Jupiter in 2013/14: Interim report no.7
The Great Red Spot in 2013/14: Faster shrinkage and evidence for faster wind speed

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Summary

In 2013/14, the Great Red Spot (GRS) is smaller than ever before, with a length of 13.6 deg. (15860 km). It also has an exceptionally short circulation period: 3.6 (±0.2) days. The inferred wind speed, 144 (±14) m/s, is faster than any previous measurement of the mean peak wind except for one (by Galileo in 2000), but the difference is less than the uncertainties. If the wind speed has truly accelerated, in 2013/14 as in 2000, this may be due to influx of vorticity from the STBn jet spots which are being disrupted along the edge of the GRS.

Introduction

The GRS has been shrinking ever since the 19th century, though with large fluctuations [Refs.1,2]. Since the GRS circulation was first charted by the Voyager flybys in 1979, this shrinkage has continued, indeed with a rather more constant rate [Refs.2,3]. Meanwhile the internal wind speeds did not show statistically significant variations from 1979 to 1996, although the later values tended to be somewhat higher (**Table 1**, extended from ref.2). Observations from the Galileo Orbiter on 2000 May 22 showed much faster wind speeds [Refs. in Table 1], for unknown reason, although the GRS was only slightly shorter than indicated by the long-term trend. Since then, amateur images have improved to the level where they sometimes record small streaks circulating within the GRS, allowing us to measure the rotation period [Refs. 2,7]. We did this in 2006, finding a period of 4.5 (±0.1) days, and again in 2012, finding 4.0 days. These results involve certain simplifying assumptions, and do not necessarily record the fastest speeds in the GRS [Ref.2]; nevertheless, they are consistent with spacecraft results before and after 2000. (Independent HST values in the same month as ours in 2006 are indistinguishable: Table 1 & Ref.6). The decrease in period has been roughly concordant with the decrease in length, implying no statistically significant change in wind speeds except in 2000 May.

We have been able to repeat these measurements on amateur images in 2014 Jan., and find evidence for a period as short, and wind speed as high, as those observed in 2000.

Observations in early 2014

The GRS is at L2 = 209 (2014 March 1) with a drift of DL2 = +1.4 deg/month, which is unusually slow. It is an isolated oval and notably orange **(Fig. 1)**. The speed, appearance, and colour are more typical of times when the SEB is fading, and are surprising as the SEB is currently so active.

Length of the GRS:

The GRS is also smaller than ever before, only 13-14 deg. long **(Fig. 2)**. As Damian Peach pointed out (**Fig.2C**), the shrinkage in 2013/14 has been exceptional, beyond the long-term shrinking trend of the GRS. This is shown more thoroughly in **Fig.2B**, which shows that the enhanced shrinkage began in 2012. There is considerable scatter in years when the outline of the GRS was variable or poorly-defined, as in the Voyager epoch; but more reliable data are obtained when the GRS is a well-defined oval. These show that there have been real fluctuations. In 2007, the GRS length increased above the long-term trend while the SEB was fading and two S.Tropical Disturbances existed, but then diminished rapidly in July during the SEB Revival, although the STropD was still preventing disturbance from reaching the GRS for several more months. Conversely from mid-2009 to mid-2011, when there was a SEB Fade then Revival, the GRS length was constant. Then it began the present rapid shrinkage some time in 2012.

Average shrinkage rates have been quoted as 0.14 deg/yr (1920-1990) [ref.1]; 0.19 deg/yr (1979-2000) [ref.3]; 0.26 deg/yr (1999-2014) [JUPOS data, G. Hahn, pers.com.]

