Juno at Perijove-3: What the JunoCam images show

--John Rogers (BAA), 2016 Dec. 22

This report was originally posted in html in three parts headed 'Juno at Perijove-3', which are here edited into a single text. Full-size versions of the figures are available in ZIP files in those posts. Unlabelled versions of the figures can be provided on request. The figures and abbreviated notes have also been posted on the JunoCam web site.

1. Introduction

This report points out features that can be identified in Juno's images taken at Perijove-3 on 2016 Dec.11. The originals have been released on the JunoCam Image Processing web page. There are 21 colour images, 12 methane-band images, and 5 long-exposure red-light images of the poles.

These images, especially the closeup ones, are clearly better than the test shots at Perijove-1. This is partly due to improved exposures and encoding, and partly due to better illumination. (The camera was viewing with higher sun angles this time, both because of the planet's orbital motion, and because the spin axis was oriented to Earth rather than to the horizontal.) The images as posted still have artefactual colour bands parallel to the terminator, but Gerald Eichstädt has shown how these arose from the compression/re-expanding procedure used, and has devised an algorithm that completely removes the bands. Mike Caplinger in the JunoCam team has also developed a technique for the same purpose.

The JunoCam views are not like typical flyby images, as they are scans taken from low altitudes, effectively taking in a wide-angle view from the nadir to the horizon – and also distorted by the rapid motion of the spacecraft during the scan. And they are taken shortly before local sunset. So there are strong gradients of illumination, darkening towards the terminator, and brightening with blue sky and haze towards the horizon. There are also issues with artefactual colour bands, as noted above. For high-latitude images I used versions of the original scans from which these bands have been cleanly removed by Gerald Eichstädt. For low-latitude images I used the less distorted versions released as 'map projections' by the JunoCam team, which appear to be reprojected as views of the scene from higher than the true altitude; I have partially reduced the colour banding in these by ad-hoc blending in Photoshop. I have also applied gradients and further adjustments to improve the visibility of features.

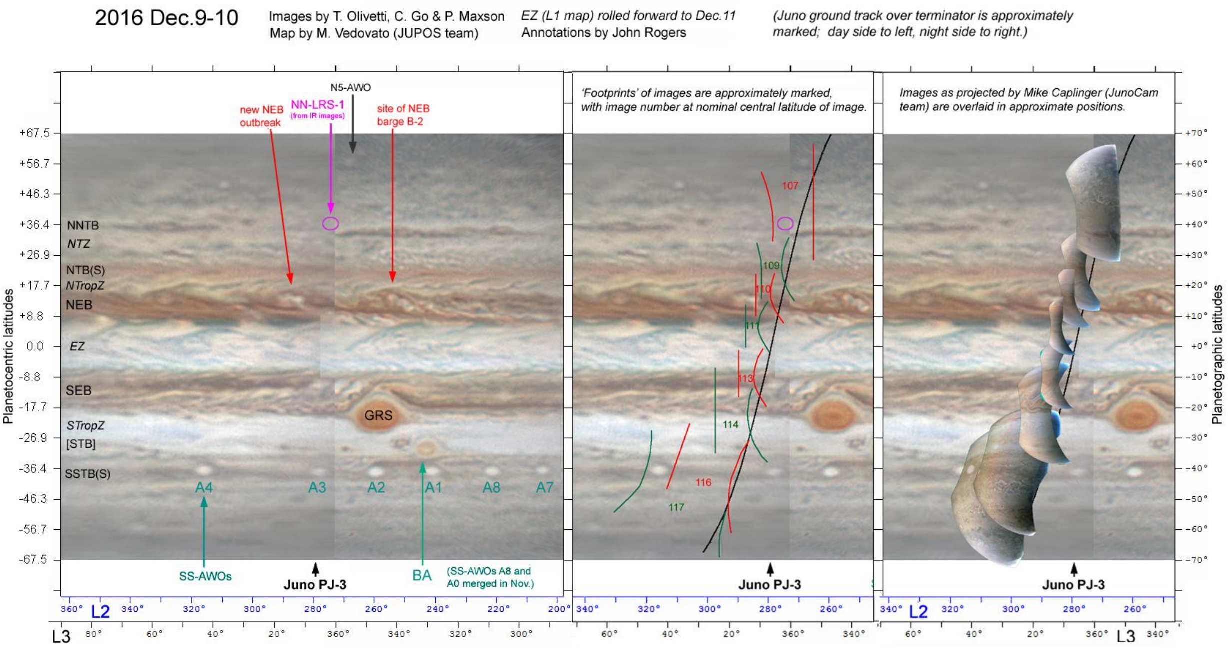


Figure 1.

