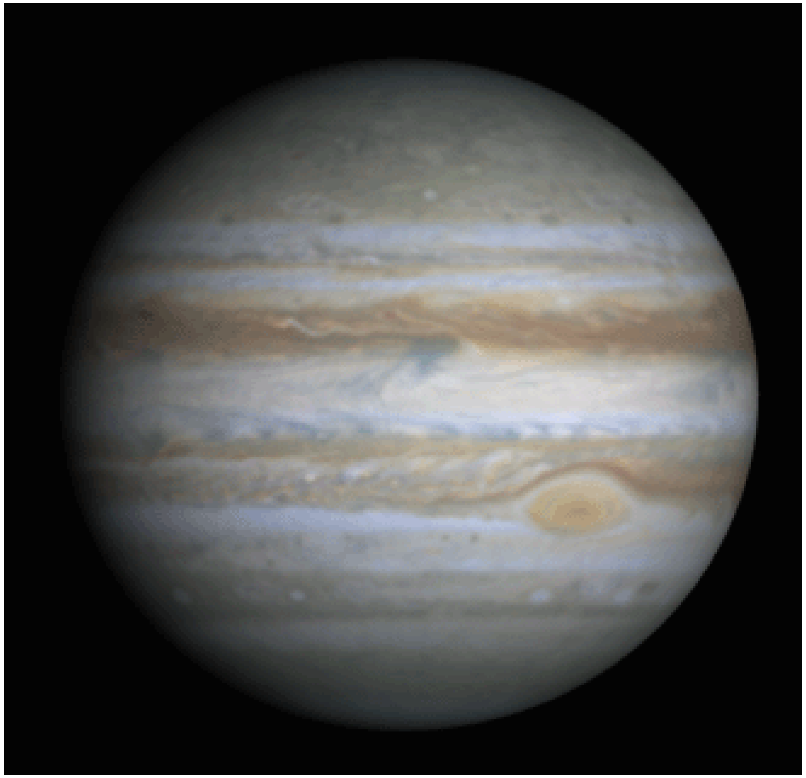
OUTLINE

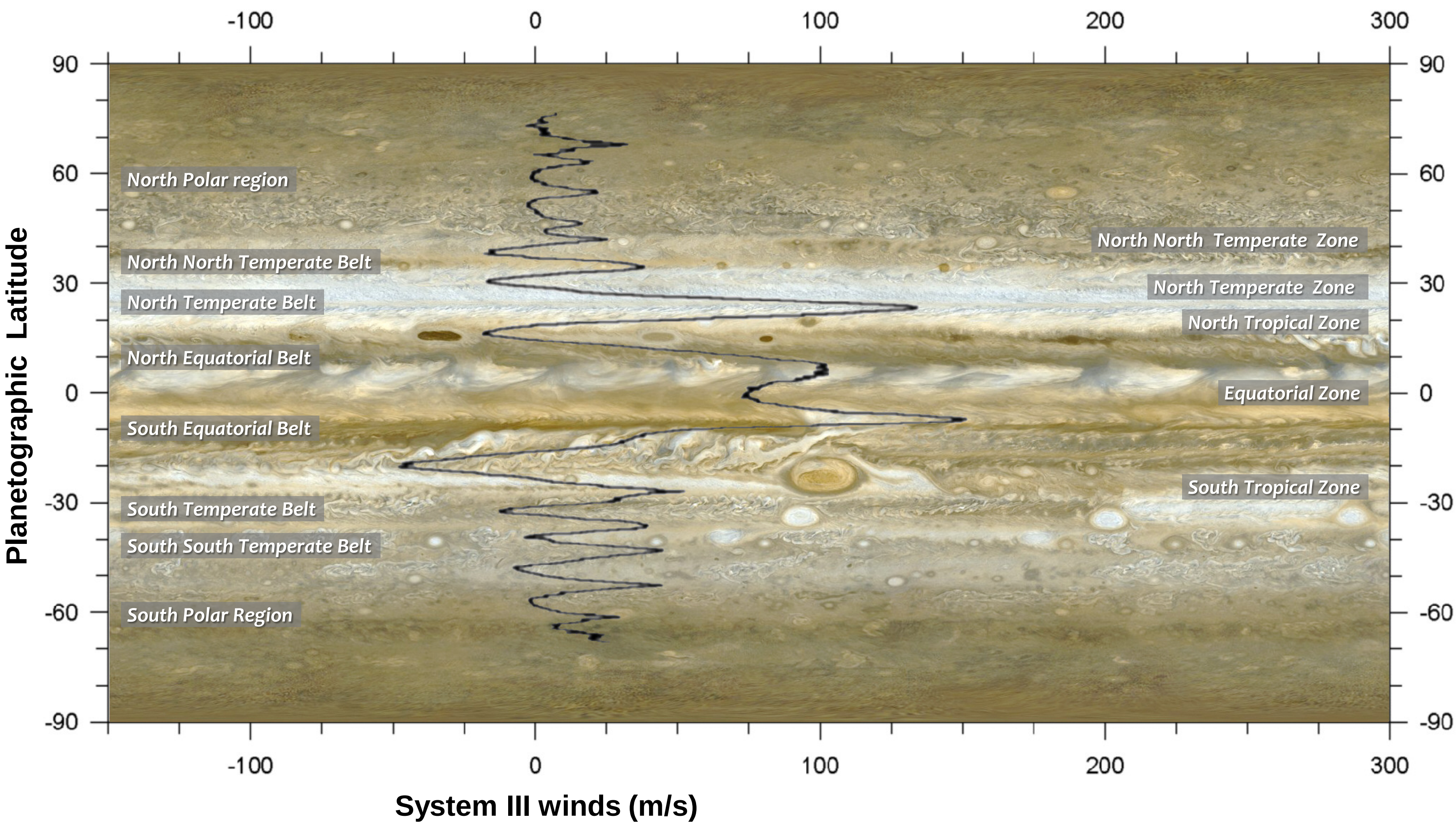
- I. Bands and winds
- II. Ovals: Anticyclones & Cyclones
- III. Convective storms & planetary-scale disturbances
- IV. Equatorial features
- V. Polar Phenomena

- VI. Observational capabilities at UPV/EHU



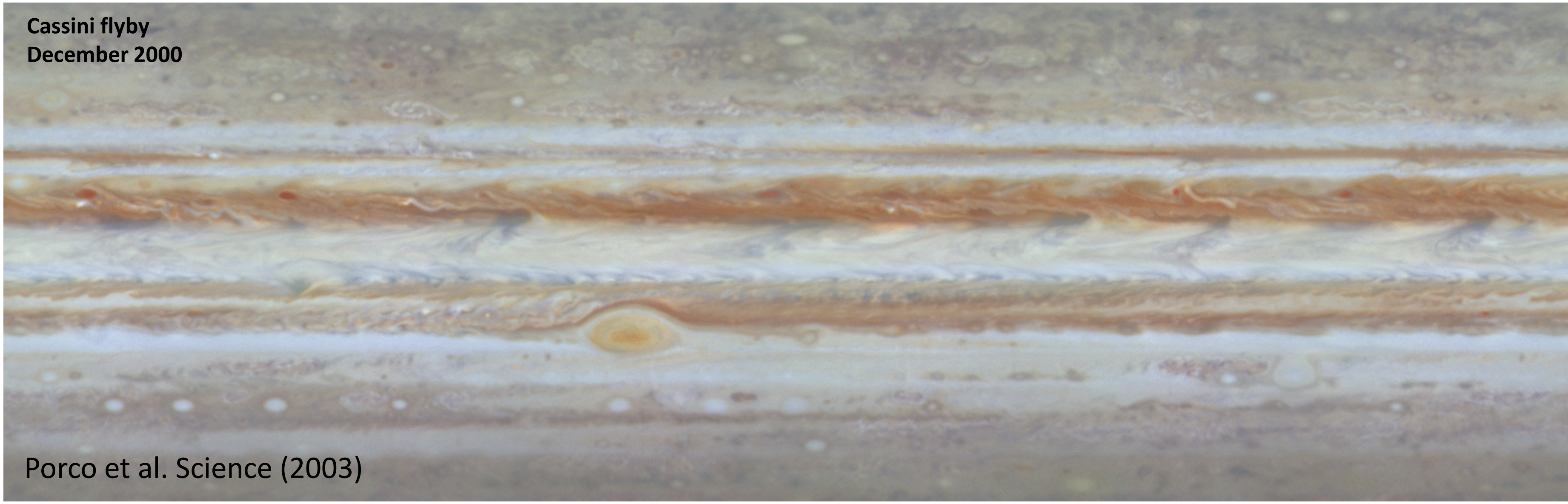
Bands (dark belts and white zones) & winds are related

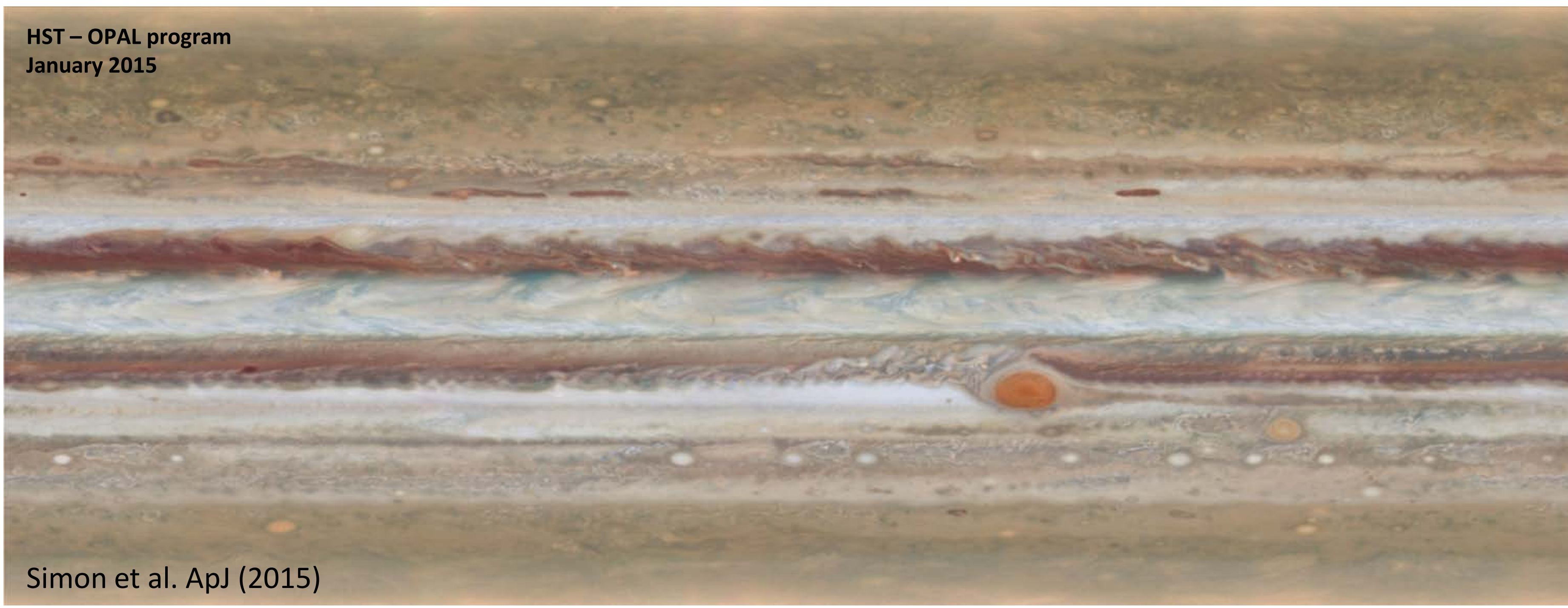
Historical observations reviewed in the books by Peek (1958) & Rogers (1995)



First precise wind motions from Voyagers: Limaye et al. (JGR, 1986)

Bands & winds in time



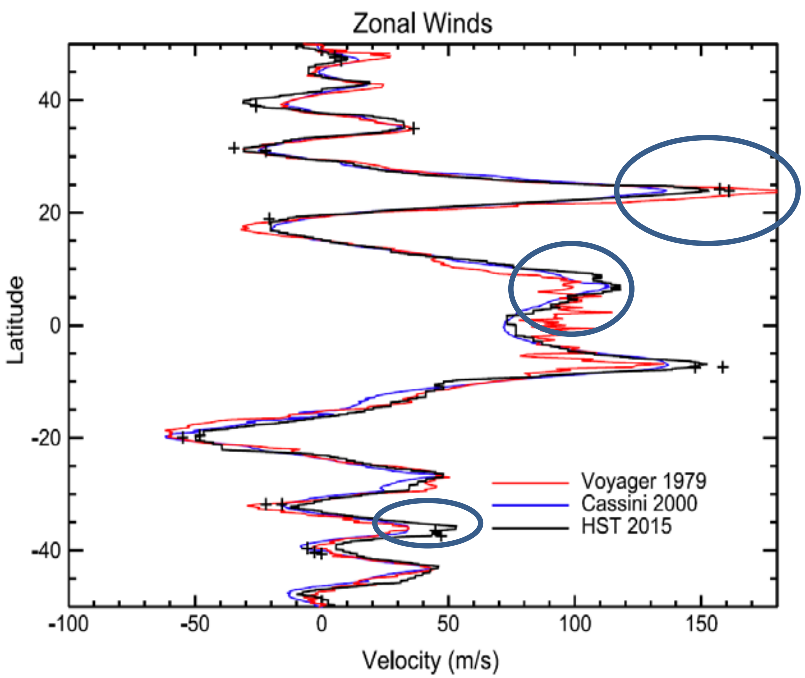


Recent studies of winds in Jupiter

HST 1995-2000
García-Melendo et al. Icarus, 2001

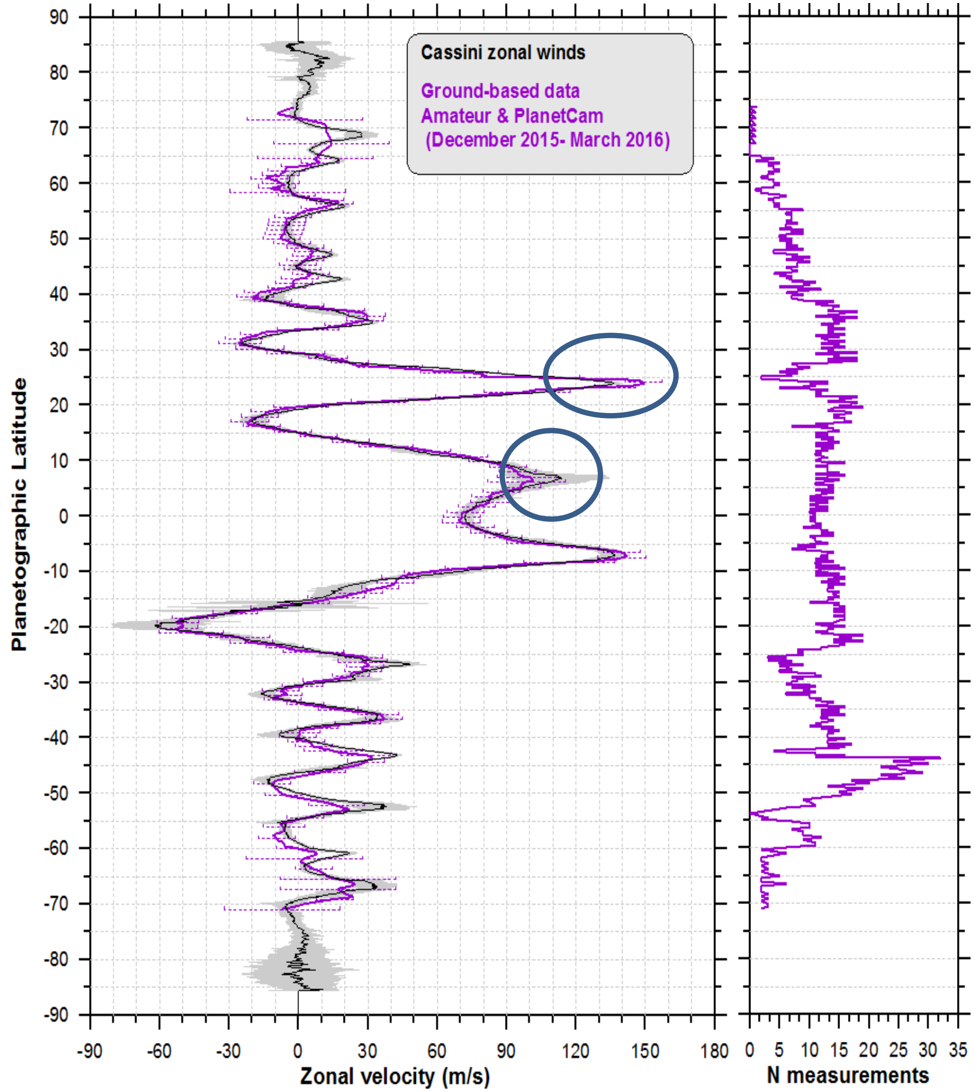
Overall wind stability. No major changes although small changes in the peak velocities of certain jets

HST OPAL images (2015)



