Jupiter and the *Juno* mission: the amateur's contribution

NASA's *Juno* spacecraft went into orbit around Jupiter on 2016 July 5: the first spacecraft to orbit the giant planet since the *Galileo* mission terminated in 2003. *Juno* will start its scientific mission this autumn. Here Jupiter Section Director John H. Rogers summarises the state of the planet's atmosphere during the 2015–'16 apparition, up to the start of the *Juno* mission, and then describes a pro-am workshop in Nice in May which set the scene for amateur involvement and ground-based support for *Juno* from Europe and around the world.

Jupiter Section

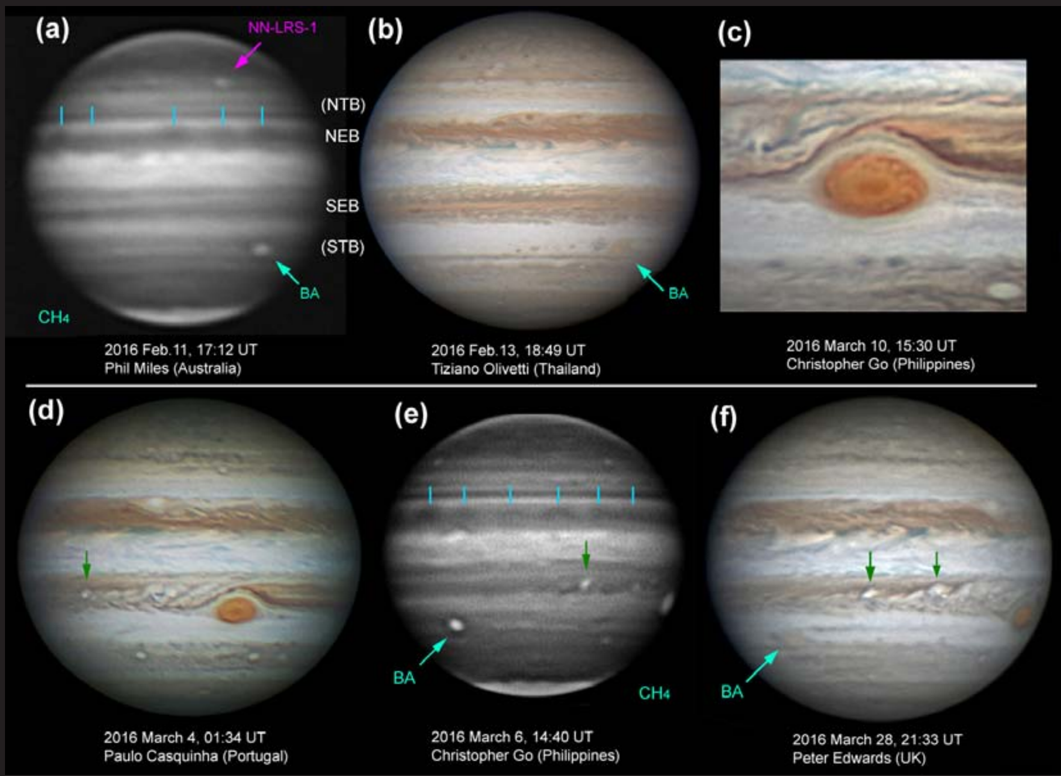

Figure 1. Images showing features mentioned in the text, including the anticyclonic reddish ovals BA and NN-LRS-1. **(a)** and **(e)** are methane-band images (889nm), showing the methane-dark waves on the NEB (indicated by blue lines). **(d)** to **(f)** show the new white plumes which erupted in the NEB on March 1 and 26 and drifted towards the GRS; both were methane-bright.

Jupiter in 2015–'16

The map in Figure 2 overleaf shows the state of the visible features in 2016 May. (In this report, and during the *Juno* mission, we will show images and maps with north up for compatability with the NASA convention.) Thanks to the improved understanding that we have gained from hi-res amateur images and analysis as well as professional studies in recent years, we can now describe the major belts in relation to their multi-year cycles of activity.

The North Equatorial Belt (NEB) has undergone an 'expansion event' every 3 to 5 years since 1987, in which the north edge of the belt shifts north from 16–17°N to 20–21°N. In 2015, both the timing (3 years after the last one), and the appearance within the NEB of rather slow-moving 'rifts' (turbulent bright streaks), suggested that a new NEB expansion event was imminent. Although it was slow to start, it eventually got going during solar conjunction and covered ~95° longitude by 2015 November. The expanded sector continued to spread to lower longitudes, as usual, covering 140° by 2016 February, and the appearance of several little brown ovals in the North Tropical Zone was another typical feature.