These images are put into context by our predictive map for Dec.11 at: https://britastro.org/node/8411 and by an actual map for Dec.9-10 (**Figure 1**). On the latter map, I have approximately marked the sub-spacecraft track of Juno and the 'footprints' of the images. (The full map without overlay is posted on our 'Jupiter in 2016-17' web pages, along with a series of images of the relevant side of Jupiter from Dec.9-14. Hopefully a hi-res map will also be assembled eventually from JunoCam's inbound and outbound images.) JunoCam covered almost all latitudes at this flyby. [*Footnote on latitudes:* Because Jupiter is flattened, not spherical, there are two alternative definitions of latitude. We always use planetographic (zenographic), but the Juno project has decided to use planetocentric. Both scales are given on the attached map.]

2. Northern hemisphere

Figure 2 [Image 107]: This stunning view of the high north temperate latitudes fortuitously shows NN-LRS-1, the third largest anticyclonic reddish oval on the planet, which we have tracked for the last 23 years. It shows very little colour, just a pale brown smudge in the centre. Consistent with this, it was invisible in all but the highest-resolution RGB images all last apparition and so far this apparition, i.e. it is the same colour as its surroundings. But it always stands out nicely in methane-band images. In fact, when the predictive map for PJ-3 was produced we had no record of it this apparition, but then it was identified in methane-band images and turned out to be precisely in the JunoCam image track.

Figure 3 shows NN-LRS-1 in three successive colour images, from the southern to the northern horizon, and a methane image, where it is bright. (The latter image will enable the distribution of methane-bright cloud within it to be mapped.)

Also in these images, note a narrow diffuse band of white haze lying across the NNTB, whch seems to cast a short shadow in image 105, and a much longer shadow 12 minutes later in image 107. (See Section 5 below.)

Figure 2

Figure 4 [Images 109-111]: These 3 overlapping images show the intricate cloud textures and colours across the newly reviving NTB and the highly disturbed NEB. Many colour closeups of these belts were of course obtained by Voyager and Galileo, but these images capture a unique transient stage in the great NTB jet outbreak which probably started in September and was discovered at Perijove-2 in October.

In the NTB (image 109), the main feature is the orange NTB(S) which developed in recent weeks as observed from Earth, plus turbulent streaks N and S of it. Two tiny dark spots within the orange belt are notable (one also visible in image 110).

The N. Tropical Zone, in ground-based images, is currently filled with grey streaks and orange-yellow shading, an intense disturbance resulting from the NTBs outbreak. In the Juno images all this is nicely resolved, including one of the dark grey streaks which appears like a multicoloured caterpillar. A conspicuous loop at right looks like an anticyclonic (clockwise) circulation, but is not so distinctive in ground-based images just before and after. I suspect that a NEBn projection has connected to a passing NTropZ streak to produce a transient circulation here, but it could develop further.