Circulation of the GRS:

Has the internal circulation period changed accordingly? The period can be measured on amateur images when suitable spots or streaks can be seen circulating within the GRS, and was 4.5 d in 2006, shortening to 4.0 d in 2012 [Refs.2,7]. This year, there have been only small, ephemeral features within the GRS: for example, in the v-hi-res images in Fig. 4. Nevertheless, it was possible to track one small dark grey spot from Jan.2-7 [Figs.3 & 2D]. Although the time-span is shorter than for previous measurements, the tracking indicates a steady circulation period of 3.6 (±0.2) d. The present spot was at ~90% of the radius of the GRS so, using the same assumptions as previously [Ref.2], the wind speed is (π x length x 0.9/period) = 144 (±14) m/s. Both the circulation period and the wind speed are similar to those in 2000 May, although the GRS itself is smaller, as the radius of observed peak wind speed is similar.

Table 1 (Extension of table in Ref.2):

		V(mean) (m/s)	*V(gusts) (m/s)*	*P (days)*	*Major axis (km) [*a]*	*Ref.*
1979 Feb-Mar	Voyager 1	110, 120	140	6-8		[*b]
		135	135			[*b]
1979 Jun-Jul	Voyager 2	110	120			[16]
1996 Jun	Galileo	135	145	5,0-5,3		[*b]
		115	150			[4]
2000 May	Galileo	165	190	3,0-3,5	~19800 x (0.7-0.8)	[3]
		145	180		= 13860-15840	[4]
		145	170	3,7-4,2	17100	[5]
2006 April	HST	121-127[*c]		4,5	15300	[6]
2006 Apr-Jul	BAA	112		4,5	19800 x 0.7	[2]
2012 Sep	BAA	135		4,0	18560 x 0.8	[7]
2014 Jan	BAA	144		3,6	15800 x 0.9	This work
Notes:	[*a] Major axis of maximum measured wind speed					
	[*b] See Ref.2.					
	[*c] Speeds were -117/+131 m/s in L3, i.e. -121/+127 m/s in GRS rest frame.					

Notes to Table 1: For Galileo and HST data, the wind speeds were measured and the period has been deduced. For BAA data, the rotation period was measured and the wind speeds have been deduced. Assumptions and caveats are explained in Ref.A. In particular, the GRS circulation is modelled as an elliptical projection of circular motion (so the mean peak wind speeds are along the N and S edges); and the features which we track may not represent the fastest wind speeds.

Similar sets of images have been assembled for 2013 Nov.11-26, Dec.9-12, and 2014 Feb.12-22. Signs of the internal circulation could be traced over short intervals, but there were no persistent tracers to determine an accurate rotation period.

STBn jetstream outbreak and S.Tropical Zone:

The GRS is in the firing line of an outbreak of dark spots on the STBn jet, which began during solar conjunction in mid-2013, as an expected consequence of the collision of a dark STB segment with oval BA and the establishment of this dark, micro-turbulent STB segment f. BA since then [Ref.8]. Hi-res images have shown fascinating structure in the outbreak. Sometimes, [e.g. Fig. 4, bottom right] one can see the narrow STBn emerging p.oval BA becoming wavy and then breaking up into the dark spots. A time sequence including this image, and further details of the STBn jet outbreak, are in [Ref.9].

The STBn jet spots are initially very dark grey, but further p. they become brown or tawny, as they become smaller but embedded in a tawny band. The spots disappear at the STB Ghost or, since it passed the GRS, at the GRS. V-hi-res images of the GRS show a chaotic scene as these jet spots are disrupted on passing the GRS (Figs. 3 & 4). Animations of these images could give a much better impression of this intense but small-scale disturbance. Sometimes part of a spot swung N round the p. edge of the GRS, or sometimes a spot was just disrupted into faint streaks in the STropZ p. the GRS. Similar processes were described during the previous STBn jet outbreak in 2010 [Ref. 10], and this is all reminiscent of the disruption of a much more substantial Little Red Spot by the GRS in 2008 [Refs.11 & 12].

A diffuse yellowish colour was notable in the STropZ p. the GRS from Nov. to Jan., and in a halo around the GRS from Jan. onwards (as noted by observers including Paolo Lazzarotti, Jan.12) (Fig. 1A), at least when these regions were not too disturbed. The origin of this colour was unclear, but I suggest it may have come from the tawny STBn jet spots themselves when they were disrupted on approaching and passing the GRS. Alternatively, as some observers suggested, it might have come from the shrunken GRS itself, possibly because its periphery was eroded by the incoming jet spots.