Notably, images in the methane band at 889nm wavelength showed a wave-like series of diffuse dark patches spaced 18° apart over the expanded sector and flanking regions (Figure 1a). These waves represented thinnings of the haze overlying the NEB. Similar waves had been imaged during the NEB expansion event in 2000, but not subsequently, so their prominence in 2015–'16 was an important feature of the event for professional as well as amateur observers.

However, in February the NEB expansion event stalled, and then regressed, even though it had not quite covered half the circumference. By June, the width had returned to normal. In contrast, all previously studied events spread all around the circumference. Why this one 'ran out of steam' is unknown, but one wonders whether it marks the end of the recent periodic series of such events. In any case, several cyclonic dark ovals ('barges') have already appeared in the NEB, and some are likely to persist for a year or more.

The South Equatorial Belt (SEB) has been in its normal state, *i.e.* dark and quiet except for a sector of 'rifts' following the Great Red Spot (GRS), as was observed during the *Voyager* and *Cassini* flybys. The rift activity has fluctuated; it almost stopped in 2015 February, but it resumed, and became more extensive in 2016 March as new white spots appeared at higher longitudes than before (Figure 1). These white spots are large thunderstorms, according to spacecraft observations, and when new they are also bright in methane-band images (Figure 1), showing that they are convective cloud plumes reaching to a considerable height.

But the activity quickly declined, and in June 2016, no new plumes appeared in the SEB. The sector following the GRS only showed intricate turbulence on smaller scales. 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 fading (whitening of the belt) could begin this autumn during solar conjunction, and the energetic revival would ensue within the next few years. The last such cycle was in 2009'10.

Meanwhile the GRS is unusually small and unusually 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 size ever recorded, just 13.5° long – a size which has been approximately maintained since. The strong red colour is normally seen only during fadings of the SEB, but now seems to be the 'new normal' – possibly because the small size means that the GRS interacts less with the adjacent jetstreams, although our observations show that some interaction is continuing. Recent improvements in