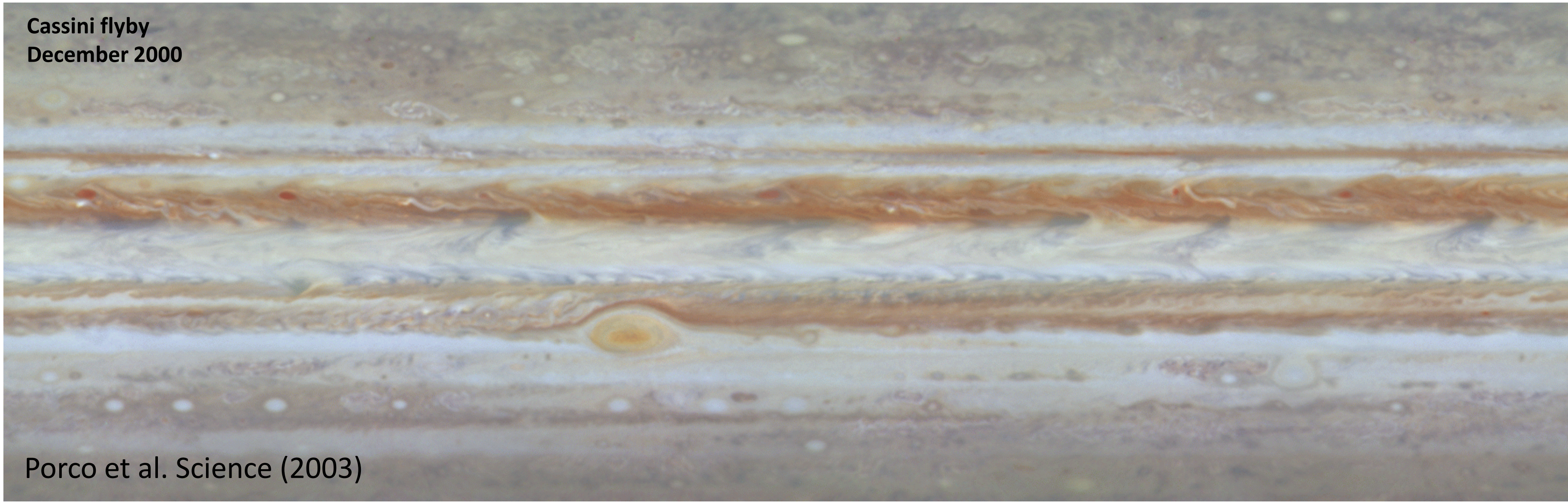
Simon et al. ApJL, 2015

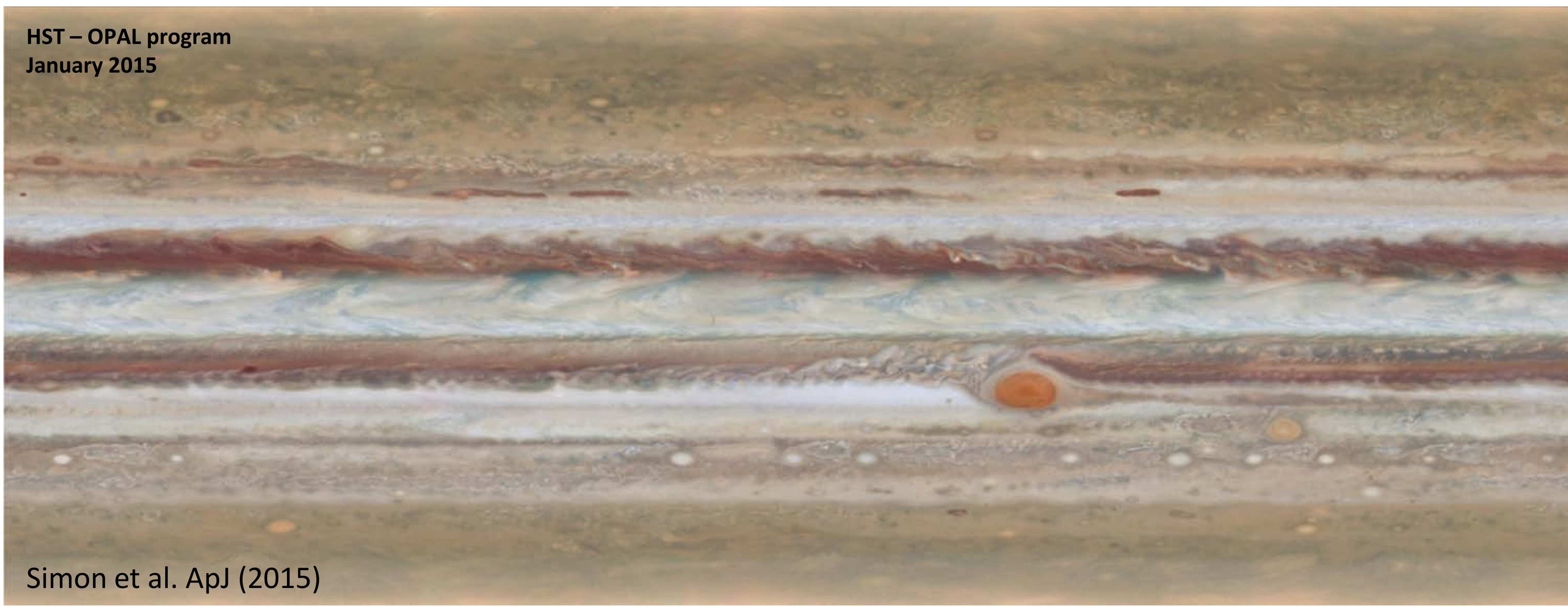
Ground based data (2015)
Amateur & PlanetCam UPV/EHU



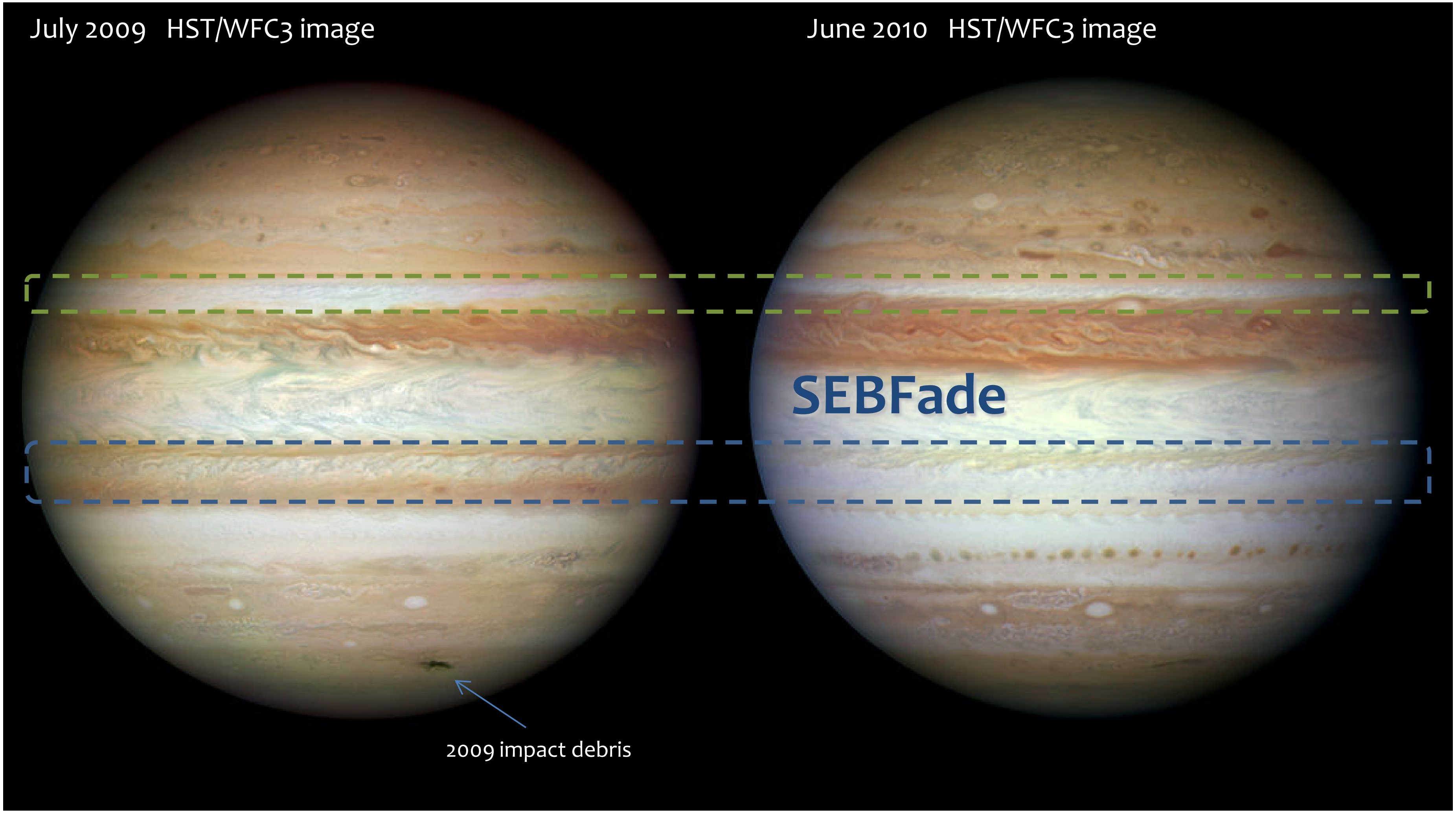
Measurements from Peio Iñurrigarro, Hueso et al. (in preparation)

Bands & winds in time





Major changes in belts & zones: SEB cycle

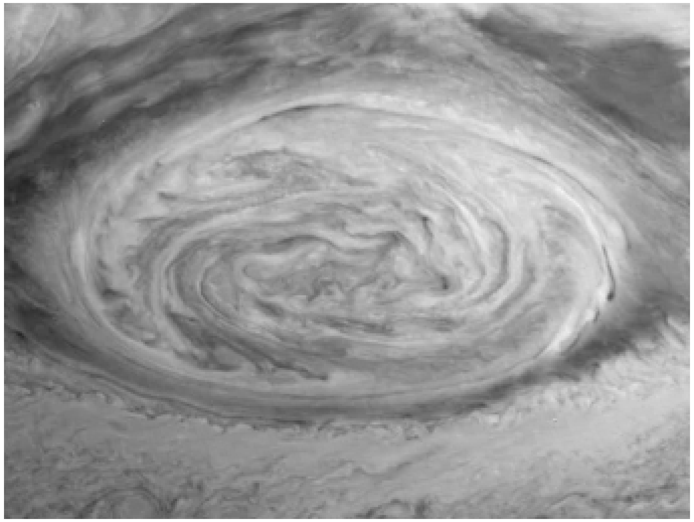


Fletcher et al. (Icarus, 2011)
Pérez-Hoyos et al. (Icarus, 2012) → Changes up to 0.3 bar.
Deep source for the phenomenon. Not convective in origin (although major eruptions can happen in the SEB)

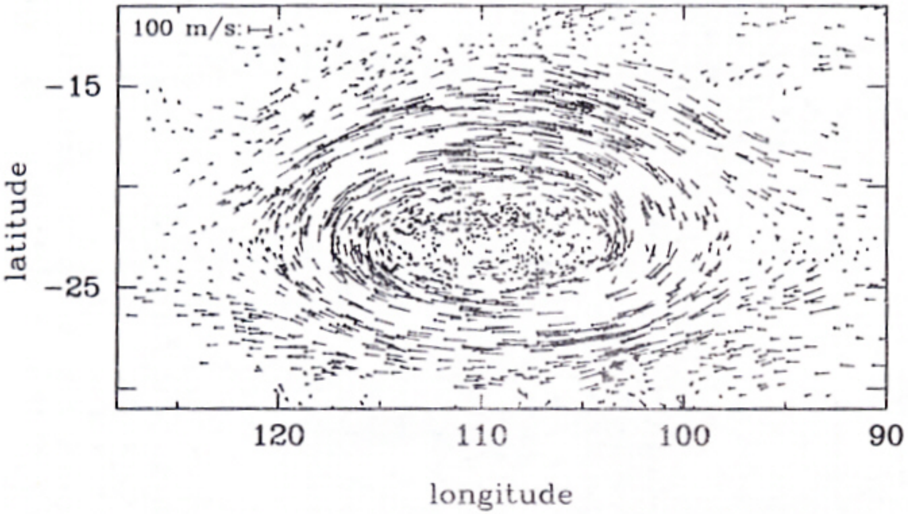
No changes in the zonal winds accompanying these morphological changes.

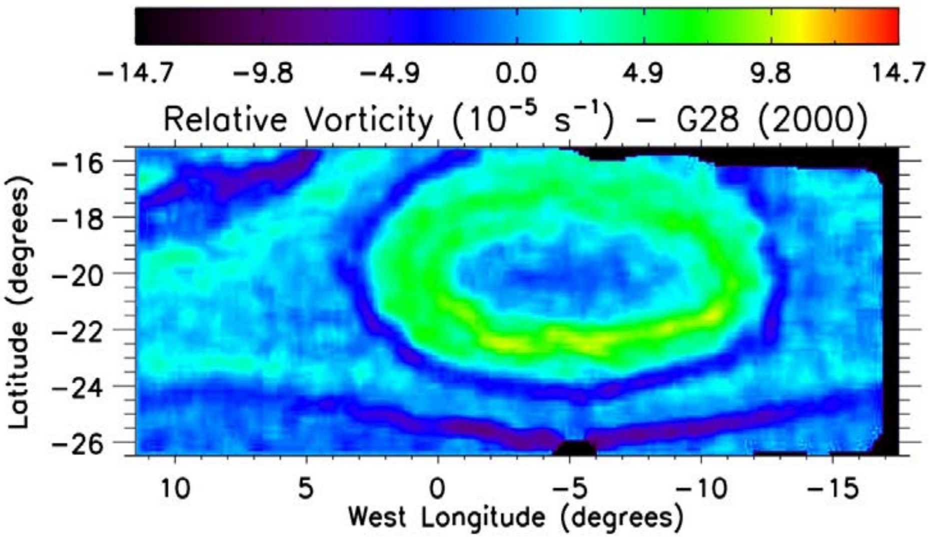
Ovals: Great Red Spot

Dowling and Ingersoll, 1988



Choi and Showman, 2007 (Galileo data, 2000)



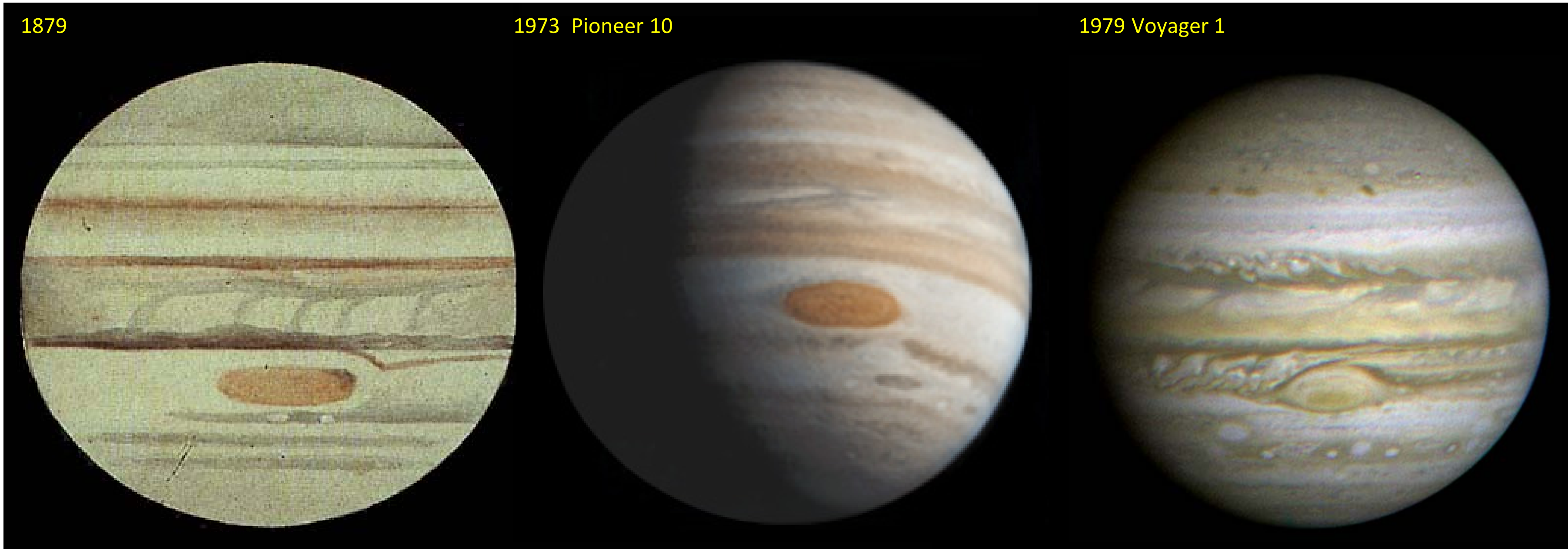


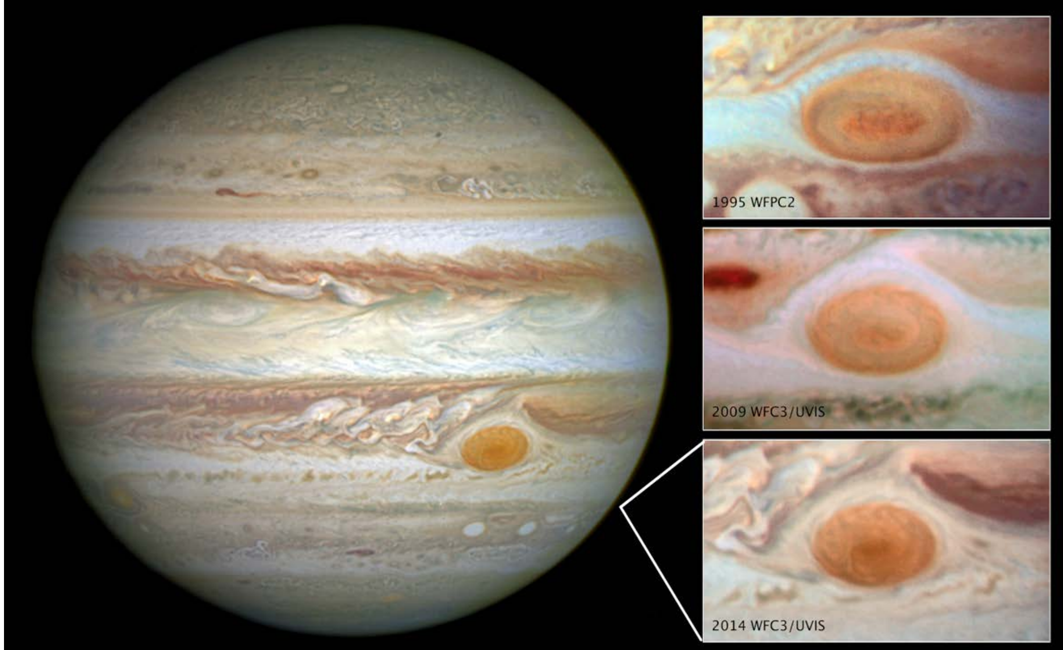
$V_T(\text{max}) \approx 120\ \text{ms}^{-1}$ (range: 100-150 ms^{-1})