From late Jan. onwards, as the source of the STBn jet spots drew closer to the GRS, they have been still dark grey when they reached it, and the yellowish colour has been less evident in the STropZ p. the GRS, although sometimes still present both there and around the GRS (Fig. 1B).

Discussion: The shrinkage and circulation of the GRS, in 2014 and 2000

The present rotation period of 3.6 d is significantly shorter than any previous measurement, apart for the exceptional one from the Galileo orbiter on 2000 May 22 (**Table 1**). Moreover, the deduced mean peak wind speed is faster than any previous measurements apart from that same Galileo data set (although the difference is within the range of uncertainty) (**Table 1**). It would be highly desirable to have higher precision and confirmation on other dates; but if this result is accurate, it suggests that the GRS in 2013/14 is exceptional in two respects. In addition to its long-term shrinkage, it has shrunk by more than expected in 2013/14, and its winds have speeded up.

There is an obvious 'smoking gun' which might explain one or both of these changes: the barrage of incoming STBn jet spots, which started in mid-2013. They are unlikely to explain all of the extra shrinkage, which seems to have started about a year earlier with no obvious cause. It is conceivable that the turbulence of the incoming STBn jet spots further enhanced the shrinkage in 2013/14, by eroding the outer rim of the GRS outside its radius of maximum wind speed. However, no such change occurred in 2000, and it may be that the extra shrinkage is an independent and unexplained phenomenon.

On the other hand, the accelerated wind speed, if real, could be due to vorticity incoming from the STBn jet spots. There was no such STBn jet outbreak during the previous speed measurements by Voyager or HST, or by ourselves in 2006 and 2012. However, could there have been such an outbreak in 2000 May, when the Galileo Orbiter reported even faster circulation? This was during solar conjunction, but as explained in the footnote*, it is quite likely that there was an ongoing major outbreak of STBn jet spots which could have been reaching the GRS, just as in 2013/14.

Dark spots on the best-studied jets are anticyclonic vortices, but it is not clear whether this is true of the STBn jet spots [Ref.18]. They do appear to be forming by eddying as the jet visibly breaks up [Fig. 4, bottom right], and they could even be a mixture of anticyclonic (northerly) and cyclonic (southerly) vortices within this complex jet. I therefore propose that the anticyclonic vorticity of STBn jet spots is transferred into the GRS as they are disrupted along its southern rim, temporarily increasing its internal winds.

This hypothesis is consistent with the long-standing theory that the GRS winds are sustained by incoming anticyclonic vortices incoming from the opposite direction, on the SEBs retrograde jetstream [Refs.14-17] The GRS wind speeds were slightly lower in the Voyager 2 data set than in those from Voyager 1 or subsequent spacecraft [Table 1, & Ref.16], and this was attributed to the development of a S.Tropical Disturbance which blocked incoming SEBs jet spots [Ref.16].

Thus there are several potential influences on the GRS wind speed: variations in the flux of incoming SEBs jet and STBn jet spots, which are conjectured to enhance it; and SEB Fades and STropDs, which could reduce it by blocking those incoming spots. To disentangle these potential influences, it would be desirable to seek measurements of the GRS rotation in many years, such as late 2007 (when a S.Tropical Disturbance blocked SEBs jet spots), and in late 2010 (when there was a vigorous STBn jet outbreak impinging on the GRS, although there was also a SEB Fade), to see whether they confirm deceleration and acceleration respectively.

Given the implications for our understanding of the GRS, further analysis of the present flow patterns would also be worthwhile, but is beyond the scope of this report. More precise projection of amateur images, and correlation of streak patterns in sequences of them, might enable measurements of the GRS wind speeds in other image sequences from 2013/14, and from other years; and also, characterisation of the flow field around the GRS, where the STBn jet spots are being disrupted. It might also be possible to estimate the influx of vorticity to the GRS. And if HST images could be obtained, a full characterisation of these flow fields and physical processes could be possible.

