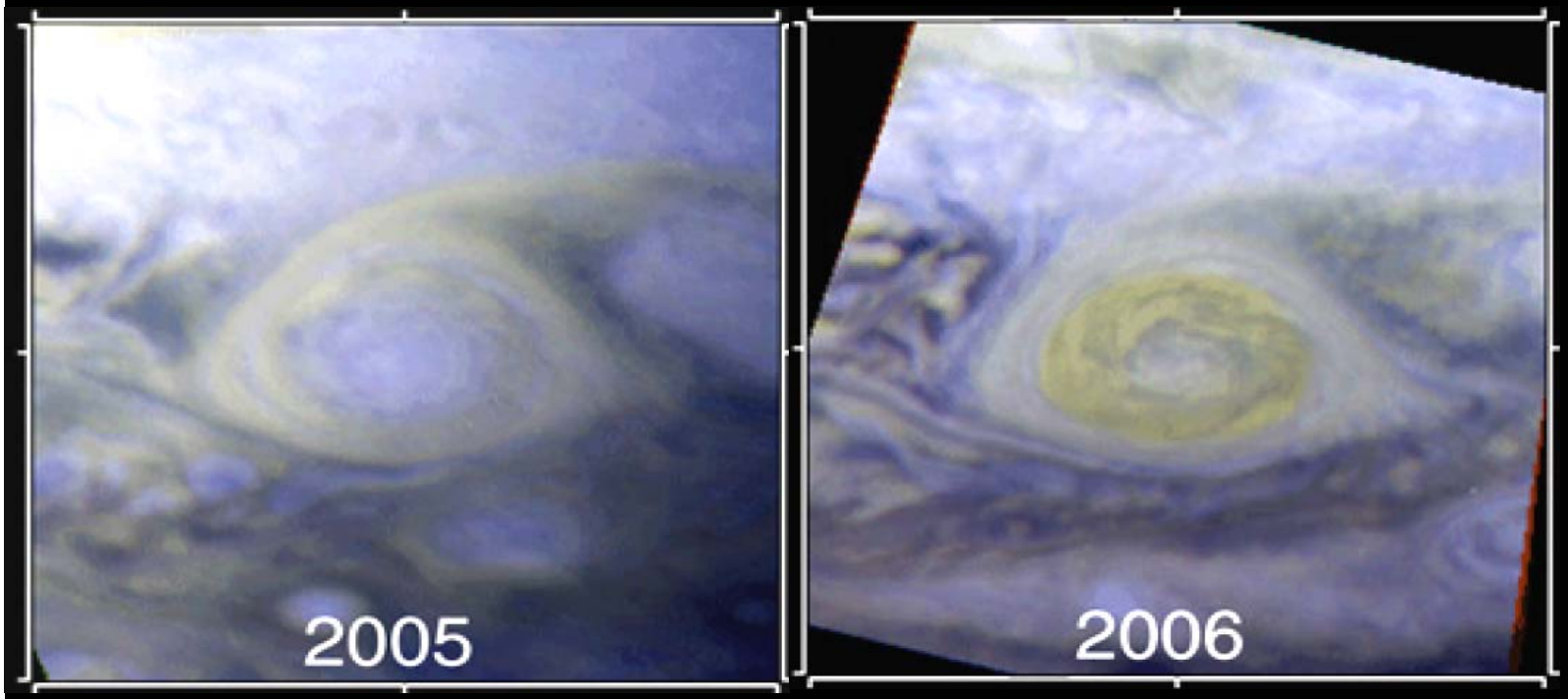
Vortex Life Cycle

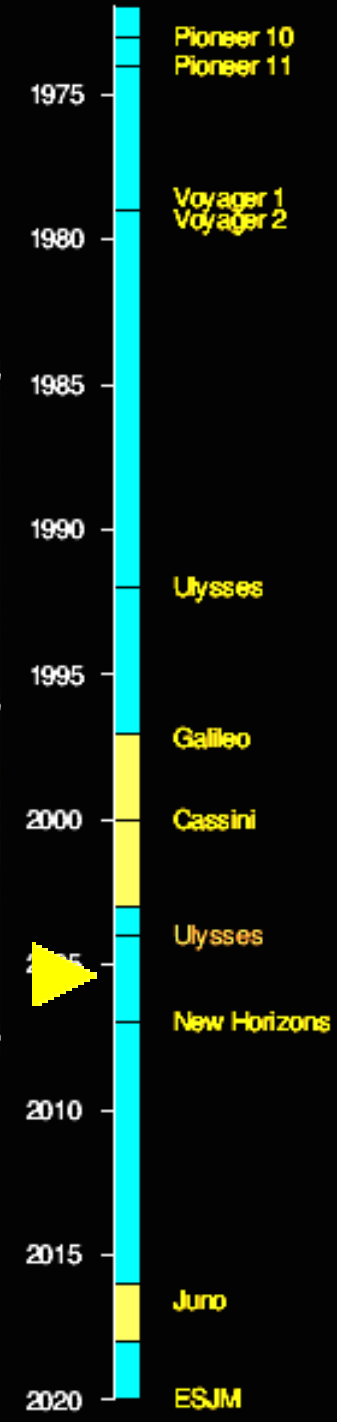


(Li et al. 2004)



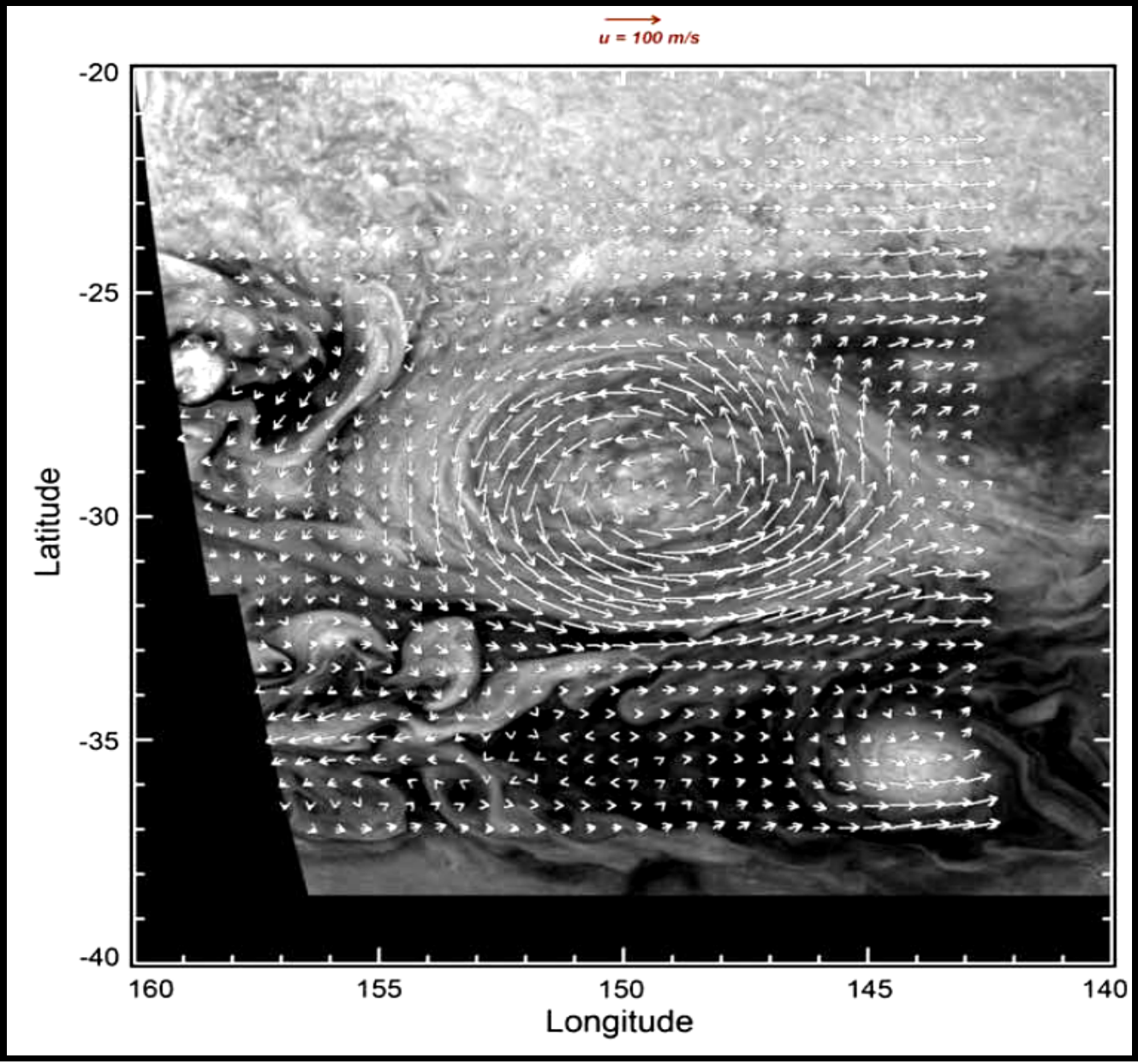
Oval BA → "Red Spot Jr"

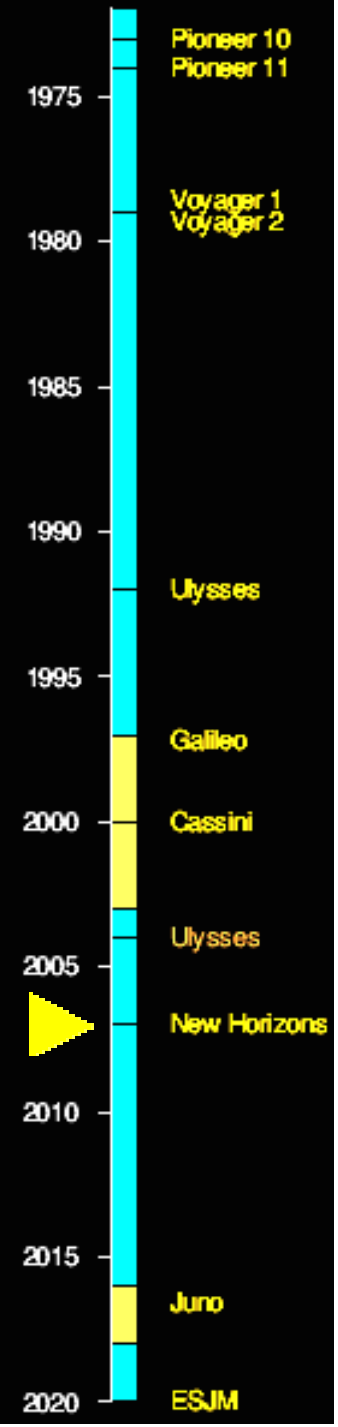




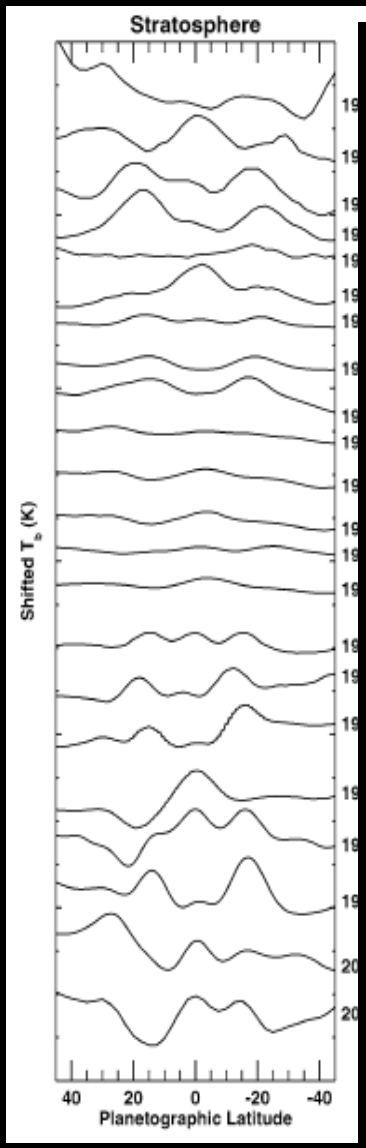
New Horizons

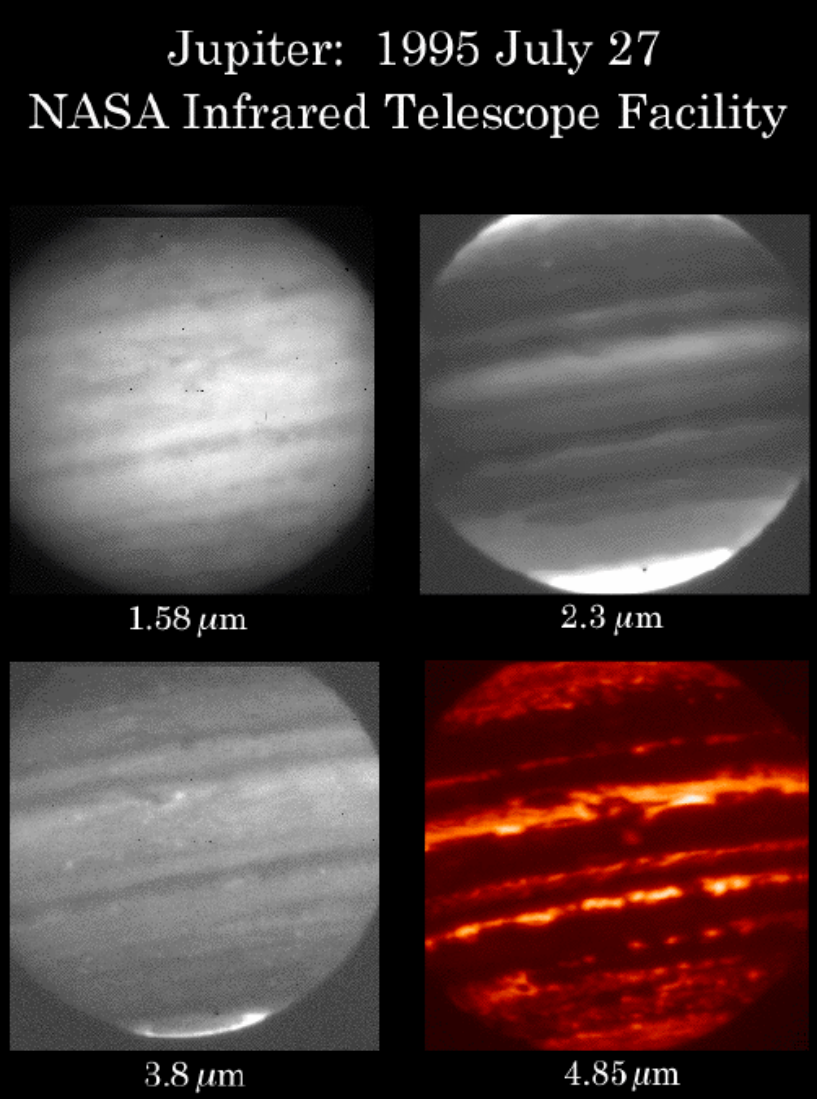
New Horizons Wind Field Measurement of Oval BA (Hueso et al. 2009)

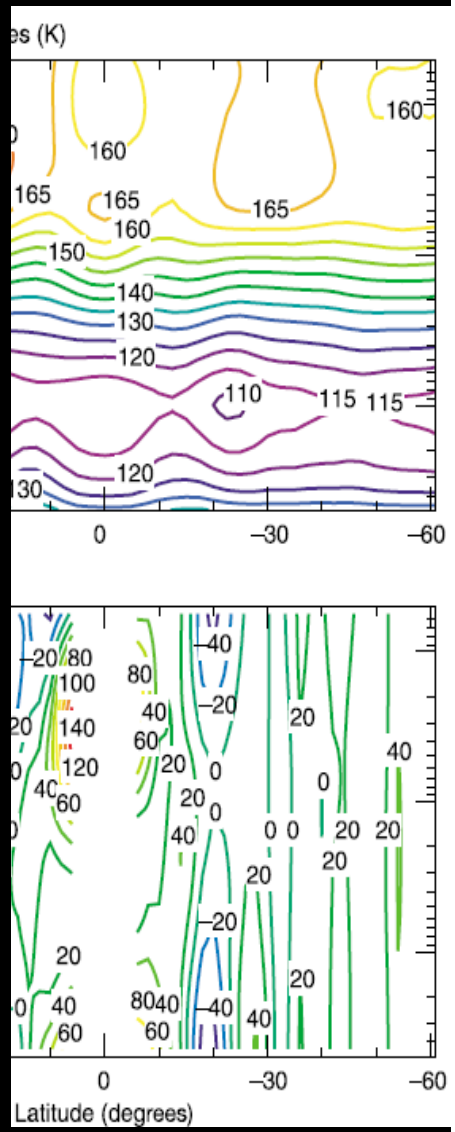




Equatorial Oscillation = "QQO"





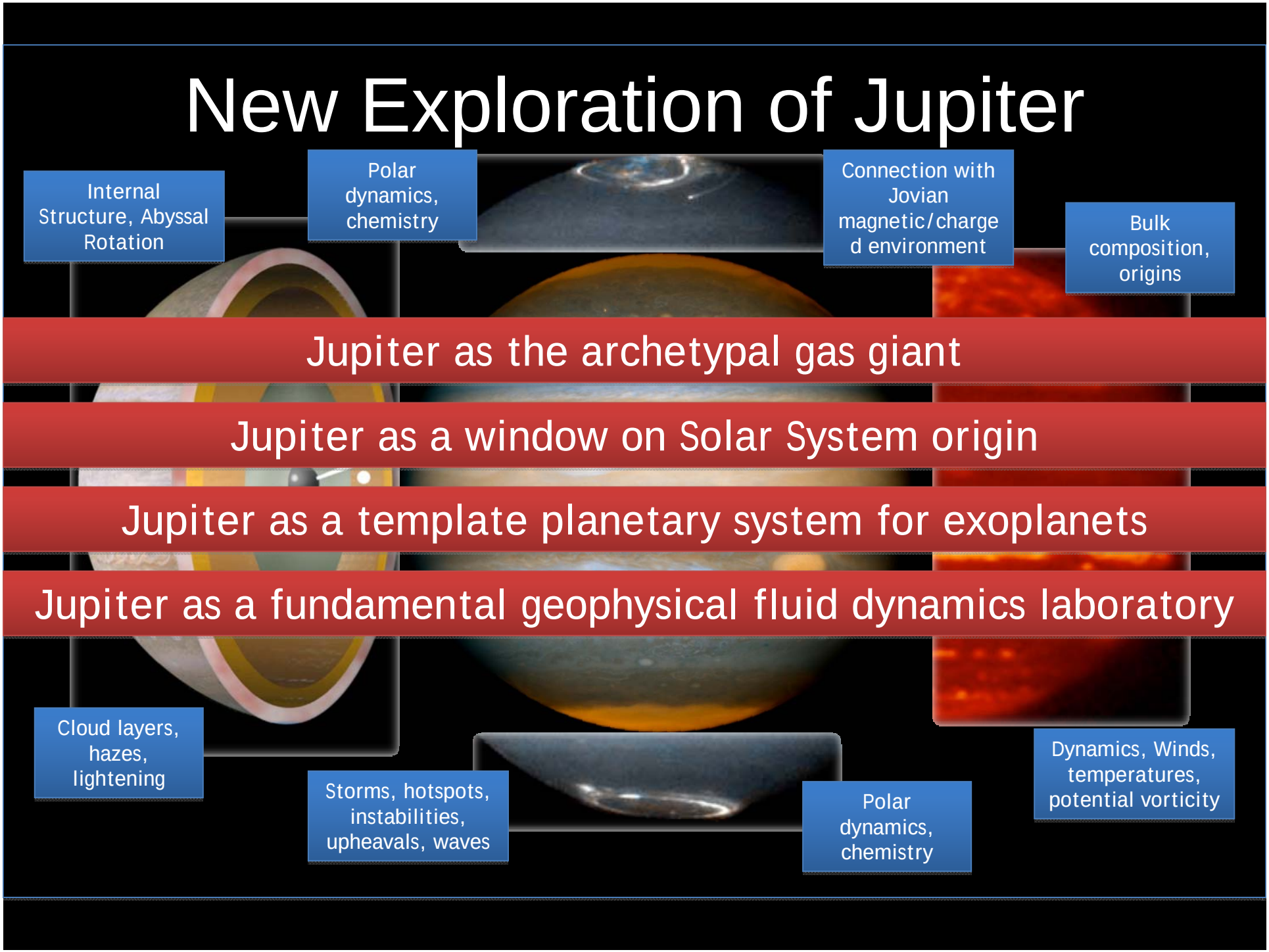


Equatorial Temp. Oscil... (Simon-Miller et al. 2006)