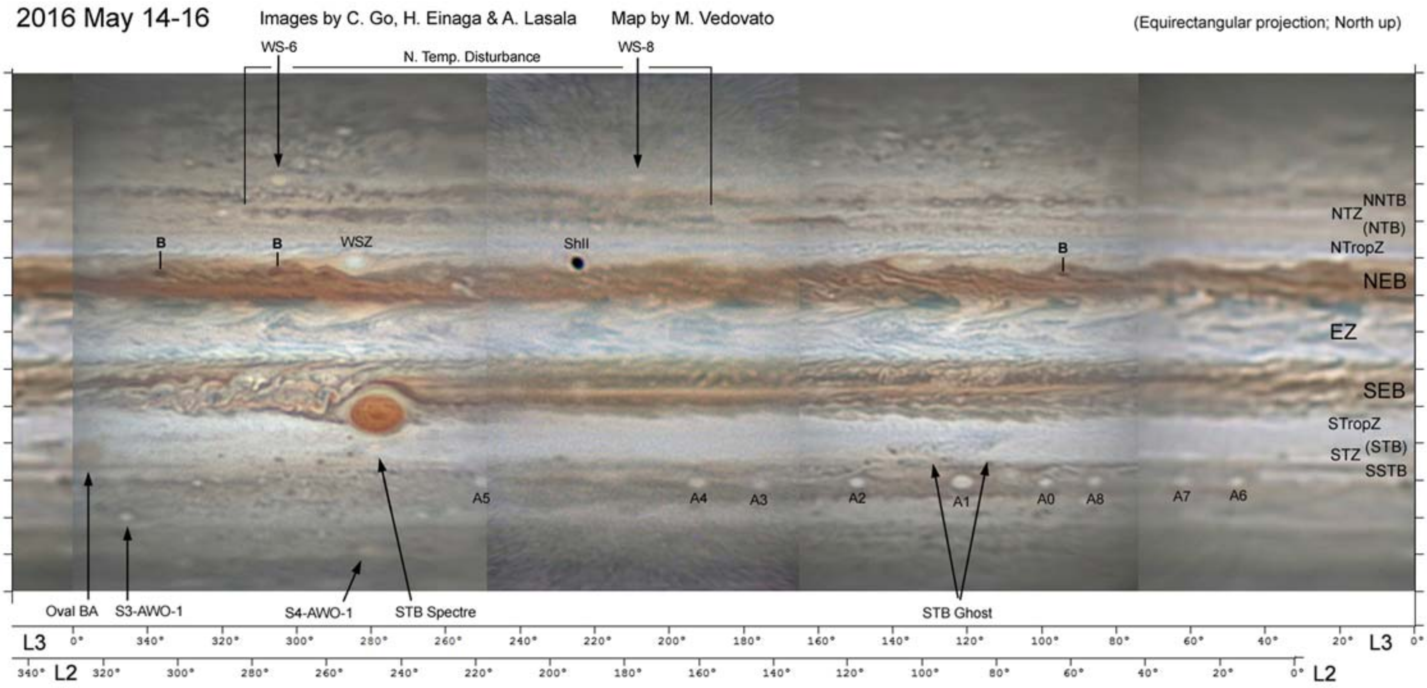

Figure 2. Map of the planet on 2016 May 14–16. In the NEB, B marks new cyclonic 'barges'; WSZ is long-lived white spot Z; ShII is the shadow of Europa. The expanded sector was to the left of WSZ, but little is left of it at this time.

image resolution have allowed us to track streaks circulating within the GRS on many occasions in 2014 and 2015 (M. Jacquesson & JHR), and the circulation period has consistently been 3.7 (±0.1) days throughout these years – shorter than we have ever recorded before, due mainly to the reduced circumference of the GRS.

The South Temperate Belt (STB) is completely absent! This domain has a unique pattern of long-term activity: it always has between 2 and 4 'structured sectors', outside which the STB is almost featureless. One of these sectors includes the large anticyclonic oval, called BA, which is usually reddish, and moves comparatively slowly. Other structured sectors drift more rapidly, and eventually collide with oval BA, while one or more new ones arise in previously undisturbed longitudes.

At present there are three such sectors, but none is dark. One is at oval BA, where the adjacent STB segment has shrunk to a tiny dark spot. Another is a pale bluish loop called the STB Ghost, a cyclonic circulation. The third arose in early 2015 as a very dark cyclonic spot, which has now faded to leave just a pale bluish loop around it; it is developing into a replica of the STB Ghost, which we now call the STB Spectre. These structured sectors are likely to proceed on fairly steady courses; but the complete absence of a dark STB is abnormal and perhaps unsustainable, so it is possible that the STB will revive in some unexpected manner, as happened in 1993.

The North Temperate Belt (NTB) undergoes cycles of activity which sometimes recur at 5-year intervals, as in 2007 and 2012. The most distinctive event is an outbreak of brilliant white plume(s) on the super-fast jetstream on the NTB south edge, which typically produces vigorous activity leading to a vividly orange NTB(S). We can now recognise further sequels of the outbreak which typically unfold over several years. One of these, observed from 2009–'11 and again at present, is a darkened sector of North Temperate Zone called a North Temperate Disturbance, induced by a sector of small-scale rifting in the revived NTB.

The NTB(S) has now faded again to a very pale state. Even so, it is sometimes possible to measure wind speeds along it, which indicate that the speed of the jet is intermediate between its normal and super-fast states. Given these conditions, and the 5-year periodicity, we may see a new outbreak in early 2017.

The principal long-lived features on the planet are anticyclonic ovals, which are marked on Figure 2. The GRS is the largest, and oval BA the second largest. Other large ones are NN-LRS-1 (the N.N. Temperate Little Red Spot at ~41°N) and S4-AWO-1 (anticyclonic oval at ~60°S). These four ovals are all reddish for most ▶

Fireballs on Jupiter

On 2016 March 17 (St Patrick's day), a bright flash lasting about one second was detected on the limb of Jupiter in videos by Gerrit Kernbauer (in Austria) and John McKeon (in Ireland). This was the fourth ground-based detection of a fireball in Jupiter's atmosphere, following similar events in 2010 June, 2010 August, and 2012 September. They are due to impacts of small asteroids or comets in the 10-metre range, comparable in energy to the smallest fragments of comet Shoemaker–Levy 9, or to the Chelyabinsk impact in Russia. They explode above Jupiter's cloud-tops and leave no trace.

