2015/16, Report No.9: Jupiter on the eve of the Juno mission

--John Rogers (BAA), 2016 June 21

This is a summary of the state of Jupiter's atmospheric features in June, 2016, just before the Juno spacecraft enters orbit around the planet. It gives more general background than usual, for the benefit of readers who are not very familiar with the planet's idiosyncrasies. It summarises what has happened during the 2015/16 apparition (i.e. the period of Jupiter's visibility, from autumn 2015 to now); but we will produce a more detailed report, including drift rates, during the summer, when the data for the apparition are complete.

All the observations were images produced by amateur observers. All the data on drift rates came from analysis done by the JUPOS team (Gianluigi Adamoli, Michel Jacquesson, Hans-Jörg Mettig, Marco Vedovato), up to early May. More about these sources of information can be found via the links at the end of this report.

The resolution of images is now diminishing, as the planet is getting lower in the sky week by week; it will pass behind the sun in the coming months. Some of the best recent images were used by Marco Vedovato to make the maps in Figures 1 & 2, with key features labelled.

In this report, maps and images are shown with north up. 'Preceding' is east, 'following' is west. Longitudes are given both in system II (L2) and in system III (L3).
Drift rates are given as degrees per 30 days in L2 (DL2, deg/month), either eastward (negative, i.e. decreasing longitude, prograde) or westward (positive, i.e. increasing longitude, retrograde). DL3 = DL2 + 8.0 deg/month.

Background

The fundamental framework of Jupiter's visible atmosphere is a pattern of alternating jets (jet-streams), blowing rapidly eastward or westward, as revealed by spacecraft – e.g. the profile in Fig.1. The eastward jets form fixed boundaries which little or no disturbance can cross, and the regions between them are called domains, each domain consisting of a belt (cyclonic, usually dark) and a zone (anticyclonic, usually bright). The belts and zones have traditional names, and so the domains are named accordingly, as labelled on Fig.1.

The larger features such as ovals are circulations, which 'roll' between the adjacent jets. They are either cyclonic or anticyclonic, as defined by their direction of circulation, which always conforms to that of the belt or zone in which they reside. They drift slowly on 'slow currents' that are characteristic for each domain.

Anticyclonic ovals are the principal long-lived features on the planet. The larger ones are marked on Figs.2-4. The Great Red Spot (GRS) is the largest, and oval BA the second largest. Other large ones are the N.N. Temperate Little Red Spot at ~41ºN (NN-LRS-1) and the oval at ~59ºS (S4-AWO-1). These four ovals are all reddish for most or all of the time, and this seems to be a feature of large, long-lived ones, perhaps because their circulation extends deeper than that of smaller, white ovals. Anticyclonic white ovals (AWOs) are present in all other domains, notably in the North Tropical domain (White Spot Z, which has existed since 1997), and the S.S. Temperate (S2) domain (an array of 9 AWOs). Many of these ovals are very long-lived; some of those in the S2, S3 and S4 domains, as well as NN-LRS-1, have existed since 1987-1998 or even earlier. All these anticyclonic ovals (except, oddly, WSZ) are bright in the methane absorption band at 0.89 μm (Figs.3 & 4), as their red or white cloud caps extend to high altitude.

The GRS and other ovals at low and mid latitudes have only modest variations in drift rates, so we can predict their positions several months in advance. But the ovals at high latitudes (>38ºN, i.e. N2 domain and beyond; >48ºS, i.e. S3 domain and beyond) have sudden, unpredictable changes in their drift rates, ranging between rapidly prograding (tens of degrees per month) and near-stationary in L2. Sometimes these comprise oscillations, but the periods are not constant. Therefore, it is not possible to predict their positions accurately.

Cyclonic features, in the belts, include some ovals, but also areas of turbulent and convective activity. Bright white spots often appear in these, changing over several days; these are convective plumes, shown by spacecraft observations to be thunderstorms. In the major belts these areas appear as 'rifts', i.e. rapidly-changing white streaks obliquely crossing the dark belt. Often there are multiple rifts in an extended turbulent tangle which we refer to as a rifted region. At higher latitudes, the turbulence is on a smaller scale with lower contrast, but such regions can be resolved in the best amateur images (Fig.2).

