Jupiter in 2016/17, Report no.4: Interim report (2017 Jan.14)

John Rogers (British Astronomical Association).

Although it is still early in the apparition, plenty of interesting things have already happened on Jupiter: new convective outbreaks in the NTB, NEB, and SEB, and the merger of two long-lived ovals in the S2 domain. This report covers events up to early Jan., with images now beginning to attain good resolution, and the first drift measurements from the JUPOS team from late Oct. to late Dec. A map of the planet around Nov.1 from the Pic du Midi was shown in our Report no.2; a map on Dec.9-10, just before Juno's perijove-3, was shown in our Report no.2C; and a map on Jan.9-11 is shown as **Fig.1** herein. Juno's perijove-3 was on Dec.11 and the images from it are presented, with interpretation, on the 'Results from Juno' page on our web site. Previous report from this apparition (referenced below as Report no.1, etc.) are on this web site at: https://www.britastro.org/node/8103.

In this report, as always, drift rates are in System II longitude (DL2, degrees per 30 days) unless stated otherwise, and latitudes are zenographic. Maps and images have north up, except for some in Supplementary Figures (a separate ZIP file) with south up.

Northern hemisphere

N.N. Temperate (N2) domain & jet

Of the four NNTZ long-lived anticyclonic ovals, three have been recovered this apparition, and appear unchanged. The Little Red Spot, LRS-1, is still bright in methane images but invisible in colour images because it currently has the same pale colour as its surroundings. (It was viewed close up by Juno at Perijove-3; also see **Fig.2**.) WS-6 is also still methane-bright and distinctly reddish, very similar to LRS-1 except brighter, so I rename it LRS-6. WS-4 is still a smaller, white oval. JUPOS data show that LRS-1 and WS-4 continue to show unpredictable fluctuations in speed between slow (DL2 ~ -1) and fast (DL2 ~ -13). LRS-6 has maintained DL2 = -11 since 2016 May (but could also switch to slow speed at any time).

The NNTBs (N2) jet still carries many dark spots, at most longitudes; its activity has not so far been suppressed by the NTBs jet outbreak, although the spots may be becoming fainter.

N. Temperate (N1) domain & jet: Maturation of the NTBs jet outbreak

The great NTBs jet outbreak was described in Report no.1 (https://www.britastro.org/node/8102) up to Oct.25. It started during solar conjunction, probably in mid-September, and we were able to track the main features using very distant Juno images taken from Oct.11-14. By Oct.14 there were 3 or 4 brilliant plumes on the super-fast jet-stream, with a long chain of very dark bluish-grey spots following them. By Oct.25 this disturbance had spread around the planet and just two of the plumes remained, named A and D.

The outbreak has matured rapidly since then, becoming a 'NTB Revival' just like previous examples. As expected, the two super-fast plumes disappeared just as they caught up with the chains of dark spots: plume D between Oct.28 and 30, and plume A between Oct.31 and Nov.2 (**Fig.2**). An updated chart is in **Fig.3**; we have not yet attempted to track NTB features since then. At that time, the reviving NTB(S) consisted of very dark spots or streaks all around the planet, which were starting to merge into a continuous dark grey belt. There was also intense streaking across the NTropZ, and small-scale turbulence in the northern NTB latitudes.

The reviving NTB(S) normally turns orange during these events, and this happened rapidly in late November. The orange colour of the NTB was conspicuous during December.
By Nov.11, a narrow orange strip had appeared along the NTB(S) south edge in one sector, and by Nov.18 the NTropZ was generally orangey in this sector; also some images showed the NTB(S)

changing from dark grey to brownish-grey (Nov.19-21). By Nov.26-28, the NTB(S) had become diffusely orange-brown at all longitudes, and its dark grey streaks were no longer visible. Conversely, dark blue-grey streaks appeared more conspicuous in the NTropZ, in a general fawn-coloured background.

N. Tropical Zone

The NTropZ has been massively disturbed by the NTBs outbreak, between the orange NTB(S) and the disturbed NEBn. It has developed streaky, dull orangey colour, with very dark bluish-grey streaks within it. In the blink images in **Fig.4**, these streaks did not show significant motion in L2 over 10-20 hours.