... (Simon-Miller et al. 2007)

...ertical Shear (Flasar et al. 2004)

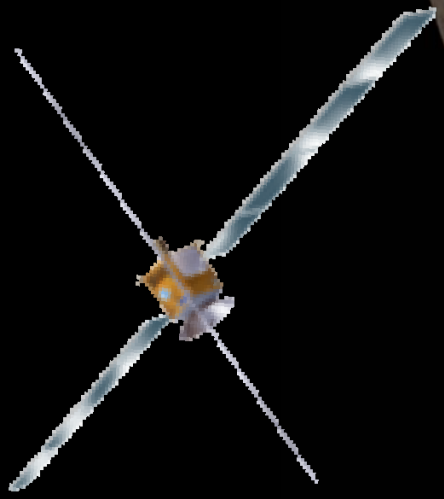
New Exploration of Jupiter



Near Future Missions

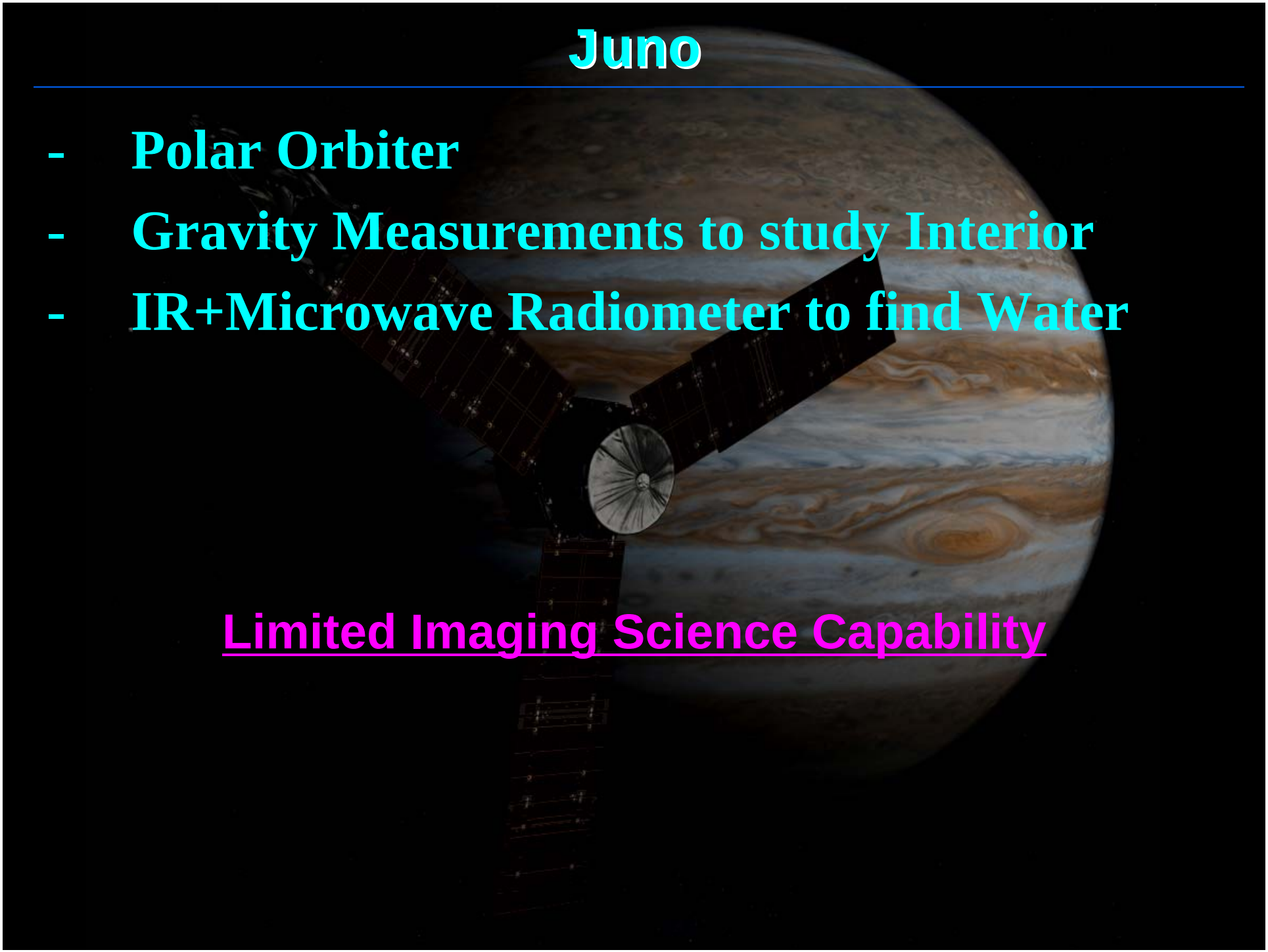
1. Juno

2. Europa Jupiter System Mission
   - Jupiter Europa Orbiter (NASA)
   - Jupiter Ganymede Orbiter (ESA)
   - Jupiter Magnetospheric Orbiter (JAXA)



Juno

- Polar Orbiter
- Gravity Measurements to study Interior
- IR+Microwave Radiometer to find Water



Limited Imaging Science Capability

Juno Payload System Overview

Jovian Auroral Distributions Experiment (JADE)

JADE will measure the distribution of electrons and the velocity distribution and composition of ions.

Gravity Science (GS)

The Juno Gravity Science investigation will probe the mass properties of Jupiter by using the communication subsystem to perform Doppler tracking.

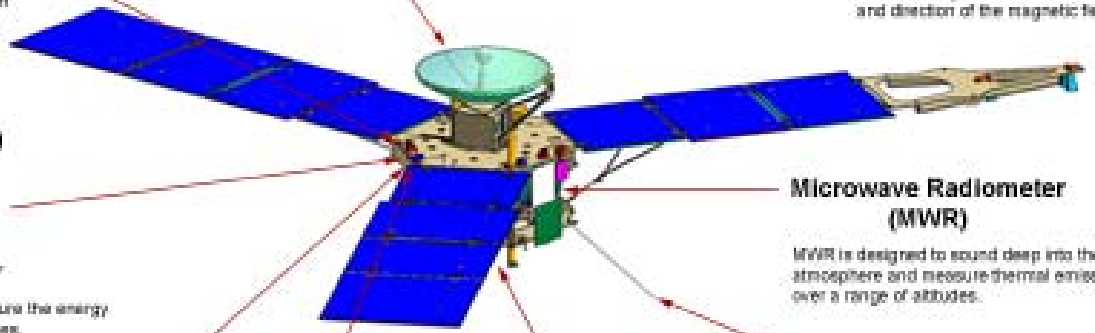
Magnetometer (MAG)

Advanced Stellar Compass (ASC)

ASC accurately measures the orientation of the magnetometers.

Fluxgate Magnetometer (FGM)

The two fluxgate sensors will measure the magnitude and direction of the magnetic field in Jupiter's environment.



Jupiter Energetic-particle Detector Instrument (JEDI)

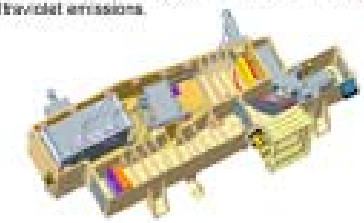
JEDI is a suite of detectors that will measure the energy and angular distribution of charged particles.

Microwave Radiometer (MWR)

MWR is designed to sound deep into the atmosphere and measure thermal emission over a range of altitudes.

Ultraviolet Spectrograph (UVS)

UVS is an imaging spectrograph that is sensitive to ultraviolet emissions.



JunoCam

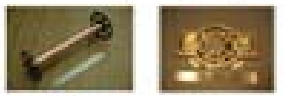
JunoCam will provide visible-color images of the Jovian cloud tops.

Jovian Infrared Auroral Mapper (JIRAM)

JIRAM will acquire infrared images and spectra of Jupiter. JIRAM is located on the aft/bottom deck.

Plasma Waves Instrument (Waves)

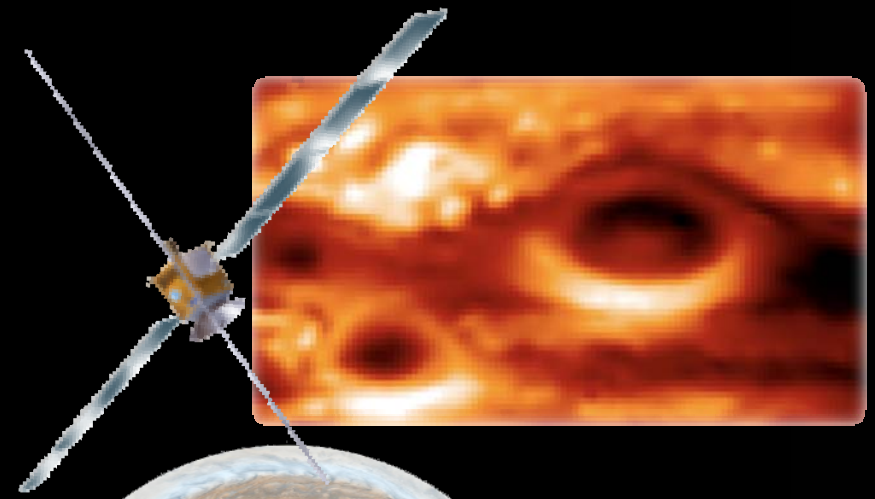
Waves will measure plasma waves and radio waves in Jupiter's magnetosphere.

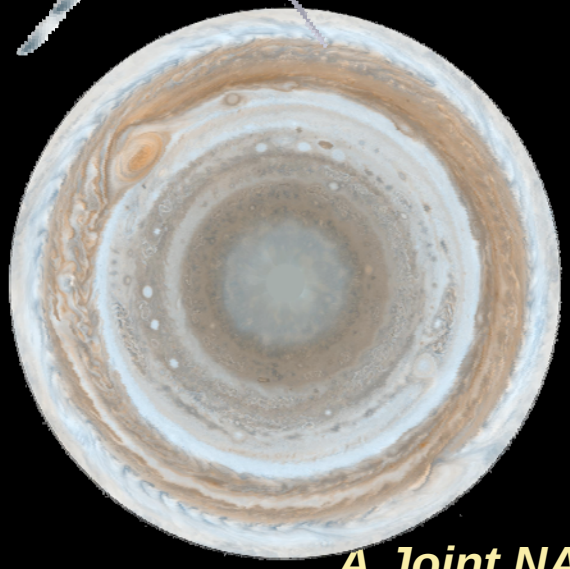


Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Jupiter's Atmosphere and Interior from EJSM



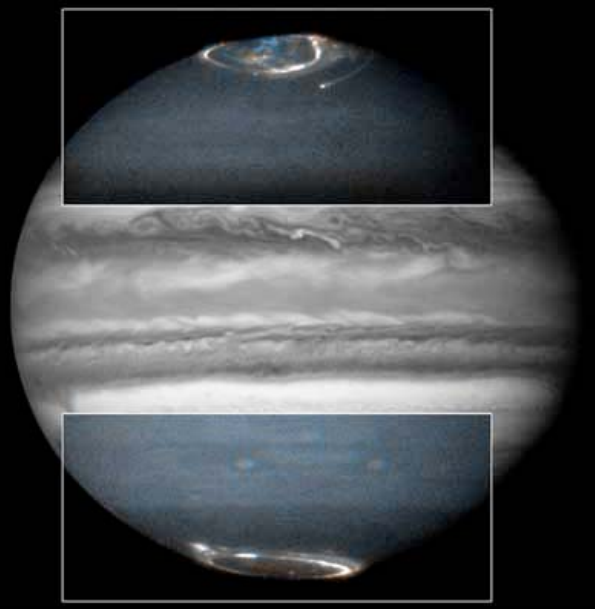


L.N. Fletcher and the EJSM SDT

A Joint NASA-ESA Outer Planet Mission Study

Jupiter Science as an Element of EJSM

- Jupiter science is a vital element of the study of interactions between the components of this complex planetary system (Jupiter, icy satellites, rings, magnetosphere and small bodies).
- Responsive to the ESA Cosmic Vision:
  - Jupiter's atmosphere and evolution serves as the paradigm for the study of giant planets in our solar system and beyond.
- EJSM Jupiter Science seeks to address two of the Science Themes of the 2002 US Decadal Survey:
  - The Origin and Evolution of Habitable Worlds;
  - How Planetary Systems Work.

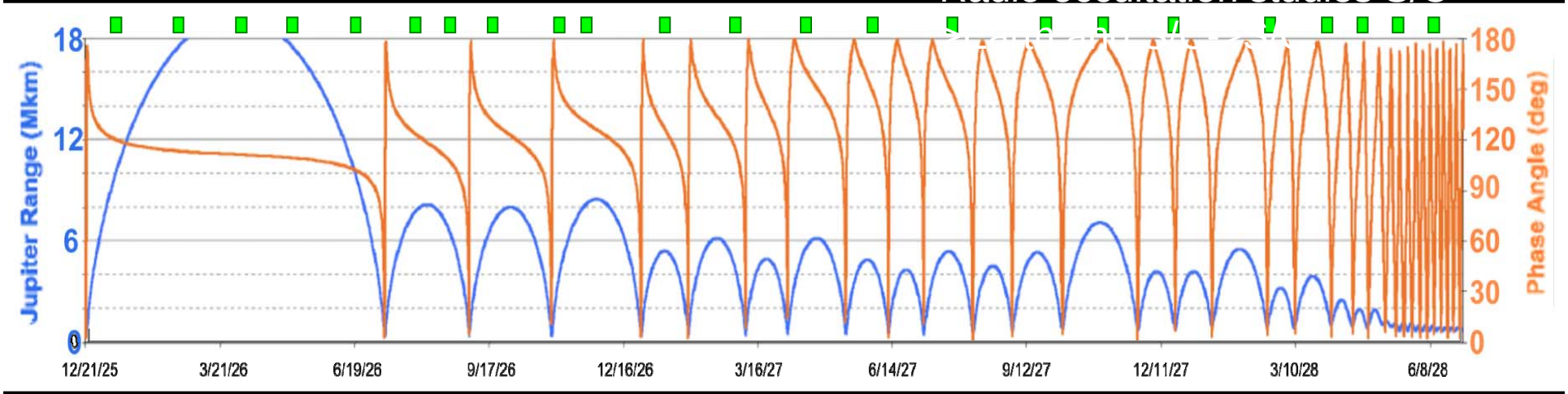


NASA/ESA/J Clarke, Boston University

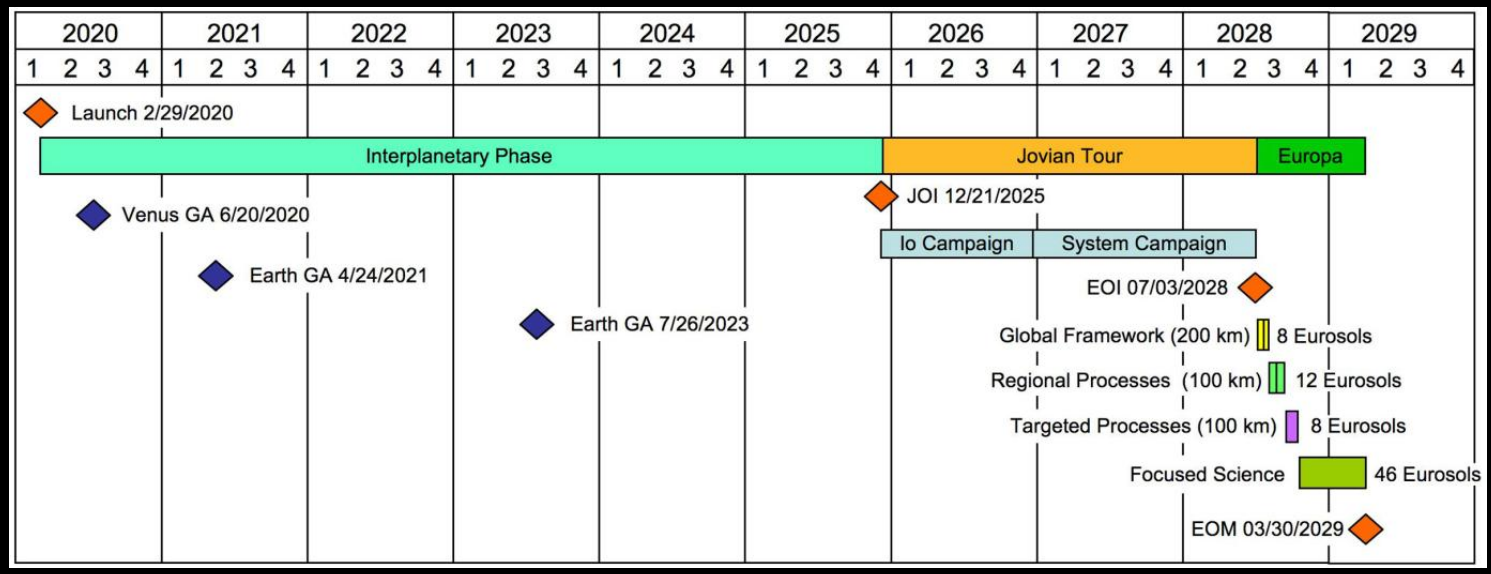
Jupiter Working Group has reassessed Jupiter science capabilities based on Decadal Survey/Cosmic Vision.