$Ro \approx 0.1 \rightarrow$ Gradient wind balance: $\dfrac{V^2}{r} + f\,V = \dfrac{1}{\rho}\dfrac{\partial P}{\partial r}$

An anticiclone with an inner turbulent region surrounded by a ring of positive vorticity

A Shrinking Great Red Spot





Lifetime > 100 years
(probably) > 300 years

Beebe et al. (1979);
Simon et al. (2015)

Drift velocity:
$\langle u \rangle$ = -2 to + 1 m/s

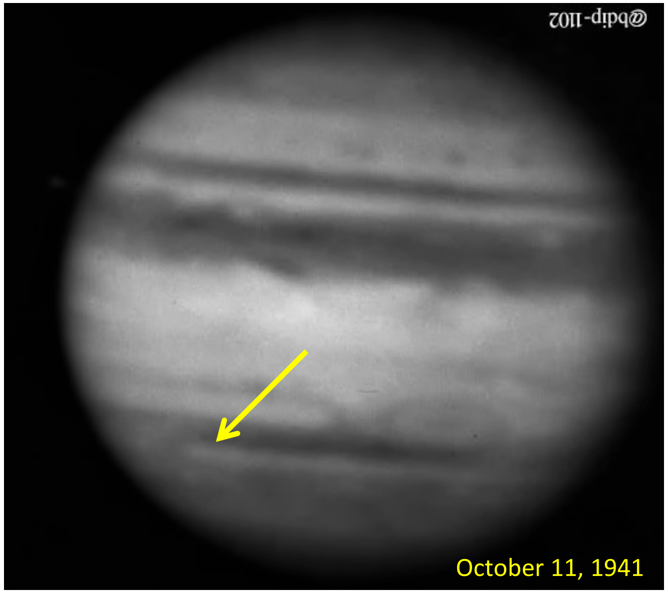
Size (km): **1879**: 40,000 x 13,000
1979: 25,000 x 13,000
2015: 16,100 x 11,200

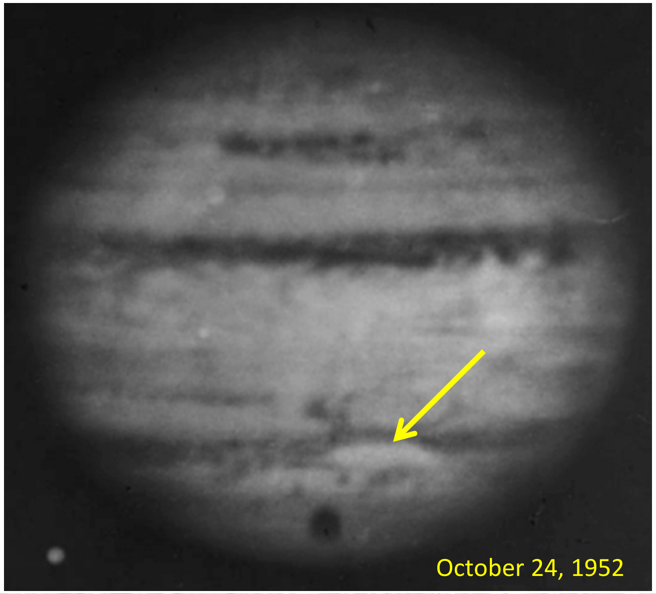
Shrinking rate: ~ 0.2°/year

Shrinking accelerated in the last few years but may have stopped now

Jupiter's White Ovals

Formed in 1938/1941 - STB: dark sections & column – East-West length of BC (1953): 26,000 km

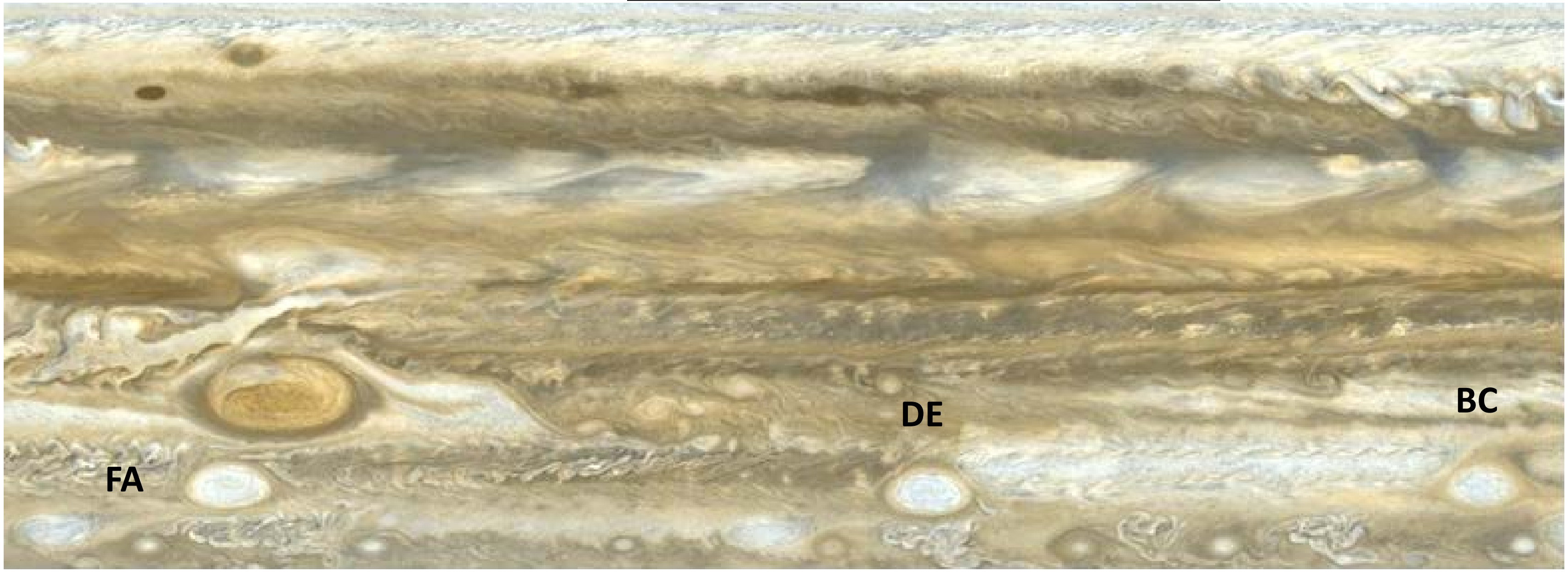




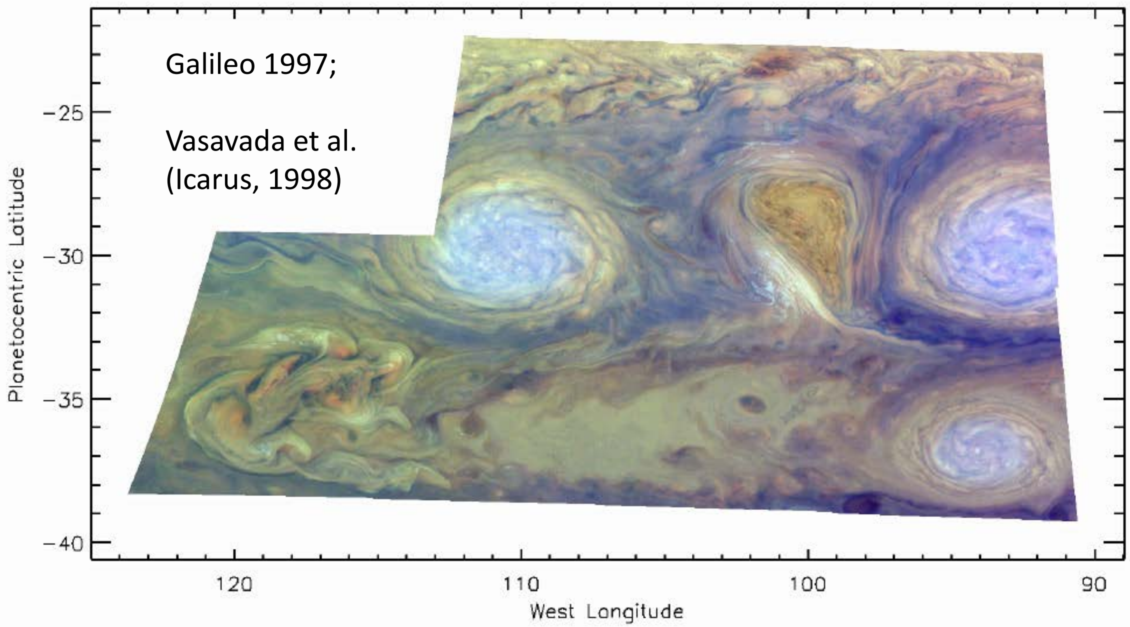
Base de données d'images planétaires

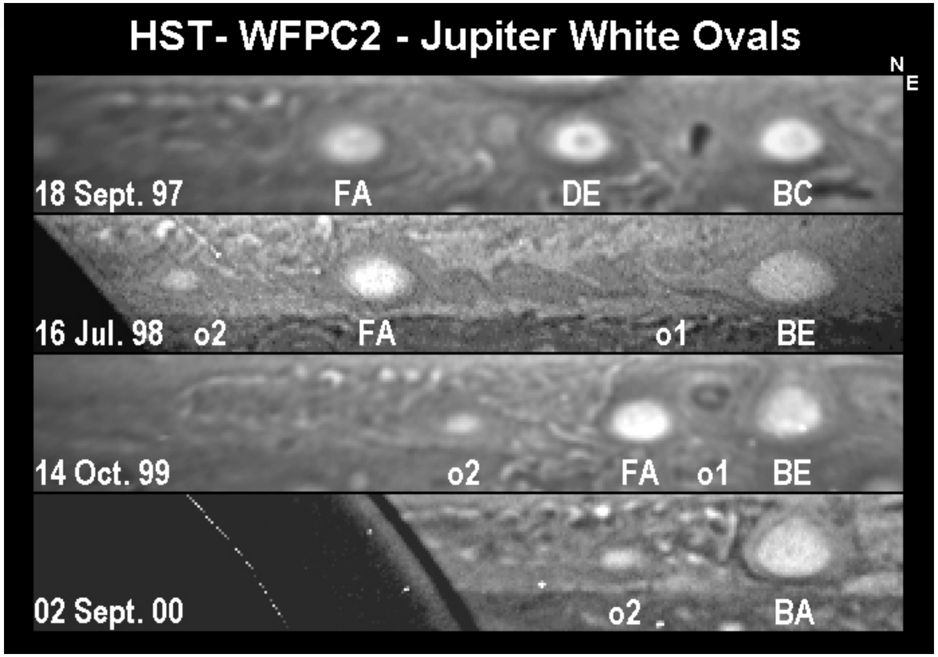
(Paris-Meudon Observatory)

Voyager 1&2 (1979)



Jupiter's White Ovals Mergers





Merger in 1998 (BC+DE) = BE

Merger in 2000 (BE+FA) = BA

Sánchez-Lavega et al. Icarus, 1998

Sánchez-Lavega et al. Icarus, 2000

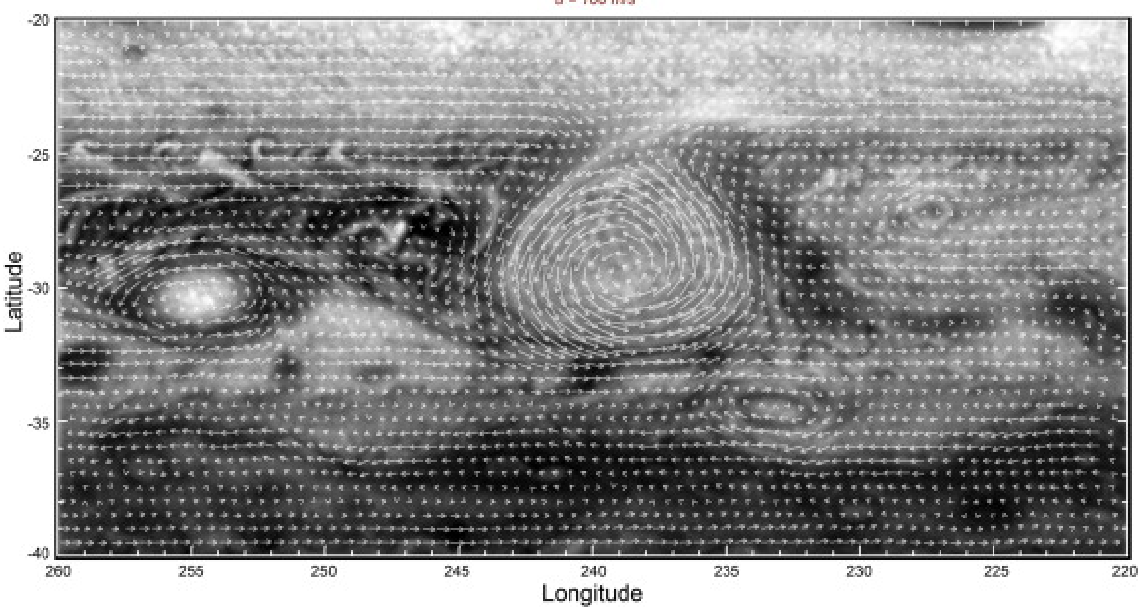
Numerical modelling of the ovals mergers:

•Morales-Juberias and Sanchez-Lavega, Icarus, 2003

Phenomenology is sensitive to the roots of the ovals at least down to the water condensation level

Oval BA dynamics and colors

Cassini ISS (2000)



Anticyclone: $V_T\,(\text{max}) \approx 100\ \text{ms}^{-1}$

Size: 10,400 km x 7,900 km (Dec. 5, 2015)

$Ro \approx 0.1 \rightarrow$

Gradient wind balance: $\dfrac{V^2}{r} + f\,V = \dfrac{1}{\rho}\dfrac{\partial P}{\partial r}$

Hueso et al. (Icarus, 2009)

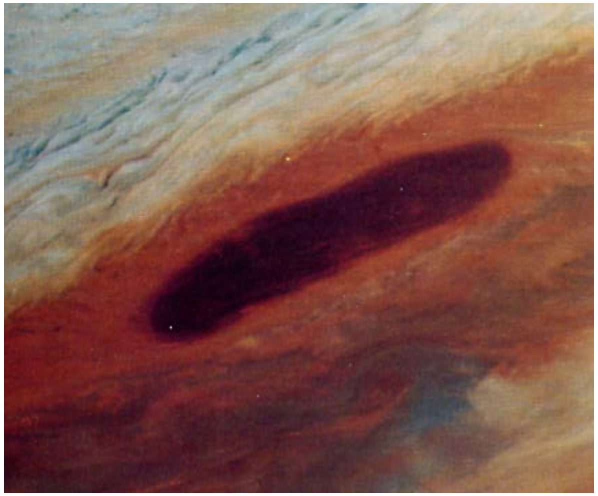
BA red ring (2006)

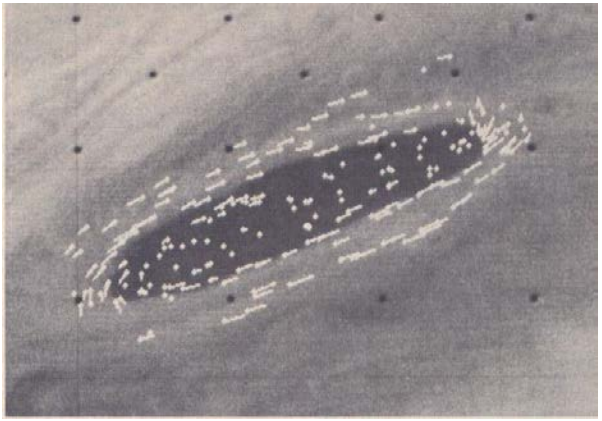
HST

White from 2000-2005
Red colour first noticed by amateur astronomer C. Go (2006)
Whitening in recent years

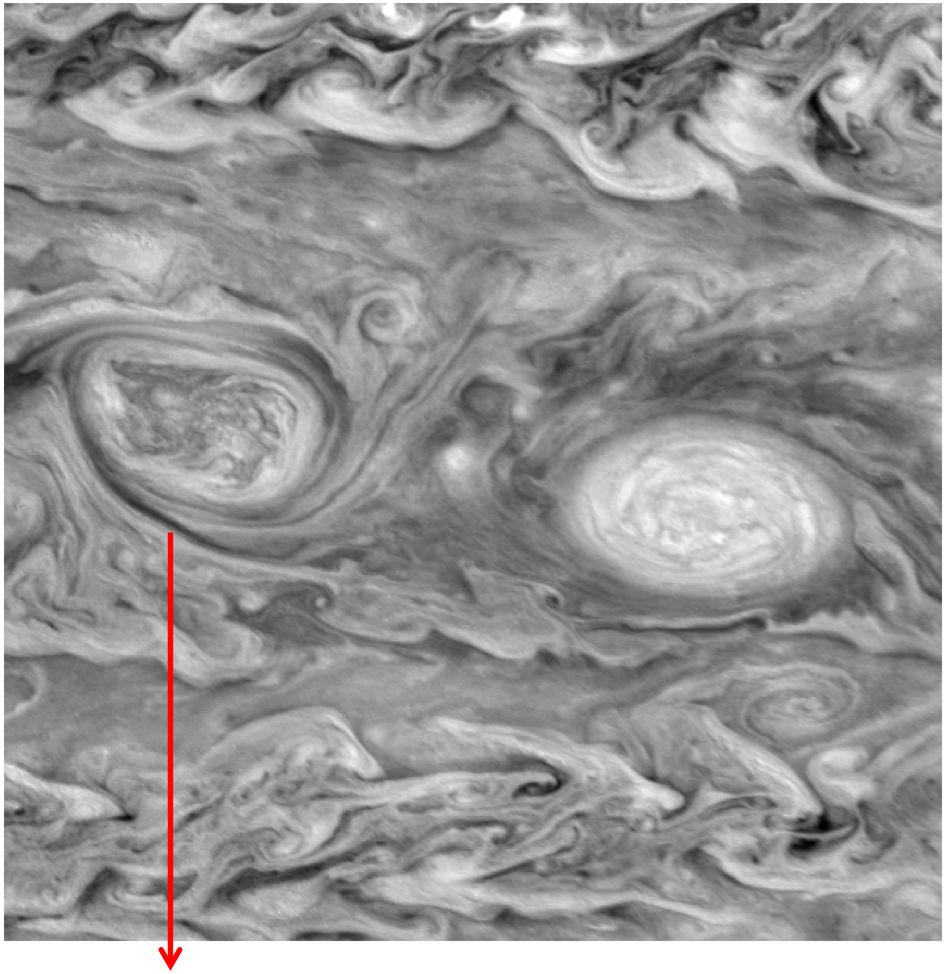
Coherent Cyclones & incoherent cyclonic regions