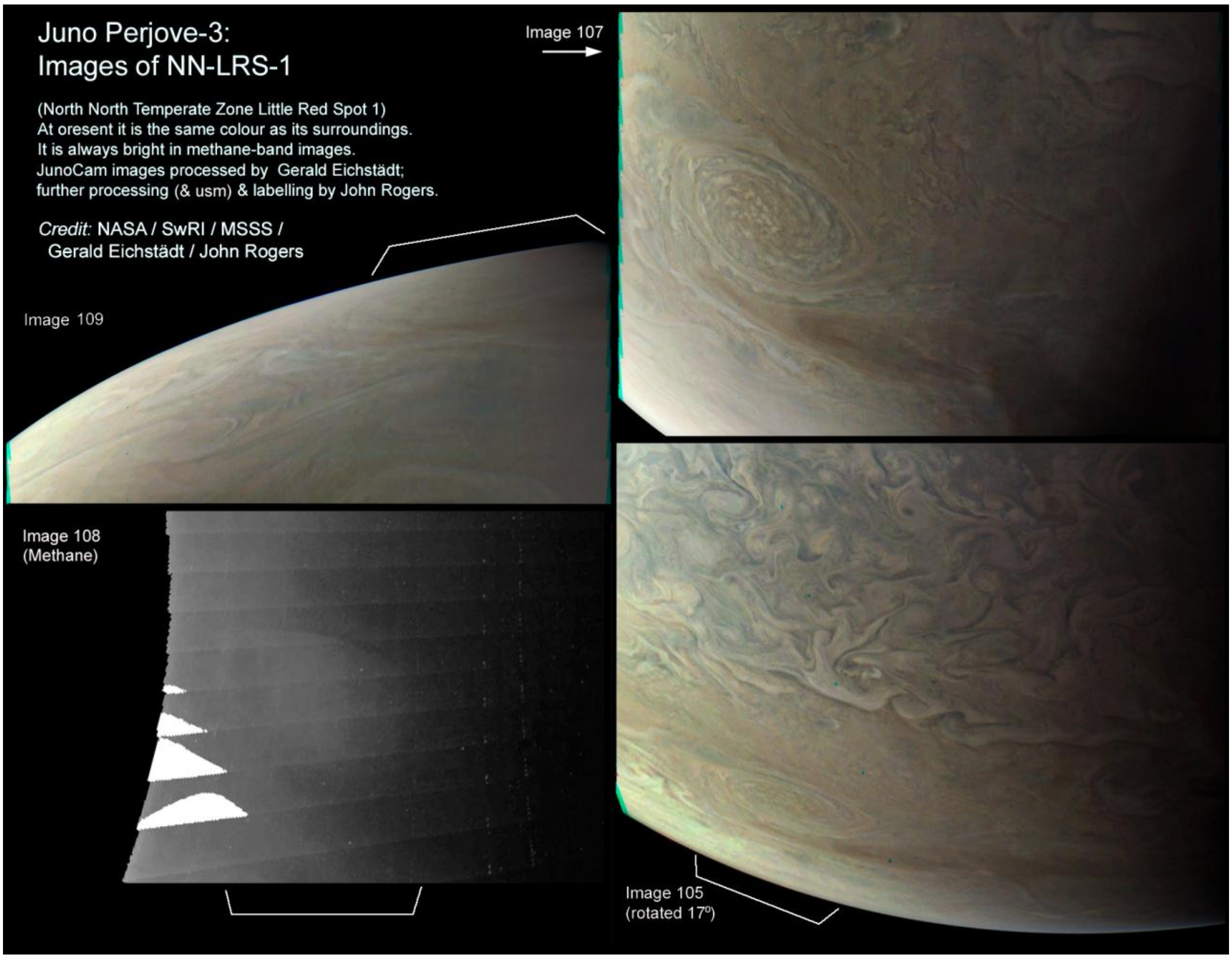


Figure 3

JunoCam targeted the northern NEB because people had voted for a spot which was actually barge B-2 from last apparition; but B-2 was not in the field of view and was also obscured by a bright 'rift'. However, the day before perijove-3, a new white spot was discovered much closer to JunoCam's target field (Chris Go on Dec.10; he showed its origin as a small spot on Dec.5). This very bright outbreak developed rapidly (Figure 5); exceptionally, it was in the northern NEB and so extended mainly to the west. JunoCam just caught it on the horizon at the edge of image 111 (see inset in Fig.4). It could develop further so ground-based observers will follow it closely.

Image 111 was taken at closest approach from an altitude of only 4147 km, so in the central region it may be the highest-resolution image ever taken of Jupiter. According to the map (Fig.1), a NEBs dark formation (infrared 'hot spot') is shown, which appears as a swathe of grey streaks. On its south edge there are two wave-trains in the EZ clouds (see inset in Fig.4), similar to wave-trains of ~200 km wavelength which have been imaged by previous spacecraft. [*Footnote*: Although this inset also shows widespread narrower vertical striations, probably due to the strong gradient and enhancement applied, the wave-trains are real as they are localised in latitude and also visible on Gerald's original. This image is of much better quality than the perijove-1 test view from 4149 km.]