Jupiter Science Opportunities

- Example tours feature dedicated Jupiter monitoring campaigns.
- Pre-JOI:
  - Extensive opportunities for global mapping as JEO/JGO approach Jupiter
- Jupiter System Tour phase (with multiple perijove opportunities):
  - 30 months before Europa Orbital Insertion, 26 months before
- End of Mission (from circular satellite orbits):
  - Potential to re-observe Jupiter 3 years after arrival if science drivers are strong enough
- Dynamical studies over hourly/weekly/monthly timescales
- Two spacecraft mission
  - Radio occultation studies S/C-

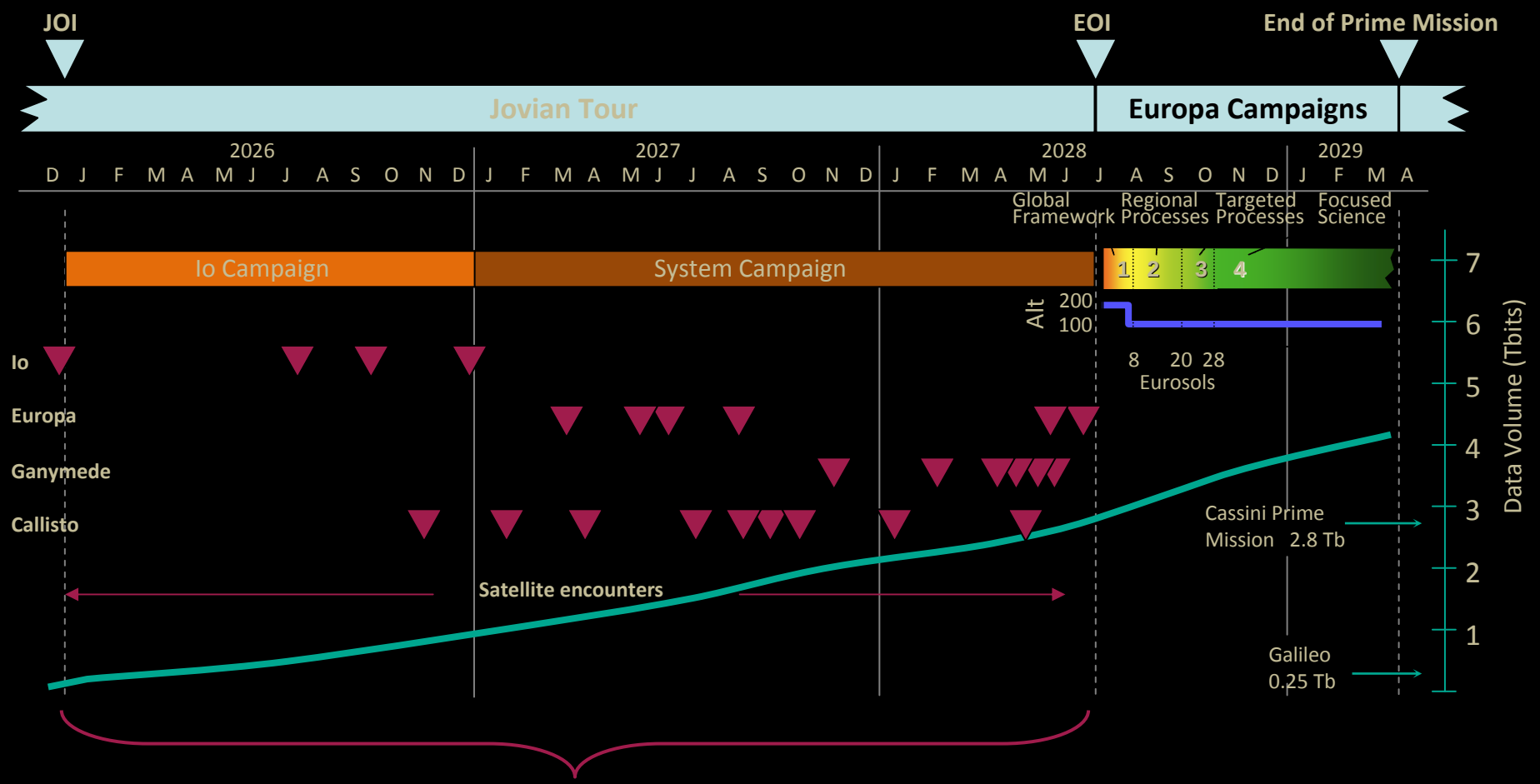


JEO Baseline Mission Timeline



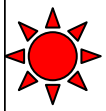
- Long Cruise to Jupiter
  - Challenges: Training, Skill Retention, Obsolescence
  - Opportunities: Process Improvement (methods, S/W, etc), IT infrastructure, ops approaches
- Two kinds of science missions
  - Tour: longer, slower, more diverse
  - Europa: Faster, more intense, more systematic and structured
  - Cruise: Specialized science not anticipated, calibrations and training use Tour capabilities
  - Need one system to meet all needs (process timelines and decision process can vary)

Baseline Science Mission Overview



Required to reach Europa,
but also targets of Jupiter system science

Model Payload Capabilities

 = vital for Jupiter **atmospheric** science

JEO model payload
Narrow Angle Camera
Wide Angle and Medium Angle Camera
Vis-IR Imaging Spectrometer
UV Spectrometer
Radio Science
Magnetometer
Ice Penetrating Radar
Laser Altimeter
Thermal Instrument
Ion and Neutral Mass Spectrometer
Particle and Plasma Instrument

JGO model payload
Narrow Angle Camera
Wide Angle and Medium Resolution Camera
Vis-IR Hyperspectral Imaging Spectrometer
UV Imaging Spectrometer
Radio Science
Magnetometer
Sub-Surface Radar
Laser Altimeter
Sub-Millimeter Wave Instrument
Plasma Package & Ion and Neutral Mass Spectrometer
Radio and Plasma Wave Instrument

Visible Camera: Narrow filters to probe strong CH_4 absorptions, cloud strucure, wind tracking

Near-IR Spectrometer: 5-10 nm to capture ice absorption; extend beyond 5 µm for H_2O mapping

Sub-mm: Stratospheric winds, temperatures, H_2O and trace species.

Model Payload Capabilities

= vital for Jupiter **atmospheric** science

JEO model payload
Narrow Angle Camera
Wide Angle and Medium Angle Camera
Vis-IR Imaging Spectrometer
UV Spectrometer
Radio Science
Magnetometer
Ice Penetrating Radar
Laser Altimeter
Thermal Instrument
Ion and Neutral Mass Spectrometer
Particle and Plasma Instrument

JGO model payload
Narrow Angle Camera
Wide Angle and Medium Resolution Camera
Vis-IR Hyperspectral Imaging Spectrometer
UV Imaging Spectrometer
Radio Science
Magnetometer
Sub-Surface Radar
Laser Altimeter
Sub-Millimeter Wave Instrument
Plasma Package & Ion and Neutral Mass Spectrometer
Radio and Plasma Wave Instrument

UV: Stellar occulations, high-altitude hazes, chemistry, ionosphere/thermosphere studies

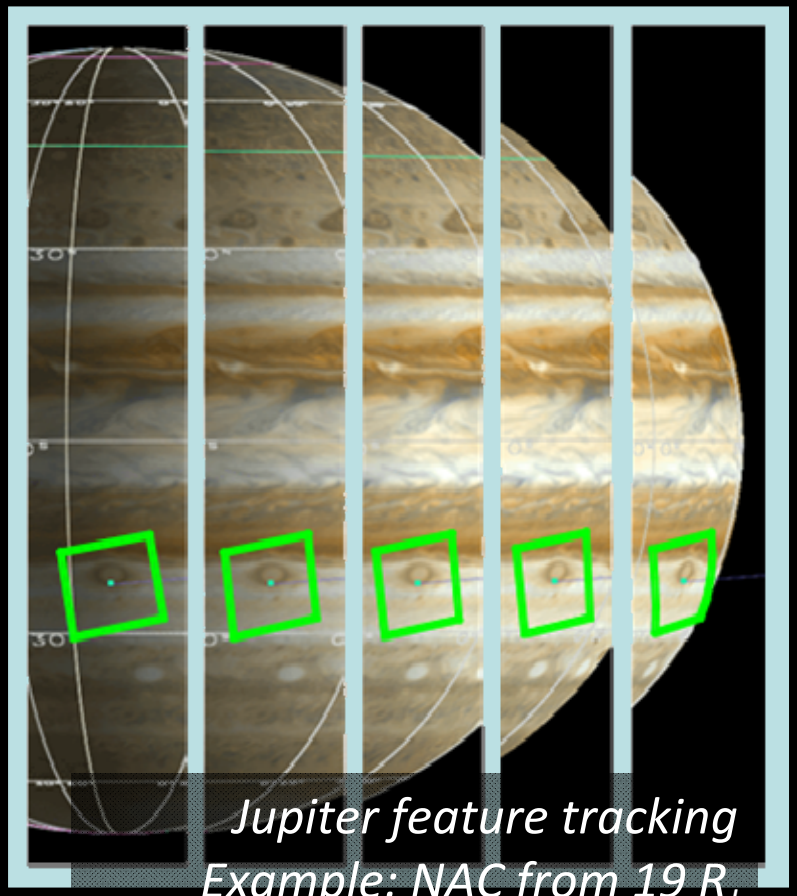
Thermal-IR: Narrow filters to probe tropospheric and stratospheric temperatures.

Radio science: USO reference, multiple opportunities to sound a range of latitudes.

+ Doppler spectroimager, thermal spectrometer, X-ray, etc?

Spatial Resolution

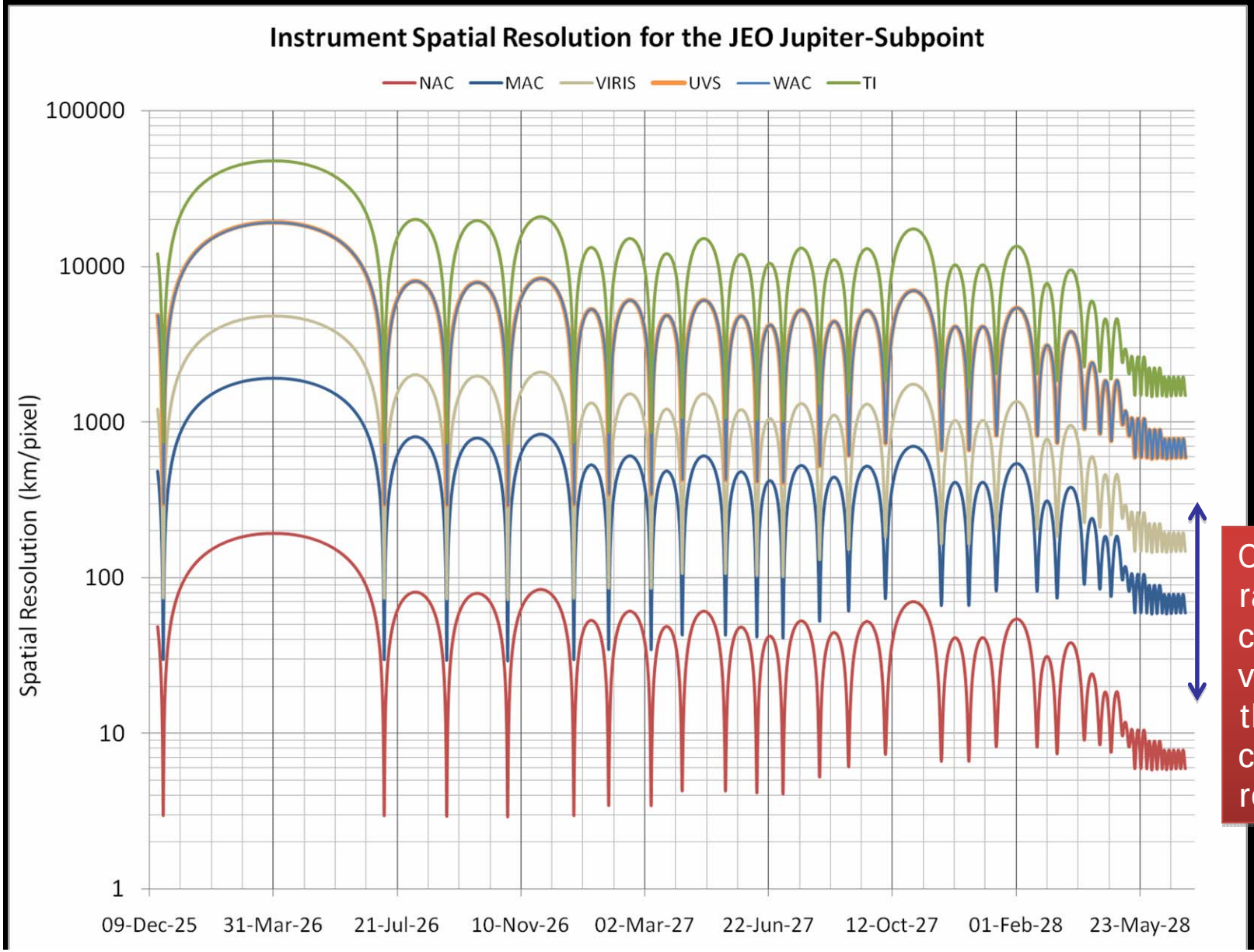
- Best VIS/NIR resolution surpasses Voyager, Galileo, New Horizons
- Spatial resolutions for JEO (per pixel at 9.5 RJ):
  - Thermal Instrument: 1700 km
  - Wide-angle camera & UV spectrometer: 700 km
  - Near-IR Spectrometer: 170 km
  - Medium-angle camera: 70 km
  - Narrow-angle camera: 7 km
- Standard JEO spatial resolution would be ~2 times these values.
- Jupiter science investigations call for higher UV/IR spatial resolutions than satellite science, a challenge to instrument providers.



Jupiter feature tracking
Example: NAC from 19 R_J

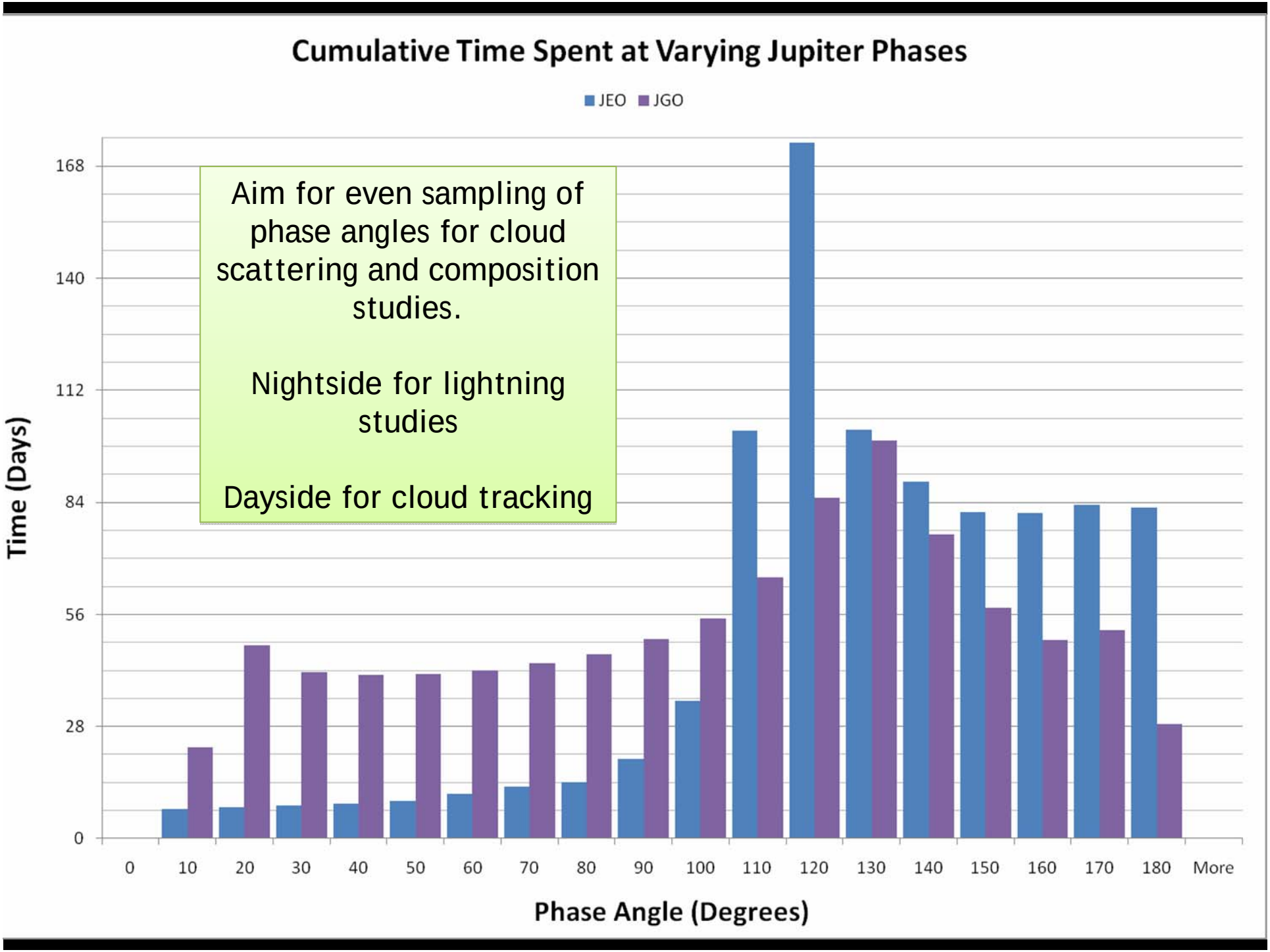
Higher UV/IR spatial resolutions are desirable to match visible imaging.