"Barges" (brown)
Evidence for a secod chromophore





Cyclone & Anticyclone pair

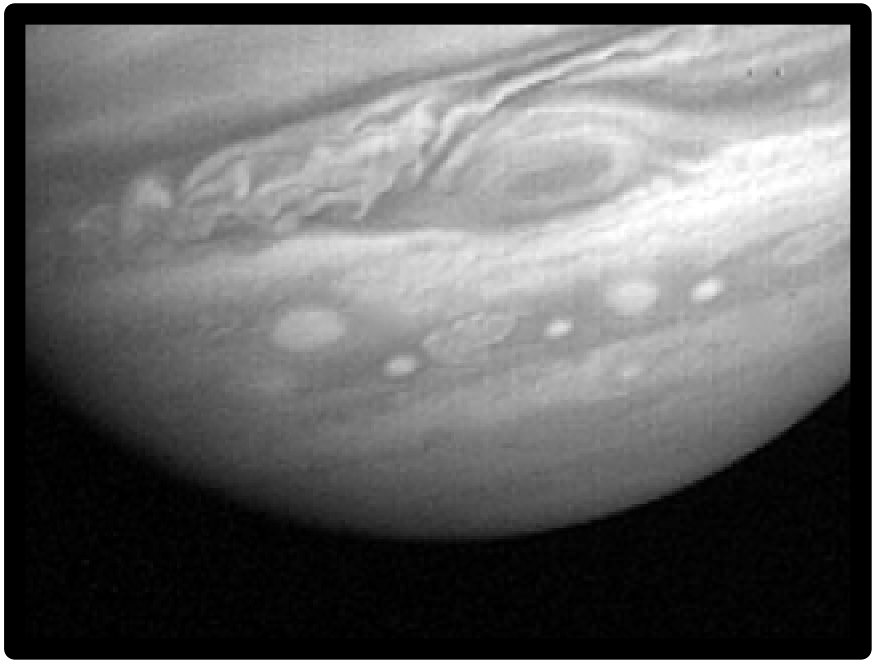


Latitude = 16°N; $L_{EW} \sim 10{,}000$ km
$V_T(r,\theta) = 30 – 60$ m/s; $Ro \sim 0.1$

Hatzes et al. (JGR, 1981)

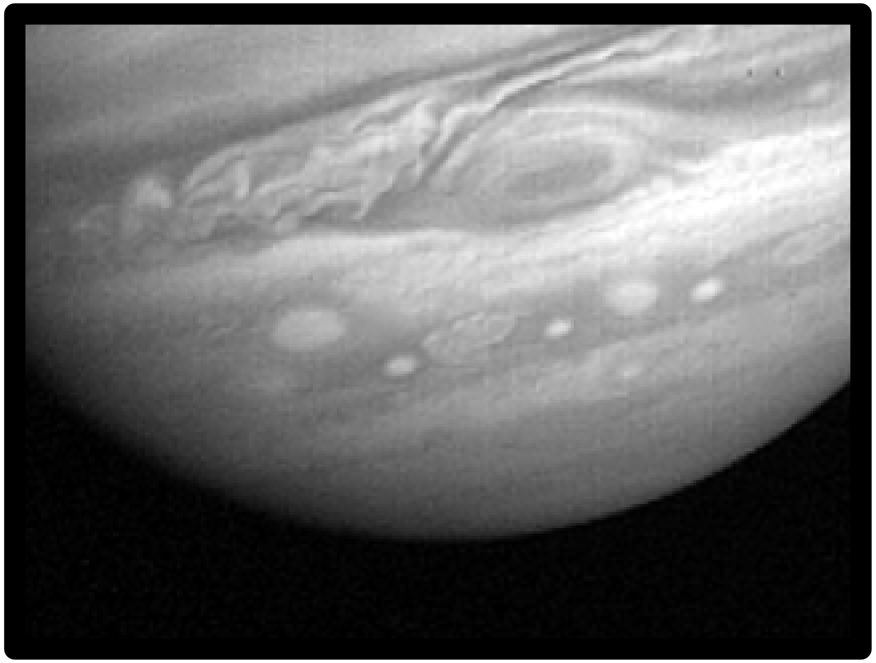
Mid-latitudes; $L_{EW} \sim 3{,}000$ km
Differ from anticyclones: Turbulent interior

Ovals interactions

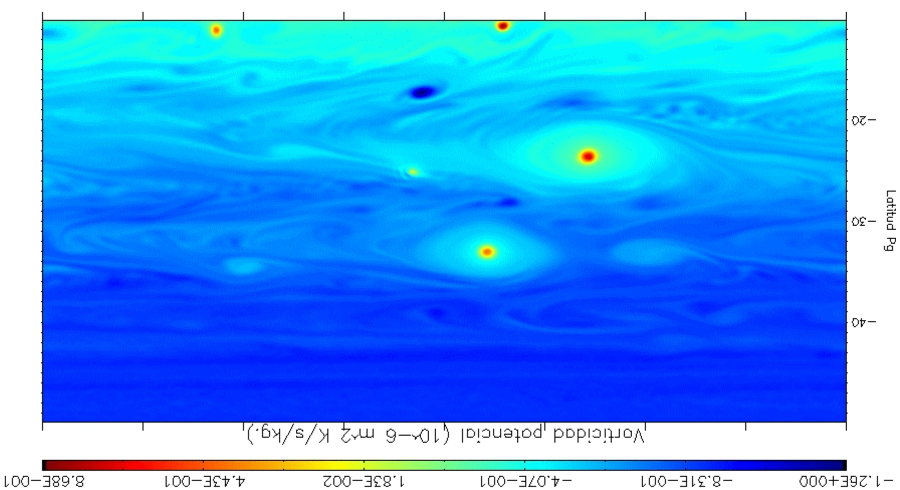


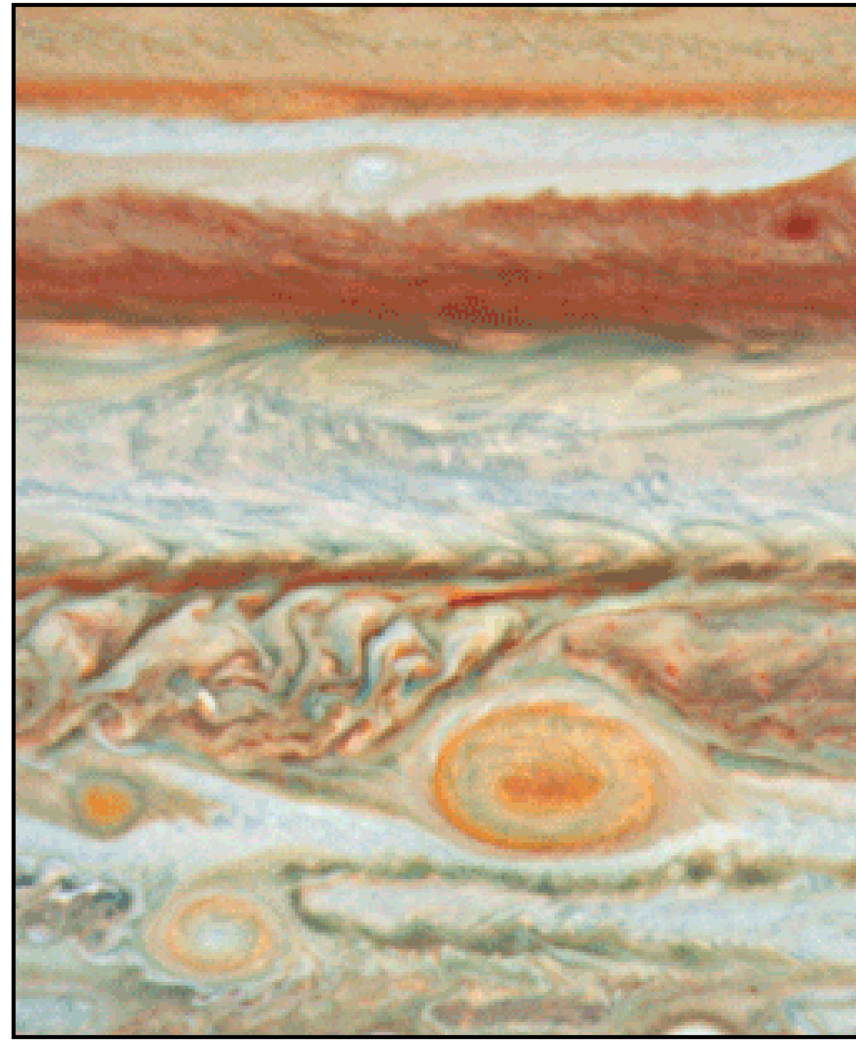
Voyager 1 (1979)

Ovals interactions



Voyager 1 (1979)



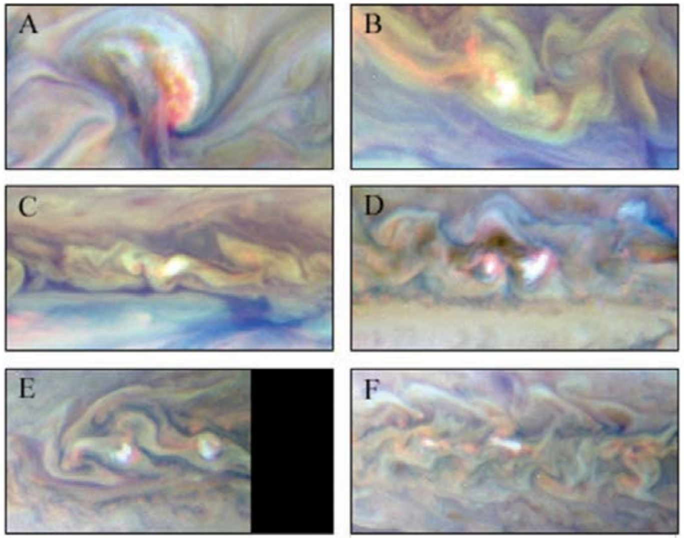


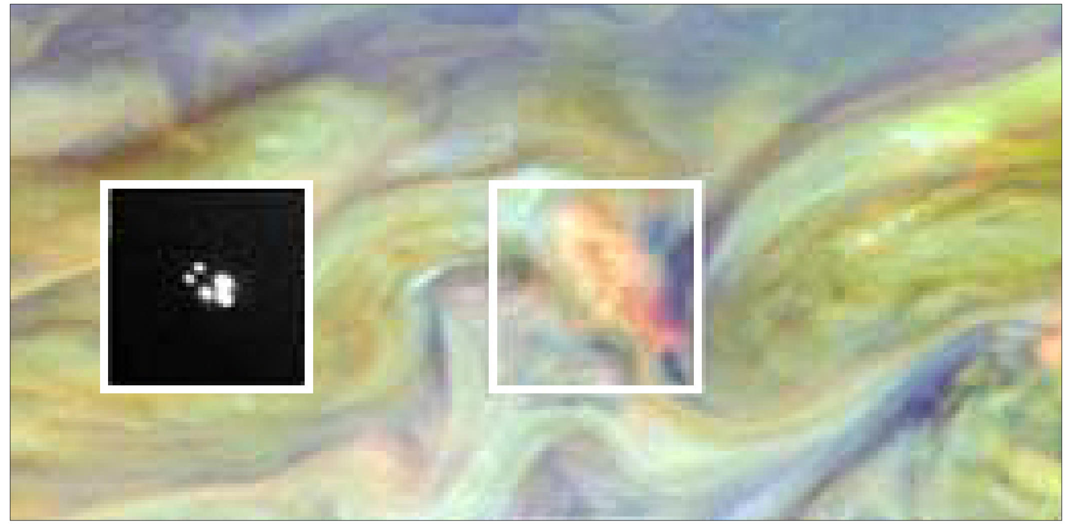
HST/WFPC2 2008

Sanchez-Lavega et al. (JGR, 2013)

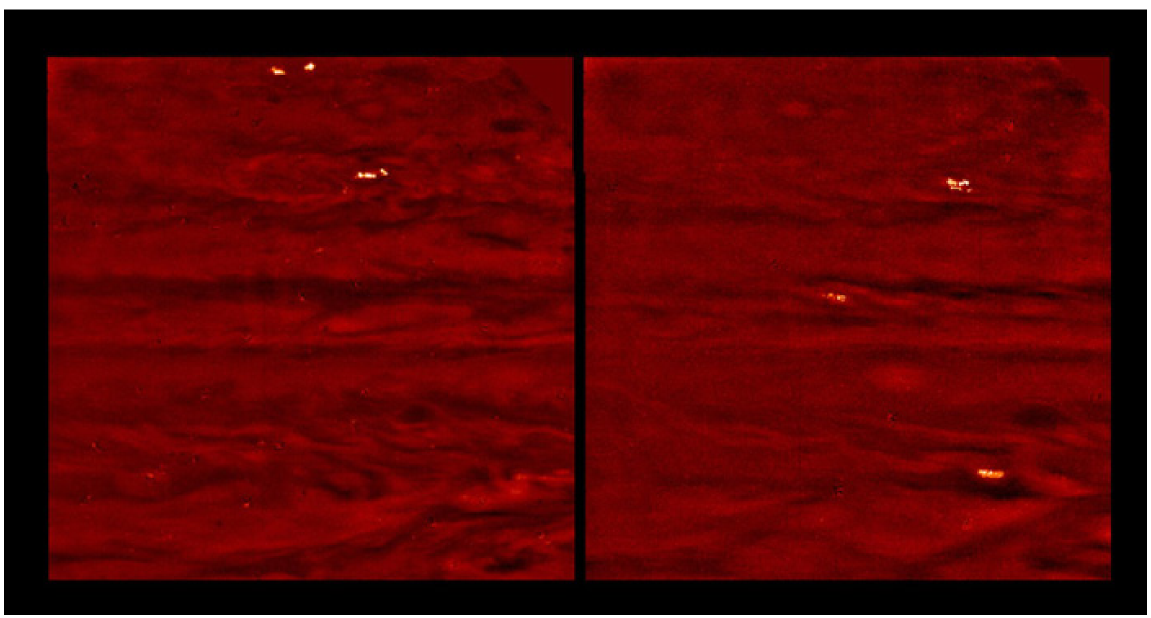
Garcia-Melendo et al. (Icarus, 2009)

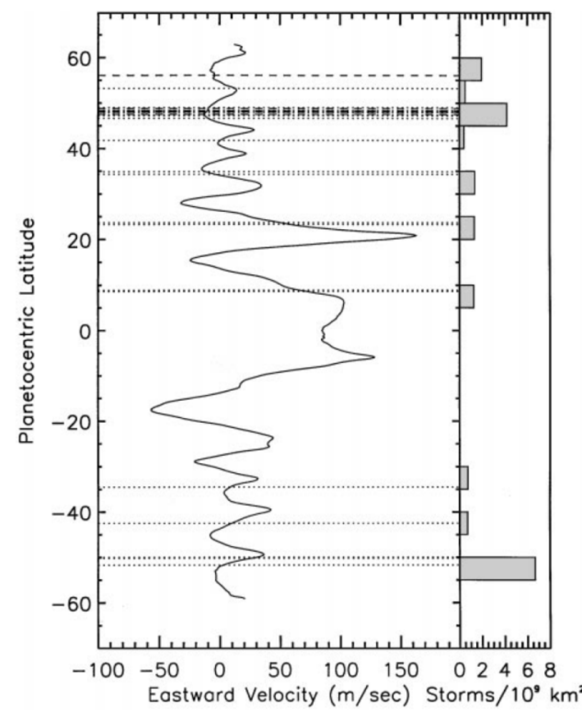
Convective storms and lightning





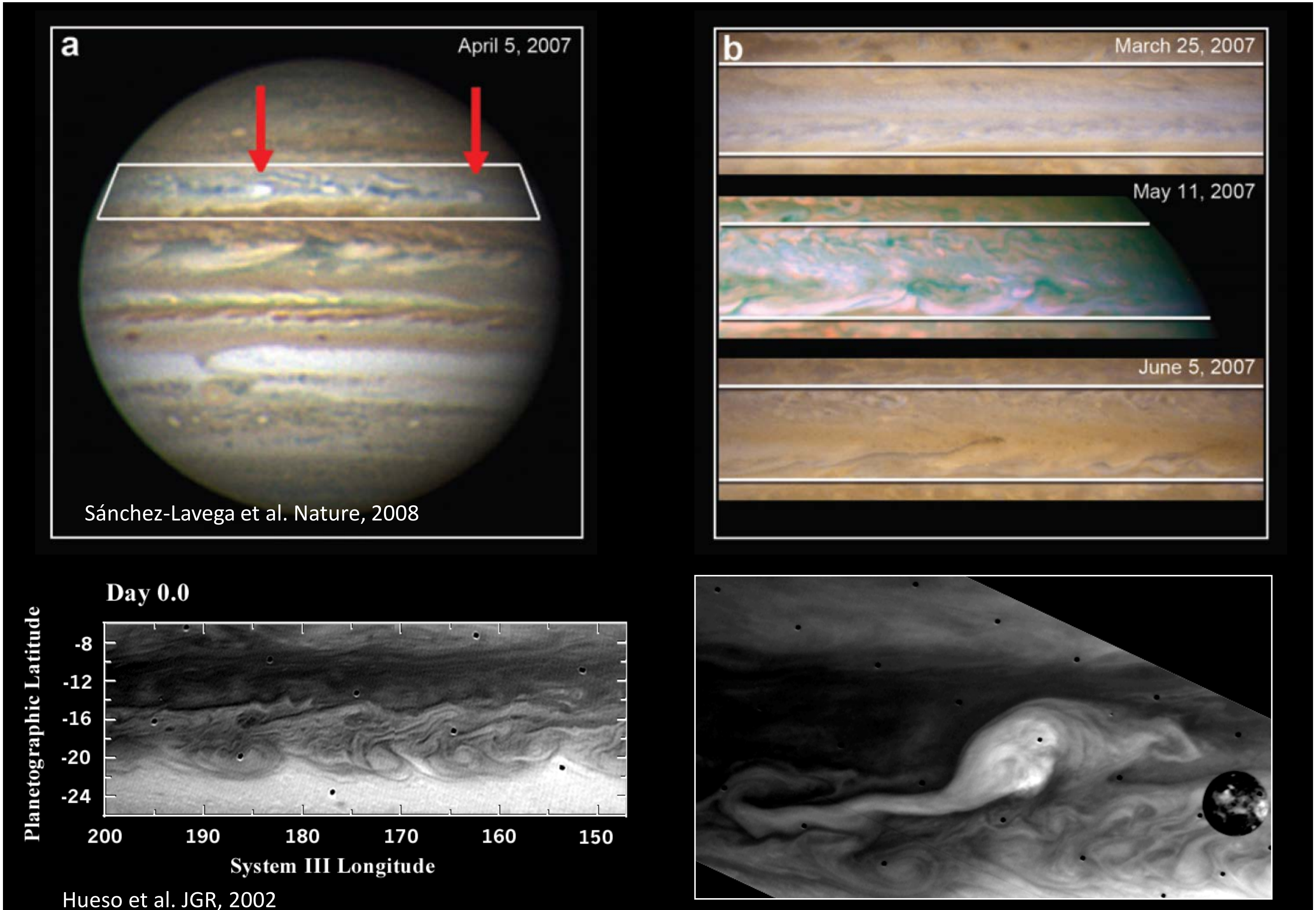
Gierasch et al. Nature, 2001; Ingersoll et al. Nature, 2001