**Footnote: The GRS in 2000 May:*

The Galileo images from 2000 May 22 (G28 perijove) were analysed in [refs.3-5]. They found mean peak winds of 145-165 m/s (on the N and S edges), with local peak winds of 180-190 m/s, implying a circulation period in the range 3.0—4.2 d (Table 1): the winds were faster and the circulation period possibly shorter than in any other data set before or since. However, the GRS and its internal circulation pattern was not exceptionally small at that time.

The Galileo imaging in 2000 May was during solar conjunction. There were two structured sectors at the time, either of which might have produced STBn jet activity:

--One comprised ovals BE and FA which merged in 2000 March, but this happened p. the GRS, so any disturbance which it produced in the STBn jet would not have reached the GRS by May.

--The other sector, f. the GRS, comprised spots DS1-DS2-DS3, which in 1999 did produce the first STBn jet outbreak since 1994. The STBn spots were not conspicuous in the images of the time (much inferior to current images), but 11 spots were tracked with mean speed DL2 = -77 deg/month, typical of later substantial outbreaks. Our published BAA report [ref.13] said:

"The STBn jetstream outbreak was the first since 1994. The tiny prograding dark spots were all arising near DS1/DS2... [The first three spots, in 1999 Aug-Nov., with speeds ranging from -60 to -113 deg/month, were the only ones to reach the GRS...] Later ones, also arising near DS1, travelled less than 90 deg. before disappearing. They had speeds between -65 and -78, and were still seen as late as 2000 Jan."

By 2000 Oct., in the Cassini images, the DS1/DS2 sector was only tens of degrees f. the GRS and several STBn jet spots could be seen running from it to the GRS.

So it is quite likely that this outbreak was still active in 2000 May and spots from it were then reaching the GRS. Only the Galileo Orbiter images themselves could determine this. One is Fig.1C, and although the area shown is small and partly obscured by the shadow of Europa, it does appear to show two high-amplitude waves approaching on the STBn, consistent with an ongoing outbreak.

[In Ref.3, Fig.2 does not show these images as stated, but the Galileo G1 images from 1996, lower pair.]

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Miniature copies of figures:

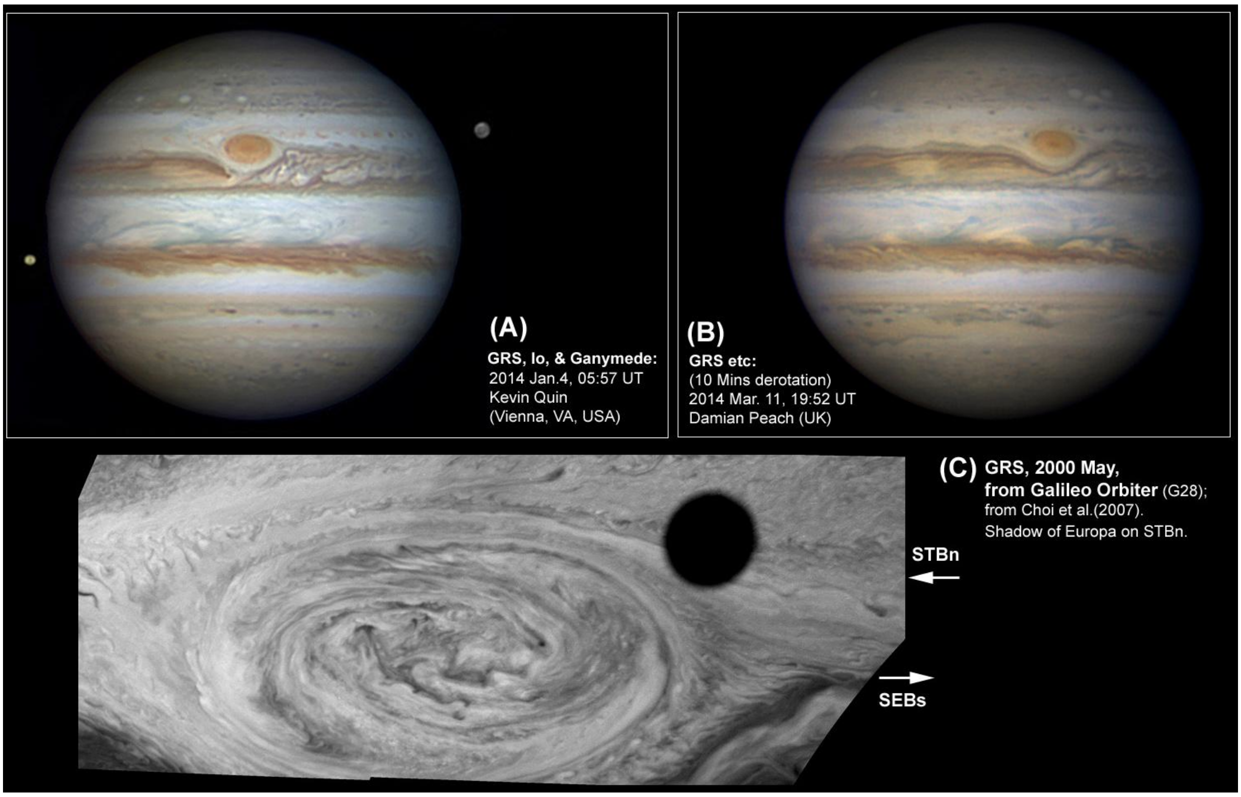

Figure 1. (A,B) Images of Jupiter on 2014 Jan.4 (K. Quin) and 2014 Mar.11 (D. Peach), showing the GRS, yellow STropZ p. it, and STBn jet spots f. it. **(C)** Image of the GRS from the Galileo Orbiter, 2000 May 22, plus shadow of Europa, from Ref.5.
South is up in all figures.