Spatial Resolution

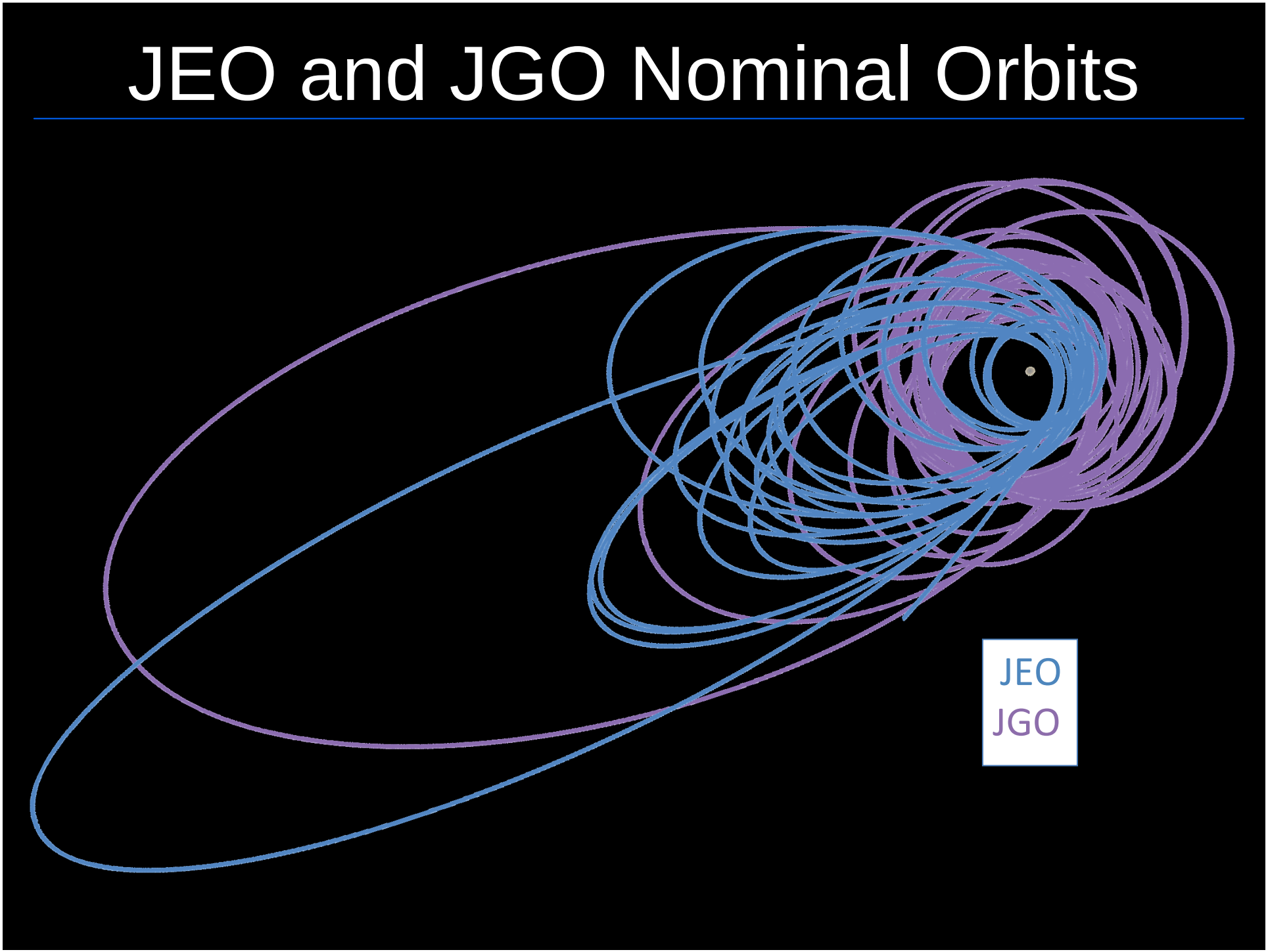


Optimum range for comparison of visible, thermal and compositional results

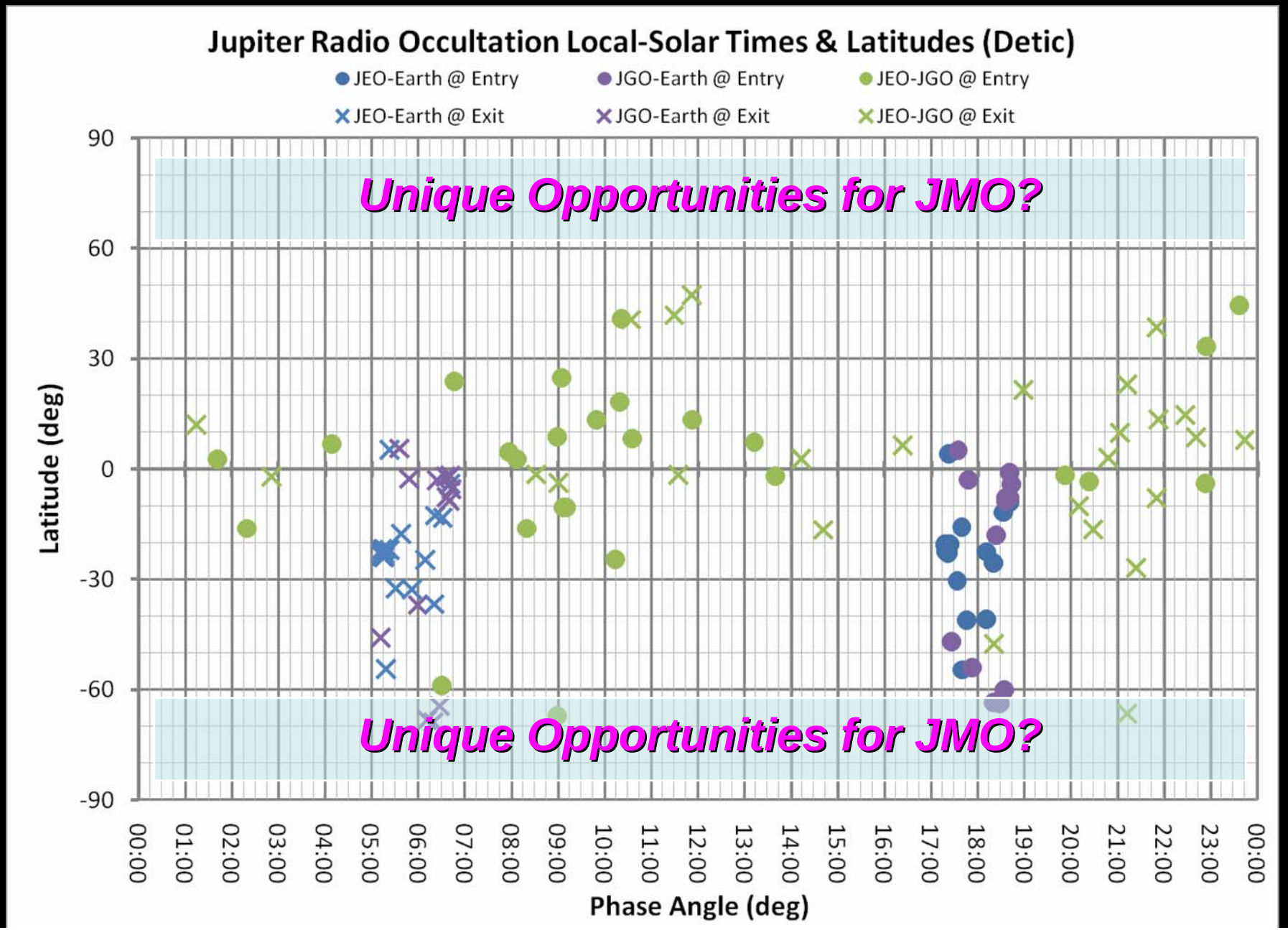
Spatial Resolution


Cumulative Time Spent at Varying Jupiter Phases
JEO
JGO
Time (Days)
168
140
112
84
56
28
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
More
Phase Angle (Degrees)
Aim for even sampling of phase angles for cloud scattering and composition studies.
Nightside for lightning studies
Dayside for cloud tracking

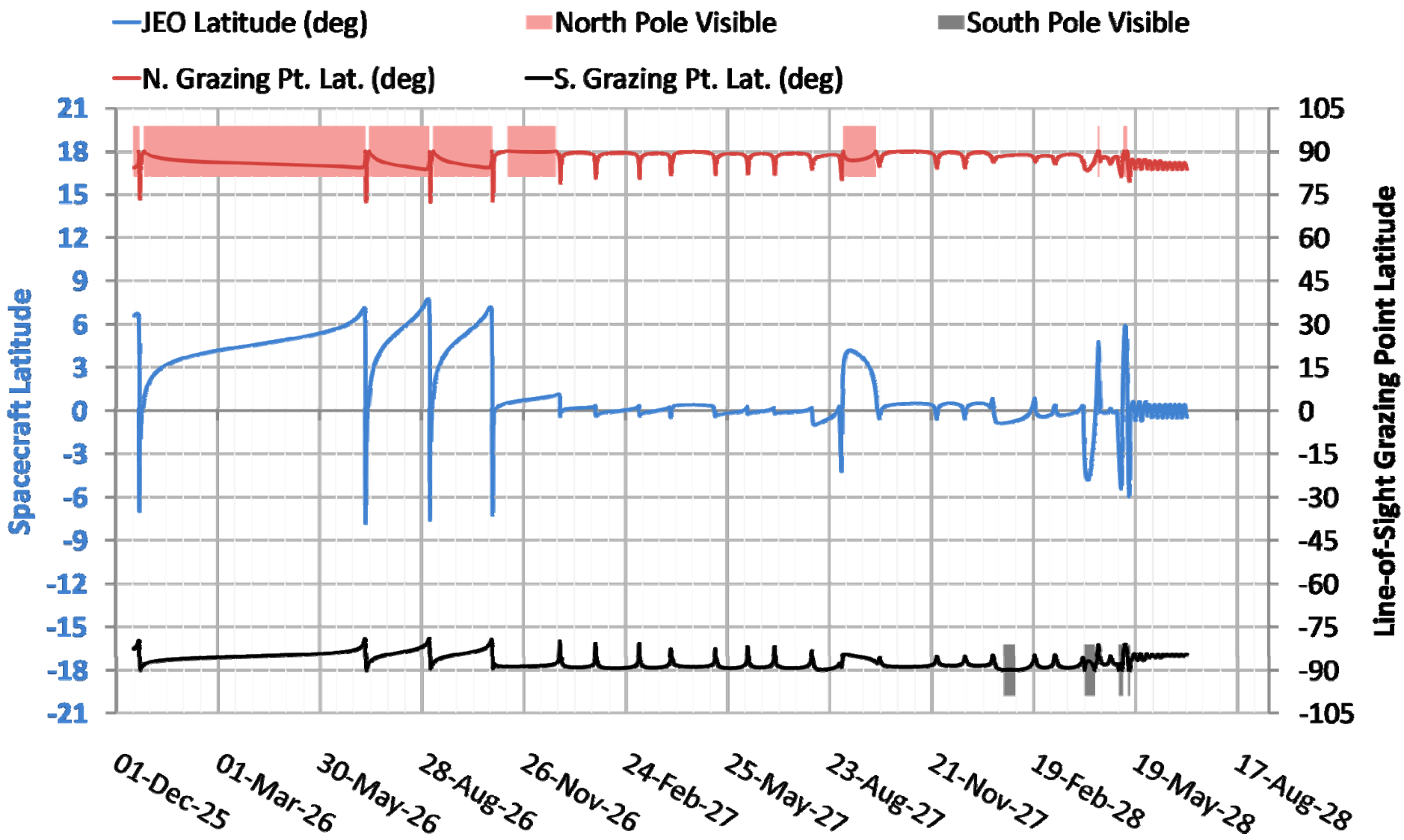
JEO and JGO Nominal Orbits



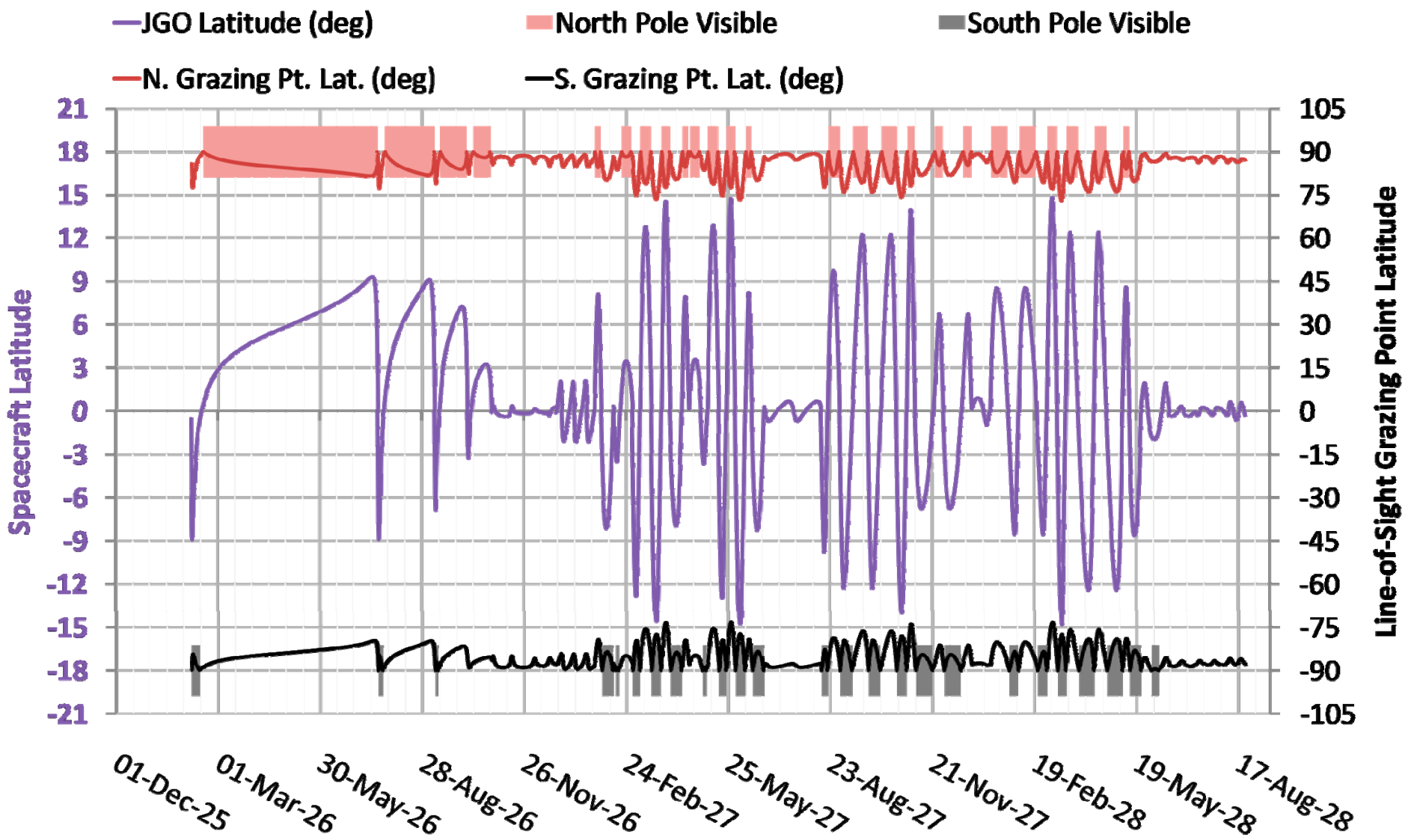
Radio Occultation – 2 Spacecraft



JEO Sub S/C Latitude: Polar Visibility

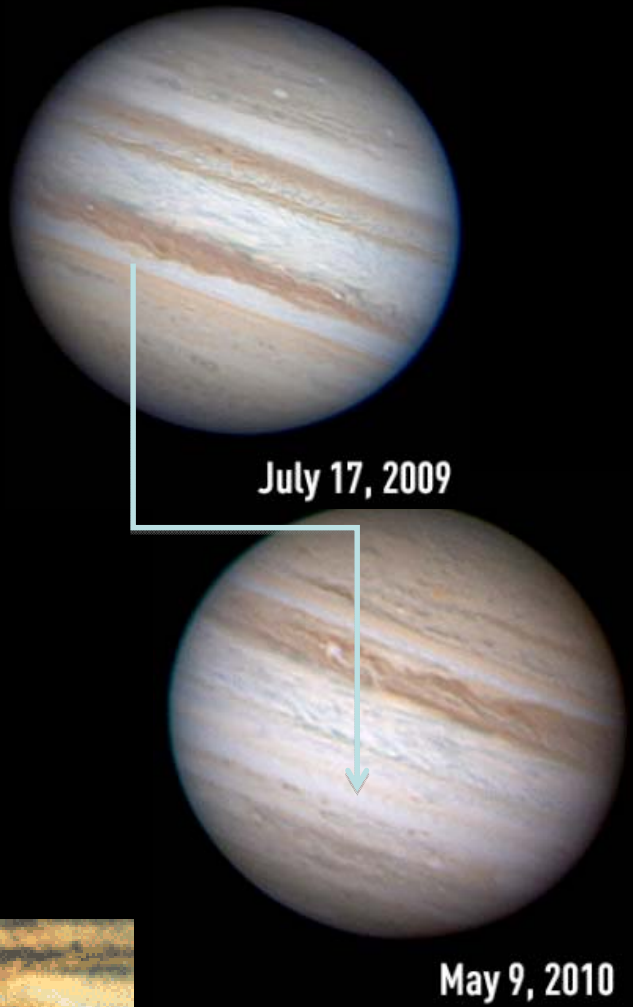


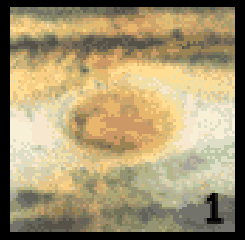
JGO Sub S/C Latitude: Polar Visibility



Science Example I: Climate Database

- Energy, momentum and material transport.
- High data capacity, long baseline and sophisticated instrumentation should permit frequent global maps of:
  - Material tracers (para-H_2, phosphine, hydrocarbons, hazes)
  - Cloud changes (NH_3 ice, H_2O ice).
  - Thermophysical properties (temperatures, potential vorticity).
  - Windspeeds at multiple levels.
  - Frequency distribution of lightning.
- Constantly evolving dynamic atmosphere:
  - Jets, waves, plumes, instabilities, upheavals, vortex interactions.
  - Origin, growth, redding and stability of large anticyclones.
- Search for relationships between variables.