Little et al. Icarus, 2000

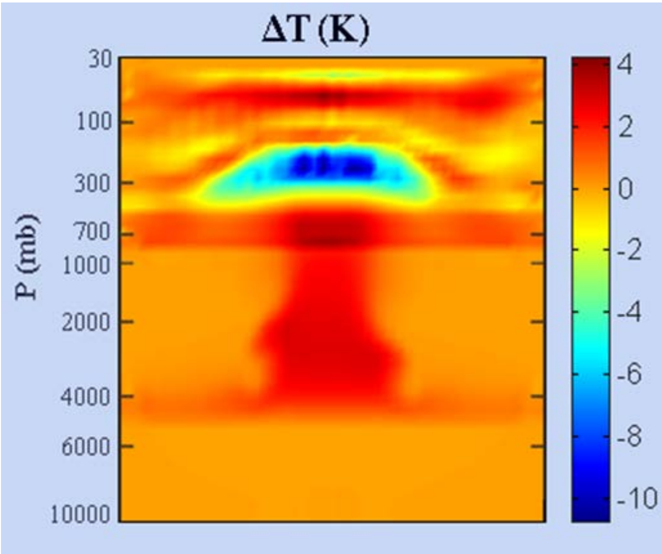
Planetary scale disturbances

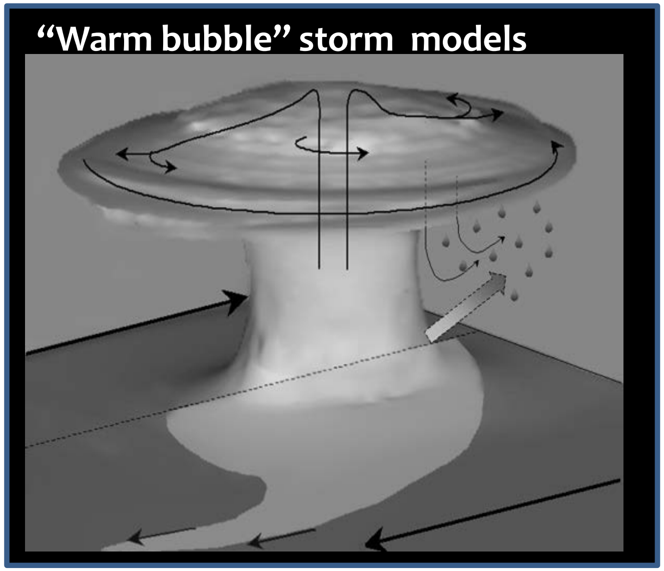


Sánchez-Lavega et al. Nature, 2008

Hueso et al. JGR, 2002

Convective Storm models



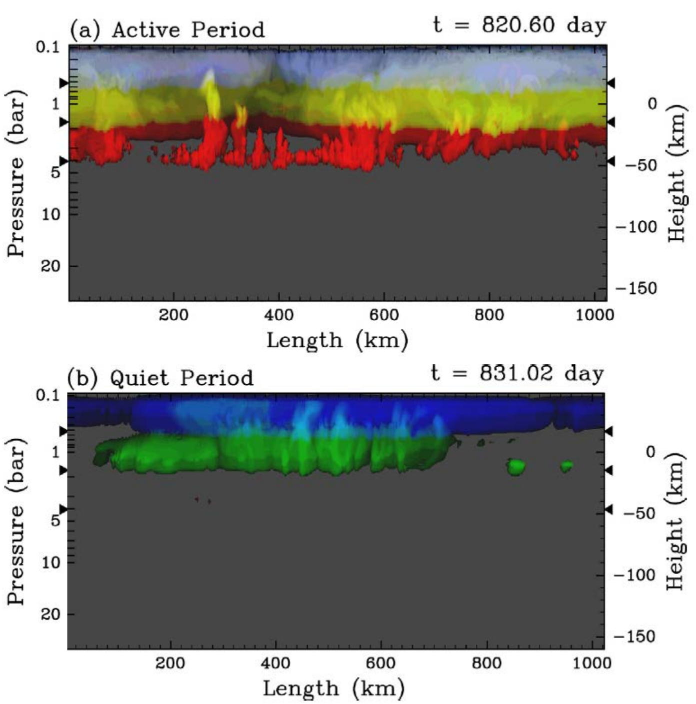


3D convective models

Extreme water moist convection:

ΔT ~ 5 K,
Δz ~ 20 - 40 km →
CAPE ~ 10^4 m^2s^{-2} →
w ~ 150 ms^{-1}

Hueso et al. (Icarus, 2001)



Radiative-convective models

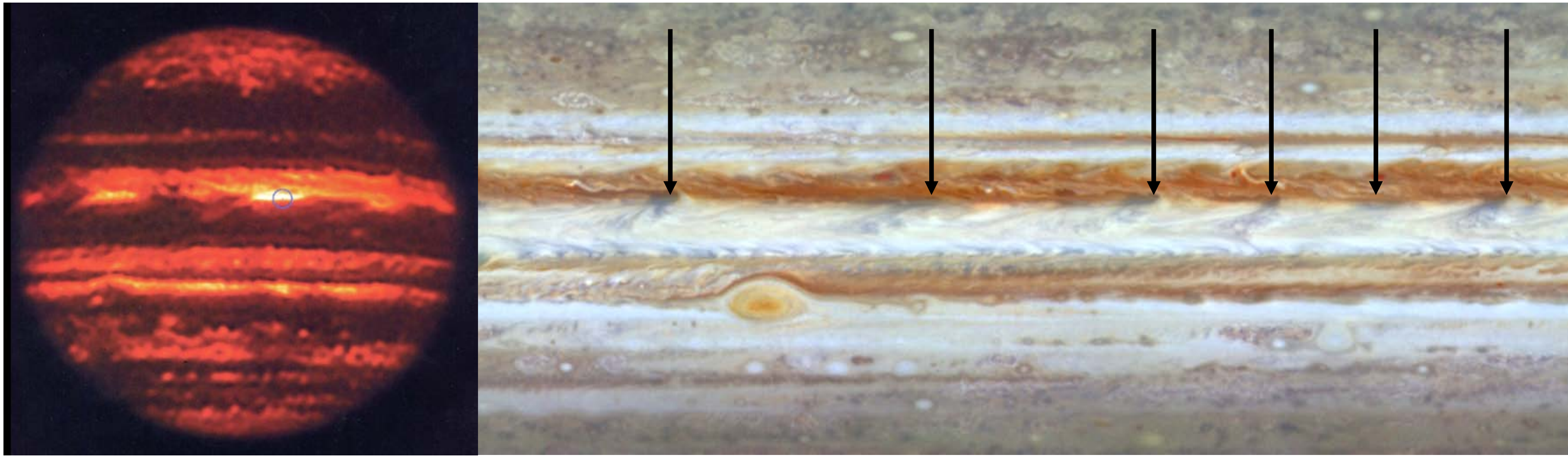
Episodic moist convection with w ~ 50 ms^{-1}

Active storms with time durations of ~ 5 days

Similar to the most common features observed

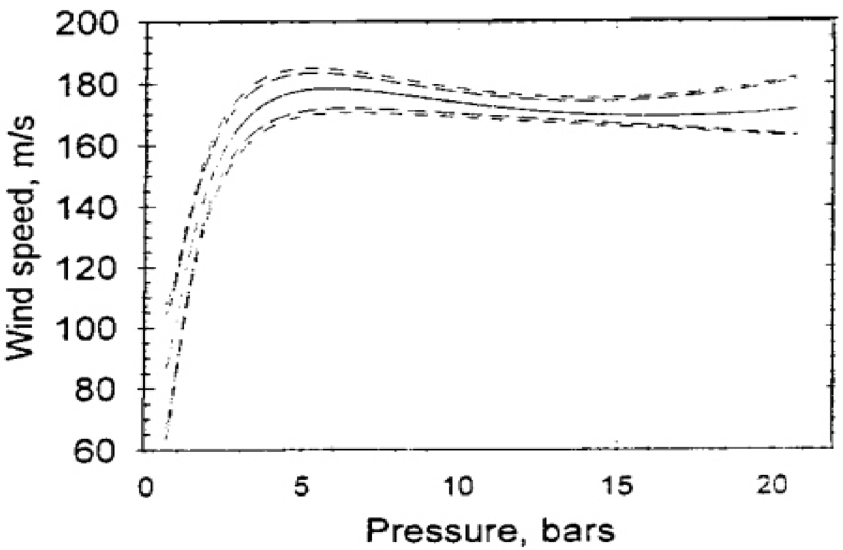
Nakajima et al. (GRL, 2000);
Sugiyama et al., (Icarus, 2014)

Dark projections, Hot Spots and plumes at 7°N



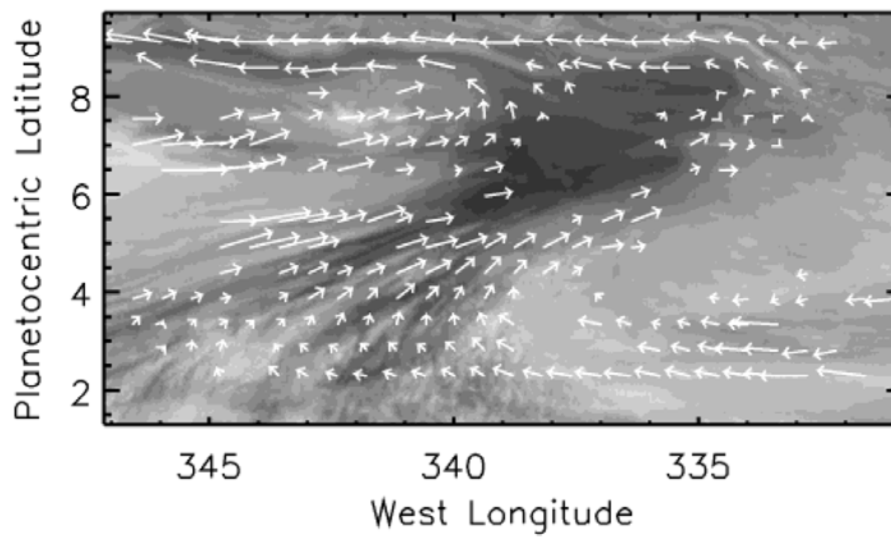
Orton et al. (Science, 1996)

Galileo Probe winds at depth



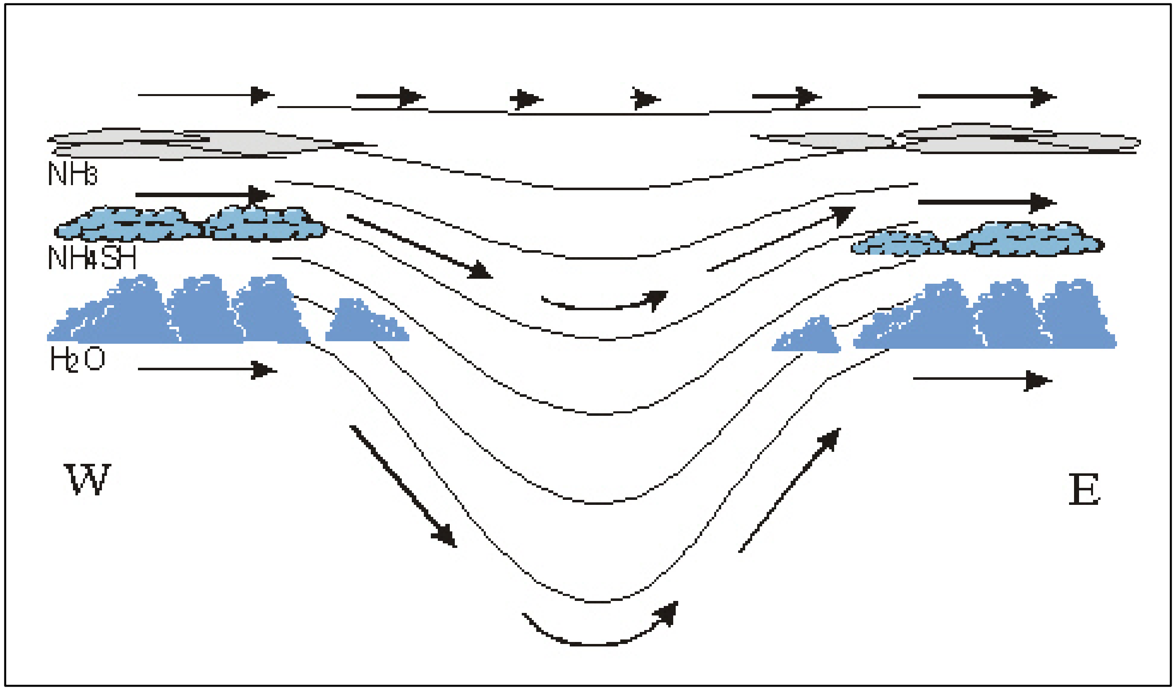
Atkinson et al., Nature, 1997

Cloud motions: Convergence or complex circulation?



Vasavada et al. Icarus, 1998, Arregi et al. Icarus, 2011
Choi et al. Icarus, 2013

Dark projections and hot spots as a wave



Rossby wave interpretation:

$$c_x - \overline{u} = -\frac{\beta}{k^2 + l^2 + \left(\frac{f_0^2}{N_B^2}\right)\left(m^2 + \frac{1}{4H^2}\right)}$$

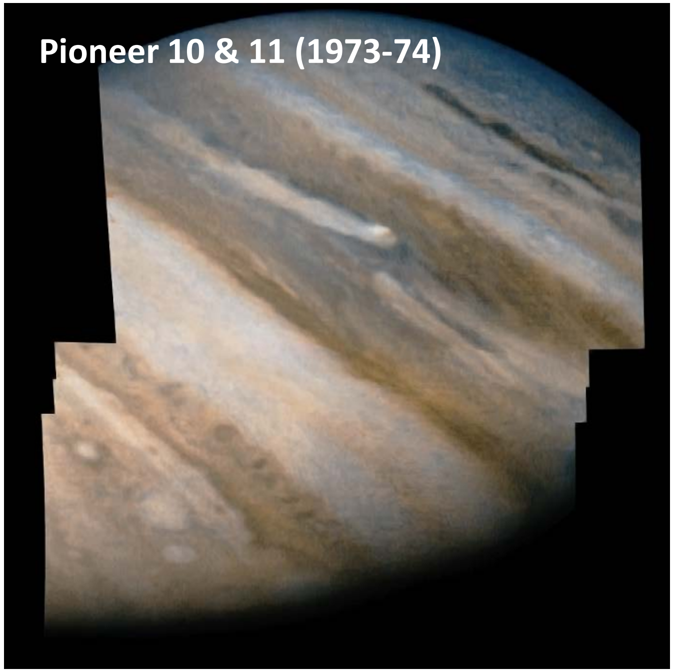
Numerical models:

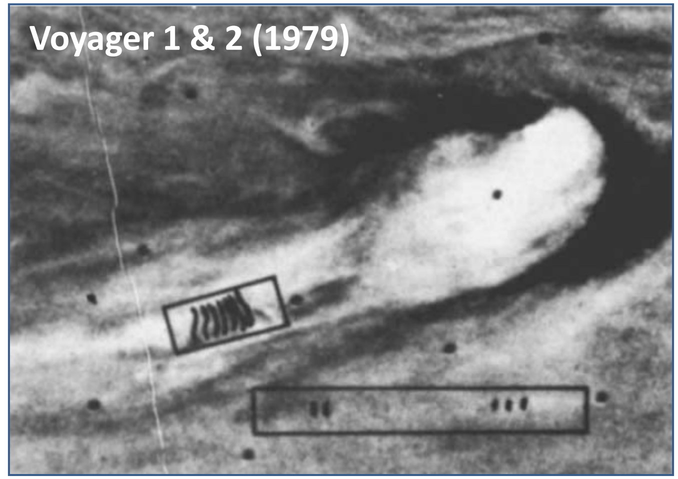
Showman and Ingersoll, (Icarus, 1998)
Showman and Downling (Science, 2000)
Friedson (Icarus, 2005)

