

Dramatic Change in Jupiter's Great Red Spot. A. A. Simon¹, M. H. Wong², J. H. Rogers³, G. S. Orton⁴, I. de Pater², X. Asay-Davis⁵, R. W. Carlson⁴, P. S. Marcus², ¹NASA Goddard Space Flight Center, ²U.C. Berkeley, ³British Astronomical Association, ⁴Jet Propulsion Lab, ⁵Potsdam Institute for Climate Impact Research.

Introduction: Jupiter's Great Red Spot (GRS) is one of its most distinct and enduring features, having been continuously observed since the 1800's. It currently spans the smallest latitude and longitude size ever recorded. Here we show analyses of 2014 Hubble spectral imaging data to study the color, structure and internal dynamics of this long-live storm.

Physical Dimensions: The GRS's red edges have contracted from a longitude length of $\sim 21^\circ$ during the Voyager flybys in 1979 to $\sim 15.5^\circ$ in Hubble data acquired in 2012, shrinking on average $0.19^\circ/\text{year}$ over the modern era [1]. Amateur observers documented a sudden decrease in longitudinal extent in early 2014, faster than the average rate of contraction, and Hubble Space Telescope time was granted to characterize the current state of the storm. In the 2014 Hubble data, the red edges of the spot span about 14.1° in longitude, a decrease of 1.4° (1760 km) in 21 months, a rate of change four times greater than typical since 1979.

The GRS's latitudinal size has been much more constant, historically spanning between 10.5° and 11° , and is currently 9.4° , the smallest size measured to date. There has been a slight overall trend toward latitude shrinkage of $0.04^\circ/\text{year}$, significantly slower than in the longitude dimension, but the fastest change of 0.7° occurred between 2012 and 2014. Though the storm has a clearly diminishing length-to-width aspect ratio, from 1.8 in the Voyager era (and much greater historically) to 1.5 currently.

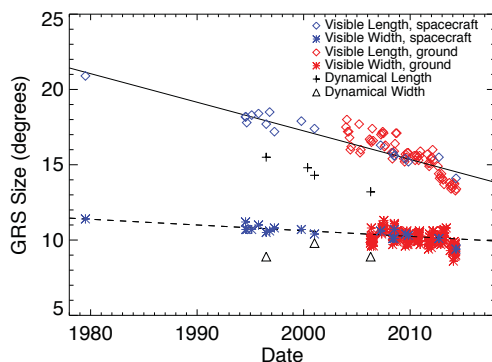


Figure 1. Measurements of the GRS's size. Visible edges, which are somewhat subjective, are often used to mark its size. Amateur measurements (red) show scatter, but are consistent with spacecraft data. Dynamical measures of the narrower high velocity collar also show a trend towards smaller size.

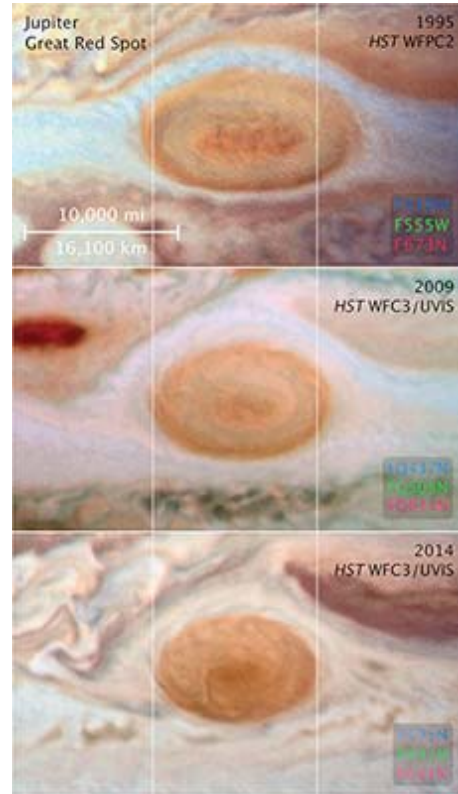


Figure 2. Visual comparison of the GRS's size in 1995, 2009, and 2014. Colors have been arbitrarily enhanced for consistency.

Spectral Analysis: Another notable characteristic of the 2014 images is the deep red color of the GRS, which is normally seen only during climatic cycles when the adjacent South Equatorial Belt (SEB) "fades" or whitens, such as during the Pioneer flybys in 1974 [2]. Spectroscopy was performed using Hubble images from 1995 to 2014 to determine the visible color of the darkest core of the storm, Fig. 3. In this region, the reflectance spectrum (I/F) is fairly constant [3,4]. The greatest change of up to 0.08 in I/F can be seen near 410 nm when comparing data from 1995 and 2008. The data acquired in 2014, however, show that the spectrum of the GRS is depressed by 0.1 to 0.15 in I/F at all wavelengths shorter than 500 nm. In addition, reflectance in the 890-nm methane gas absorption band has increased by ~ 0.11 in I/F since 2009, using the same filter, implying the altitudes and/or the concentrations of upper tropospheric aerosols have increased [5]. Spectra of other red regions on the planet do not show simultaneous increases in methane-band reflec-

tivity and visible reddening, ruling out calibration issues. Spectral change is also obvious in the core of the GRS; ratio images indicate that the spectral slope from 630 to 500 nm has steepened in 2014 compared with previous dates over most of the GRS.