Present state of the planet

N.N. Temperate (N2) domain:

Here there are three long-lived anticyclonic ovals, plus a new one. [NN-]LRS-1 is virtually invisible because it has the same colour as its surroundings, but is very bright in methane-band images. [NN-]WS-6 appears creamy white, and also methane-bright; it has recently expanded into a near-duplicate of LRS-1. WS-4 and the new one (WS-8) are white, but smaller, and barely detectable in methane images.

The N.N. Temperate Belt (NNTB) is present all round the planet, but irregular in latitude. One sector consists entirely of a chain of vortices rapidly prograding in the jet, which carries similar vortices on the NNTB south edge in other sectors.

N. Temperate (N1) domain:

The North Temperate Belt (NTB) is almost absent, except for long, very dark streaks of NTB(N) between L3 173-253 (L2 133-213) in the June map (Fig.1). F. these, there is still a darkened sector of North Temperate Zone called a North Temperate Disturbance (NTD). The NTD is induced by a sector of small-scale rifting in the revived NTB. In the last few months, the dark NTB(N) streaks may have grown to partially replace these mini-rifts, but some rifting is still present (Fig.4). The features in this domain have drifts ranging from DL2 = +14 to +34 deg/month.

The NTB undergoes cycles of activity which sometimes recur at 5-year intervals. The most distinctive event is an outbreak of brilliant white plume(s) on the super-fast jet on the NTB south edge, as happened in 2007 and 2012, followed by revival of the dark belt. The present state of the domain, including the NTD, has been observed at a similar stage in some previous cycles. The NTB(S) is now very pale again, and the jet speed is intermediate between its normal and super-fast states. Given these conditions, we may see a new outbreak in early 2017.

N. Tropical domain:

The North Equatorial Belt (NEB) underwent a partial 'expansion event' last winter, but this has now regressed so the NEBn edge appears disturbed but otherwise fairly normal.

In these expansion events, which have occurred every 3-5 years since 1987, the NEB north edge (NEBn) shifts north from 16-17ºN to 20-21ºN, and there are changes in circulation patterns right across the belt. The event started in 2015 as predicted (though slowly, and during solar conjunction), and the expanded sector covered 140º by 2016 Feb.; but then it stalled, and began to fade from both ends. This was unprecedented: all previously studied events have spread all around the circumference. Nevertheless, at least three cyclonic dark ovals (small 'barges') have appeared within the NEBn, as a typical consequence of the expansion event.

White spot Z is still the most prominent AWO, embedded in yellowish surroundings. Its speed has been slow and fluctuating during this apparition; it is now DL2 = -7 deg/month.

Notably, methane-band images have shown a wave-like series of diffuse dark patches over parts of the NEB throughout this apparition (Fig.4). In Feb. they were mostly spaced 18º apart over the expanded sector and flanking regions. These waves represent thinnings of the haze overlying the NEB. Similar waves had been imaged during the NEB expansion event in 2000, so their reappearance in 2015-16 is an important feature of the event for professional as well as amateur observers. The methane-dark waves are still present in June (Fig.4). They are prominent from L3 ~ 230-35 (L2 ~ 190-355), and more subtly up to L3 $\geq$ 35 (L2 $\geq$ 75), thus covering the whole of the formerly expanded sector and beyond.

The rifting within the NEB has also declined. The rifted regions which existed in April had DL2 ~ -3.1 to -3.3 deg/day, indicating that they had accelerated since the slow rifts of 2014-15 which we suspect initiated the NEB expansion event. In June there are few if any rifts.

Equatorial region:

The equatorial region has a typical appearance: the EZ is white with many subtle blue-grey streaks and festoons, the latter emerging from the major dark formations or 'projections' on the NEBs edge which are still present all around the planet. Since Feb., they have settled down to a typical pattern of 11 formations all round the planet, with DL1 ~ 0 to +10 deg/month (DL2 ~ -229 to -219 deg/month), with little evidence for faster drifts.

S. Tropical domain:

The South Equatorial Belt (SEB) has been in a state of normal activity since 2011; i.e. the belt is dark and quiet except for a sector of 'rifts' following the GRS. This rift activity extended to higher longitudes with new outbreaks of white plumes in March, up to L2 = 313, making the disturbed sector longer and more spectacular. However, this activity has quickly declined again. While the new rifts prograded towards the GRS, the activity was not renewed; the last white spots to appear in mid-SEB were in late May. Otherwise, the sector still shows intricate turbulence, evolving towards smaller scales; there are still some white spots in the northern part, but these are not methane-bright and probably do not represent full-scale convective activity.