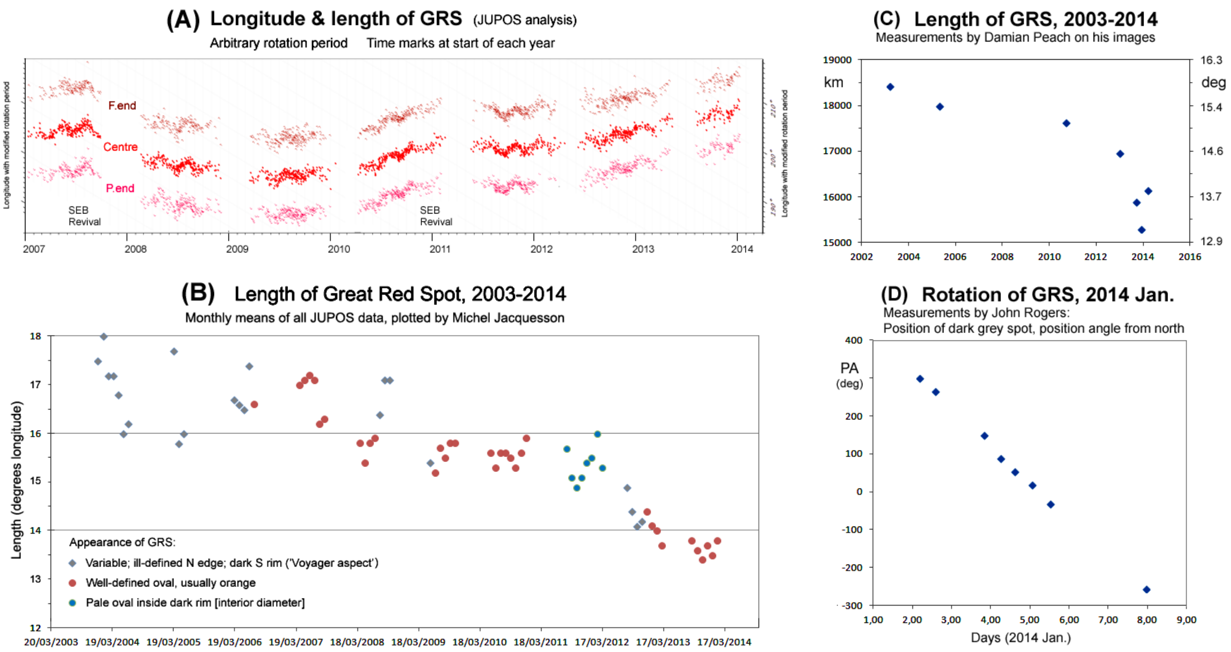

Figure 2. Charts showing the shrinkage and internal circulation of the GRS.
(A) JUPOS chart of the GRS, 2007-2014, adjusted an arbitrary rotation period to match its mean motion over this interval. Note the progressive reduction in length; the 90-day oscillation, and the deceleration before the SEB Revivals in 2007 and 2010 followed by acceleration afterwards. The GRS has also decelerated in 2013-14, as it has again become an isolated red oval, even though the SEB is not fading.
(B) Shrinkage of the GRS, 2003-2014: monthly means of all JUPOS measurements, compiled by M. Jacquesson, colour-coded by the aspect of the GRS at the time. There is some scatter when the GRS has the usual 'Voyager aspect', as the dge may be ill-defined or disturbed by incoming spots and dark rim. Measurements are more consistent when the GRS is a well-defined oval.
(C) Shrinkage of the GRS, 2003-2014, measured by Damian Peach from his own images.
(D) Rotation of the GRS, 2014 Jan: Position angle of the dark grey spot measured on Fig. 3 (by John Rogers). The points fall on a straight line indicating P = 3.6 d from Jan.2-5, or P= 3.7 d if the Jan.7 point is included.

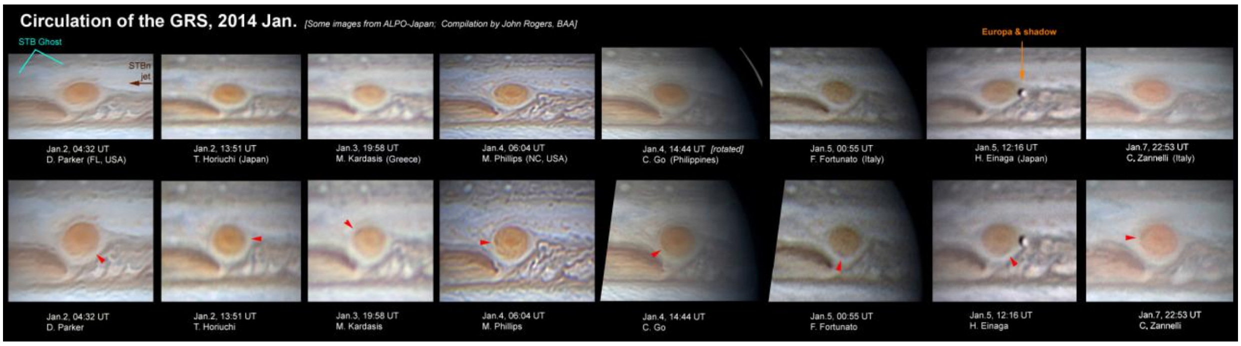

Figure 3. The GRS in 2014 Jan., showing its internal circulation, and STBn jet spots dissolving into low-contrast chaos as they approach or pass it. South is up. *Top row*, images; *bottom row*, the same stretched to approximately circularise the GRS for measurement of the position angle of a small dark grey spot circulating around it (red arrowhead). Measurements are in Fig. 2D. (Images on the following days showed no trackable features in the GRS.)