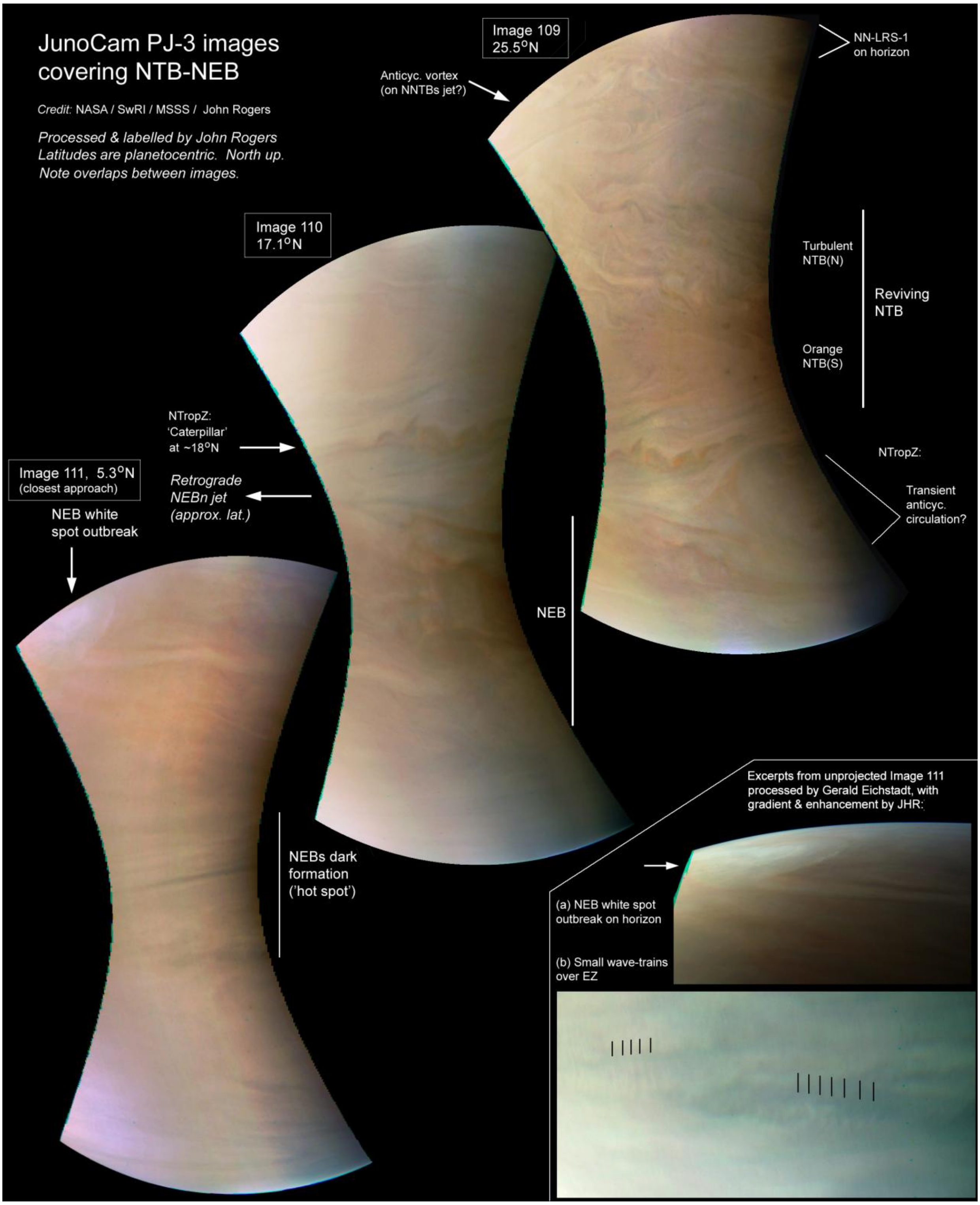


Figure 4

3. Southern hemisphere

Here are enhanced and annotated versions of the Perijove-3 images of the southern hemisphere. The general remarks (Section 1) and map (Figure 1) also apply here. The positions of the permanent prograde jets are marked approximately, by reference to the cloud textures, as determined by previous spacecraft; but the highest-latitude jets are not well determined and could be irregular.

Figure 6 (Images 113, 114, 116) shows the close-up views from the SEB to the SSTB, and Figure 7 shows better-processed details from them, showing the beautiful cloud textures. The SEB is the sector west of the GRS with its ongoing large-scale convective 'rifts'. The S. Tropical Zone and STBn jet and whitened STB are all essentially white but show contrasting cloud textures (which look three-dimensional when near the horizon, although it remains to be determined whether this is real).

In the S. Temperate Zone, the images show one of the dark spots that have been emitted westward from the dark patch beside oval BA (its shape suggests it is weakly anticyclonic), and a rimless white oval (which has beautiful anticyclonic spiral structure).

The SSTB in this sector (between ovals A3 and A4) is split into north and south components separated by a pale sector, shown more completely in the next image (117). Pale sectors like this are thought to be cyclonic circulations and this impression is reinforced by its appearance in these images, although it now appears pale orange rather than white.