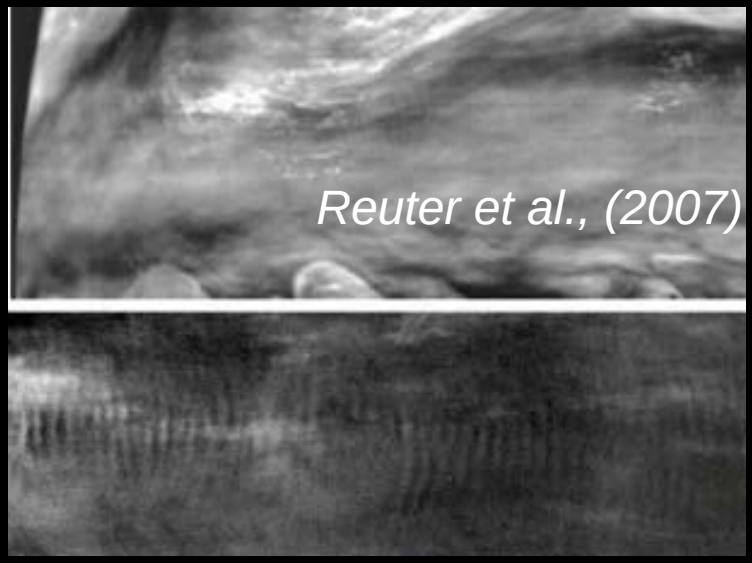




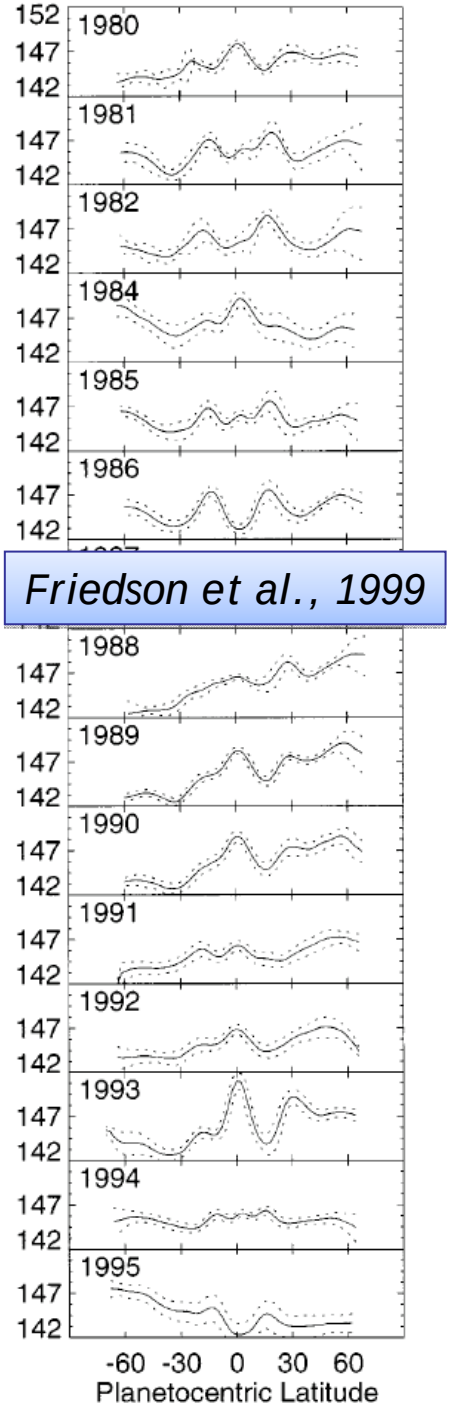
GRS 1992-1999

II: Waves, Periodicity & Coupling

- Waves permit exploration of fundamental fluid properties and meteorology, e.g.
  - Origin of instabilities and mesoscale wave production.
  - Physics of the Quasi-Quadrennial Oscillation and influence on equatorial dynamics
- Vertical waves couple different atmospheric layers
  - Origin of thermospheric energy crisis?



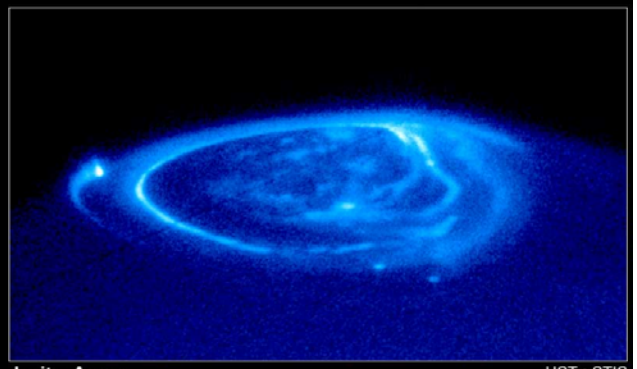
- Understand non-seasonal periodicities
  - Causes of upheavals: fading and revival sequences
  - Changing turbulence surrounding GRS
- Acoustic Waves sample density gradients of deep interior

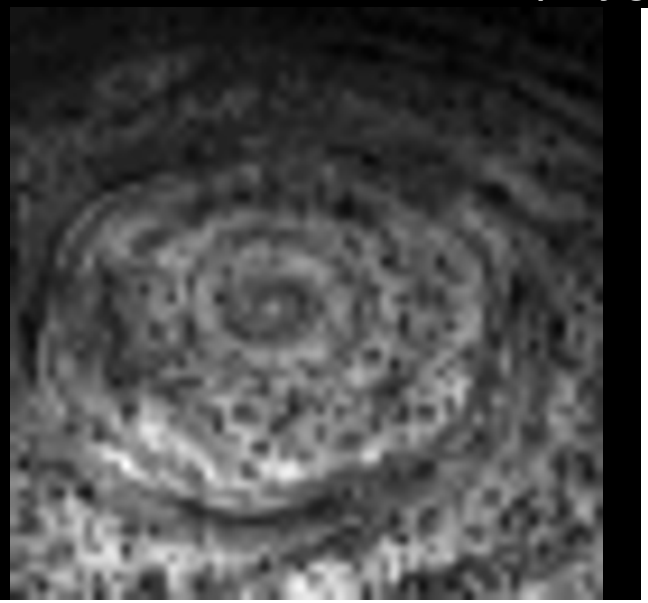


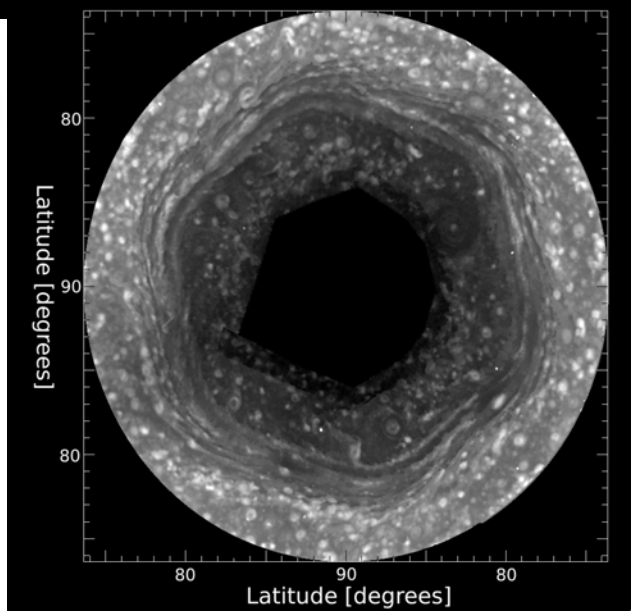
Friedson et al., 1999

III: Polar Processes

- Relationship between middle atmosphere and charged particles of aurora/magnetosphere
  - Unique polar chemistry, energy sources?
- Nature of the polar hazes, origins of asymmetries, aerosol production mechanisms.
- Understand the UV ‘dark spots’ at high altitudes
- Meridional transport of energy and chemicals from equator to poles.
  - Polar vortices and polygonal waves like Saturn?



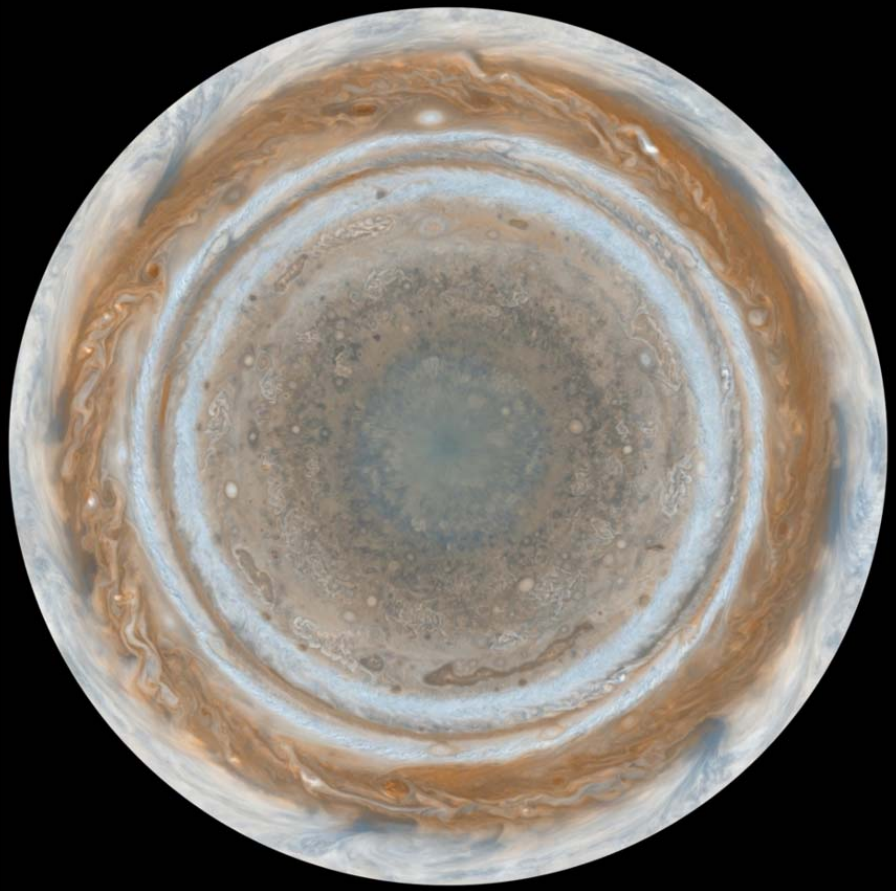


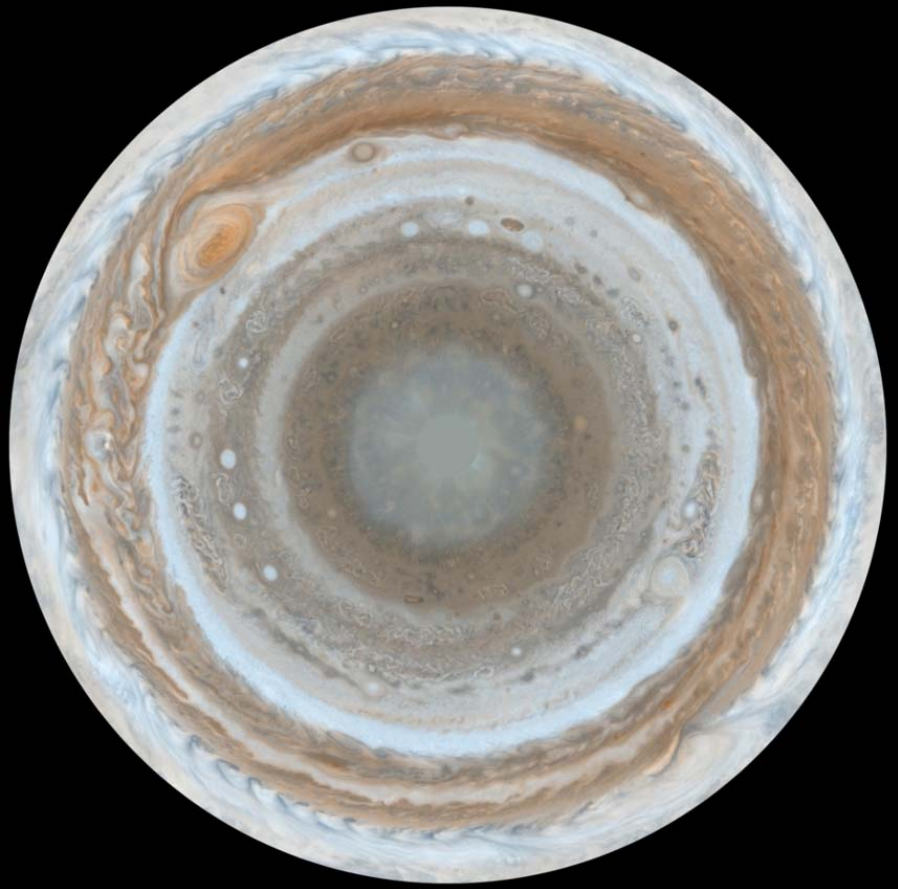


Jupiter's Poles: Unexplored Frontier

North Pole

South Pole





Jupiter's Poles: Unexplored Frontier

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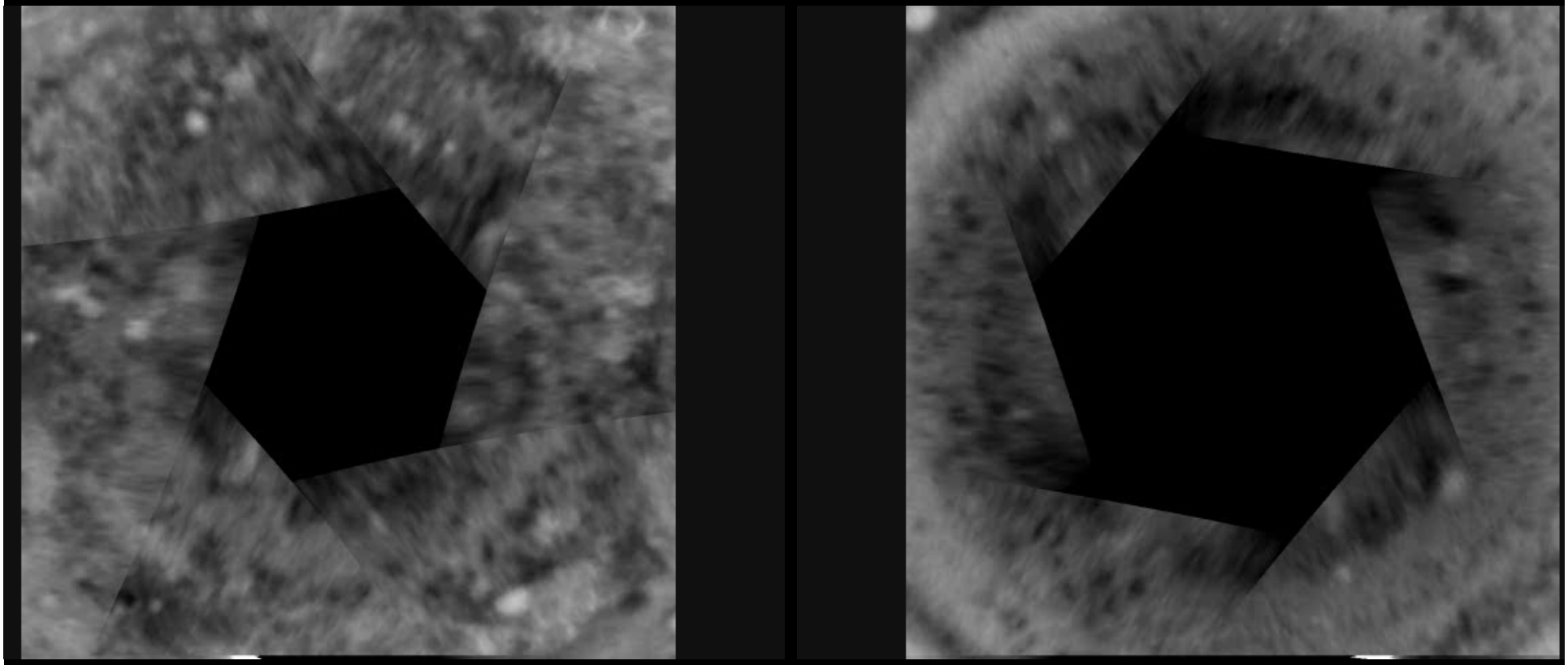
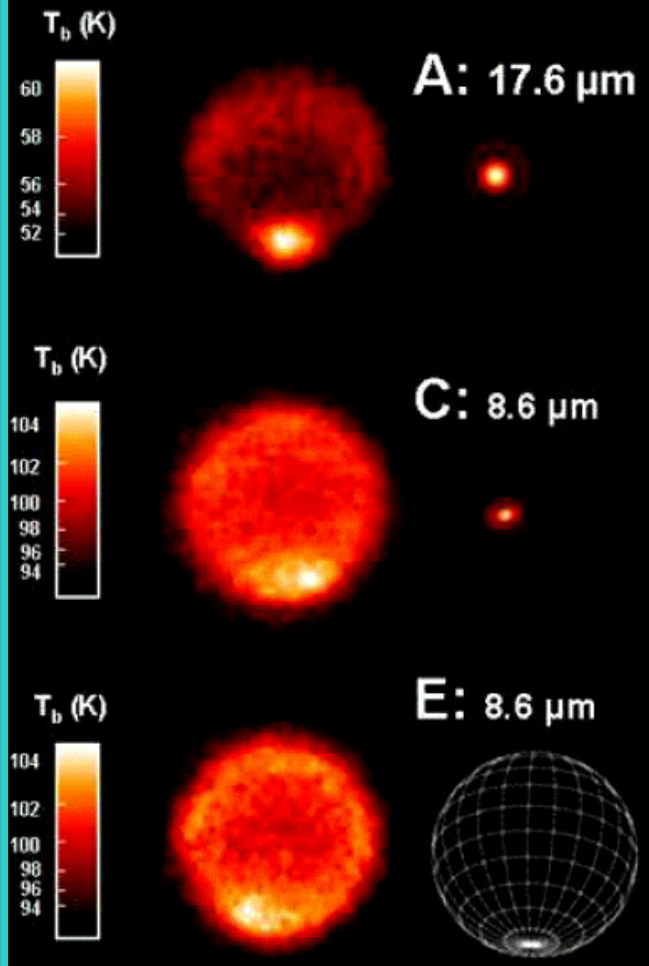
South Pole



Sun et al. (unpublished ISS Data)