We have to wait and see whether convective plumes reappear soon. If the convective activity has really stopped, this could lead to the onset of an entirely different and more spectacular mode of behaviour: a cycle of fading and revival of the SEB. In that case, the Fade (whitening of the belt) could begin this summer during solar conjunction, and the energetic Revival would ensue within the next few years. These cycles occurred most recently in 2007 and 2009-10.

The retrograding jet on the SEBs edge has not carried distinct retrograding vortices since Feb. (except for a final one which converged very slowly on the GRS but finally slid into the Red Spot Hollow on April 1). Instead, there have been several wave-trains, sometimes of high amplitude. (Some are visible in Fig.2.) We recently showed that the SEBs sometimes carries wave-trains retrograding more slowly than the jet, in proportion to their wavelength [Rogers et al., 2016, Icarus vol.277 p.354]. Preliminary analysis of one wave-train in 2016 May showed that it belongs to the same type, and we are now analysing these wave-trains more thoroughly.

The GRS is at L2 = 248 (L3 = 288) in mid-June. Its longitude is increasing unusually fast: mean DL2 = +1.5 deg/month this apparition, but perhaps now as much as +1.8 deg/month. (It oscillates with a constant period of 90 days, so the mean drift rate can only be determined over longer intervals.)

The GRS is unusually small and red, as it has been since 2013. It has been shrinking, with fluctuations, since the early 20th century, and in early 2014 reached the smallest length ever recorded, just 13.5º long – a size which has been approximately maintained since. Recent improvements in image resolution have allowed us to track the internal circulation of the GRS on many occasions since early 2014, and the circulation period has consistently been 3.6 to 3.8 days throughout these years – shorter than we have ever recorded before, due mainly to the reduced circumference, but partly due to increased wind speed. The best recent images often show a consistent pattern of mottling within the GRS, and Michel Jacquesson's ongoing analysis of this is revealing even faster wind speeds, consistent with measurements from the Hubble Space Telescope.

S. Temperate (S1) domain:

The South Temperate Belt (STB) is completely absent, with just three inconspicuous cyclonic structures along it, and no STBn jetstream spots. This domain always has between 2 and 4 long-lived 'structured sectors', outside which the STB is almost featureless. At present there are three such sectors, although none is dark:

(1) Oval BA and the small dark spot f. it. Oval BA has been gradually reddening during the apparition and is now quite strongly orange. The dark spot f. it, which had been turbulent and contracting, has been small and quiescent since March. With the decline of this activity, oval BA has decelerated to a speed typical of this condition (see below).

(2) The STB Ghost: a pale bluish loop which is a cyclonic circulation. On its south edge, spots from the SSTBn jet sometimes recirculate anticyclonically, and we are investigating this phenomenon in recent images.

(3) The STB Spectre: a duplicate of the STB Ghost. This arose in early 2015 as a very dark cyclonic spot, which faded to pink in early 2016. In May it passed the GRS, and the spot completed its fading to white as expected, leaving just a pale bluish loop around it. This is now p. the GRS and is likely to persist.

Their speeds from January to mid-May have been typical: Oval BA, DL2 = -11.0 (±0.5) deg/month, though with some fluctuations; STB Ghost and Spectre, both DL2 = -16.4 (±0.3) deg/month. These structured sectors are likely to proceed on fairly steady courses; but the complete absence of dark STB is abnormal and perhaps unsustainable, so it is possible that the STB will revive in some unexpected manner, as happened in 1993.

S.S. Temperate (S2) domain:

This domain is always distinguished by a large number of stable AWOs. This apparition there are nine major ones, whose ages range from 8 to >30 years, and they form a nearly continuous chain covering 210º of longitude. As the original sequential order has been disturbed by replacements and rearrangements over the years, they are now numbered A6 to A8 then A0 to A5. A1 is now obviously larger than the others. There was a long whitened cyclonic sector between A4 and A5, rapidly lengthening, but this filled in with darker material during April-May, leaving A4 and A5 almost 60º apart. A new whitened cyclonic sector developed between A1 and A2 during April-May.