White spot Z (WSZ), the long-lived AWO, became increasingly entangled and distorted by dark grey streaks (see blink on Dec.23-24 in **Fig.4**). In Dec. it could still be made out in most hi-res images as a small, pale white oval, but its present status is uncertain. (In the last two NTBs jet outbreaks, WSZ turned dark grey, but then revived as a white oval, so it will probably do the same again.)

N. Equatorial Belt: Resumption of diverse rift activity

Since the premature termination of the NEB expansion event in spring 2016, the NEB has had a fairly normal width, and few rifts were visible from 2016 May to October. But now, three impressive new rifts have developed in succession, all in a limited L2 range, but with notably different drift rates (**Fig.5 = maps***). Rift A, first seen on Oct.20, had DL2 = -1.4 to -2.4 deg/day; Rift B, which appeared on Dec.5, in the northern edge of the NEB, had DL2 = -0.5 to -1.1 deg/day; and Rift C, which appeared on Dec.24, more southerly, has DL2 = -3.4 deg/day. All these appeared in the sector f. WSZ, where new barges had formed during the expansion event, although only barge B-2 was still visible. Rifts A and B first appeared close to where barge B-1 had been, and rift A became much more conspicuous and twisted on Nov.28 as it passed B-2, which may have been destroyed in that interaction.

Details* (see **Suppl. Figs.S2-S4 for day-by-day sequences of images):

Rift A was first definitely imaged as a very small white spot at L2 = 278 on Nov.18, and it expanded thereafter into a rift whose f. end – and another small white spot that appeared on Dec.26 -- moved with DL2 ~ -1.4 to -1.5 deg/day. However, it may have begun shortly before Oct.20, when a white spot was imaged at L2 ~ 309 on the same track. The expanding Rift A was ~40º long in late Dec., its p. end having moved with DL2 ~ -2.4 deg/day.
Rift B appeared as a tiny white spot at L2 = 287 on Dec.5, which was very bright by Dec.10-11 (and Perijove-3). It was unusually far north and slow-moving, with DL2 ranging from -0.5 deg/day (locus of 3 successive brilliant white spots) to -1.1 deg/day (p. end), and also produced visible disturbance on the retrograding NEBn jet.
Rift C appeared as a brilliant white spot at L2 = 357 on Dec.24, more southerly in the NEB, and consequently had a much faster drift, DL2 = -3.4 deg/day.

In addition, since the last days of December, a sector of northern NEB at L2 < 180 (i.e., p. WSZ) has faded and appears merged with the turbulent orangey NTropZ!

Discussion

The present disturbance of the NTropZ, perhaps even extending into the northern NEB p. WSZ, has produced a scene identical to that in 2012 – the only difference being that in 2012 the NEB was undergoing a great Revival from an exceptionally narrowed state, while in 2016-17 the NEB is undergoing new outbreaks within a more-or-less normal state. Could these NEB outbreaks actually be a consequence of the NTBs jet outbreak? There was also intense NEB rift activity in the months after the NTBs jet outbreaks in 1975 and 1990 (though not after some other outbreaks), which could be no more than coincidence, but could perhaps indicate that NTBs and NEB outbreaks can interact more than was thought.

To my eyes, the NEB in this apparition's images also appears redder than usual; but some experienced observers such as Chris Go say they do not see any definite change. We do not yet have a method for objectively measuring colours. Enhanced red colour now could be a sequel of the partial NEB expansion event, or perhaps associated with the reddening of the NTropZ and NTB(S).

The diverse speeds and latitudes of the three NEB rifts preclude prediction of future activity. *Rift A*, at ~14ºN, had DL2 = -1.4 to -2.4 deg/day, so was typical of rifts associated with NEB expansion events. Could it be about to trigger a new expansion event after the failure of the 2015-16 event? *Rift B*, exceptionally far north at ~16ºN, had DL2 = -0.5 to -1.1 deg/day, which was typical of slow-moving rifted regions in the 1970s. Could this signal reversion of the NEB to this type of activity? *Rift C*, at ~12ºN, has DL2 = -3.4 deg/day, typical of rifts in normal times. Could it indicate that the NEB has now returned to normal activity?