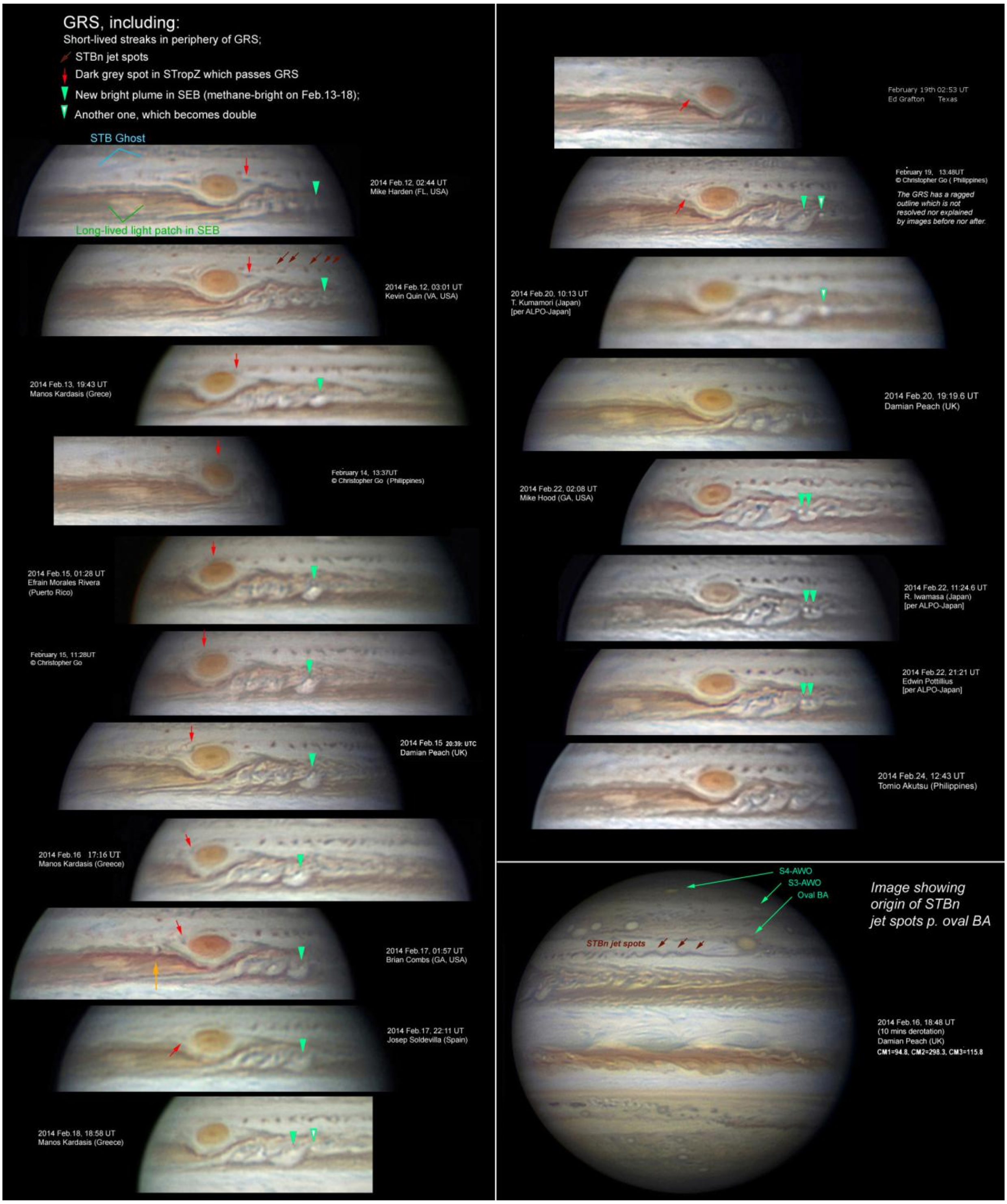

Figure 4. The GRS in 2014 Feb., with nearby features marked including new bright plume eruptions in the SEB. Signs of the internal circulation can be traced over short intervals (notably a short dark streak moving around the periphery on 4 consecutive planetary rotations on Feb.14-15) but there are no persistent tracers to determine an accurate rotation period. *Bottom right:* Image showing the origin of the STBn jet spots p. oval BA (2014 Feb.16, D. Peach). For a sequence of such v-hi-res images, see Report no.6 [Ref.9].