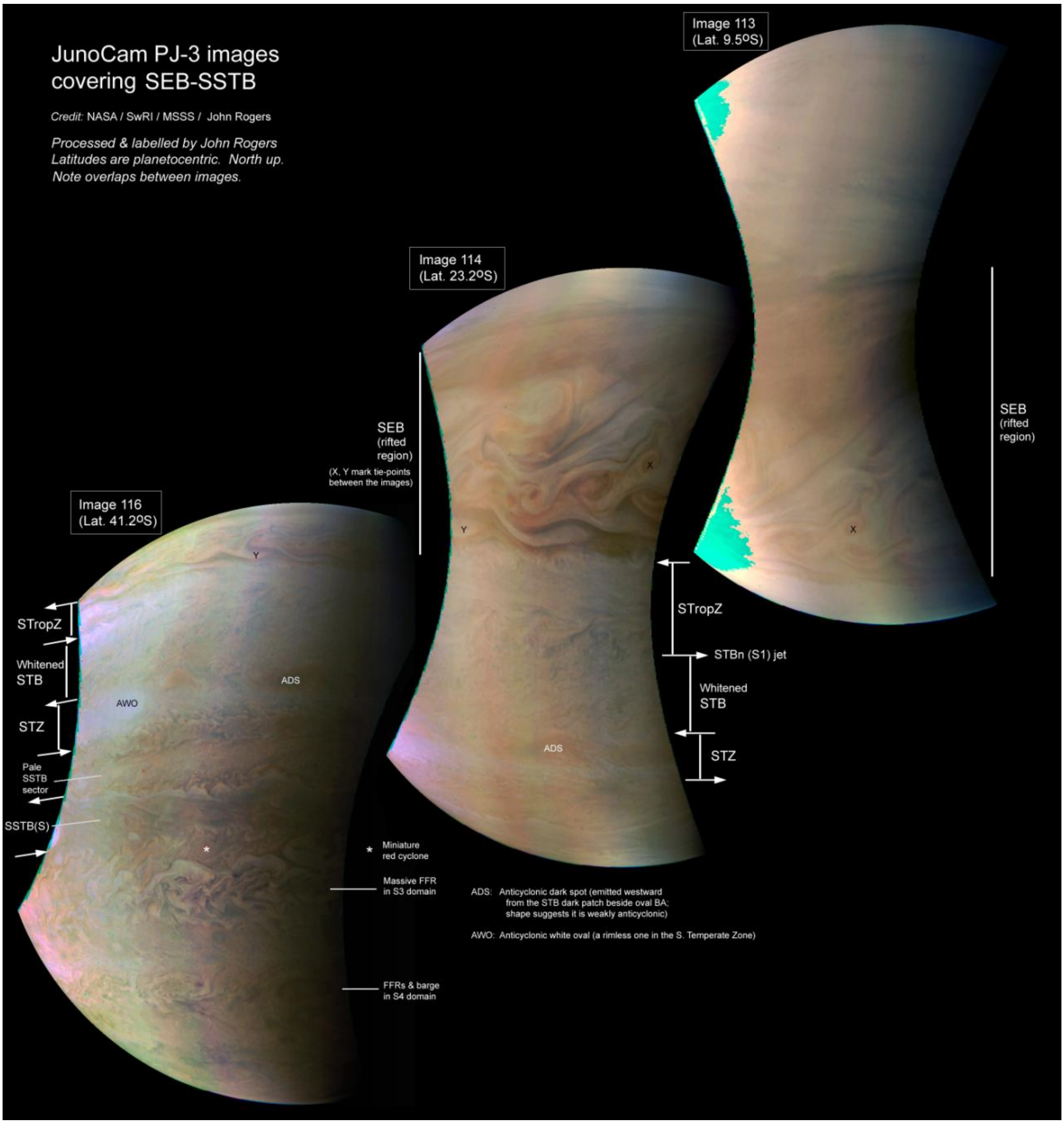


Figure 6.

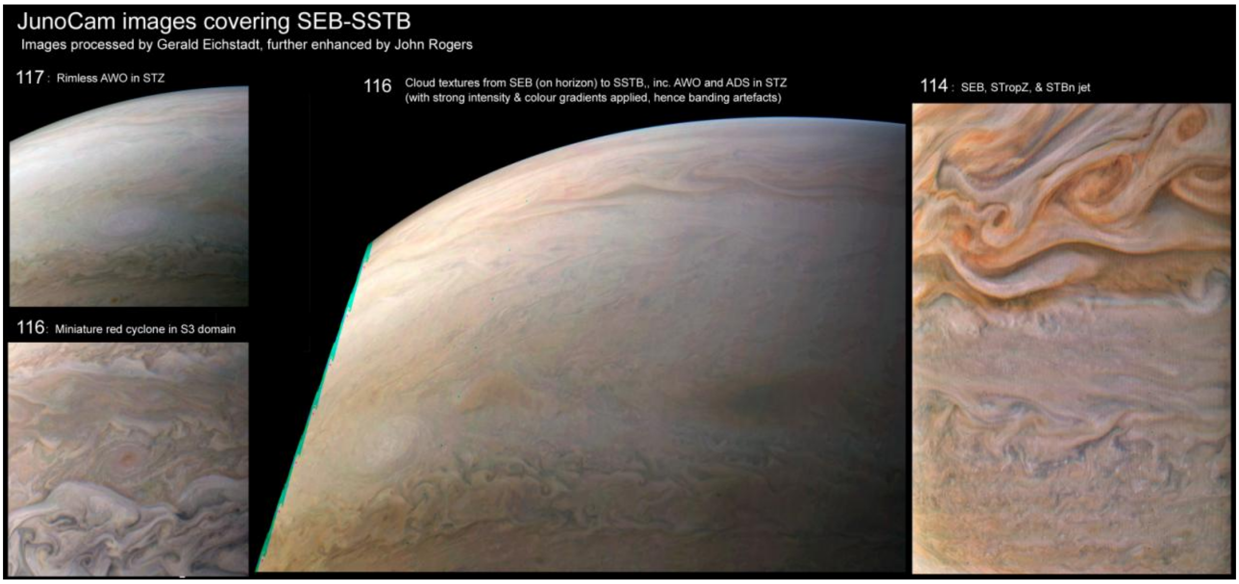


Figure 7.

Anticyclonic white oval (AWO) A4 of the S.S. Temperate (S2) domain, labelled S2-A4 on the images, was one of the publicly voted targets at this perijove (one of the "string of pearls"); it was also imaged at perijove-1. It has been tracked certainly since 2001 and possibly as far back as 1994.