NEBs/EZ

There are plenty of conspicuous dark blue-grey formations on the NEBs edge, as usual, but there does not seem to be a stable pattern to them at present: they are varying rapidly, and have a range of drifts, both positive and negative in L1 (see maps in **Suppl.Fig.5**, with south up).

Southern hemisphere

S. Equatorial Belt: A new mid-SEB outbreak

While the usual convective activity f. the GRS continues at a low level, a new white plume has erupted in a previously undisturbed sector of the SEB, initiating the first 'mid-SEB outbreak' since the SEB Revival in 2010-11. This brilliant white spot appeared on Dec.29 at L2 = 208. The first few days were described in our Report no.3 at: https://britastro.org/node/8817.
The gallery of images in **Fig.6** continues the story. Since the first white spot was twisted and stretched to lower longitudes by the wind gradient across the SEB, new white spots have appeared at the original source on Jan.4 and Jan.8-9. So the outbreak seems to be behaving in the usual way, and is likely to continue impressively for some time.

The GRS is still exceptionally small (14º long) and red, and detached from the SEB. JUPOS data show that it continues on the same track as in 2016, with mean DL2 = +1.8 deg/month. It is at L2 = 262.

S. Temperate(S1) domain

There has been no change in appearance here; there is still no dark STB anywhere, just a small dark spot f. oval BA which has been quiet since last summer. Oval BA is still notably orange, and passed the GRS on Nov.1. Its speed continues to show unpredictable variations. Since its major deceleration at the start of 2016, it had mean DL2 = -10.9 (±0.3) deg/month from 2016 Jan. to June, but then -12.3 (±0.3) from July to Dec.; and it may also have been oscillating with period ~2 months. The STB Ghost and Spectre are unchanged and drifting with DL2 = -17 and -15 respectively (JUPOS data).

S.S. Temperate (S2) domain

Major changes here were revealed by Juno's perijove-1 images in late August, including the close approach of two long-lived AWOs (A8 and A0), which led to the prediction that they would soon merge.* This indeed happened on Nov.18-23, just as they passed oval BA (**Fig.7**); the images show them moving around each other until there was only a single oval on Nov.23 (which we call A8).

*Ref: our 'Results from Juno' page (https://www.britastro.org/node/8004) or Appendix 3 to our final report for 2015/16 (https://www.britastro.org/node/8263).

Discussion: This was a rare event – the first merger of long-lived SS-AWOs since 2002. (In contrast, smaller short-lived ones merge quite often.) As the merged oval has settled down into an evenly-spaced chain with the others, I do not expect any more mergers. However it is notable that most of this chain, from A6 to A3, now have an unusually high speed, DL2 = -30.5 deg/month. Whether this is cause or effect, it is associated with the expansion of the whitened sector of SSTB between A3 and A4 (which was viewed by Juno at perijoves-1 and -3, showing the typical outline of a cyclonic circulation). This expansion is expected to continue.

S4 domain

The 3 anticyclonic ovals tracked last apparition are still present, and are marked on the map (**Fig.1**). All continue to show 'stop-go' motion alternating unpredicatbly between fast and slow. The largest, S4-AWO-1, is now well known to be somewhat reddish, so I am redesignating it as S4-LRS-1.

Figures

Miniature versions are shown here. Full-size figures are in the attached ZIP file, along with the Supplementary Figures.