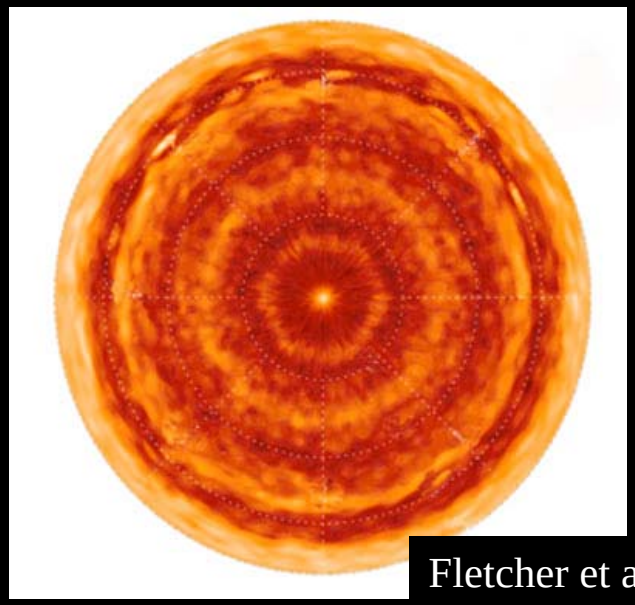
Hot Poles of Giant Planets

Neptune

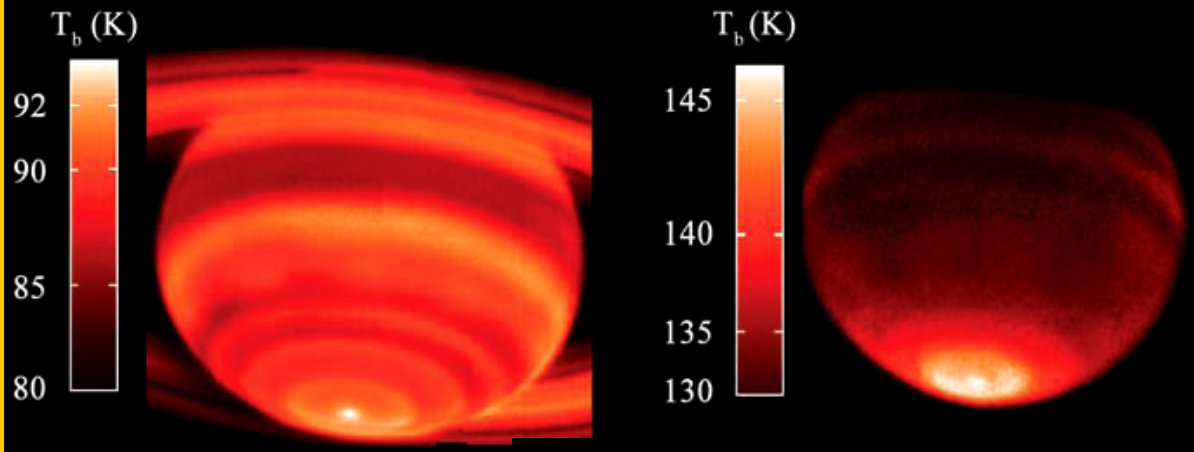


Orton et al. 2007

Saturn

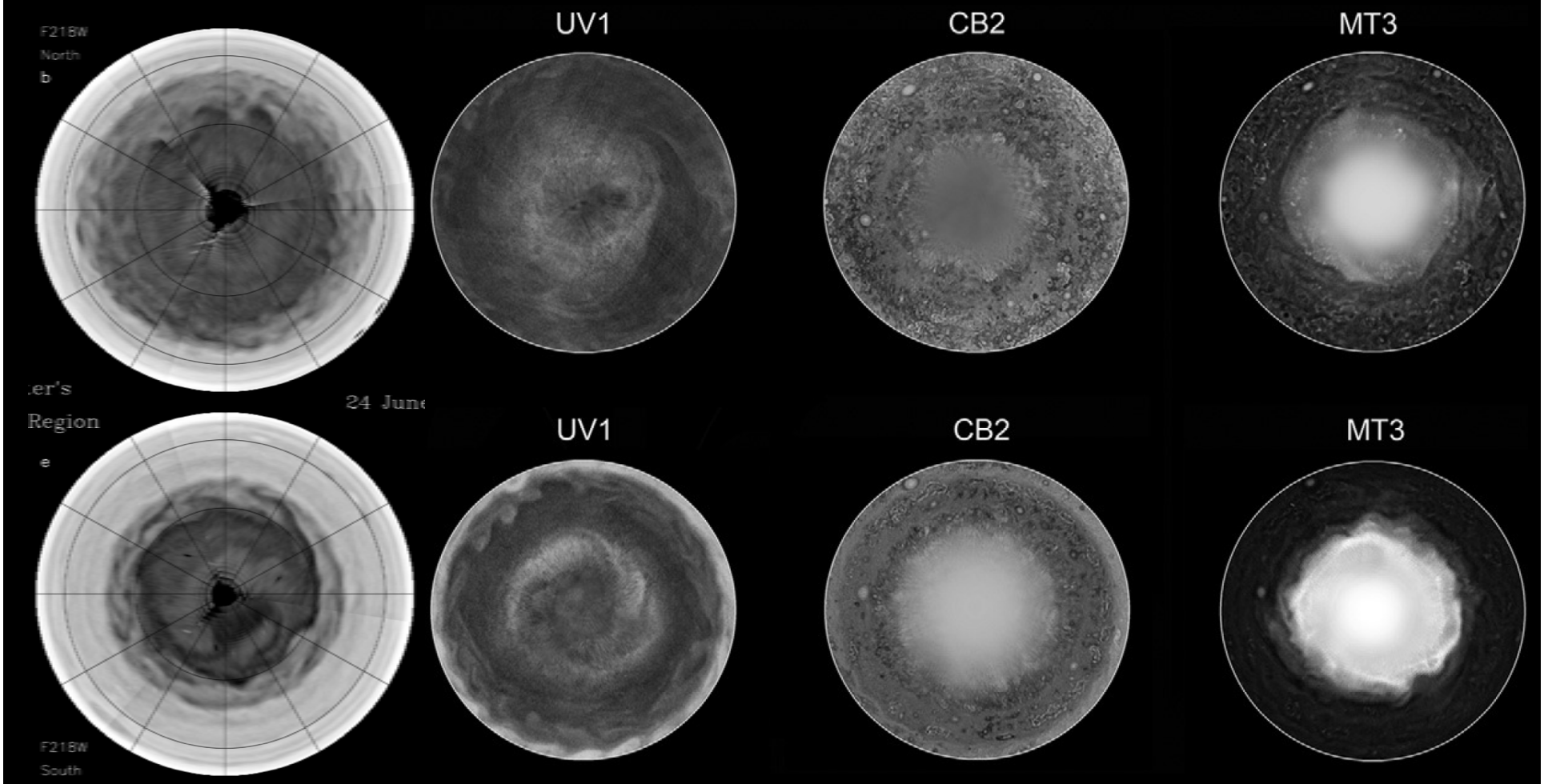


Fletcher et al. 2007



Orton and Yanamandra-Fischer 2005

Polar Waves of Jupiter



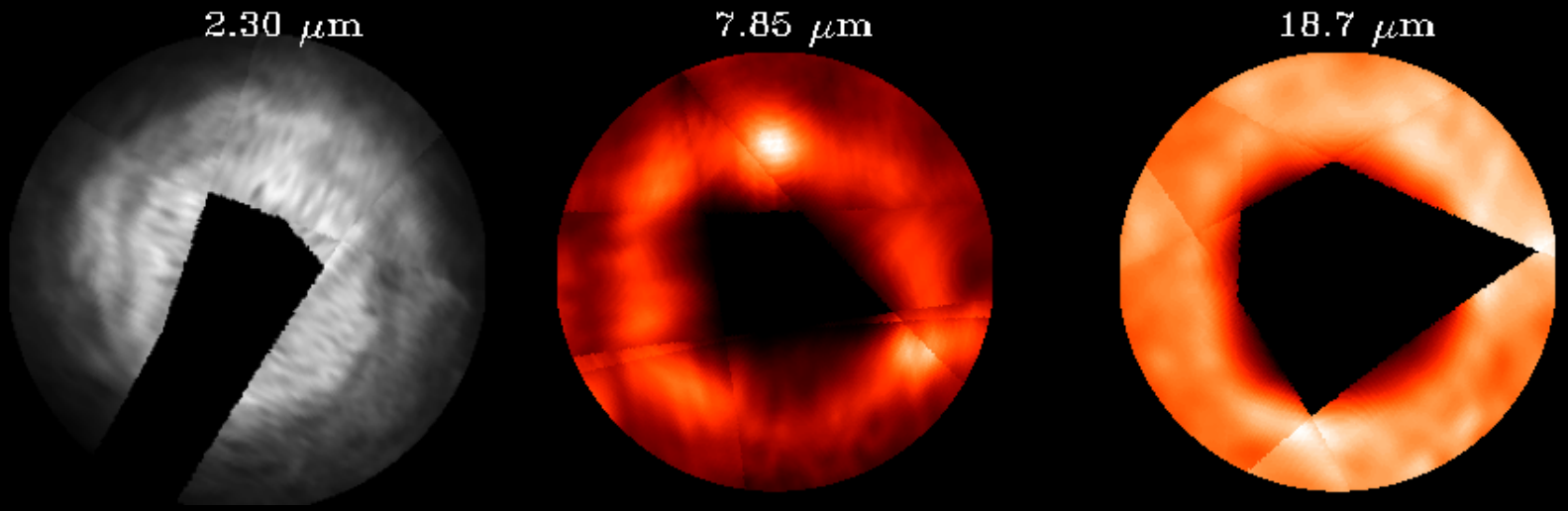
Polar Hood in UV
Vincent et al (2000)

Polar Wave in UV – Near IR
Barrado-Izagirre (2008)

Polar High-Altitude Spots

2000 DECEMBER 29–30

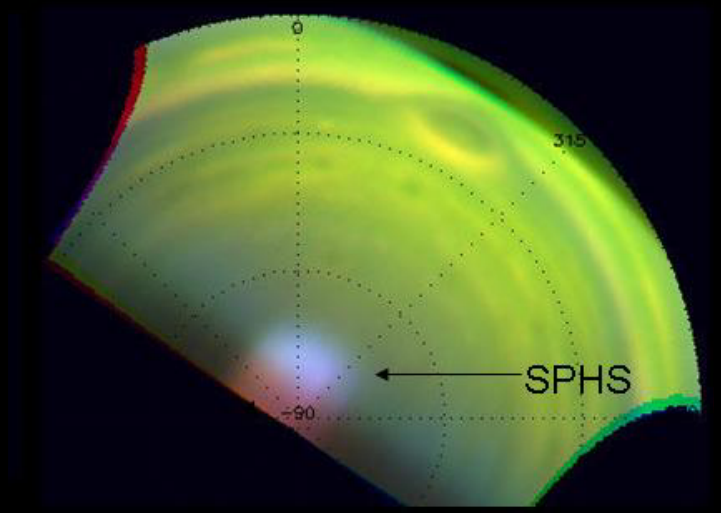
Orton (personal communication)



Feb. 12, 2007: South Polar Hot Spot

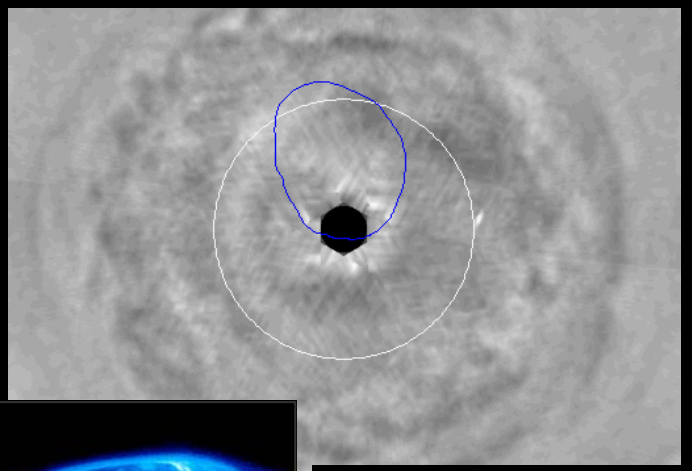
Orton (personal communication)

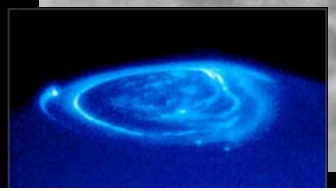
0° longitude



UV Dark Spot

http://photojournal.jpl.nasa.gov/catalog/PIA03473





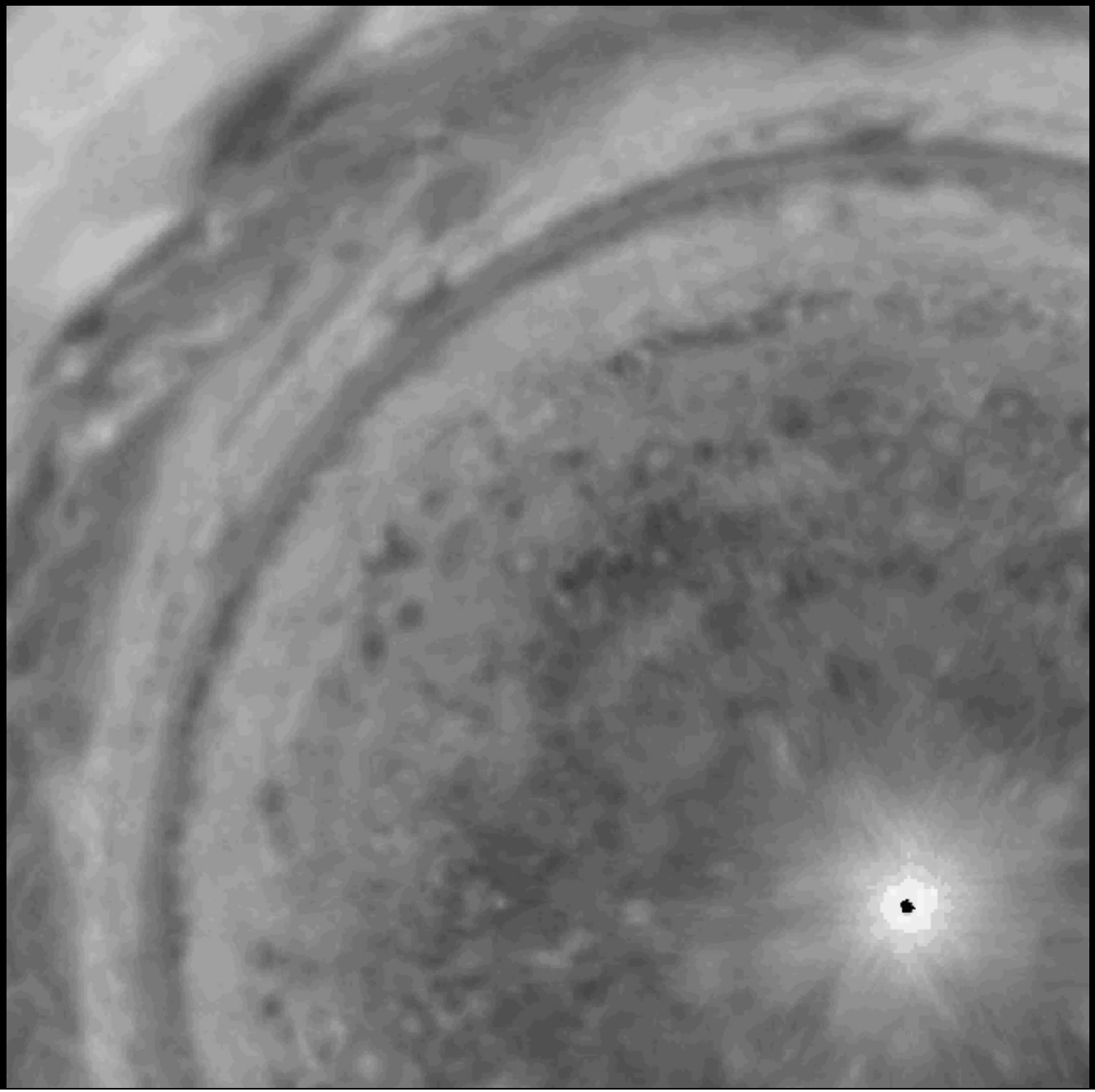
Blue Circle = Persistent Auroral Zone

While Circle = 60degN

Jupiter Aurora

Saturn Aurora (Cassini View)

Polar Turbulence

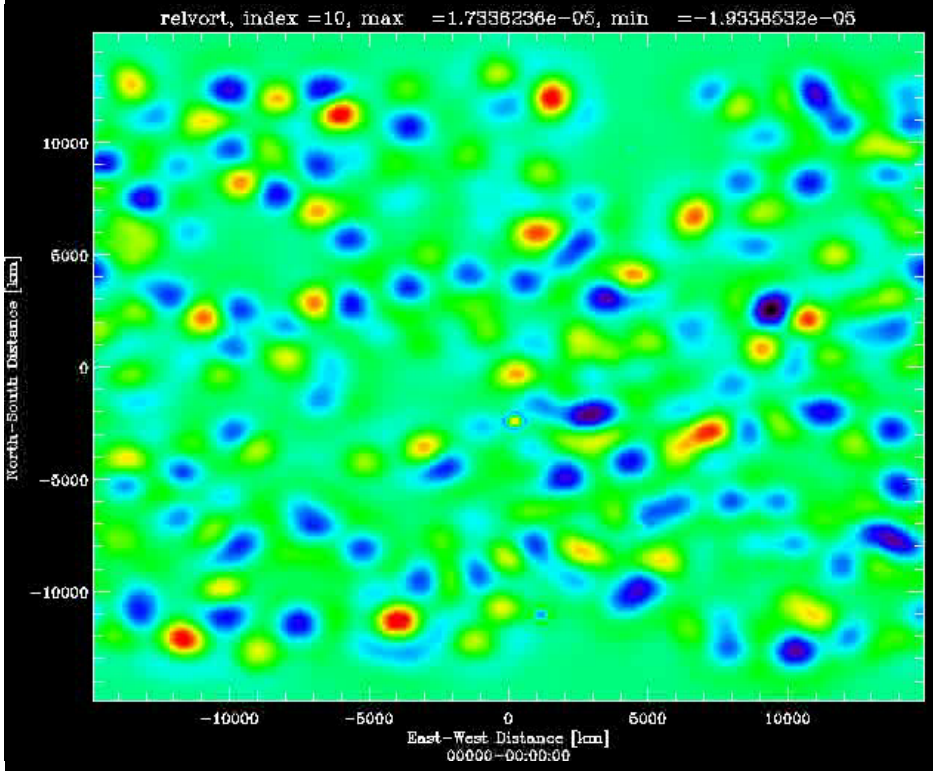


Three Dynamic Regimes

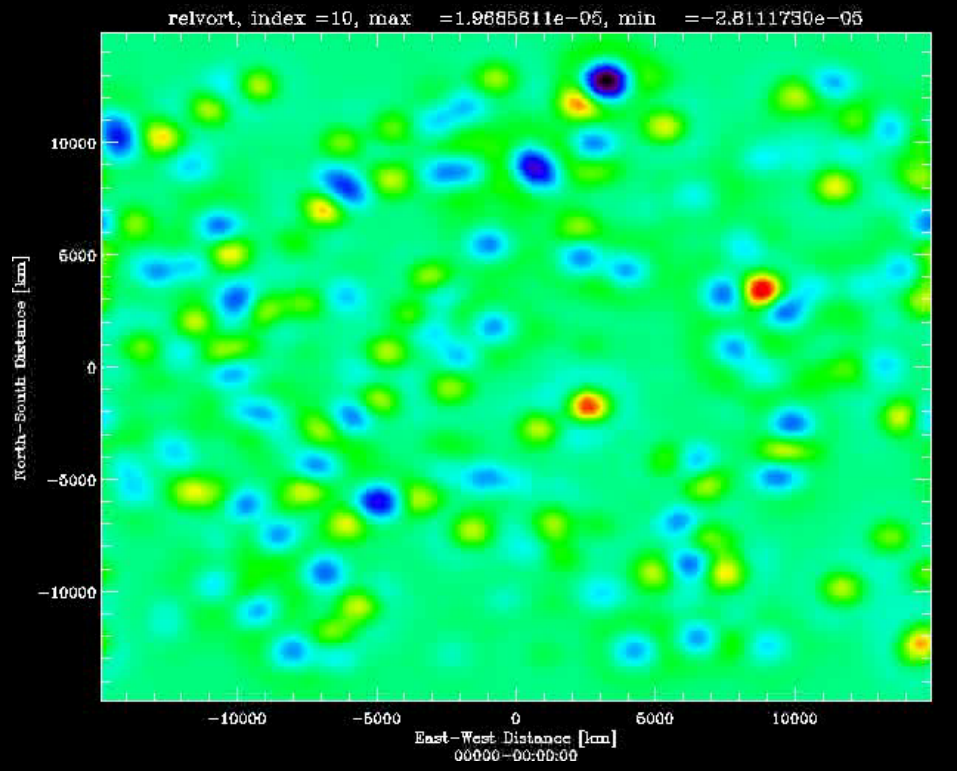
- **Equatorial Jet**
- **Mid-Latitude Mixed Jets + Vortices**
- **Polar Turbulence**

Low-lat Jets → Polar Turbulence

Low-Latitude Condition



High-Latitude Condition



Sayanagi et al (2008)

Conclusions

- **Community Input developed Three Science Themes**
  - Three themes encompass 11 investigations, designed to address cross-disciplinary, 'big picture' science.
  - Complement and extend Juno/Galileo results, address Cosmic Vision/Decadal Survey questions.
- **ESJM offers considerable potential for Jupiter science:**
  - Long baseline for regular temporal monitoring observations.
  - Wide spectral range.
  - Dual spacecraft synergies.
  - Data volume capability for global 4D mapping from the upper troposphere to the thermosphere.