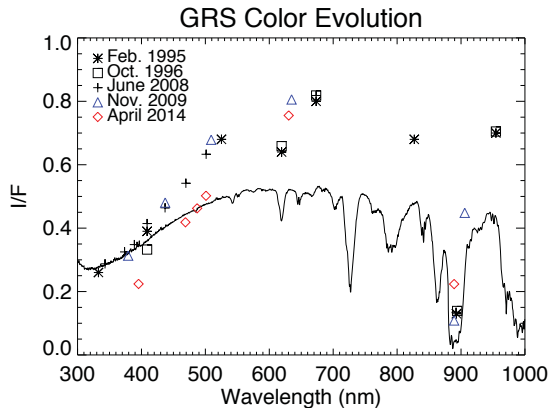
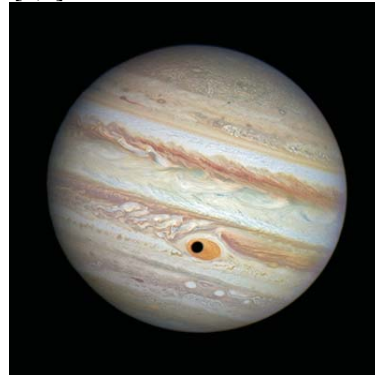


Figure 3. Spectral Imaging from Hubble shows dramatic change in brightness and slope in 2014.

Winds: The internal wind speed of the GRS can top 150 m/s, in a high-velocity collar that is smaller the visual diameter of the storm [1,6,7]. Automated velocity field extraction was attempted from the 2014 data, using the ACCIV method with correlations calculated for box sizes of 5° in latitude/longitude, between pairs of velocity field advected images [6]. The quality of the extracted velocity field was insufficient to accurately constrain the location and magnitude of the high-speed collar around the vortex due to limitations of the imaging data, *e.g.*, the shadow of Ganymede over the western side of the vortex in the later three frames resulted in only tie point pairs from short 43-min separations over large parts of the GRS rather than 10 hours. The eastern area of later frames in both orbits also suffered from reduced contrast due to proximity to Jupiter's limb. We identify tangential velocities in the 100–150 m/s range, with higher speeds at the north-south extrema of the vortex, where it interacts with zonal jets, but with larger uncertainties than typical. Thus, preliminary manual and automated measurements of cloud motions showed no significant increase in wind speed when compared with winds measured from 1996 to 2006 [1,6,7], implying an internal circulation period of about 3.2 days.

Wind Jet Interactions: The sudden shrinkage of the GRS and its observed color change are likely to be in response to changes in jet interactions. The reduction in width is due to shifts of both the northern edge (latitude mean 1979–2012, 16.8° S ± 0.3 ; 2014, 17.4° S) and the south edge (latitude mean 1979–2012, 27.4°

S ± 0.2 ; 2014, 26.8° S). This causes reduced deflection of the jets north and south of the GRS, altering the zonal wind shear environment sensed by the vortex. Decreased interaction with small vortices carried by those wind jets may be the reason for the intensified red color in 2014. In particular, the GRS is now sufficiently withdrawn from the westward jet at 19.5° S that it does not ingest vortices carried by that jet. Similarly, during SEB fading events there are no vortices being carried by the jet toward the GRS and its color intensifies [2,8].



Conclusions: The GRS interacts with the zonal wind jets, with energy or momentum exchange of unknown magnitude. It is not yet understood what colors the clouds and why they can vary in spectral slope and absolute brightness, though the current spectrum may be indicating a change in colored-particle production. Further analyses of the temperatures, winds, and size of the GRS, especially in epochs of change, will provide interesting constraints to analytic models of geostrophic balance in the region. In addition, global circulation modeling of the GRS in its flow field for different dates will show which configurations are most stable to decay.

Acknowledgments:

This work was based on observations made with the NASA/ESA Hubble Space Telescope under programs GO12045 and GO13631. Support for program number GO13631 was provided by NASA through a grant from the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. The changes were initially identified, and supporting data provided, by amateur observers, especially Damian Peach, and the JUPOS team, especially Michel Jacquesson.

References: [1] Simon-Miller et al. 2002 *Icarus* **158** [2] Rogers 1995, [3] Sanchez-Lavega et al. 2013 *JGR-P* **118**, [4] Simon et al. 2014, submitted, [5] Perez-Hoyos et al. 2009 *Icarus* **203** [6] Asay-Davis et al. 2009 *Icarus* **203** [7] Shetty and Marcus 2010 *Icarus* **182**, [8] Peek 1958.