Polar regions

The Juno mission is largely concerned with the polar regions and specifically the aurorae. For amateur imagers, the polar regions are highly foreshortened and subdued by haze, and the aurorae are not detectable at all; nevertheless, the best images do show much detail, as shown in the polar projection maps from April 28-29 (**Figs.5 & 6**), which are typical of these regions. The south polar region appears largely calm, with well-defined belt structures including a boundary at 53ºS, and long-lived AWOs at 50ºS and 59ºS. In contrast, the north polar region is packed with chaotic, rapidly-changing details, and has no visible belts; nevertheless, many ovals there are long-lived and confined between permanent jets, as at lower latitudes.

Links for further information

For more about our sources and methods, see:

--Databases of amateur images:

ALPO-Japan: http://alpo-j.asahikawa-med.ac.jp/Latest/index.html

PVOL: http://www.pvol.ehu.es/pvol/

--JUPOS project: http://jupos.org

--Regular maps: http://pianeti.uai.it/index.php/Giove:_Mappe

(including unlabelled versions of Figs.1 and 2, and later maps)

--Description of methods:

Kardasis E et al.(2016), 'The need for professional-amateur collaboration in studies of Jupiter and Saturn.' JBAA 126 (no.1), 29-39 (2016). https://britastro.org/node/7134

More detailed background information is on our web sites, especially:

--Guides: http://www.britastro.org/jupiter/guide.htm

(& also see Wikipedia under 'Atmosphere of Jupiter'):

http://en.wikipedia.org/wiki/Atmosphere_of_Jupiter

--Reference articles: http://www.britastro.org/jupiter/reference.htm

--Previous reports on the 2015/16 apparition:

https://www.britastro.org/node/6809

Figures

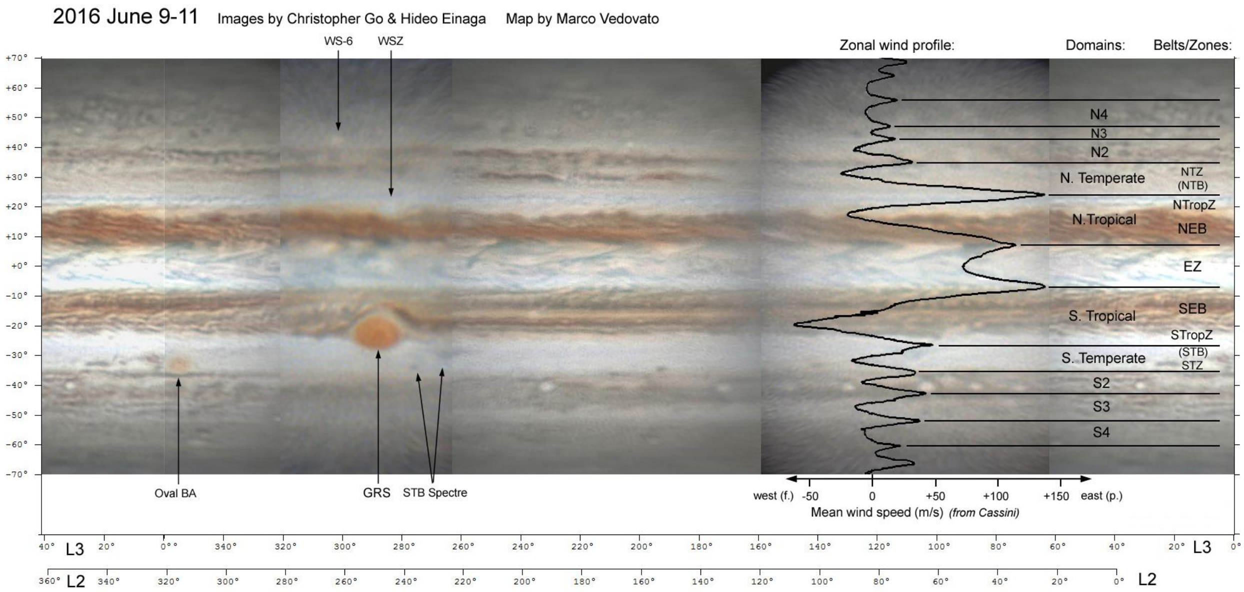


Fig.1. Map of the planet, 2016 June 9-11. A chart of average wind speed versus latitude, from the Cassini spacecraft (Porco et al., 2003), is superimposed, together with the names of the domains, separated by the eastward jets.