Figure 8 (Images 117, 118, 126) shows the high southern latitudes. The S3 and S4 domains are each visibly divided into a cyclonic 'belt' and an anticyclonic 'zone', like lower-latitude domains, although this distinction becomes less evident towards higher latitudes. Here, in each of these domains, there is a very large cyclonic folded filamentary region (FFR), and west of (following) it is a notable cluster of small anticyclonic vortices. From our ground-based studies of lower-latitude domains and recently the S3 domain, I think these vortices are likely to be moving westward relative to the FFRs, and they may prevent S4-AWO-1 (the 'South Polar Little Red Spot) from drifting eastward for a while.

In the S4 domain there are also three conspicuous orange-brown cyclonic circulations ('barges').

At high latitudes, in both hemispheres, the polar regions are almost completely filled by FFRs, with scattered small AWOs. These images also reveal a few small cyclonic spirals with circular outlines, but they are much smaller than the circumpolar cyclones (see below).

The S5 and S6 jets (recorded only by Hubble and by Cassini) have never yet been observed clearly because of their high latitudes. In these images, it is not clear if they are uniform in longitude; the S6 jet is hard to make out. A conspicuous albedo boundary seems likely to coincide with the S5 jet in one sector and the S6 jet in another, with a series of large-scale waves joining the sectors, but the dynamics along here is not precisely known. The S5 domain, between these jets, is very narrow, and has a mixture of cyclonic and anticyclonic vortices (quite unlike the similar narrow N6 domain in the northern hemisphere, which mostly has bland texture with a long sinuous line along it; see below).

The JunoCam images suggest a novel retrograde jet at ~72ºS (see below). I do not see obvious signs of prograde jets south of this, but in principle there could be one just to the south, and/or, one enclosing the cluster of circumpolar cyclones (CPCs) (see Section 4 below). Given the spacing of the visible CPCs, this could be roughly pentagonal, with small AWOs just outside it. [*Footnote*: The spacing of the CPCs suggests there are five of them surrounding the central one, at both PJ-1 and PJ-3; but they were not in a regular pattern with AWOs at PJ-1, so there may not be a stable pentagonal jet.]

High-altitude white haze bands are seen up to the terminator, as in the northern hemisphere (see Section 4 below) and at PJ-1. I suppose these may be thickenings in the polar hoods (but see 'methane images' below). Several bands are tilted as though they may be affected by the jets. The most conspicuous is a large <-shaped one which projects slightly over the terminator; it encloses a notable dark brown area like a brown shadow on the terminator. Several others of these white haze bands, in the north and also at PJ-1, may likewise cast 'brown shadows' (to be discussed in Section 5, below).