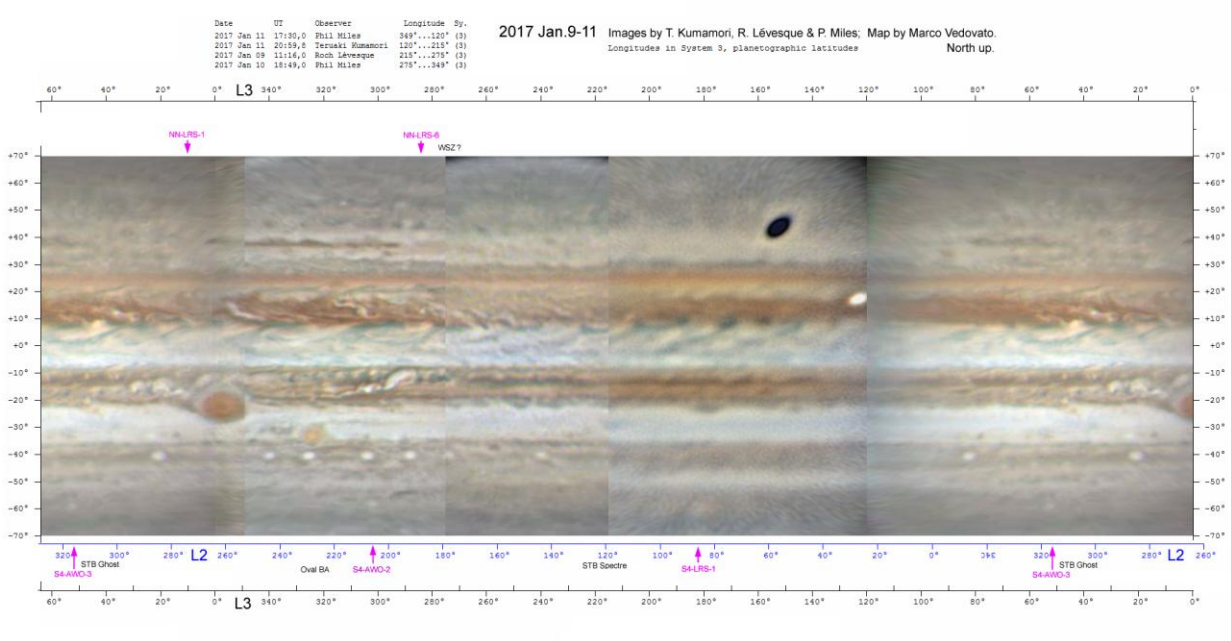

Figure 1. Map of the planet, 2017 Jan.9-11.
(**Suppl.Fig. S1** is a version with south up, in L2, with further labelling.)

