Circulation of Jupiter's Great Red Spot measured from amateur and Hubble images

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1. Introduction

The GRS has been shrinking ever since the early 20th century [1,2]. The shrinkage was particularly rapid in 2012-2014, so in 2014 the GRS had the smallest size ever recorded [4]. At the same time, the GRS became darker and redder, and its drift rate decelerated, which usually occurs only during SEB Fades. Changes in the internal circulation of the GRS can also be studied from amateur images, which are now good enough to record small streaks circulating within the GRS, as measured in 2006 and 2012 [2,3]. We have now measured amateur images in 2014-15, and on HST images for comparison, characterising the acceleration and shrinkage of the flow field within the GRS.

2. Shrinkage of the GRS

Methods: The length of the GRS was taken from the general JUPOS database [http://jupos.org]. The latitude was measured specially using WinJUPOS on selected images where the limb was clearly defined.

Results: The longitudinal shrinkage of the GRS since 2003 has been similar to the long-term trend overall, but it was static for several years, then shrank very rapidly from 2012-2014. In 2013-14, the GRS was smaller than ever before: 13.5º (±0.2º) long [4,5] – recovering slightly to 14.2º (±0.4º) in 2014 Oct-Nov.

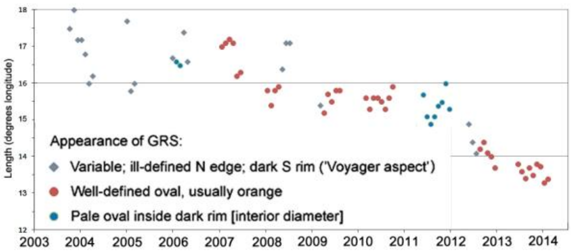

Figure 1. Chart showing length of the GRS, 2003-2014: monthly means (updated from [3]) .

The GRS has shrunk in latitude as well as longitude: in 2013/14, when the width in latitude was only 9.4º, compared with 10.2º from 2008-2012, and 11.9º historical average (1952-1990 [1]). The width has changed less than the length, so the ellipticity has continued to decrease.

3. Circulation period measured from amateur images

Methods: Amateur image quality increased greatly in the early 2000s, due to the use of webcams for taking short sequences of hundreds of images, coupled with programs such as Registax for selecting and stacking the sharpest images. In the last two years, further improvement has resulted from a new function in WinJUPOS for 'derotating' images, which extends the useful timespan for integration from ~3 min to ~20 min. These imaging techniques have allowed many amateur images to detect features within the GRS, e.g. dark streaks near the outer edge, which persist for days or weeks and allow its circulation to be measured. As we can obtain higher precision for changes in position angle (PA) than absolute displacements in these images, we make the simplifying assumption that the GRS circulation is an elliptical projection of circular motion [2]. In some sequences we use images on which the GRS is near the central meridian or is placed on it by digital rotation. In others, we project the images into cylindrical projection maps. The image is then stretched in the north-south direction until the GRS appears circular. The position angle of the streak is then measured, and plotted against time. Despite the approximations in the assumptions and projections, we generally find an excellent linear fit giving a precise rotation period over 1-4 rotations.

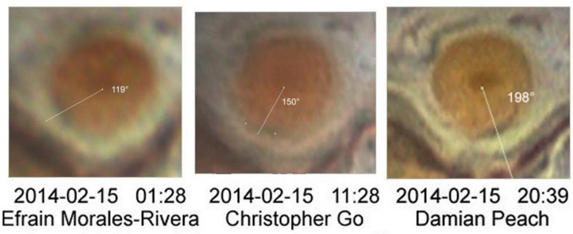

Figure 2. Circulation of the GRS, 2014 Feb. Excerpt from a set of reprojected images with PA measurements.

Results: We first measured the rotation period for 2006, finding a period of 4.5 (±0.1) days [2]. We have now measured images for 2005 May, finding 4.7 (±0.1) days. In 2012, the period was 4.0 days [3]. Each value was determined over ~3 rotation periods. From 2014 Jan. to 2015 March, the best images (e.g. Fig.2) often detected small grey streaks within the GRS and have allowed nine separate determinations (Fig.3). (All were from measurements of a single spot or streak around 1-4 rotation periods, except the last, which is an average of 6 separate measures over ~10 hours each on 6 different dates.) The observed period has been 3.6 to 3.8 days throughout.

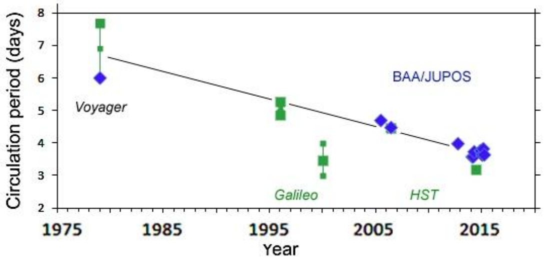

Figure 3. Rotation period of the GRS: Chart from [2] plus data from [5,6] & this paper. Dark blue, rotation periods measured directly; green, calculated from hi-res wind field.

In 2014-15, improved images sometimes resolve multiple features within the GRS, revealing its rotation over ~1 hour as it crosses the jovian disk, although the interval is too short for measurement.

4. Circulation rate measured from HST images

Method: We use the same technique as for ground-based images, but measure the angular velocity over ~10 hours between images, and express this as an implied rotation period. Errors due to the approx-imate assumptions and projections are likely to be no greater than the uncertainties due to the extended size of the features, and are minimised by sampling features all around the GRS.

Results: We made preliminary measurements of the rotation rate within the GRS from HST image pairs on 2009 Sep.22, 2012 Sep.20, and 2014 April 21, as compared with the published wind field from 2006 April [6]. The HST and ground-based measurements agreed on the periods for large streaks: 4.5 days in 2006, 4.0 days in 2012, 3.8 days in 2014. This confirms that amateur images can track the circulating features accurately. However, they do not always capture the fastest wind speeds. Most features in the HST images in 2009-2014 had faster rotation rates, which were consistent within the high-speed collar from r~6000 km to r~7000-8000 km **(Fig.3)**. The rotation period decreased from 3.8 d (2009 Sep.) to 3.5 d (2012 Sep.) to 3.2 d (2014 April; agreeing with professional analysis [5]), entirely due to the physical shrinkage of the GRS. The peak wind speeds in these years were always in the range 147-152 m/s, higher than in 2006 but not accelerating further.

5. Discussion

The GRS appears to be evolving towards the state of Cassini's spot of 1665-1713 [ref.1, pp.262-3]. At the recent rate of shrinkage, it could even become circular by ~2030. If the smaller GRS is interacting less with the SEBs jet [5], this could explain its increased redness and slower drift rate, resembling the situation during a SEB Fade.

This evolution of the GRS size and the circulation appears to be intrinsic to the GRS itself. It does not appear to be a response to any major external factors which occurred during these years, such as SEB Fades and Revivals, or STBn jet spot outbreaks, apart from transient lengthenings in 2007 and 2008 possibly due to interactions with other spots. Most notable is the high wind speed in 2009, when a prolonged SEB Fade began, cutting off the supply of mid-scale vortices to the GRS from the SEBs jet. This contradicts the prevailing view that influx of these vortices sustains the circulation of the GRS.

References

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[3] Rogers J.: 'The accelerating circulation of the Great Red Spot.' http://www.britastro.org/jupiter/2012_13report07.htm

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