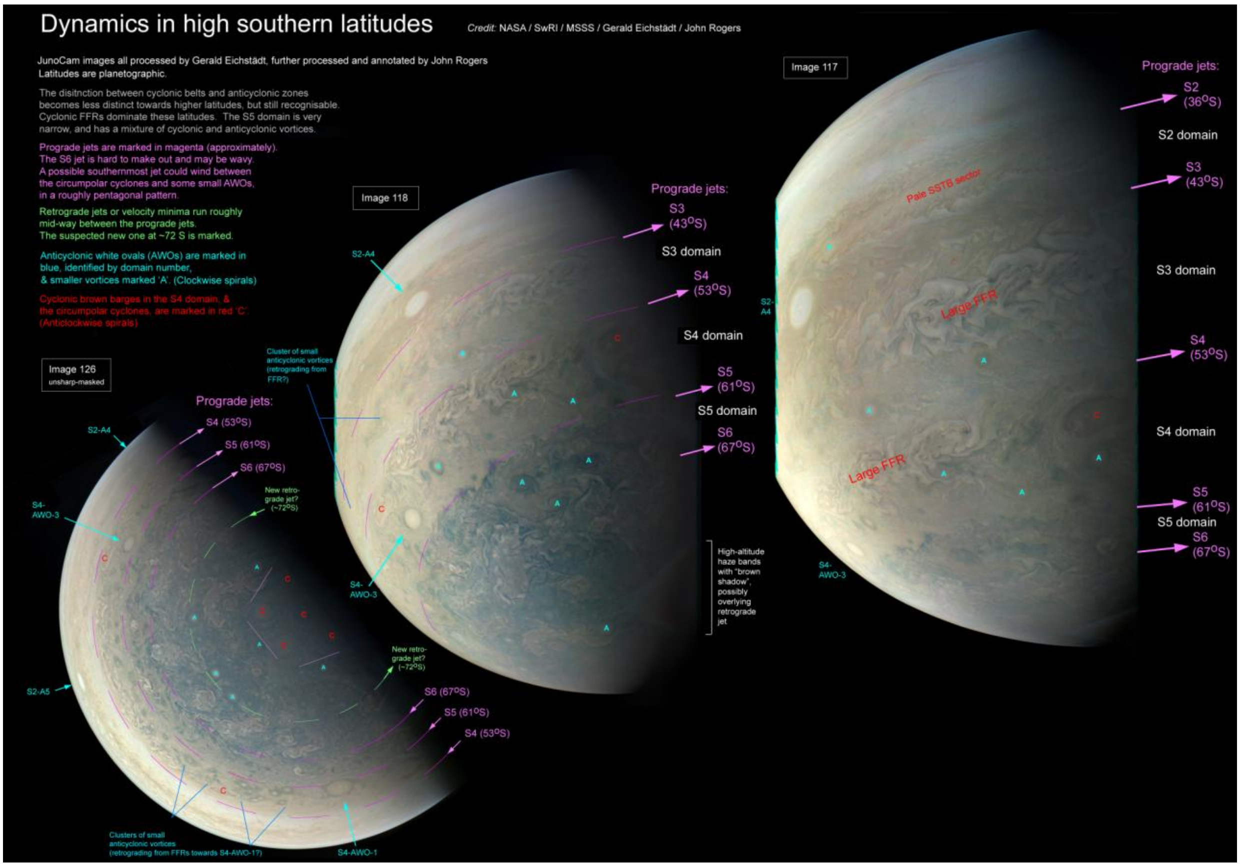


Figure 8

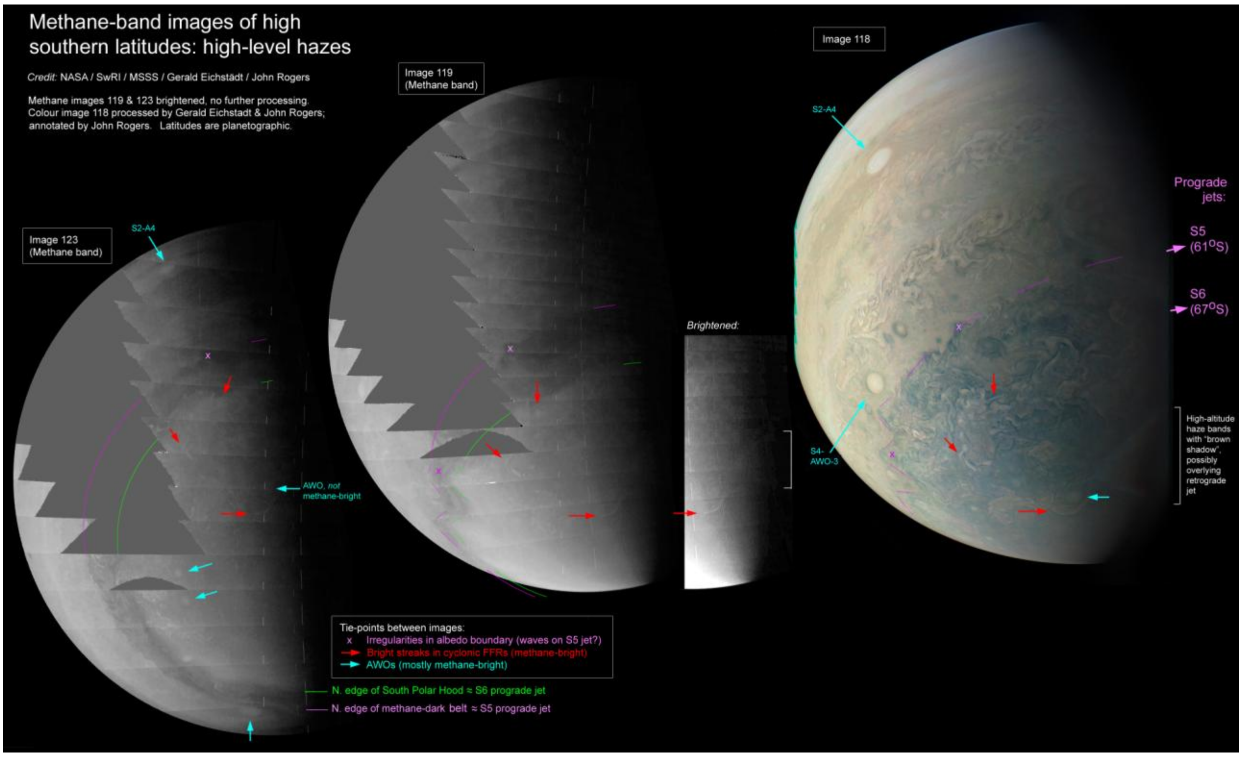


Figure 9

Figure 9 shows methane images (119, 123) of the high southern latitudes. Methane-bright features are high-altitude clouds or hazes, notably the well-known AWOs and South Polar Hood (SPH). These images will allow the boundary of the SPH to be mapped in detail, although accurate mapping and photometry of the images will be needed to reach firm conclusions; the following comments are provisional. There is a very methane-dark 'belt', whose north edge seems to coincide with the visible S5 prograde jet; its south edge is the north edge of the SPH, and seems to be close to the S6 prograde jet. Both edges undulate along with the visible albedo pattern, which may be large waves on the jet(s).

Within the SPH, two small AWOs are methane-bright though another is not. As in the north polar region, there are many small methane-bright streaks, which coincide with bright lanes in FFRs.