Atmospheres Objectives:

A. Dynamics and Circulation

B. Composition and Chemistry

C. Vertical Structure

- **Addresses unanswered, cross-disciplinary questions about gas giant phenomena and processes in the outer solar system.**
  - Gas Giant Archetype
  - Planetary system template
  - Paradigm for Exoplanets
  - Laboratory for fundamental physical processes.

JMO Participation in EJSM

Imaging Science by JMO can nicely complement the current JEO + JGO plan

- **Current EJSM = JEO + JGO plans do not have extensive polar imaging science coverage**
- **Day-side observation has further room for improvement**
- **Imaging Science Topics enabled by high-inclination orbit include:**
  - **Polar Waves/Atmospheric Dynamics**
  - **Vortex Life-Cycles**
  - **Polar Hood and North/South Asymmetry**
  - **Auroras and Magnetospheric Connection**

Atmospheres Objectives:

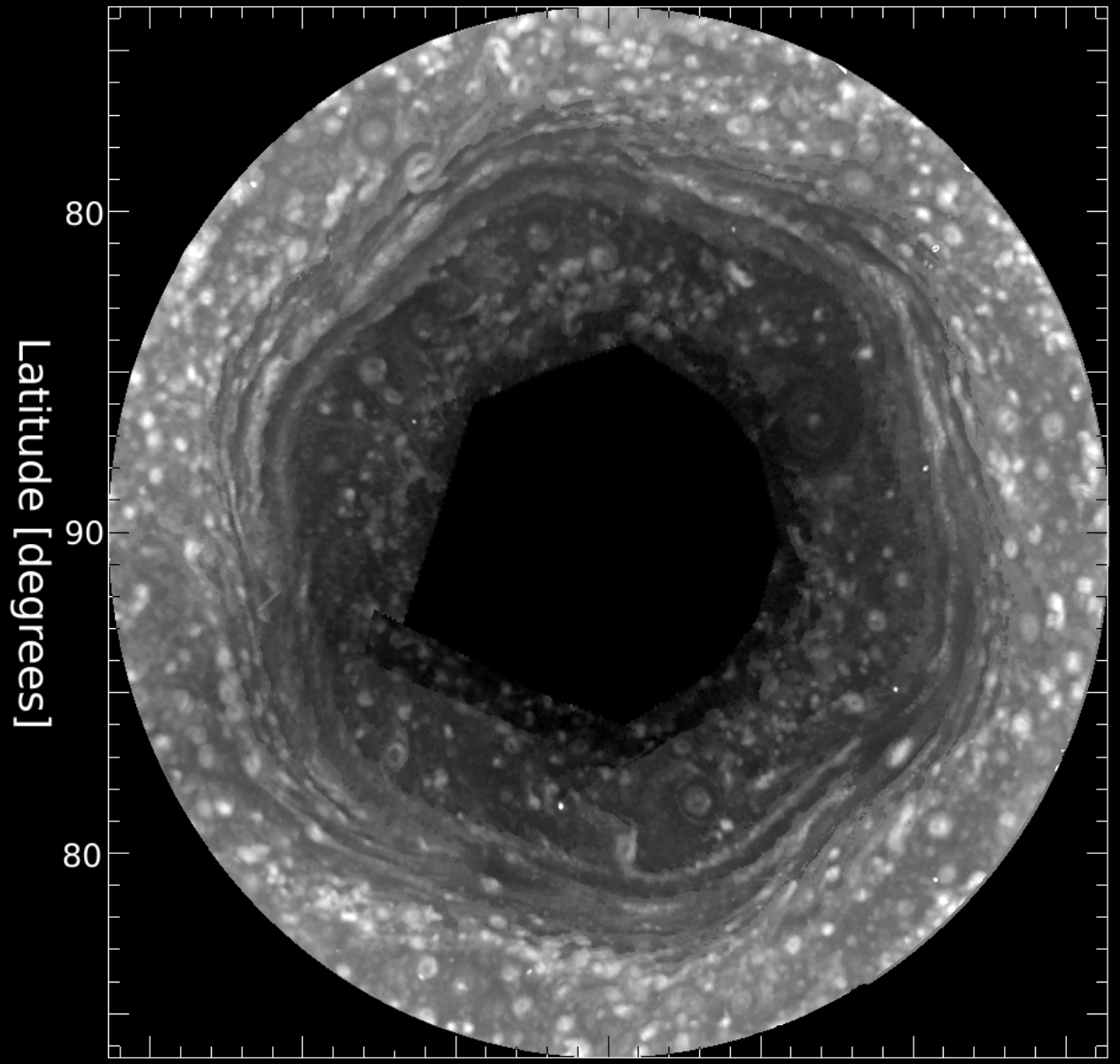
A. Dynamics and Circulation

B. Composition and Chemistry

C. Vertical Structure

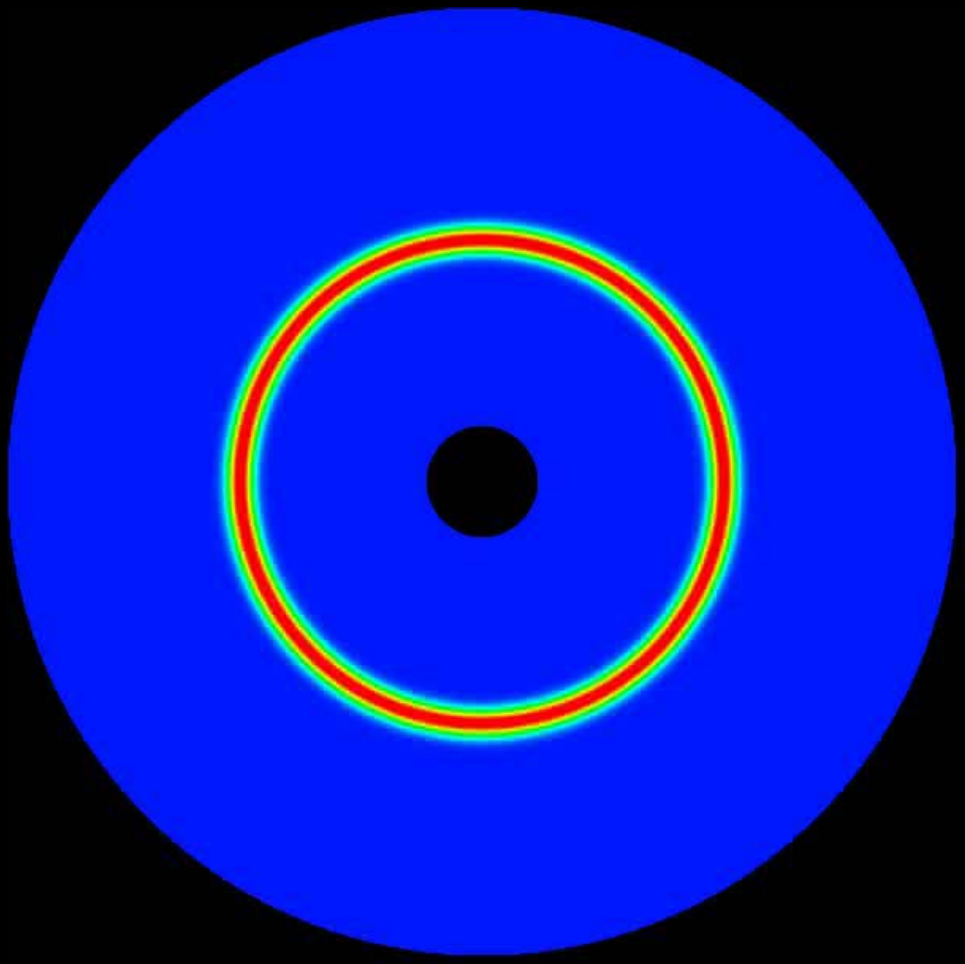
A little bit about my own recent work

Saturn's Polar Hexagon

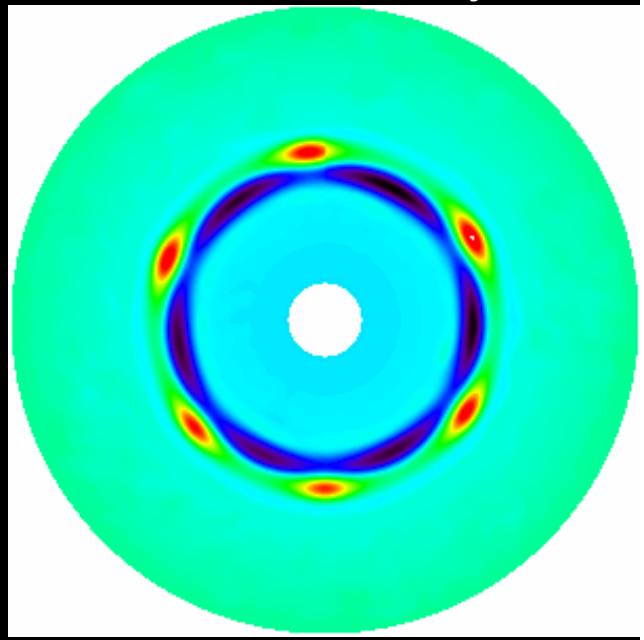


Hexagon: Seeing is Believing

Eastward
Wind Speed
in m/s



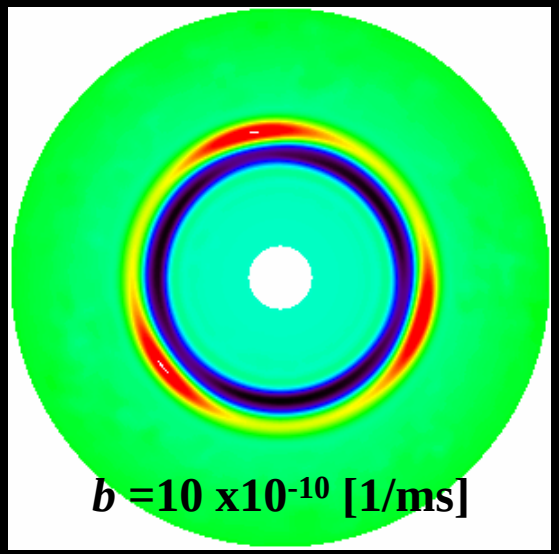
Relative Vorticity



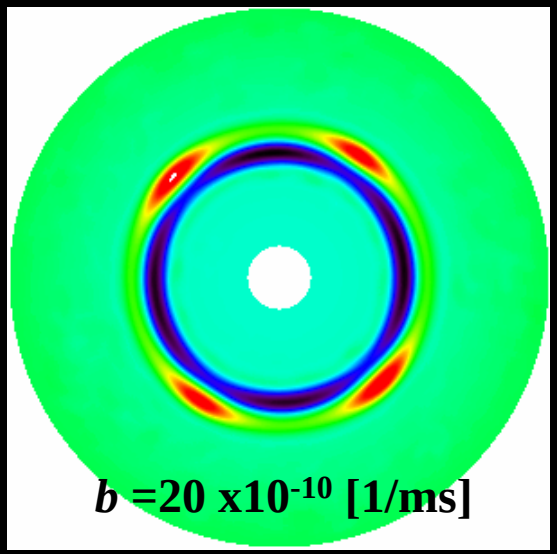
Red = Anticyclonic
Blue = Cyclonic
Green = Zero

Morales-Juberias et al.
(under review)

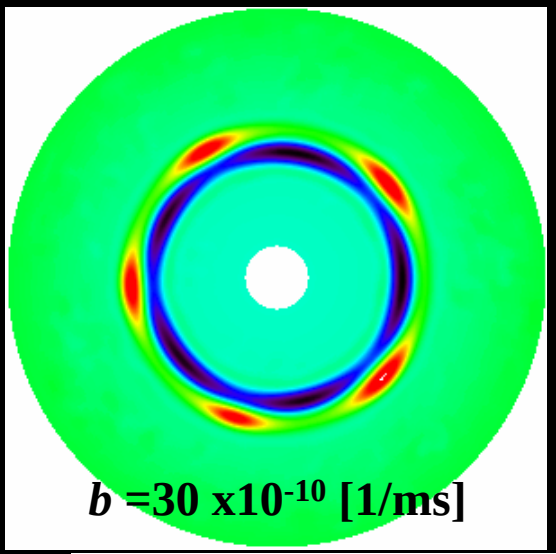
Jet Width controls the Dominant Wavenumber



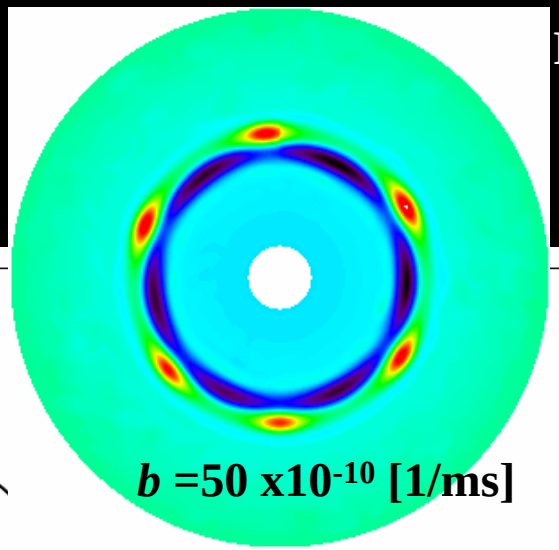
b =10 x10^{-10} [1/ms]



b =20 x10^{-10} [1/ms]

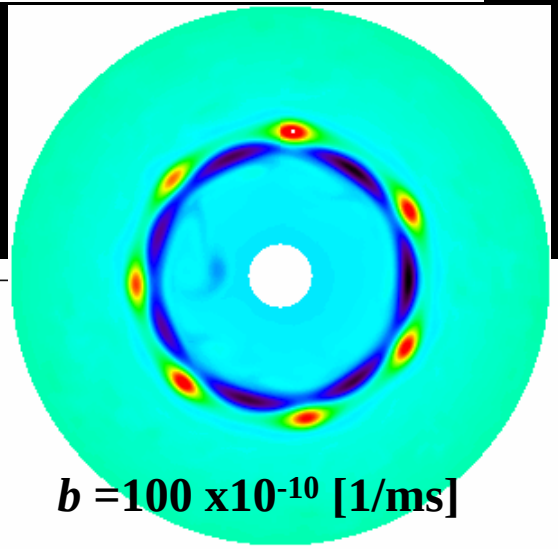


b =30 x10^{-10} [1/ms]



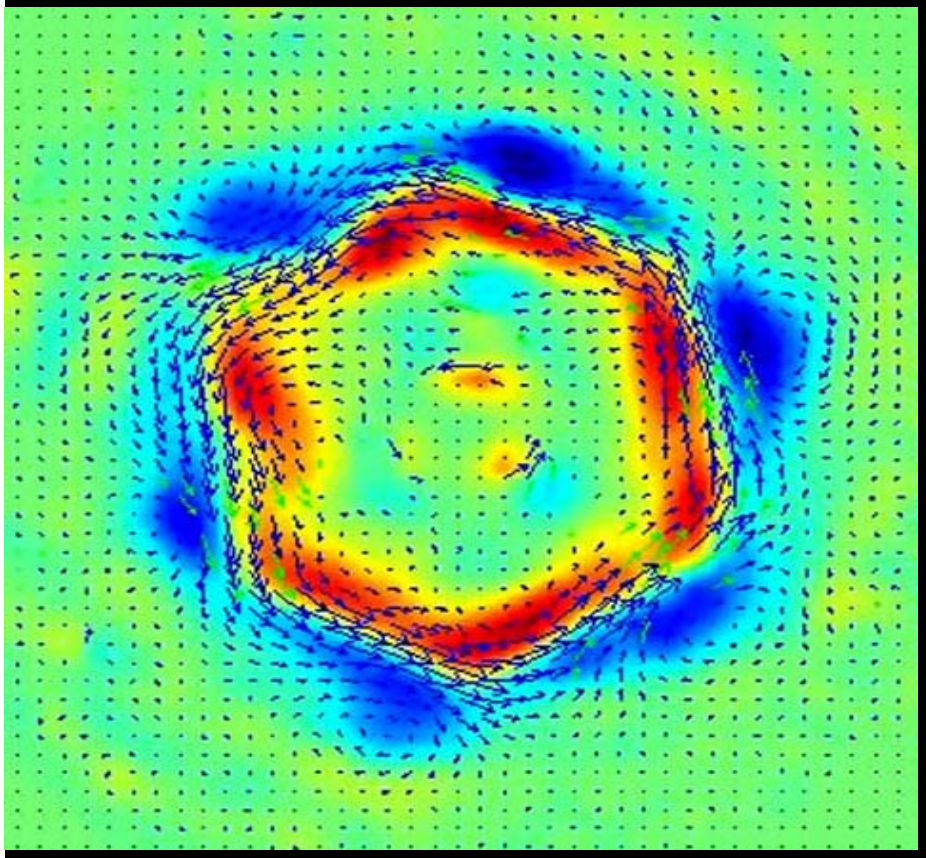
b =50 x10^{-10} [1/ms]