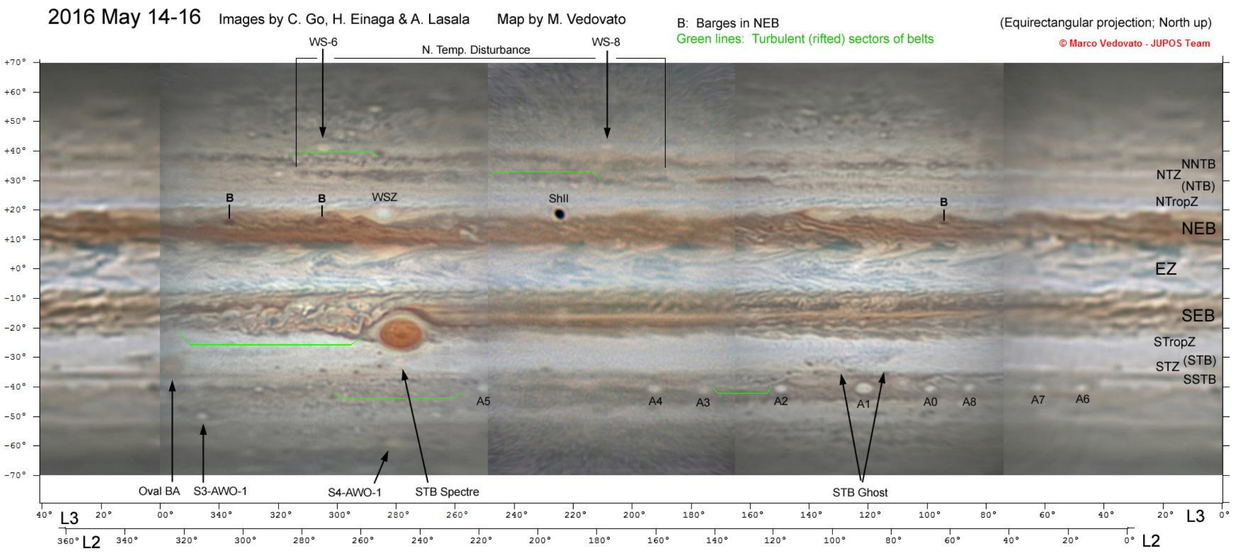


Fig.2. Map of the planet, 2016 May 14-16, with features labelled. This was the last map with such uniformly high resolution before the end of the apparition.