At the Nice workshop described below, McKeon described his observation which confirmed the latest event, and the entertaining media circus which followed. Isshi Tabe described how Japanese astronomers conducted intensive, sensitive searches for such fireballs from 2012 to 2015, using a range of apertures from 0.4m to 2.0m, in the methane as well as visible wavebands. In over 160 hours of videos, no fireballs were detected. Marc Delcroix described the DeTeCt project, which he developed incorporating work by Ricardo Hueso. The software is available for any observer to use to screen their own videos for fireballs, and all serious imagers are encouraged to use it: **http://www.astrosurf.com/planetessaf/doc/project_detect.shtml**.

So far over 56 days of video have been analysed, with no new detections – which is disappointing as some theoretical estimates predicted one or more impacts in this time. As each event so far has been recorded by at least two observers – some of them hitherto little known in the wider astronomical community – it seems that the amateur video coverage of Jupiter is not missing as many events as might have been thought. If the St Patrick's day event is included in DeTeCt, the nominal rate is ~6.5 per year; but this may be regarded as an upper limit, as that event was only included subsequent to its independent discovery. The lower limit for observable impacts is the actual observed frequency: 4 in 6 years, which should be multiplied at least two-fold to cover the periods when Jupiter is not being observed much (when it is low in the sky from Europe, America, and the Far East, and during solar conjunction): thus, ~1.3 per year. (Both upper and lower limits are, of course, also subject to the statistical uncertainty inherent in small numbers.) – ***JHR***

Figure 3. Composite image of the planet and fireball and galilean moons, on 2016 March 17 at 00:17 UT, produced by Sebastian Voltmer from the raw images from Kernbauer and McKeon.

A pro–am Jupiter workshop in Nice, 2016 May 12–13

In preparation for the professional–amateur (pro–am) collaboration which is expected during the *Juno* mission, a workshop on '*Juno* ground-based support from amateurs' was held in Nice, France, on 2016 May 12–13. It was organised by Dr Ricardo Hueso and Dr Paolo Tanga, and funded by the European Union through the EuroPlanet network. It took place at the Observatoire de la Côte d'Azur, high on a hill with a spectacular view over the city and the sea.

The aims were to inform amateur observers about the *Juno* mission and the plans for obtaining both professional and amateur observations of Jupiter during this mission; and to enable amateurs to improve their own imaging by sharing best-practice techniques.

This was a valuable opportunity for some of the best-known amateurs from Europe (and several from the USA and the Far East) to meet each other, and to meet professional planetary scientists. The participants were united in enthusiasm that we are all part of a shared enterprise, producing new results, valued by professional scientists as well as ourselves. There were 30 talks, of which only some can be mentioned here.

Dr Glenn Orton (NASA Jet Propulsion Lab), who represents the JunoCam team and has been travelling the world to liaise with amateurs, explained the *Juno* mission and the JunoCam project [see below], urging all amateurs to participate. Dr Tristan Guillot (Observatoire de la Côte d'Azur) explained one of the main scientific purposes of the *Juno* mission, the gravitational probing of the planet's interior. Dr Leigh Fletcher (University of Leicester) showed how large ground-based telescopes can now produce spectacular images and spectra of Jupiter's mid-infrared thermal emissions (and will do so during the *Juno* mission), contributing to a three-dimensional understanding of the atmosphere. John Rogers described the current state of Jupiter's atmosphere [see above], pointing out phenomena of possible interest for JunoCam, with hi-res maps provided by amateur imagers and the *JUPOS* team.

1. Jean-Pierre Prost
2. Isshi Tabe
3. Paulo Casquinha
4. Kuniaki Horikawa
5. Dominique Albanese
6. Gerald.Eichstäedt
7. Constantin Sprianu
8. Matej Mihelčič
9. Leigh N. Fletcher
10. Marc Delcroix
11. John Sussenbach
12. François Xabier Schmider
13. Matic Smrekar
14. Manuel Scherf
15. Emil Kraaikamp
16. Alessandro Bianconi
17. John McKeon
18. Michel Jacqueson
19. Paolo Tanga
20. Glenn S. Orton
21. John H. Rogers
22. Padma Yanamandra-Fisher
23. Marco Vedovato
24. Johan Warell
25. Damian Peach
26. François Colas
27. Christopher Go
28. Jean-Pierre Rivet
29. Agustín Sânchez Lavega
30. Ricardo Hueso
31. Jean-Luc Dauvergne
32. Christophe Pellier

Figure 4. The participants in the Nice workshop, at the Nice Observatory.