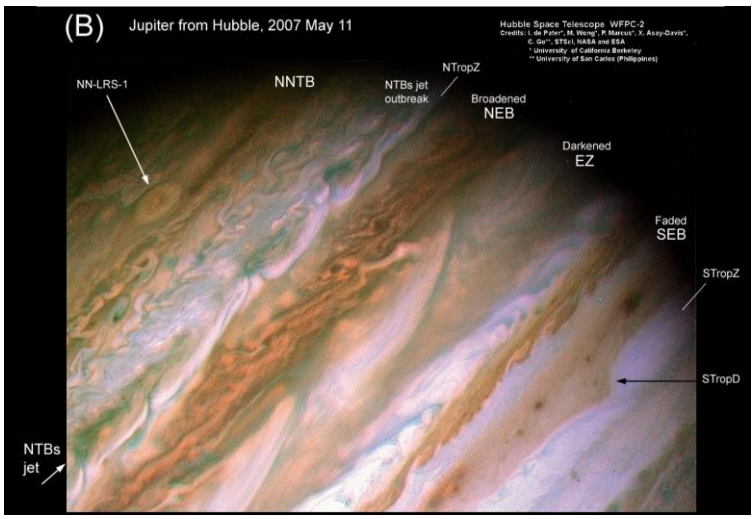

Figure 2(A) – *[next page]*
Figure 2(B) – *[right]*

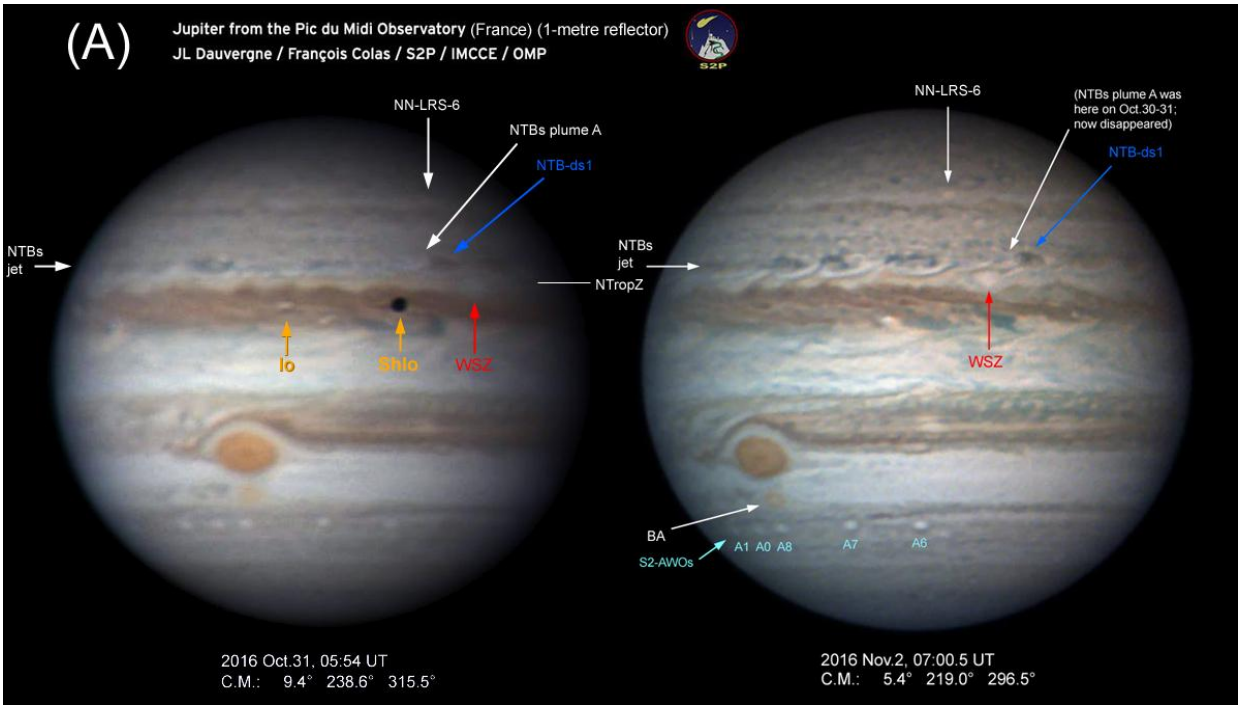

Figure 2. (A) A pair of images taken by Jean-Luc Dauvergne with the 1-metre telescope at the Pic du Midi, showing the disappearance of the last super-fast NTBs plume (A) as it collides with dark spot 1. Pale orange colour in the southern NTropZ is probably a remnant of the partial NEB expansion event. Also note NN-WS-6 (now renamed LRS-6) and WSZ (still white).
(B) Hubble image at the same stage of the NTBs jet outbreak in 2007, showing very similar textures. (Here the southern NTropZ was still darkened within an expanded NEB.) This is also a good closeup of NN-LRS-1, which was imaged by Juno at perijove-3 on 2016 Dec.11.

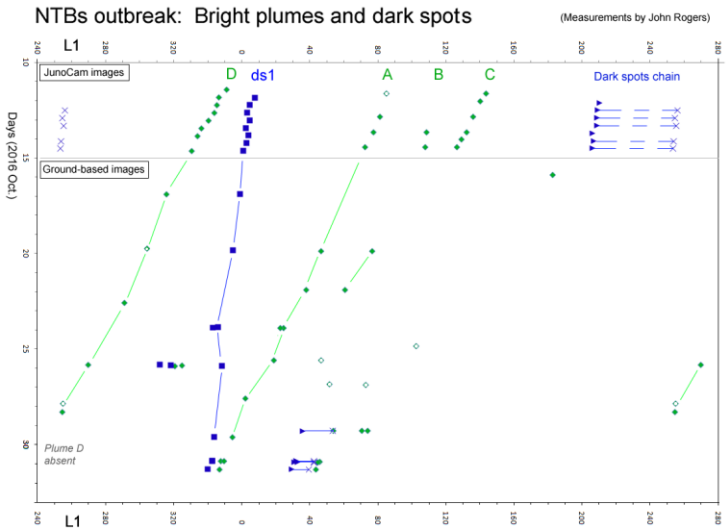

Figure 3. Chart of the white plumes and some dark spots in the NTBs jet outbreak, updated from Report no.1.