Observational and analytical models:

Ortiz et al. (JGR, 1998)
Arregi et al. (JGR, 2006)

Equatorial convective plumes & gravity waves



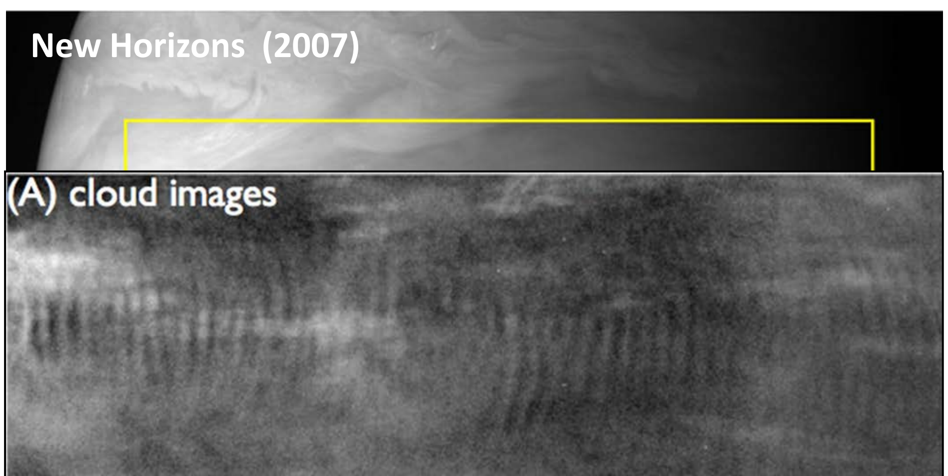


Hunt and Muller,
Nature, 1979

Gravity wave interpretation:

$$c_x - \bar{u} = \pm \frac{N}{\sqrt{k^2 + m^2}}$$

Gravity waves slso present in Galileo data (2000)
without convective plumes
Phase speeds 10-40 m/s (Arregi et al. Icarus 2009)



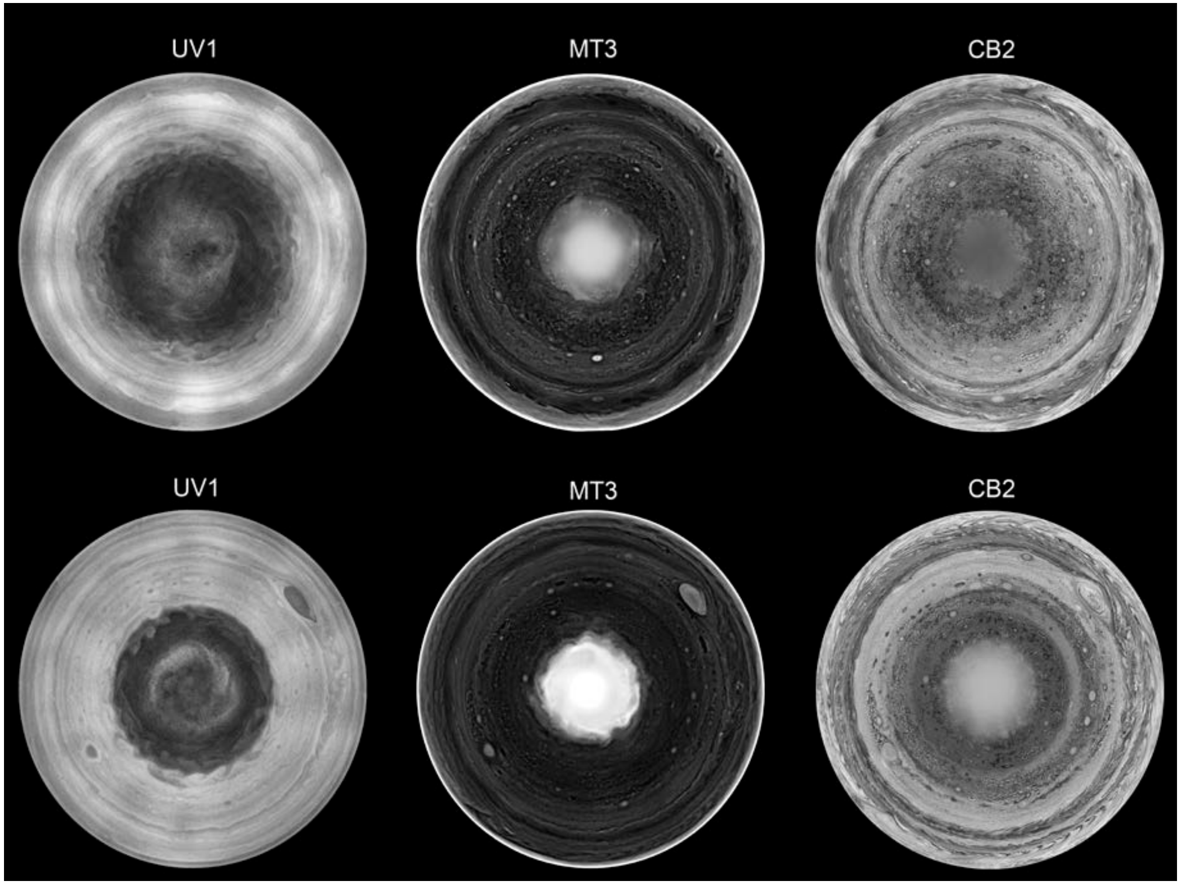
Wavelength ~ 200 – 300 km;
Fast waves: c_x ~ 100 m/s (controversial)
(would require too strong stability;
difficulties in measurements)

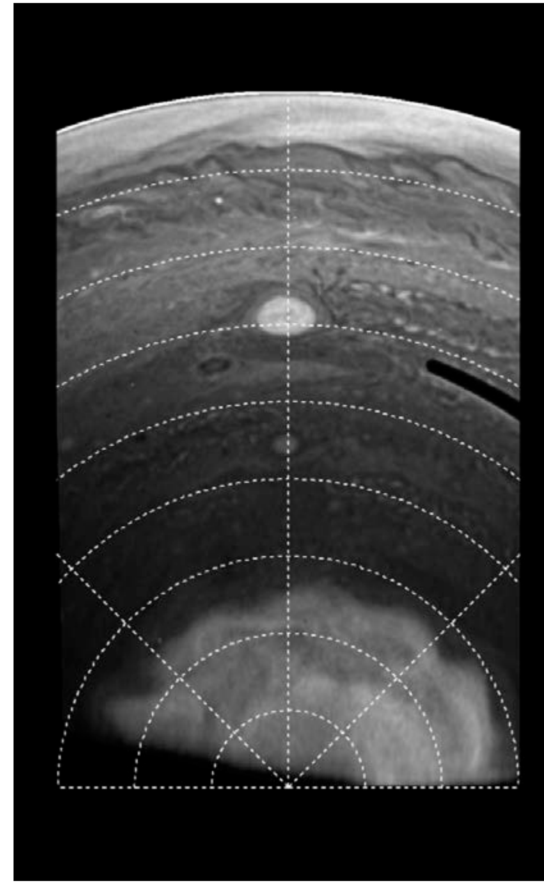
Reuter et al. ApJ, 2007

Also present in HST observations in 2015 only
(Simon et al. ApJ, 2015)

Polar waves

Cassini data (2000) | Systems of waves observed since the Voyagers **HST 2008**





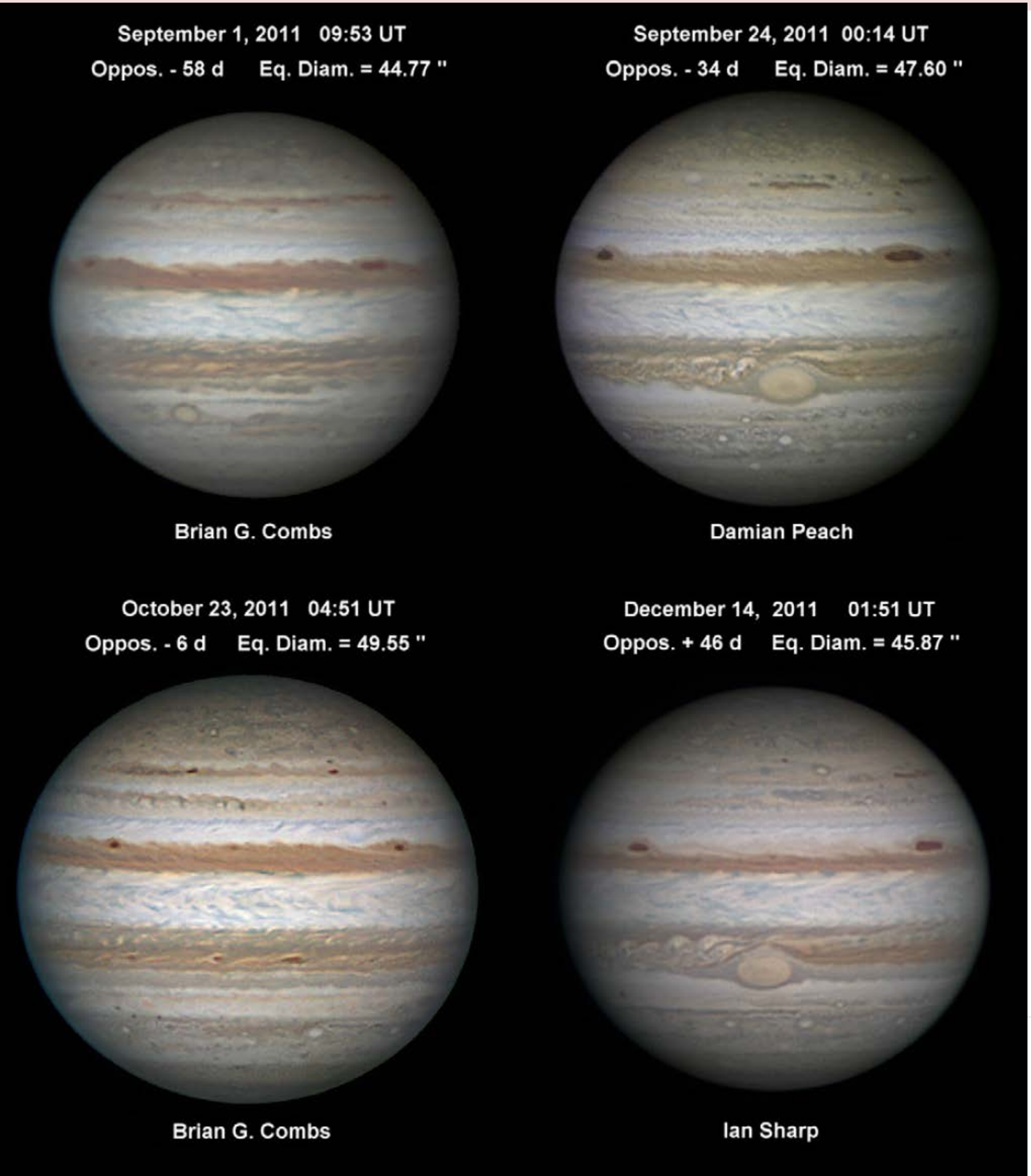
Permanent polar waves at ~ 100 mbar

Latitude	*n*	C_x *(ms^{-1})*	$c_x - u$ *(ms^{-1})*
67ºS - 57ºS	12-20	0-10	-10 to -30
67ºN	5-12	5	-5

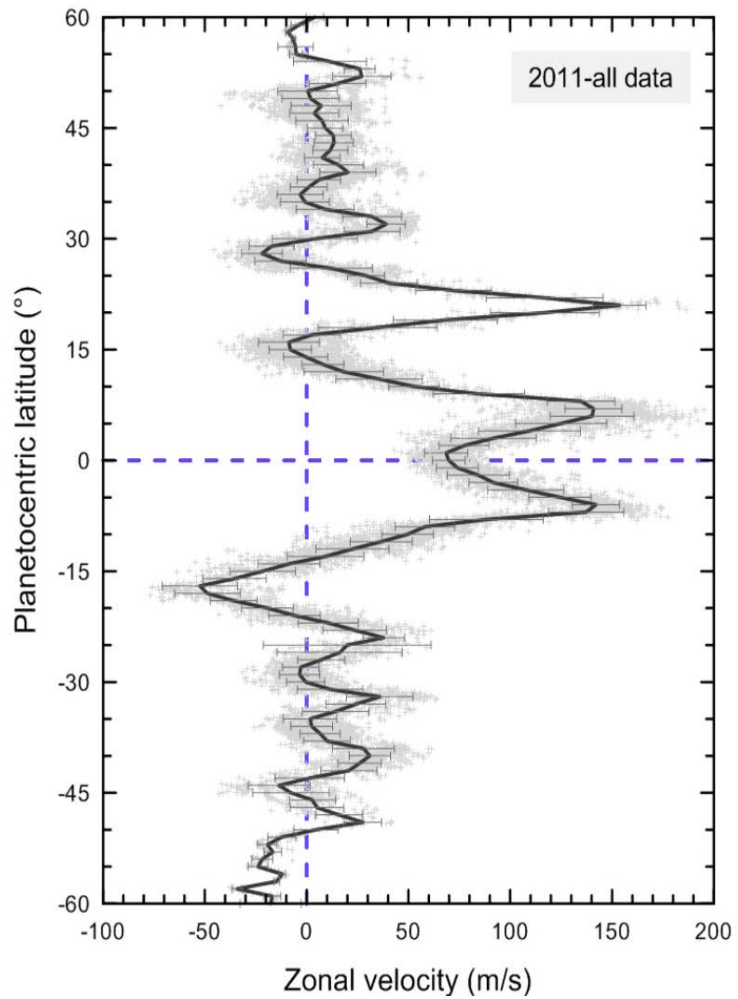
Rossby waves (westward slowly propagating)

Sánchez-Lavega et al. (GRL, 1998)
Barrado-Izagirre et al. (Icarus, 2008)

Atmospheric dynamics from ground-based amateur observations



Barrado-Izagirre et al. 2012



Ground-based Jupiter observations from Spain

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Universidad del País Vasco Euskal Herriko Unibertsitatea

PlanetCam UPV/EHU at Calar Alto 2.2m telescope
PI: A. Sánchez-Lavega   Instrument from UPV/EHU, Bilbao (Spain)

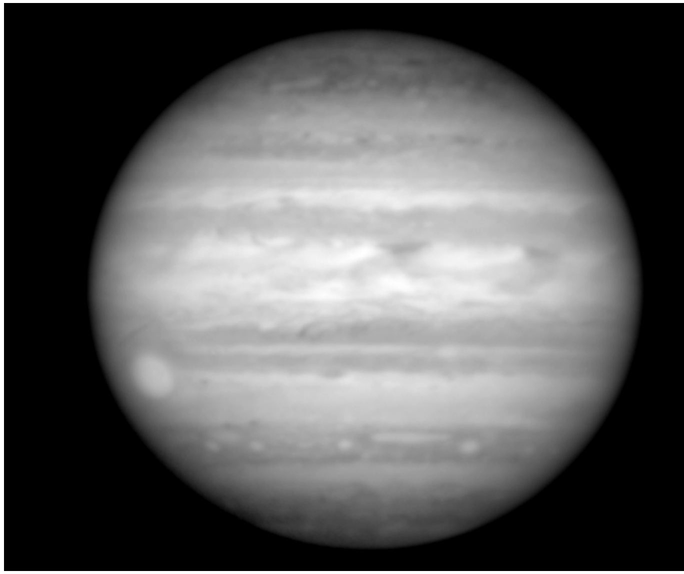
Lucky imaging technique

Dual fast Camera (Visible) and Short Wave Infarred (1.0-1.7 μm)
Up to 100 frames per second

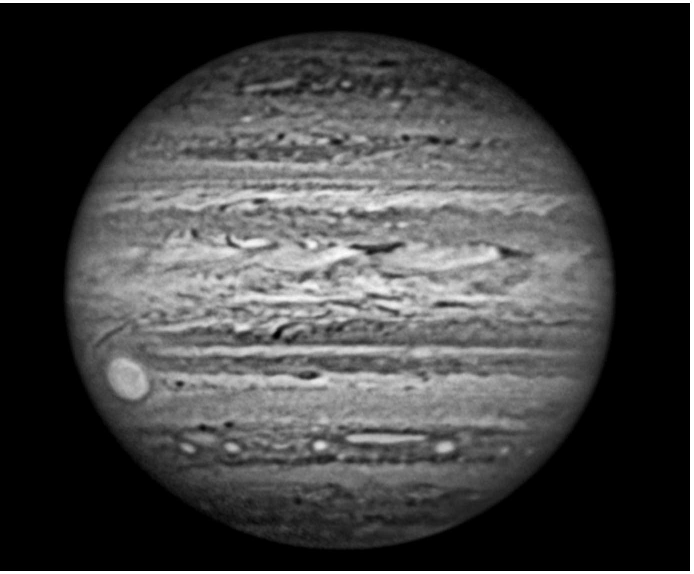
Jupiter at opposition

Date: 2016-03-03 Time: 23:32 UT | Filter: RG1000

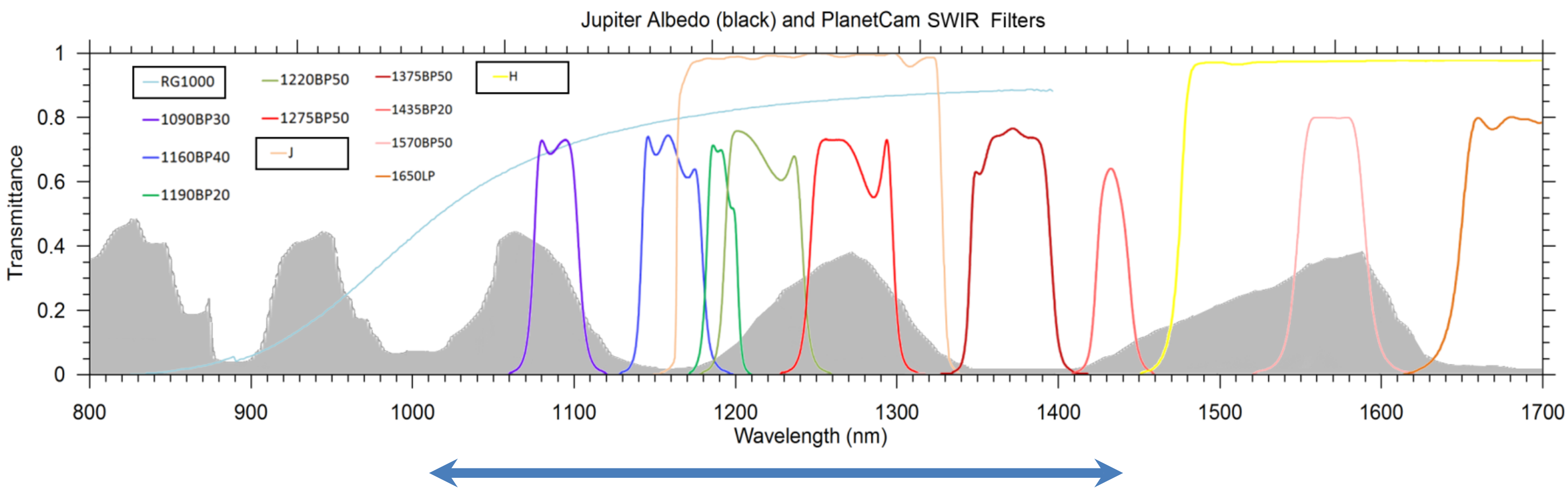
Resolution: 0.088 arcsec/pixel



Photometric image (radiative transfer, cloud properties)