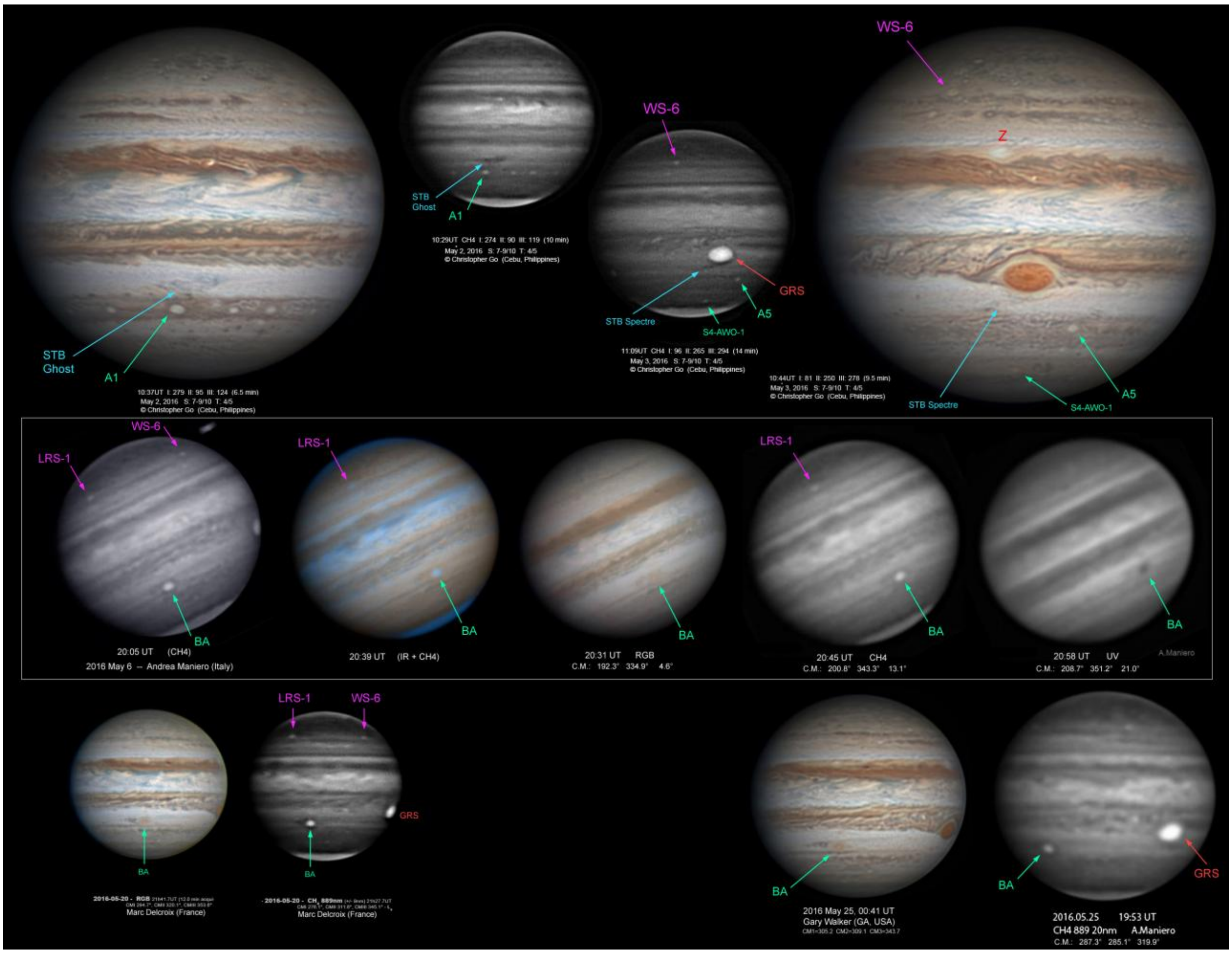


Fig.3. Images in 2016 May, in colour and in the methane absorption band at 889 nm (CH4), showing anticyclonic ovals (methane-bright) and the cyclonic ‘STB Ghost and Spectre’ (methane-dark).

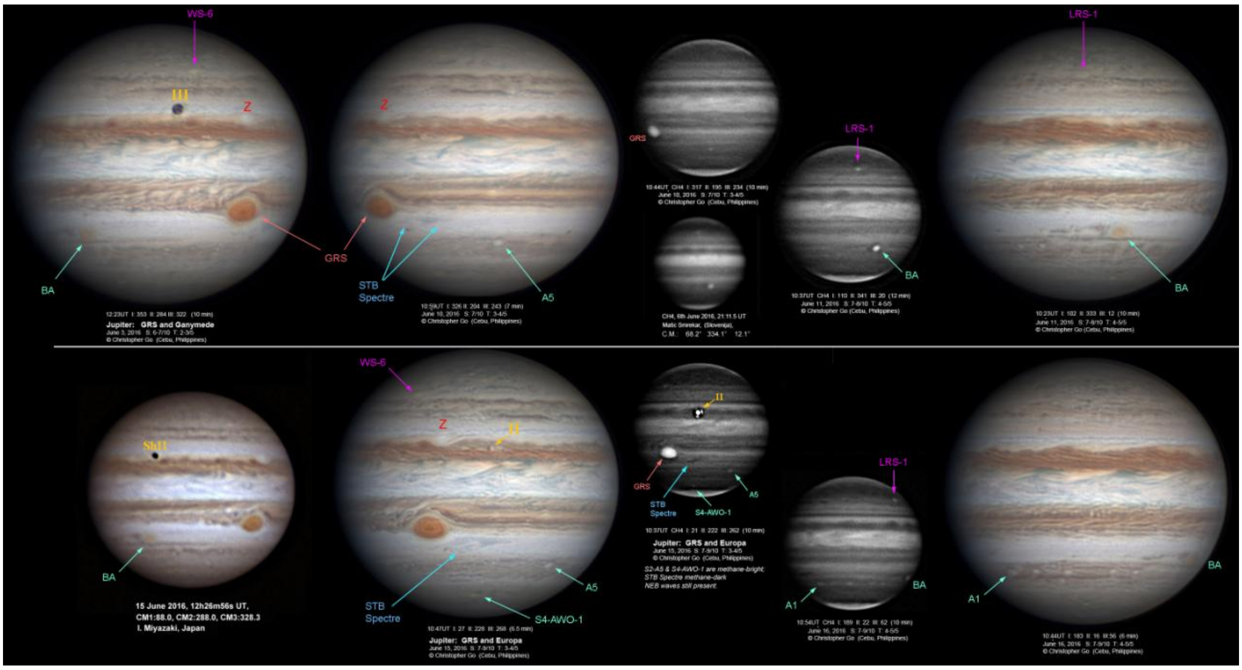
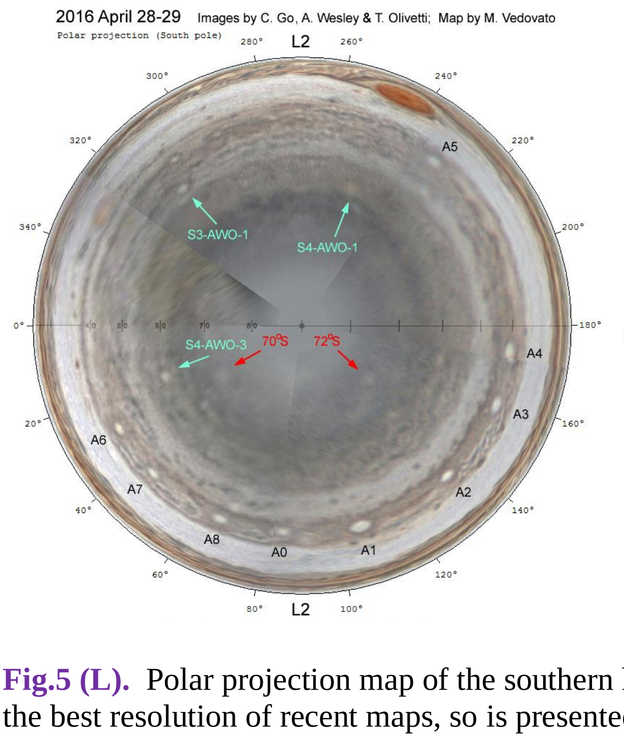