Figure 4 *[Animated GIF posted separately]***.** Four pairs of blink images. They clearly show the motion of the equatorial jets and the shearing across the NEB and SEB. Rapid NTBs jet motion can be discerned, but only in a few small streaks or the tapered Np. ends of some of the dark streaks in the NTropZ; the peak of the jet may be concealed by the new orange belt.

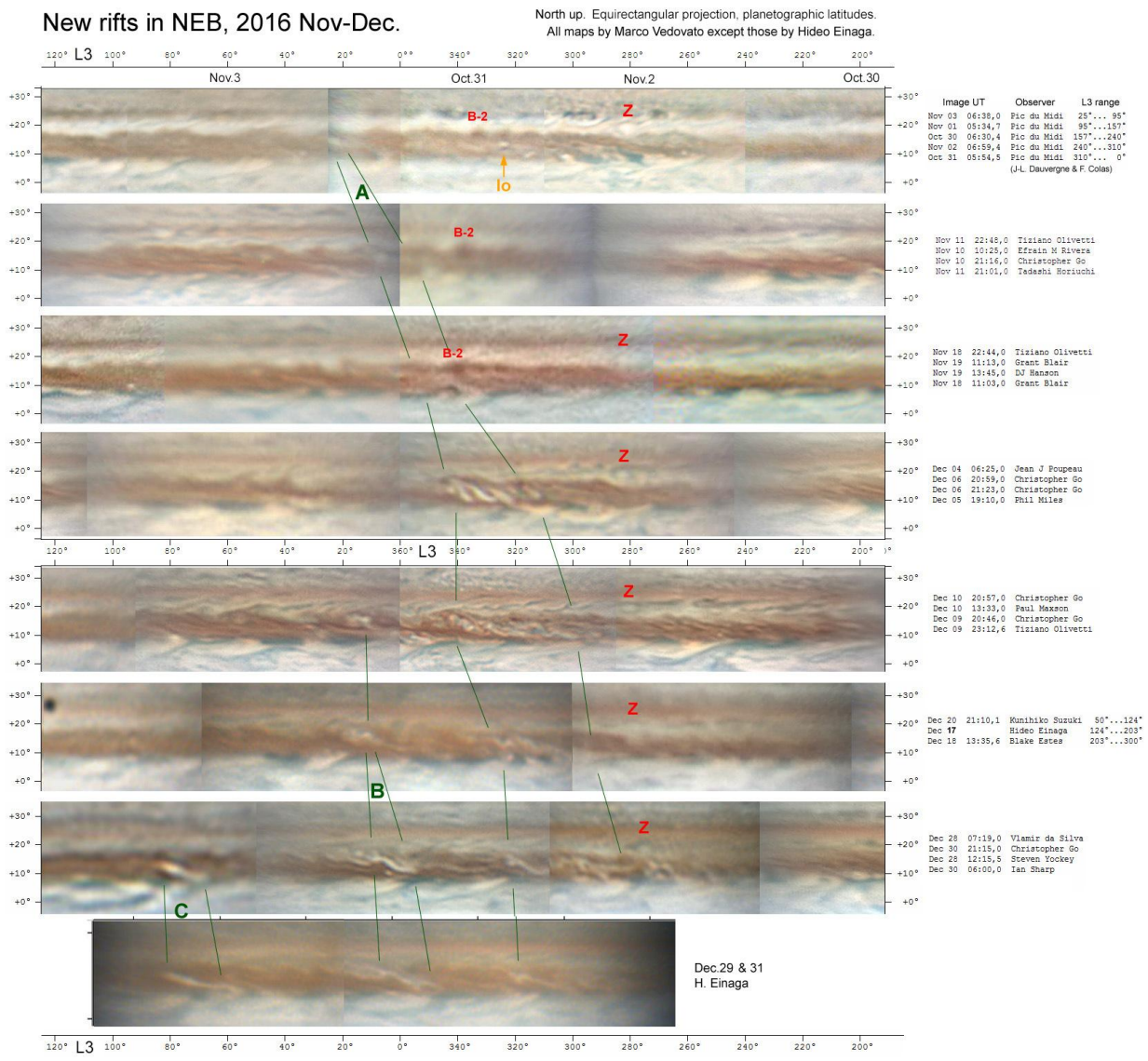

Figure 5. Maps of the NEB, Nov-Dec. showing the origins of the three rifts (A,B,C). (**Suppl.Figs. S2-S4** present day-by-day sequences of the original images.)