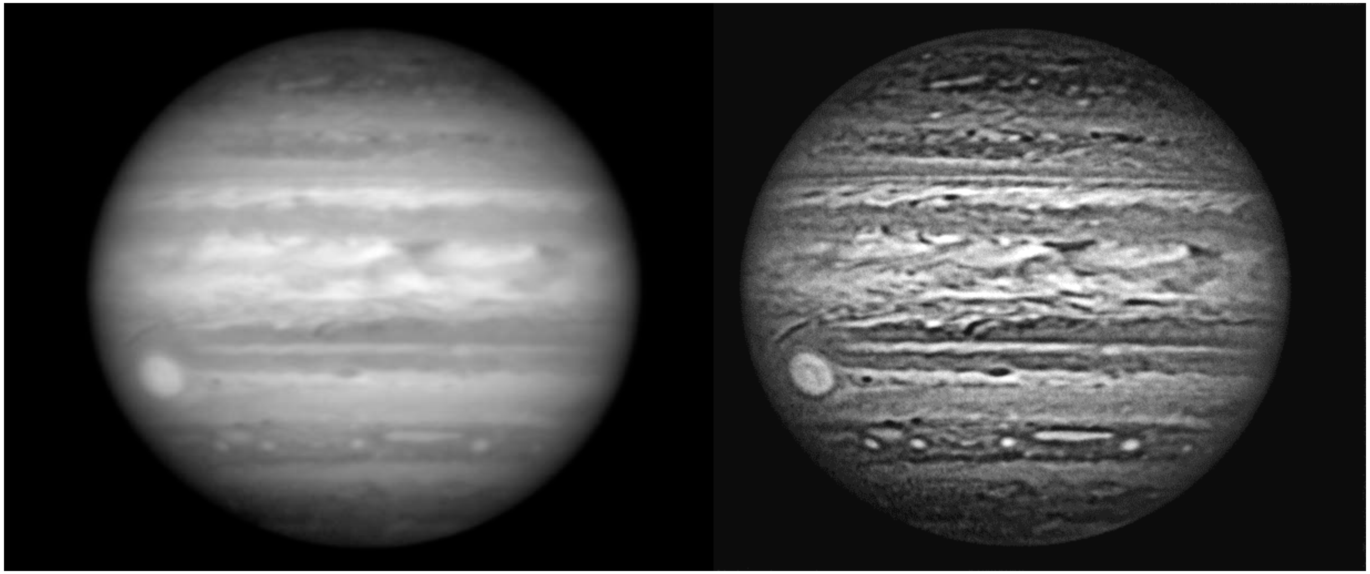


Enhanced image for dynamics (morphology & winds)



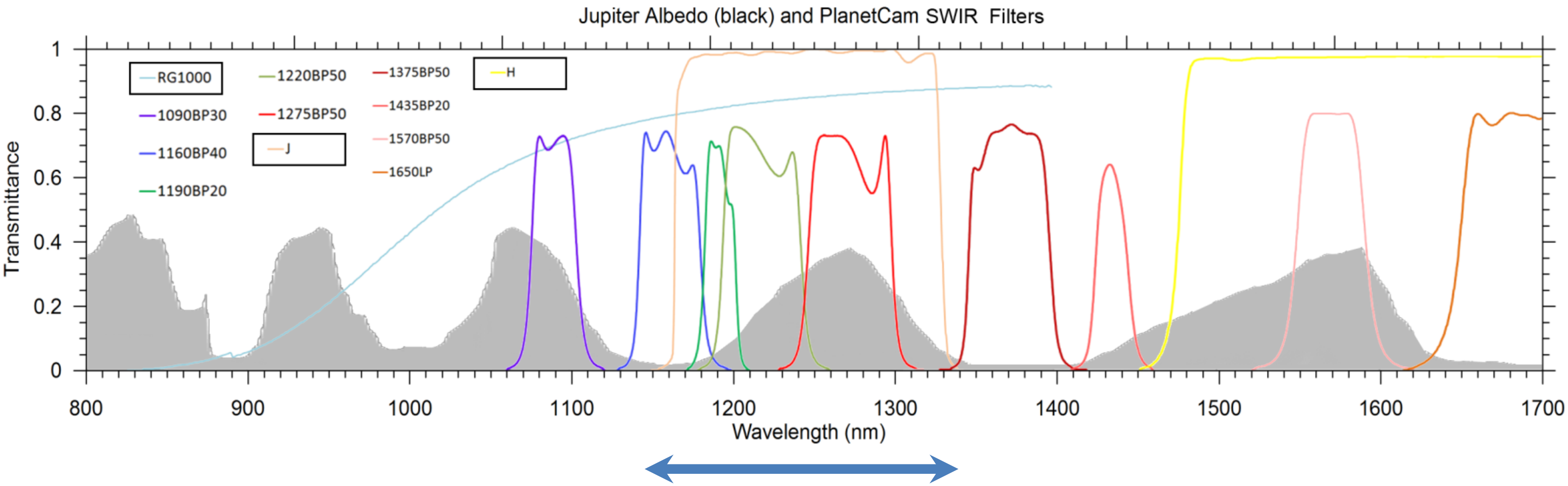
Jupiter at opposition

Date: 2016-03-03 Time: 23:37 UT | Filter: J



Resolution: 0.088 arcsec/pixel

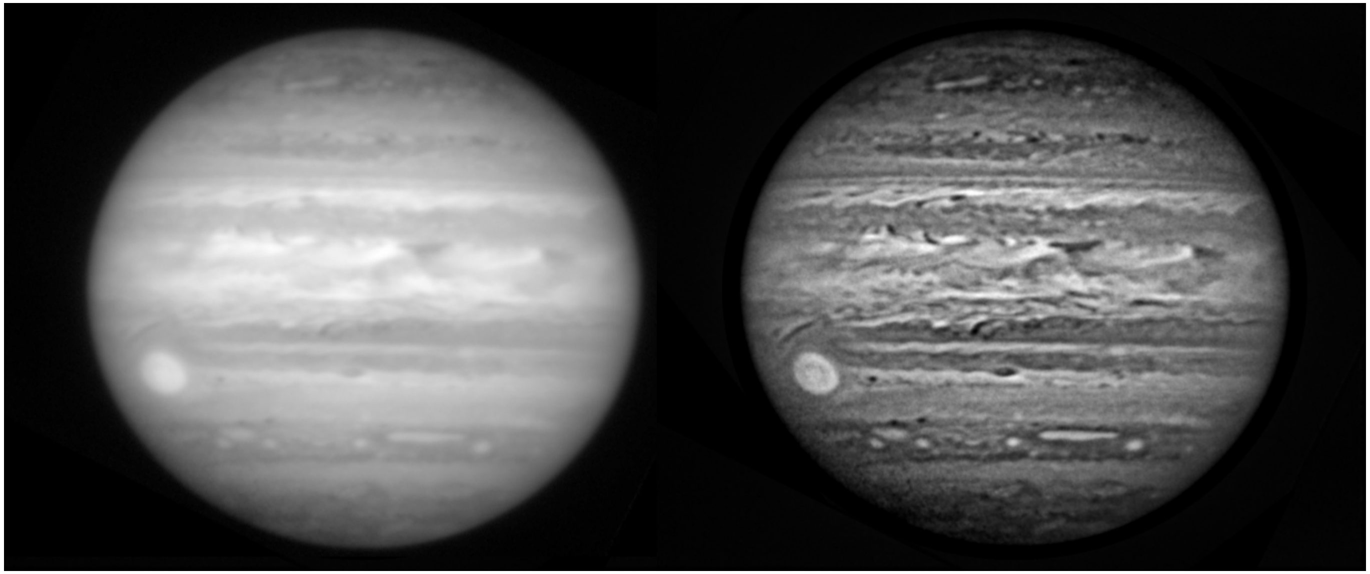
Photometric image (radiative transfer, cloud properties) **Enhanced image for dynamics (morphology & winds)**



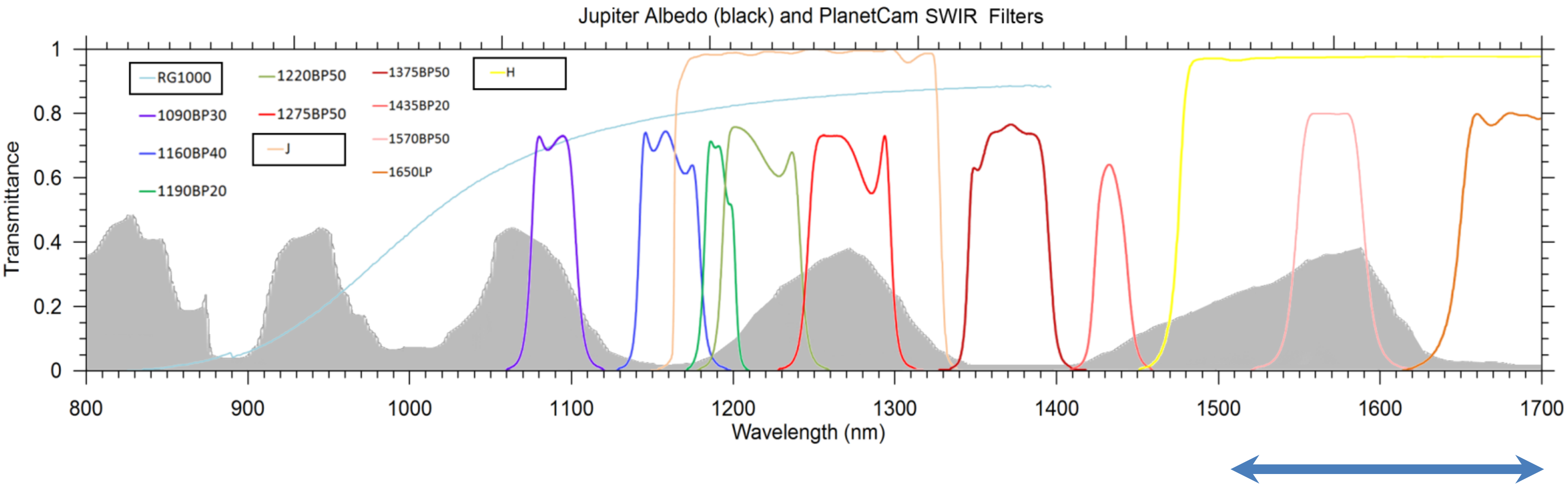
Jupiter at opposition

Date: 2016-03-03 Time: 23:41 UT | Filter: H

Resolution: 0.088 arcsec/pixel
Smallest details ~ 500 km



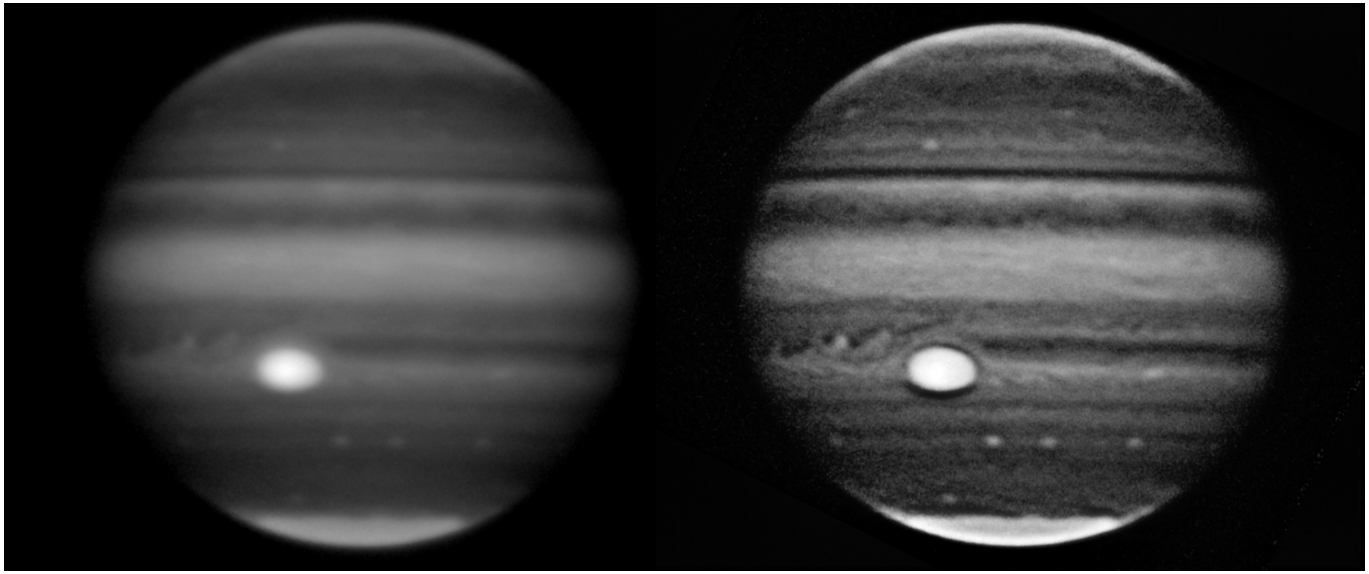
Photometric image (radiative transfer, cloud properties) **Enhanced image for dynamics (morphology & winds)**



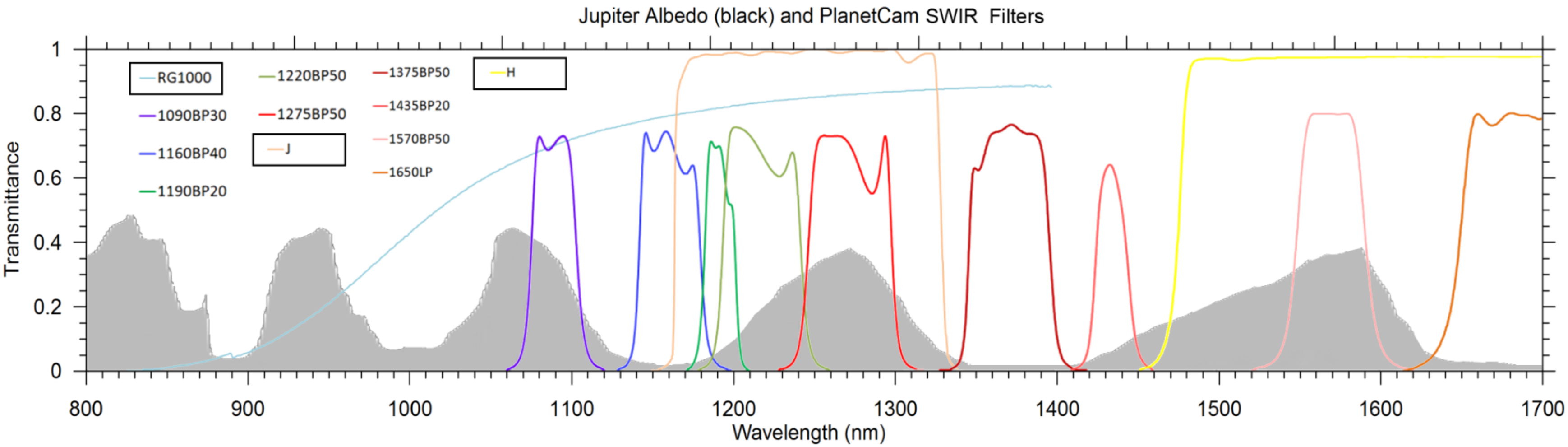
Jupiter at opposition

Date: 2016-03-04 Time: 00:41 UT | Filter: 1160BP40

Resolution: 0.088 arcsec/pixel

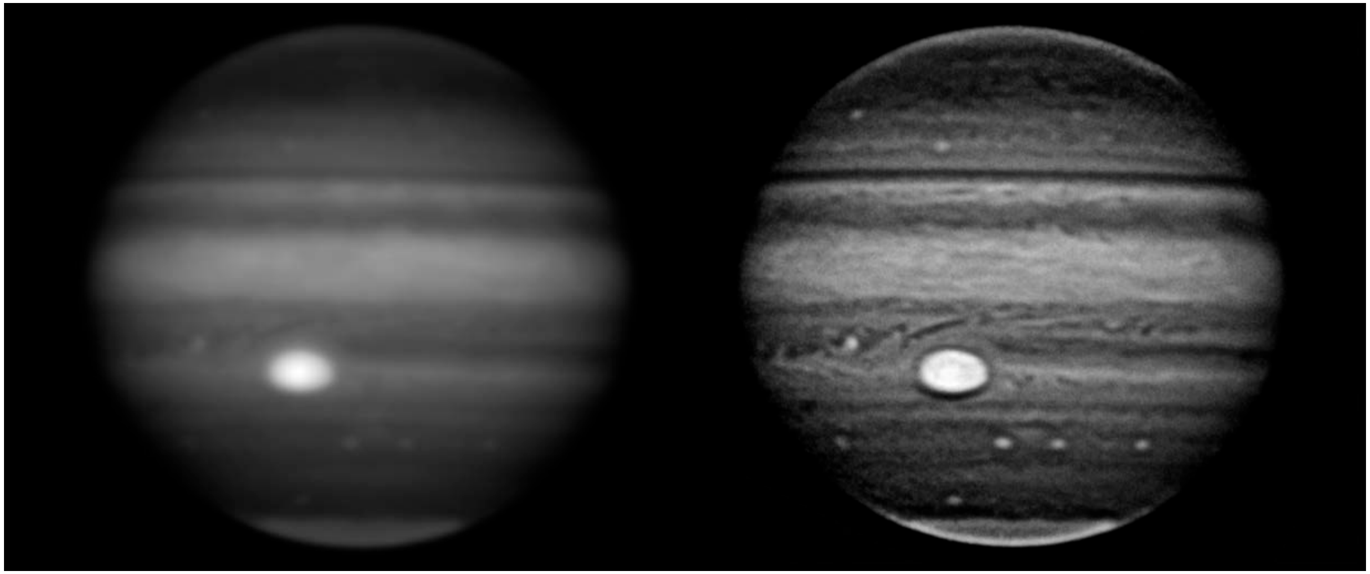


Photometric image (radiative transfer, cloud properties) **Enhanced image for dynamics (morphology & winds)**