Fig.4. Images in 2016 June, in colour and in the methane absorption band at 889 nm (CH4), showing anticyclonic ovals and the cyclonic 'STB Spectre'. The methane images also show the series of dark waves over the NEB. II and III are Europa and Ganymede in transit.



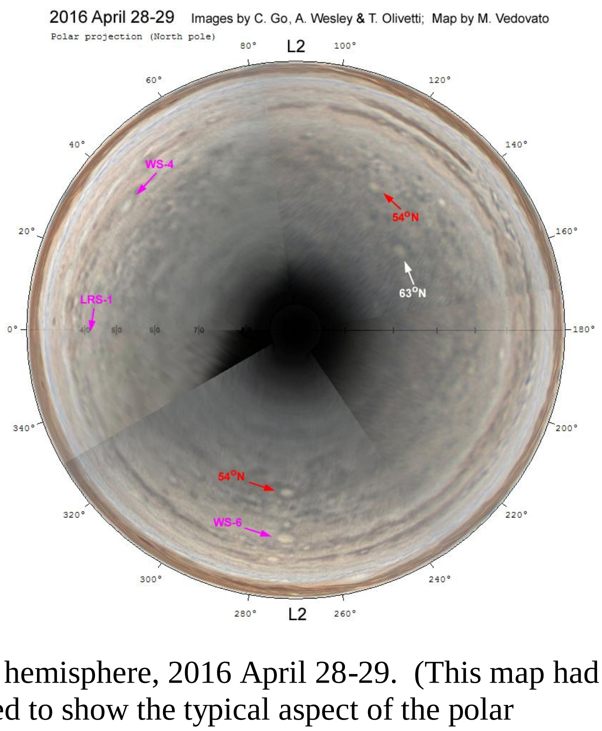


Fig.5 (L). Polar projection map of the southern hemisphere, 2016 April 28-29. (This map had the best resolution of recent maps, so is presented to show the typical aspect of the polar region.) The more prominent AWOs are labelled, including two at 70-72ºS.

Fig.6 (R). Polar projection map of the northern hemisphere, like Fig.5. AWOs are labelled in the N2 domain (41ºN), N4 domain (54ºN) and N5 domain (63ºN).