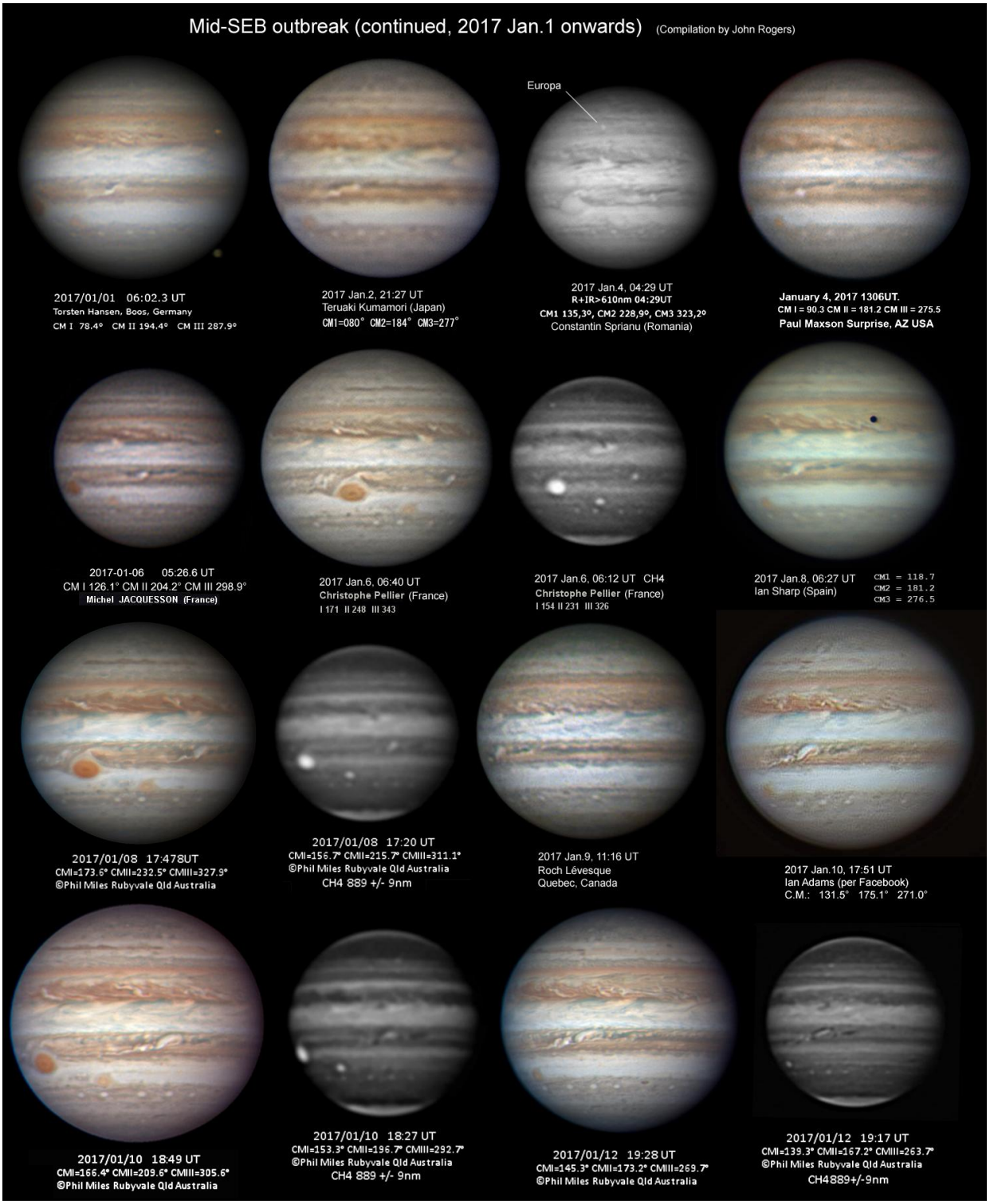

Figure 6. Images showing the mid-SEB outbreak from 2017 Jan.1-12. including some methane-band images.