Jupiter at opposition

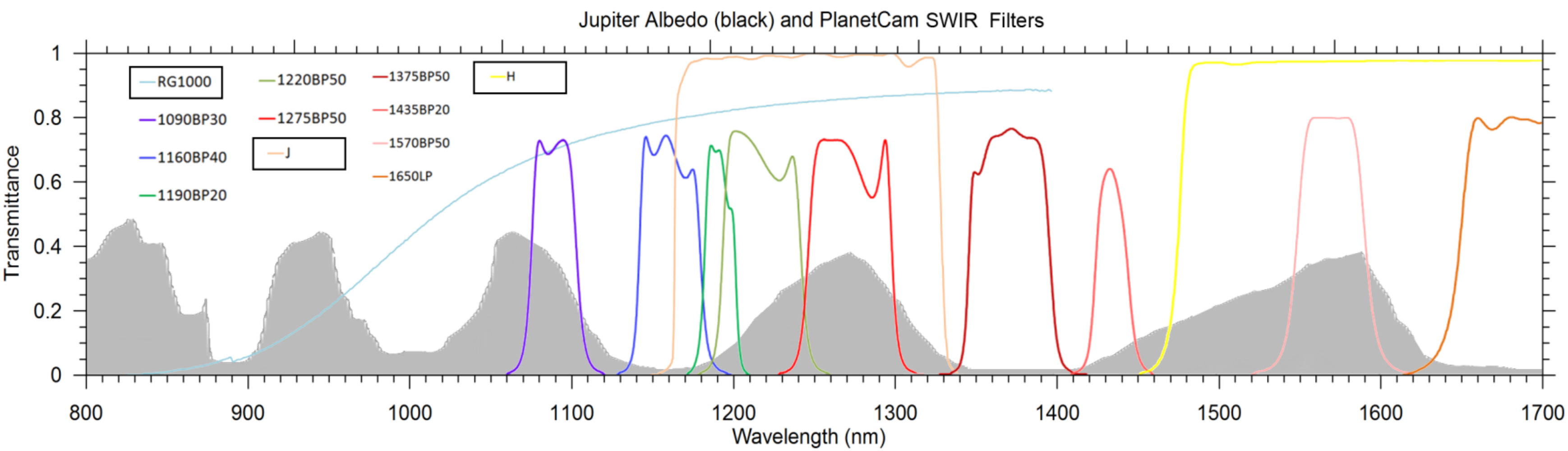
Date: 2016-03-04 Time: 00:46 UT | Filter: 1190BP20



Photometric image   (radiative transfer, cloud properties)   **Enhanced image for dynamics (morphology & winds)**

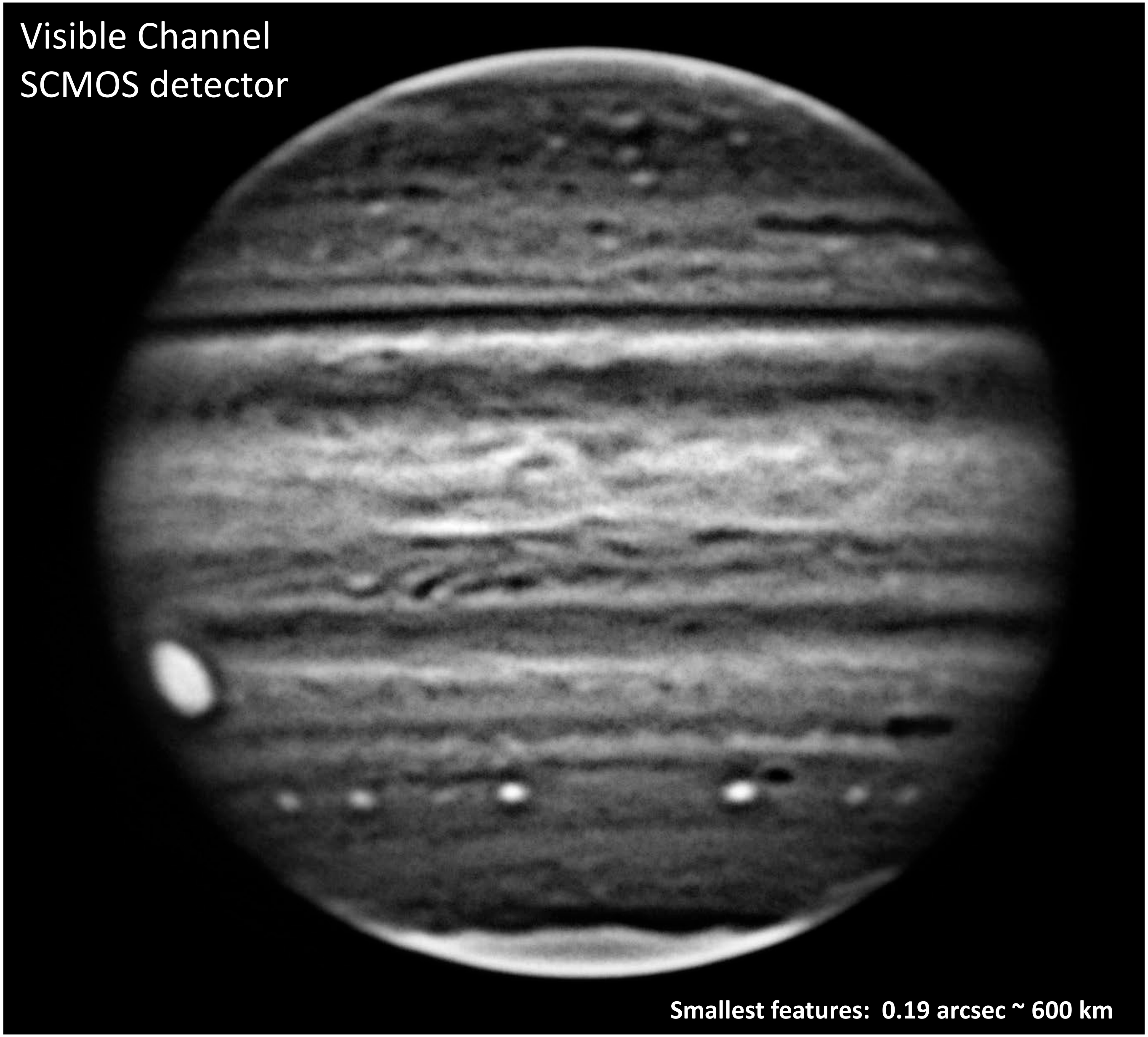
Resolution: 0.088 arcsec/pixel

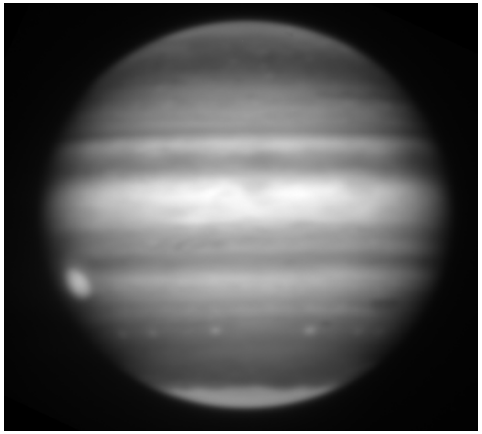
We can constrain dynamics at altitude levels of the clouds at the same time and at high-spatial resolution



Jupiter at opposition

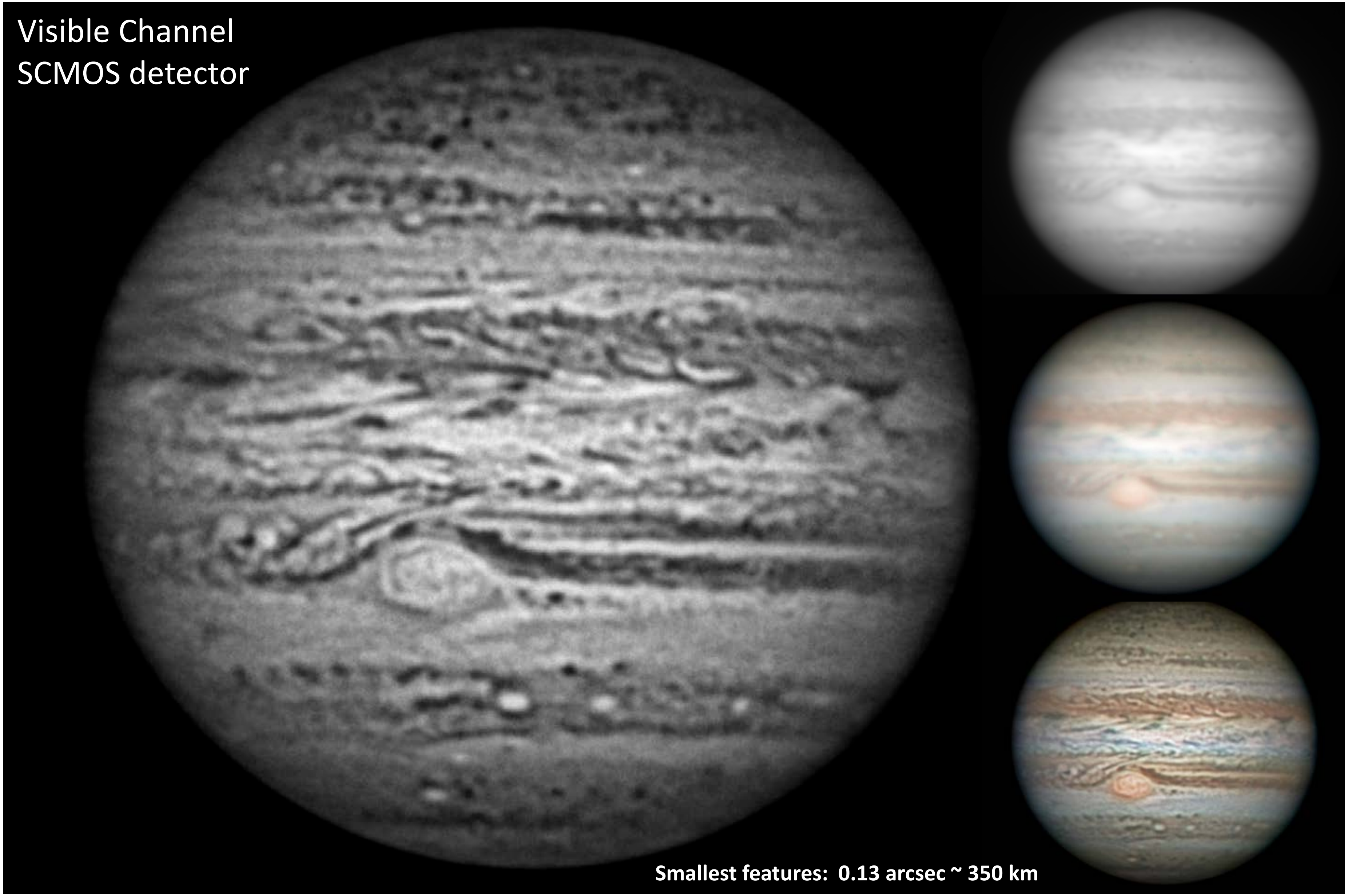
Date: 2016-03-03 Time: 23:27 UT | Filter: 890 nm **Resolution: 0.038 arcsec/pixel**





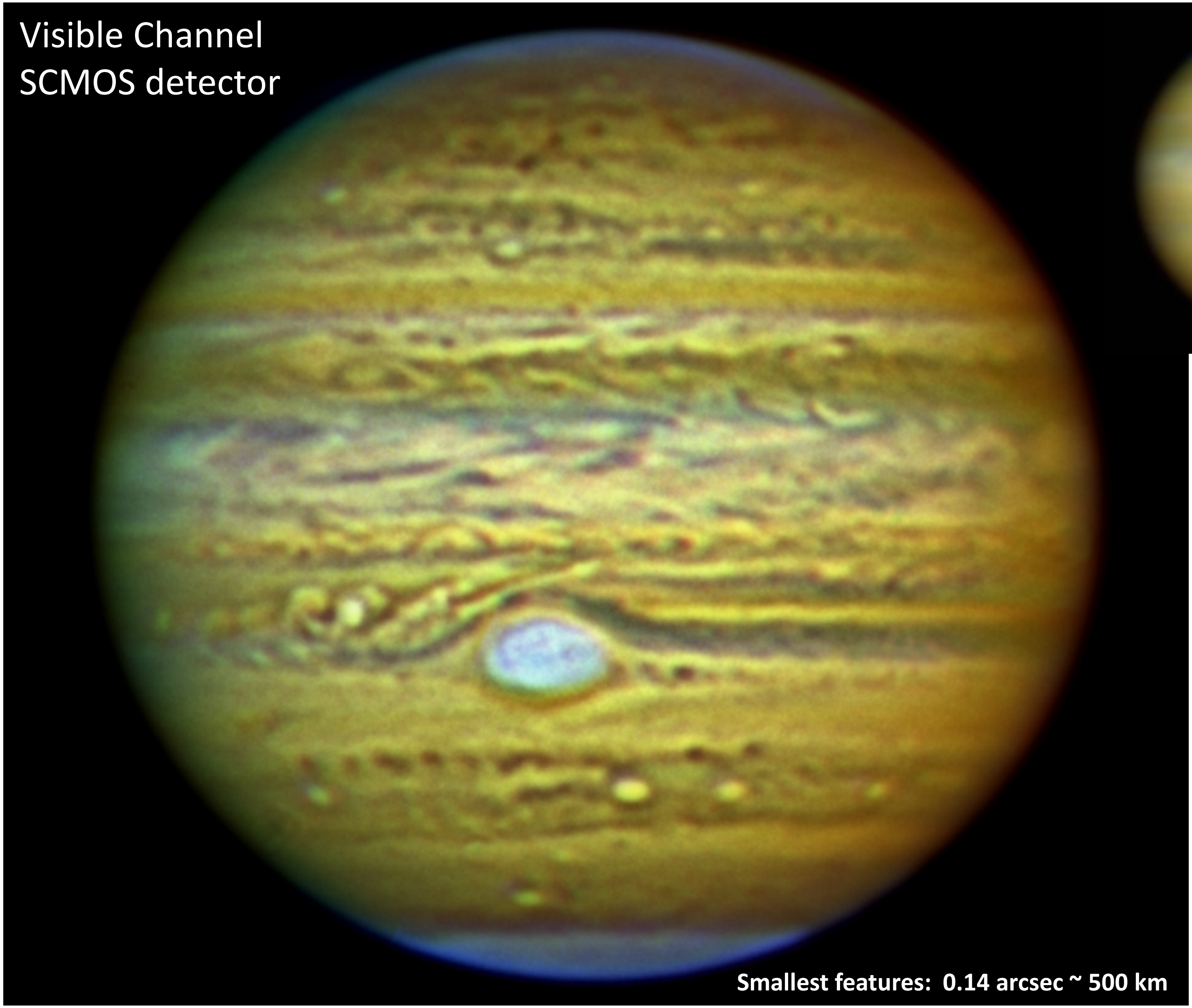
Jupiter at opposition

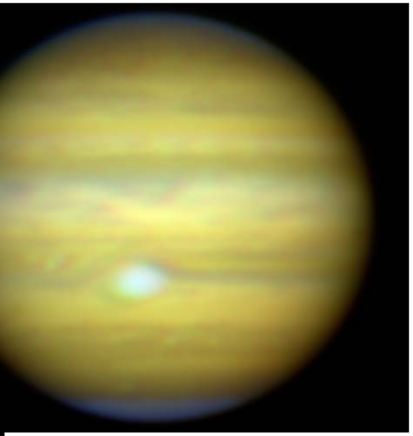
Date: 2016-03-04 Time: 00:43 UT | Filter: Johnson I **Resolution: 0.026 arcsec/pixel**



Jupiter at opposition

Date: 2016-03-04 Time: 00:57 UT | Filter: M1, M2, M3 **Resolution: 0.026 arcsec/pixel**





Bilbao's High-Res. Robotic telescope

Currently being installed in Calar Alto observatory
Meade 14''(36cm) + ASI120MM + filter wheels
0.25'' diffraction limit ~900 km resolution
Controled remotely from Bilbao
Should be operative at the end of May

<u>Regular frequent monitoring of planets</u>

Strong collaboration with amateur astronomers

- PVOL database (Planetary Virtual Observation Laboratory <u>redesigned</u>)
  Public database of amateur observations (some of them of outstanding quality)
  http://pvol.ehu.eus

- Juno Ground-Based Support from Amateurs workshop in Nice (May 12-13)

Both actions with support from Europlanet-2020 RI