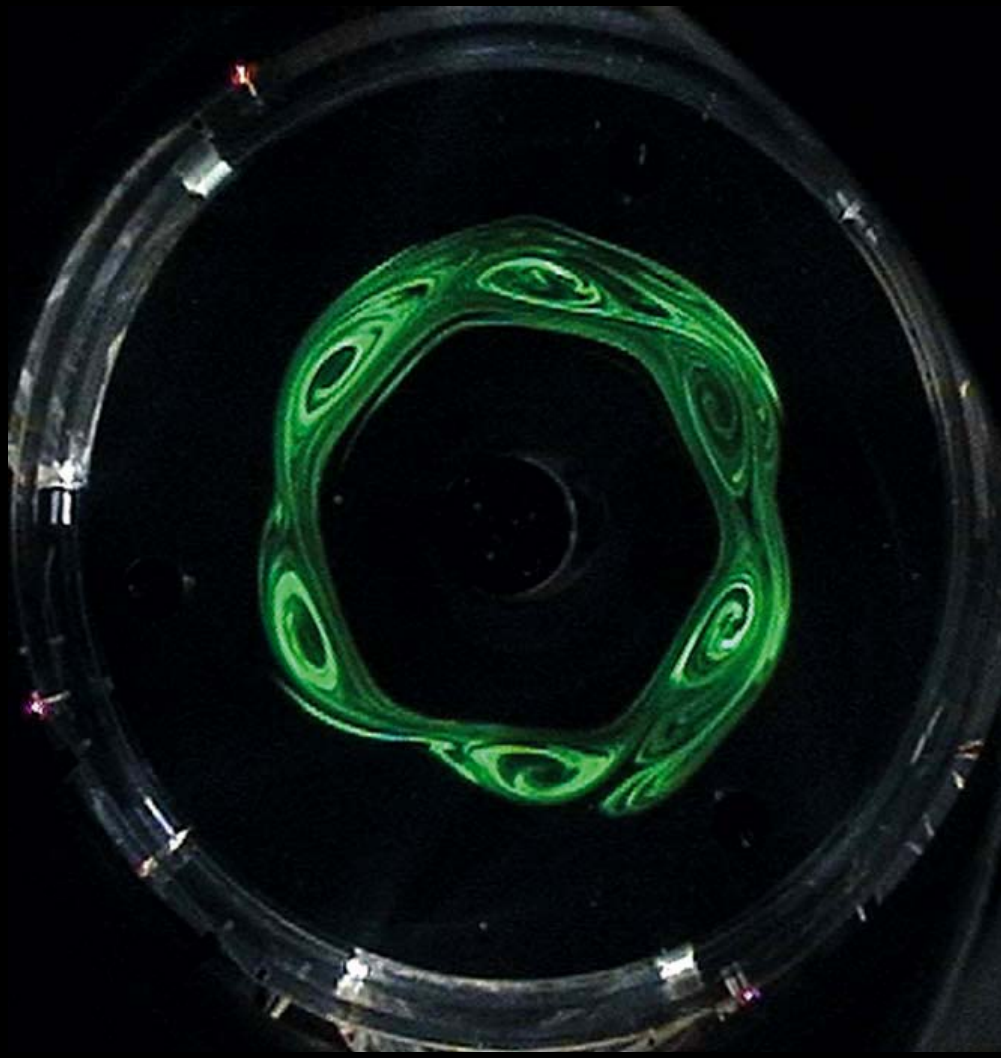
Relative Vorticity:
Red = Anticyclonic
Blue = Cyclonic
Green = Zero



b =100 x10^{-10} [1/ms]

Comparison to Lab Experiment Study

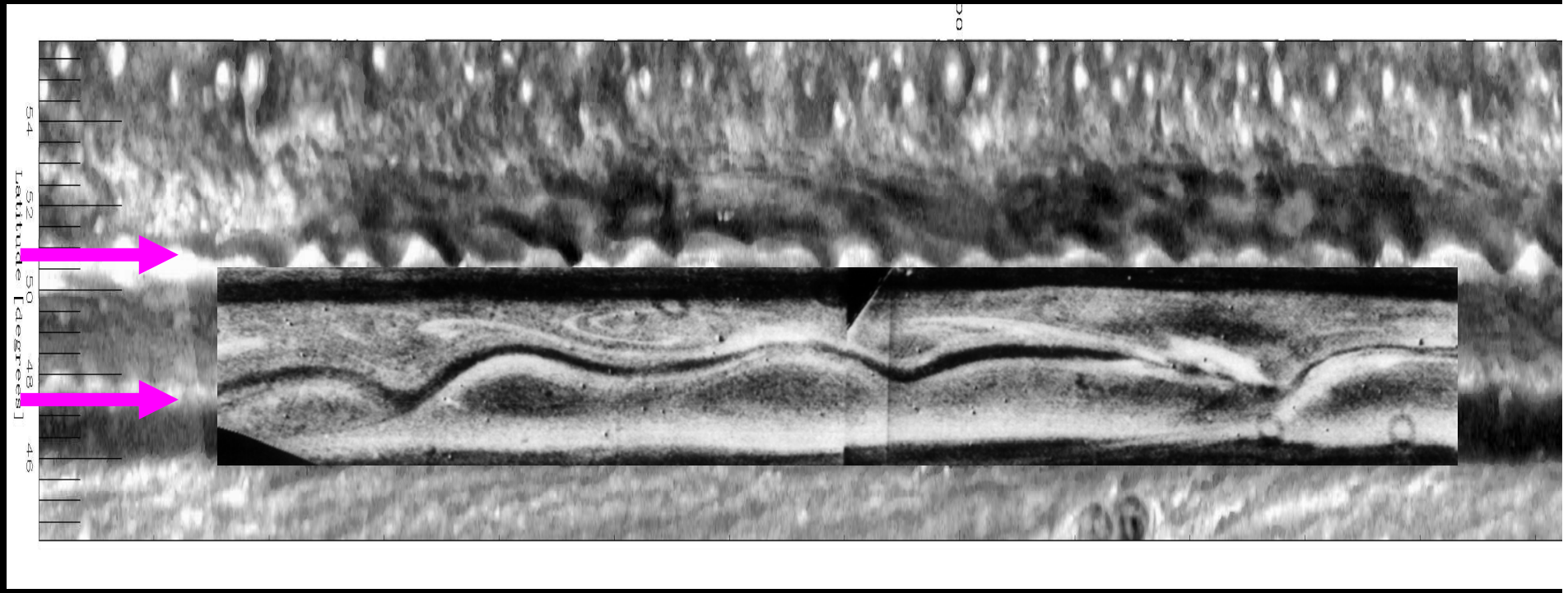




Barbosa-Aguiar et al. (2010)

Saturn's "Ribbon" Wave

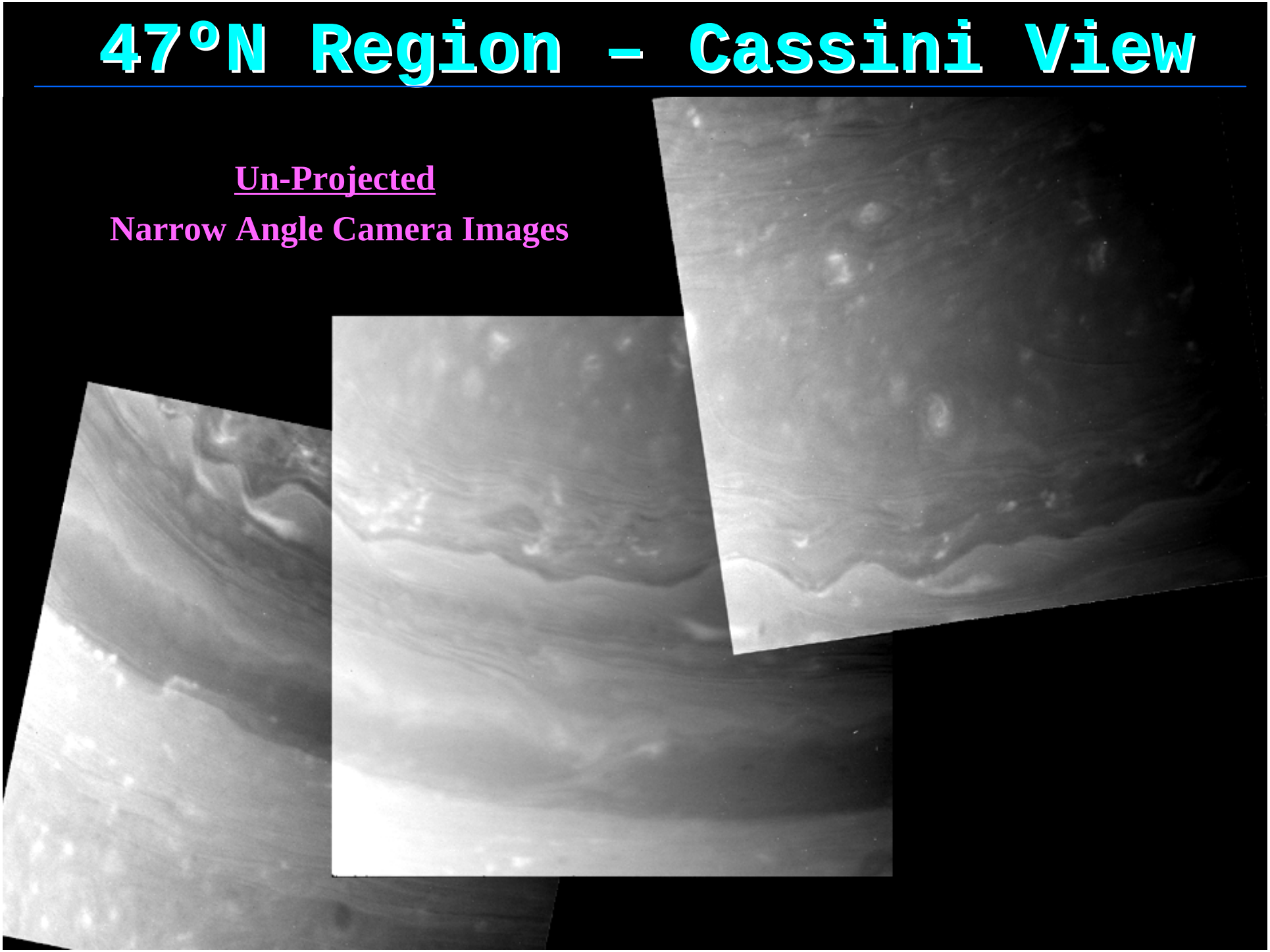
Wavy Feature at New Latitude (~51ºN, 4000-5000 km wavelength)



47°N Region – Cassini View

Un-Projected

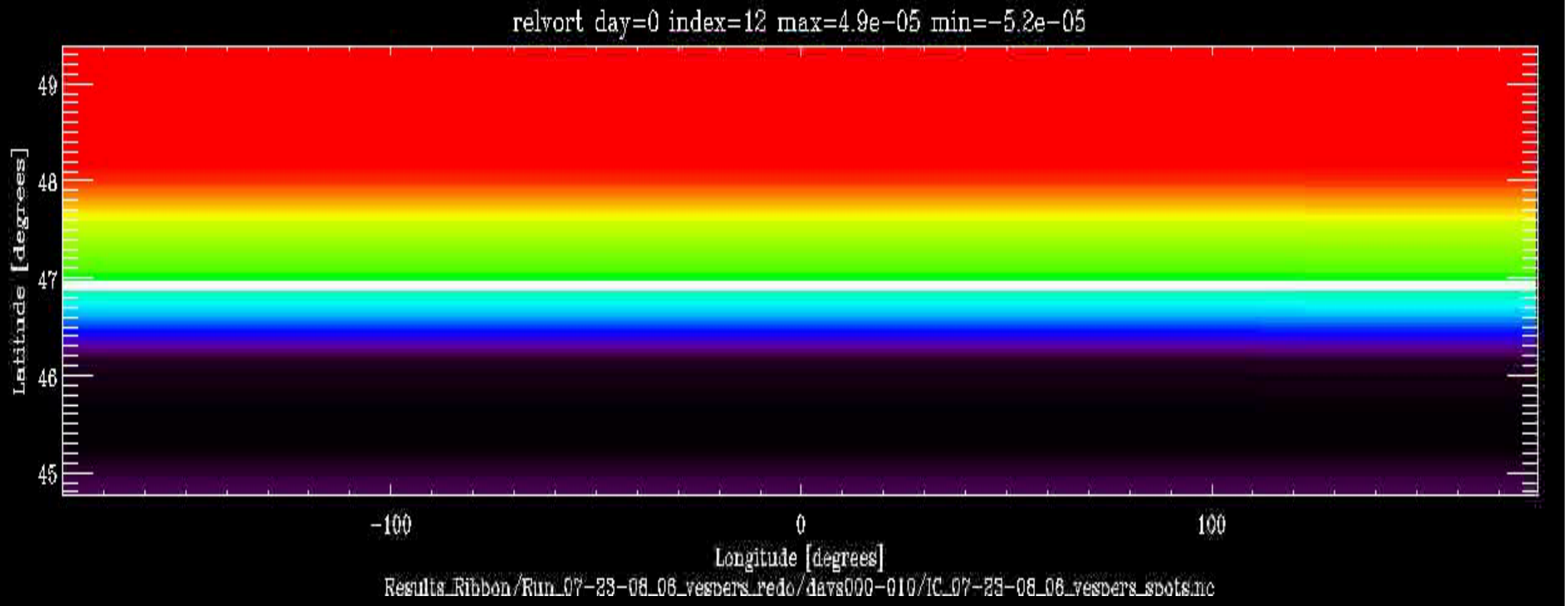
Narrow Angle Camera Images



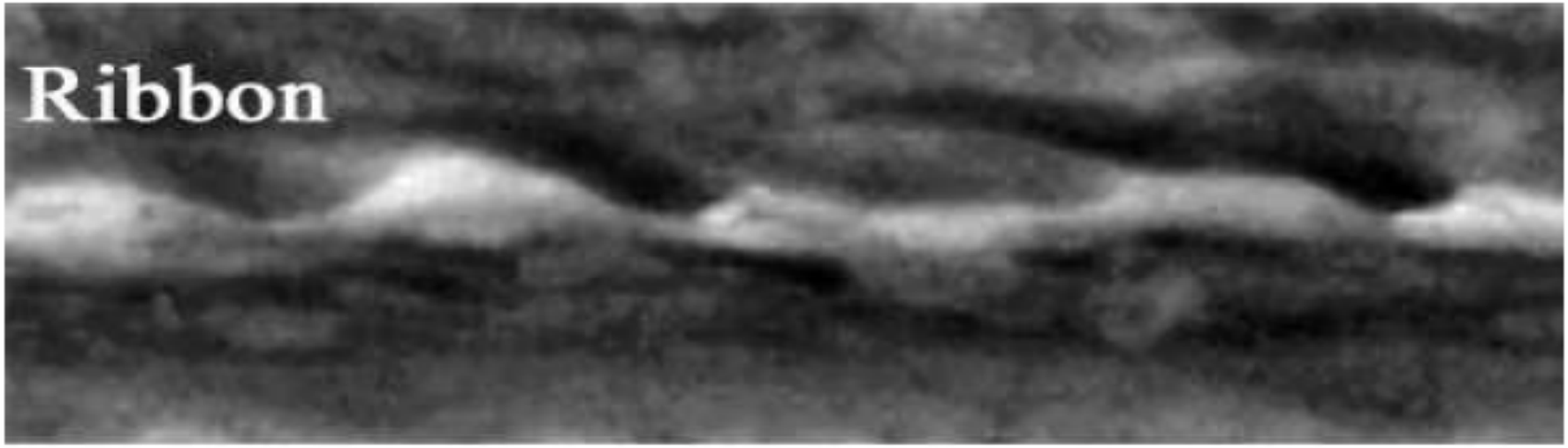
Ribbon Simulation

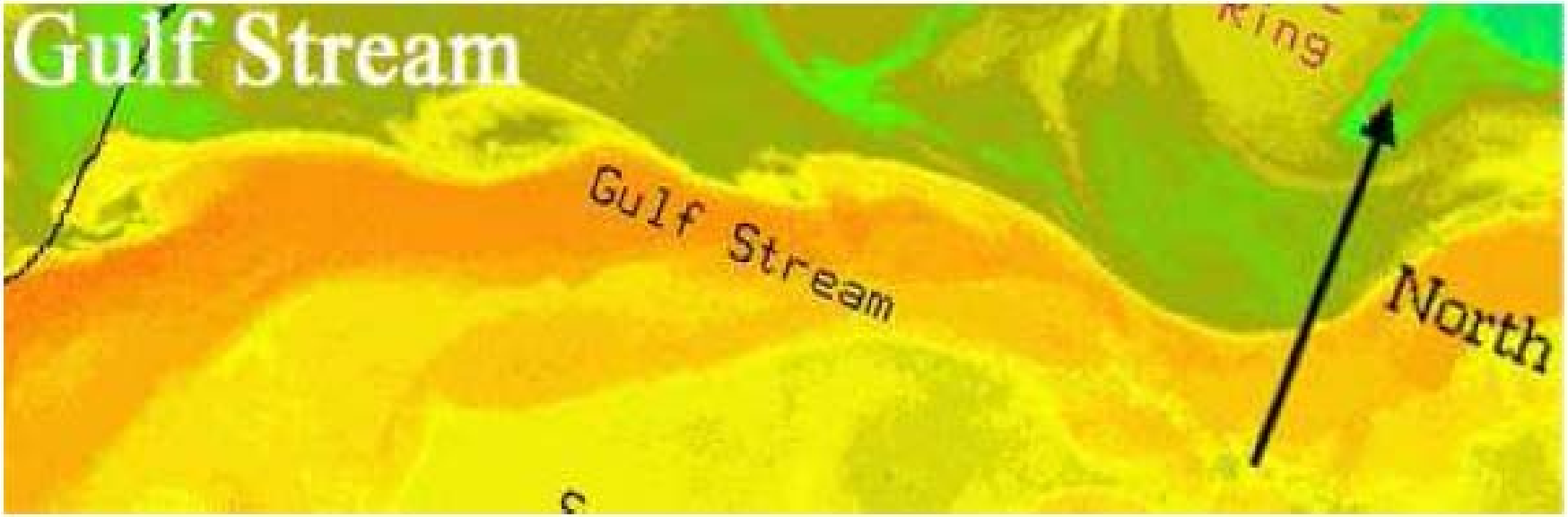
Relative Vorticity at the 100-mbar level

White Line traces the velocity peak of the 47degN jet



Comparison with Gulfstream Meandering





Jupiter Atmospheric Science Goals

1. **Chemical Composition** — In-situ Sampling, Spectroscopy
2. **Thermal Structure** — Radio Occultation, In-situ, Multi-wavelength Imaging
3. **Nature of Cloud, Haze, Aerosols, Their Layering** — In-situ, Multi-wavelength Imaging
4. **Radiative Energy Balance** — In-situ, Multi-wavelength Imaging, Bolometer
5. **Atmospheric Dynamics** — In-situ, (Multi-wavelength) Imaging