Several leading amateur observers presented aspects of state-of-the-art planetary imaging, including Christopher Go (visiting from the Philippines) and Damian Peach (UK) who described how they produce their top-quality images. Go uses at least six programs sequentially: *Firecapture* for image capture, *Autostakkert!2* for stacking, *Registax* for wavelets, *GoogleNik* for sharpening, *Photoshop* for noise reduction, and finally, *WinJUPOS* for combining several images by derotation. All this takes four times as long as the imaging session itself. Christophe Pellier (France) gave a masterly review on the use of filters for observing Jupiter.

Currently, amateurs use small(ish) telescopes frequently, mostly in the visible waveband, whereas professionals use large telescopes for short periods, mostly in the infrared. But this gap is being bridged. On the professional side, Dr Agustin Sanchez–Lavega (University of the Basque Country, Spain) described how his group is now accessing medium and large telescopes, including the 2.2 metre telescope at Calar Alto, using 'PlanetCam' to take hi-res images from 0.38 to 1.7 microns.

He has also set up a Meade 143 [355mm] SCT at Calar Alto for remote operation. Whereas remote imaging is now well established for deep-sky objects, it has not been optimal for planets up to now, because careful manual control is needed for best results. However, several organisations are now installing suitable systems with telescopes in the one-metre range, which will be available for amateur use. J–P. Rivet and J–P. Prost (France) described one such setup using a pair of 1-metre telescopes owned by the University of Nice. Damian Peach mentioned another being installed near La Silla, Chile; and the Sierra Stars Observatory in California is also installing one. Also, the 1-metre telescope at the Pic du Midi is available for experienced amateurs to use on site, as described by Jean–Luc Dauvergne and Dr Francois Colas.

John Rogers, Damian Peach, Christopher Go & Glenn Orton.

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▶ or all of the time, and this seems to be a feature of large, long-lived ones, perhaps because their circulation extends deeper than for 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 domain (an array of 9 AWOs). [Many of these are also very long-lived; they typically last for at least several years; NN-LRS-1, S4-AWO-1, and some of those in the S.S. Temperate domain, have existed since 1987–'93 or even earlier.] They are readily identified on hi-res methane-band images, as all these anticyclonic ovals (except, oddly, WSZ) are methane-bright, as their red or white cloud caps extend to high altitude (Figure 1).

More details of these phenomena in 2015–'16 have been posted as interim reports on the Jupiter Section's new web pages at **https://www.britastro.org/section_front/15**. Articles explaining the long-term background to these phenomena, along with many previous interim reports, are on our older web site at **http://www.britastro.org/jupiter**.

John H. Rogers, *Director*

Notes and News

Among several talks on the software used for creation and analysis of amateur images, Marco Vedovato described the construction of maps and zonal wind profiles in *WinJUPOS*. Dr Ricardo Hueso (University of the Basque Country) showed how his professional team are likewise using amateur images to extract zonal wind profiles. Johan Warell (Sweden) presented the 'Voyager 3' project by Swedish amateurs to create a continuous animation of Jupiter's winds from amateur images.

The JunoCam data will also require a different kind of processing by amateurs to produce fully aligned and realistic images [see below]. Gerald Eichstädt (Germany) showed how he had done this with the images from *Juno*'s Earth flyby, to produce many of the images posted by NASA.

Several organisational issues were addressed in a concluding discussion:

1) Submission of images to databases: At present, observers are asked to submit to three worldwide databases (PVOL, ALPO-Japan, and JunoCam), and there are also some national databases. Several observers suggested that there should be just one global database with direct uploading from the image processing software. In fact, *AutoStakkert!2* already has a direct uploading facility. There was no enthusiasm for discontinuing any of the existing databases, but the operators of all of them will continue working to make uploading and sharing as simple as possible.

2) Software maintenance: Current amateur imaging depends heavily on a few software suites created entirely by individual dedicated amateurs, notably *Registax*, *AutoStakkert!2*, and *WinJUPOS*. It was pointed out that the whole process is vulnerable in case these people were to become unable to maintain them. (*Registax* is already unsupported.) Emil Kraaikamp said that he is personally committed to maintaining and upgrading *AutoStakkert!2* (and Grischa Hahn is doing likewise for *WinJUPOS*). It was generally recognised that the success of these programs depends on the personal flair, enthusiasm and experience of these individuals, so professional or group support would not be practical even if it were desirable; vulnerability comes with the package.

NASA graphic of *Juno* firing its main engine as it flies low over the dark side of the planet to enter into orbit on 2016 July 5.