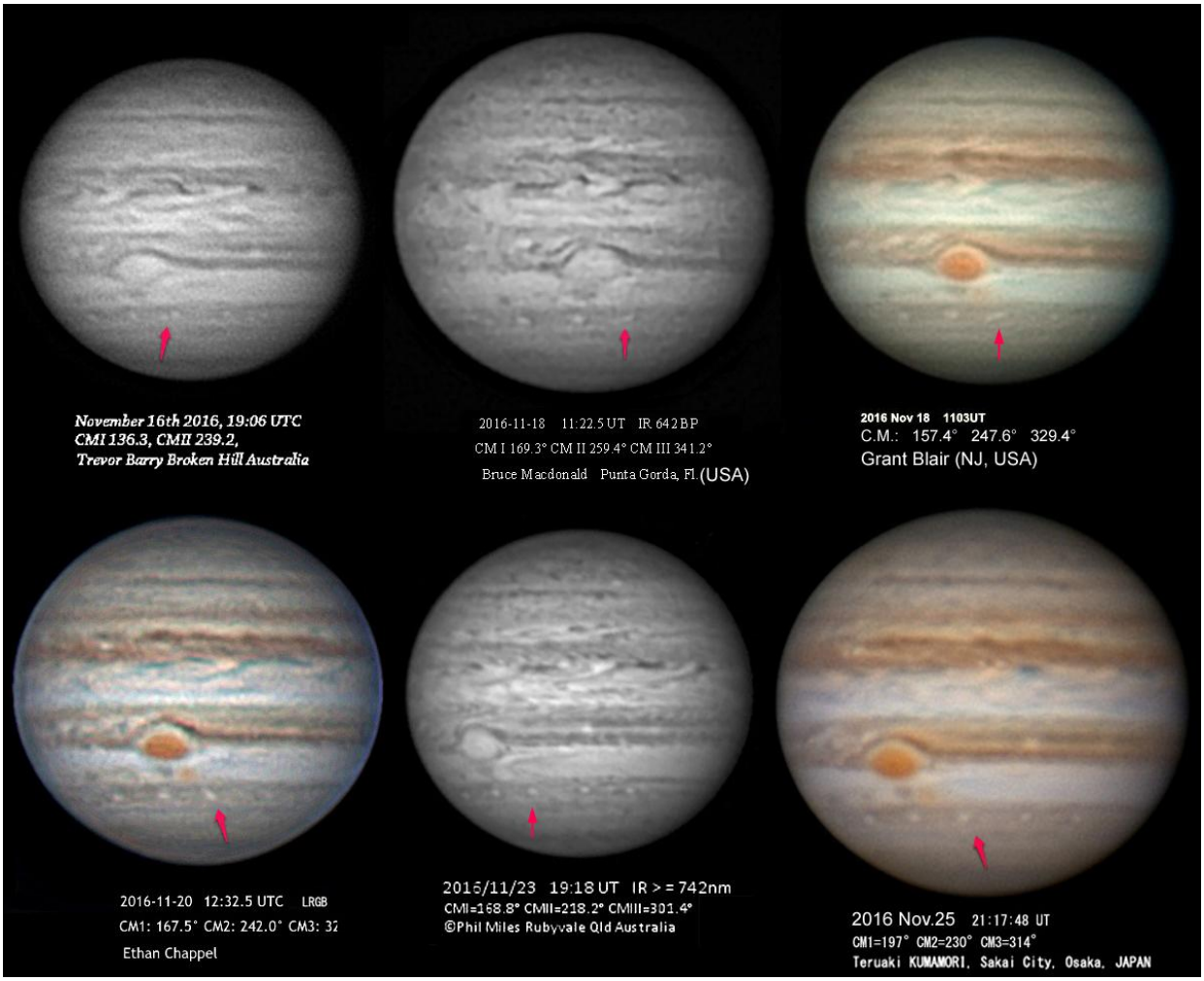

Figure 7. Images showing the merger of SS-AWOs A0 and A8 in 2016 Nov., just as they passed oval BA, which in turn was passing the GRS. The configuration of ovals was almost identical when two SS-AWOs merged in 2002 March.