3) There is still debate about whether image analysis should be done with north up (the convention used by professionals) or with south up (the historical convention used by amateurs). This was not resolved, but during the *Juno* mission, the BAA Jupiter Section will be showing north up, for compatability with NASA output.

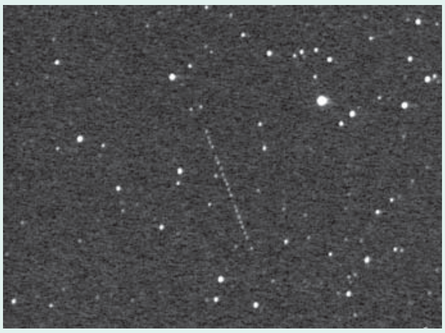
All the talks are posted at: **http://www.ajax.ehu.es/Juno_amateur_workshop/talks/index.html**

John H. Rogers

The *Juno* mission and JunoCam

The mission is intended to study the internal constitution of Jupiter – not the visible atmosphere. There are three main goals, to be achieved by a series of very close flybys covering every part of the planet. First, to map the gravitational field in great detail; this will give information on the internal density layering, possibly including detection of a rocky core and of deep-penetrating jetstreams. Second, to map the magnetic field and magnetosphere in detail, along with intensive study of the polar aurorae by UV and IR imaging spectrographs. Third, to probe the temperature and pressure of the atmosphere below the visible clouds by means of a microwave radiometer; the results should reveal the abundance of water vapour in the deep atmosphere, and possibly clues to the atmospheric dynamics.

None of these goals requires a camera; but at some point it was realised that politicians and public would expect to see pictures from such an expensive mission, so JunoCam was included, with the official goal of 'public outreach'. It has a comparatively small data allocation, so only around 10–15 full-colour images will be returned on each perijove. Some of these will be used to support the main scientific goals, by imaging the polar regions and the microwave radiometer targets; but others will be taken at various points below the spacecraft track as determined by public input.



Juno flying past Earth on 2013 Oct 9. Image sequence by Dave Storey on the Isle of Man.

This will be done through a website set up by NASA's JunoCam team (Dr Candy Hansen and Dr Glenn Orton & Tom Momary). Amateur imagers are uploading their images of Jupiter to this site; Tom Momary makes a map from these images every two weeks; members of the public (including ourselves) flag up features of interest; and on each orbit, the public will vote on which features should be imaged. The targeting will be determined by the JunoCam team based on these votes and discussion as well as scientific criteria. Meanwhile, amateur images will also provide valuable context for the narrow fields targeted by JunoCam and the microwave radiometer.

The *Juno* spacecraft is spinning (unlike spacecraft such as *Voyager* or *Galileo*), so the JunoCam 'images' will be assembled from scans taken as the spacecraft spins twice a minute – a technique not seen since the *Pioneer* 10 and 11 flybys of Jupiter in 1973 and 1974. Thus, the raw images to be released by NASA will consist of 3-colour strips, and amateurs will be invited to process them further, de-rotating and combining them to make more realistic images.

On July 5 (July 4 in the USA), *Juno* came in over Jupiter's north pole and performed a 35-minute main engine burn at closest approach, passing only 4547km above the cloud-tops. The burn took place perfectly, and *Juno* is now in its first orbit. All orbits will be highly elliptical and polar, so the key event on each orbit will be the perijove (closest approach to Jupiter). The spacecraft is currently performing several 'engineering orbits', during which the orbital period will be shortened and the instruments checked out; these perijoves are on 2016 Aug 27 (just 4147km above the cloud-tops), Oct 19, and Nov 2. The first normally operational perijove will be on 2016 Nov 16; this will also be the first one for which the public will be able to vote on targets for JunoCam. From then onwards, perijoves will occur every two weeks, at altitudes around 4300km until 2017 March, after which the altitude gradually increases. (There will be no satellite flybys.)

The timing is not ideal for ground-based observers, as Jupiter is in solar conjunction on 2016 Sep 26, so we will have no hi-res images from Earth until November. By the New Year, hopefully the amateur input will be up to standard. However, JunoCam will probably become degraded by Jupiter's intense radiation belts over several months, so the quality of the images may not be sustained beyond Spring 2017. Nevertheless, the main mission continues until 2018 Feb 20 (or possibly later), when the spacecraft will be sent on a final plunge into Jupiter's atmosphere. – ***JHR***

All about the *Juno* mission is at: **https://www.missionjuno.swri.edu/**. For collaboration on JunoCam see: **https://www.missionjuno.swri.edu/junocam**.