4. South Polar Region

Images of the north and south poles beautifully confirm and extend the discoveries made by JunoCam at PJ-1: clusters of circumpolar cyclones (CPCs), ubiquitous FFRs, and high-altitude haze streaks.

Figure 10 (Image 126): This image was taken directly above the south pole, which is in sunlight. Five CPCs are visible, 4 surrounding a fifth which is distinguished by being largely dark, and the latter may well overlap the south pole (whose position is approximate). Similarly at PJ-1 there were 3 or 4 CPCs visible surrounding a darker fifth, with the S. Pole estimated to be on the edge of this dark central CPC.

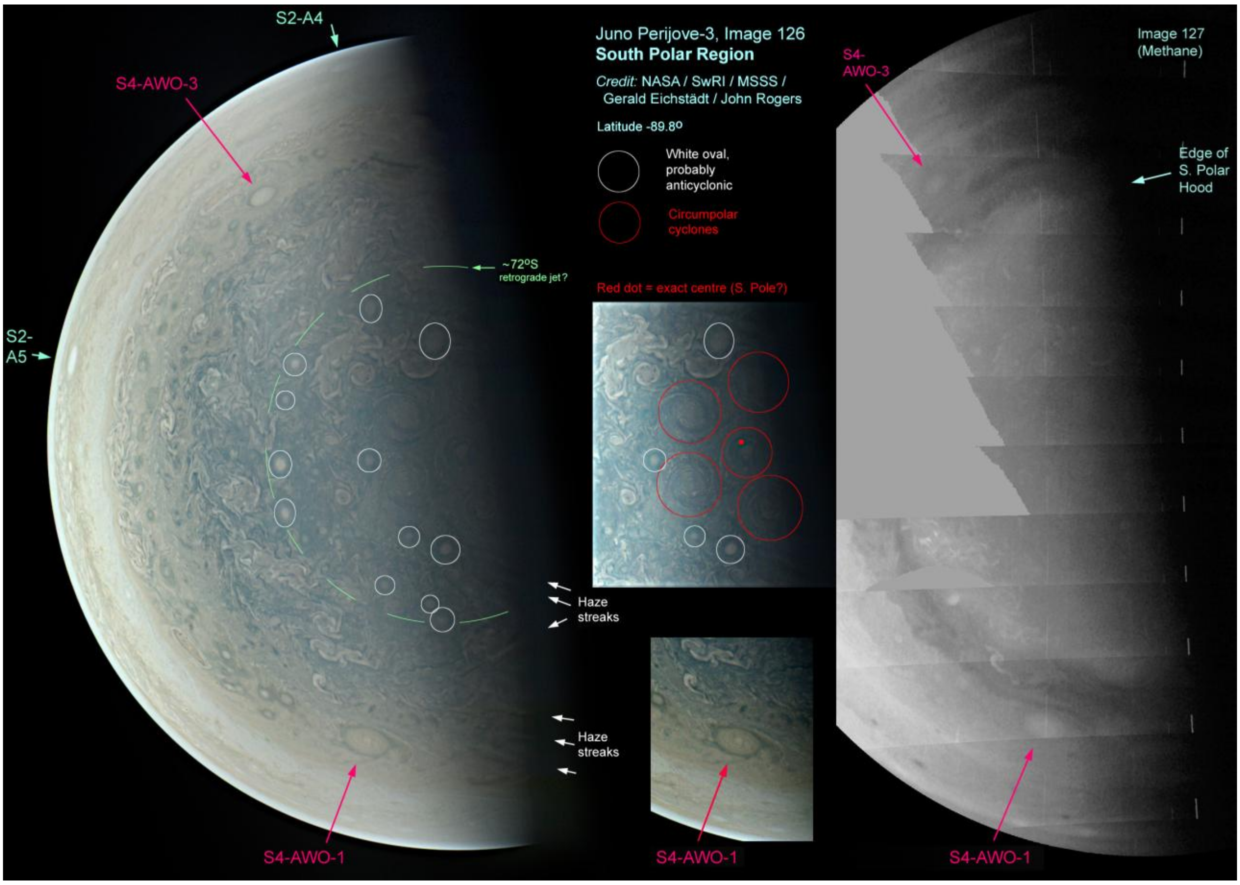


Figure 10.

The rest of the south polar region is, again, largely filled with FFRs, plus a scattering of small white ovals which are probably all anticyclonic. A loose ring of them again suggests the presence of a retrograde jet at ~72°S. Also marked are some AWOs which we have tracked from Earth, including S4-AWO-1 (the South Polar Little Red Spot).

At right is a methane-band image for comparison. As in Figure 9, the methane-bright areas are the SPH, and AWOs, and small bright streaks in FFRs.

Many short diffuse white streaks can be seen which are relatively bright up to the terminator, although they do not project significantly beyond it, so they are presumably streaks of haze just slightly above the main clouds. Some seem to coincide with bright cloud lanes in FFRs, while others do not.

Figure 11: Here are two images taken directly over the south pole, from PJ-1 and PJ-3.

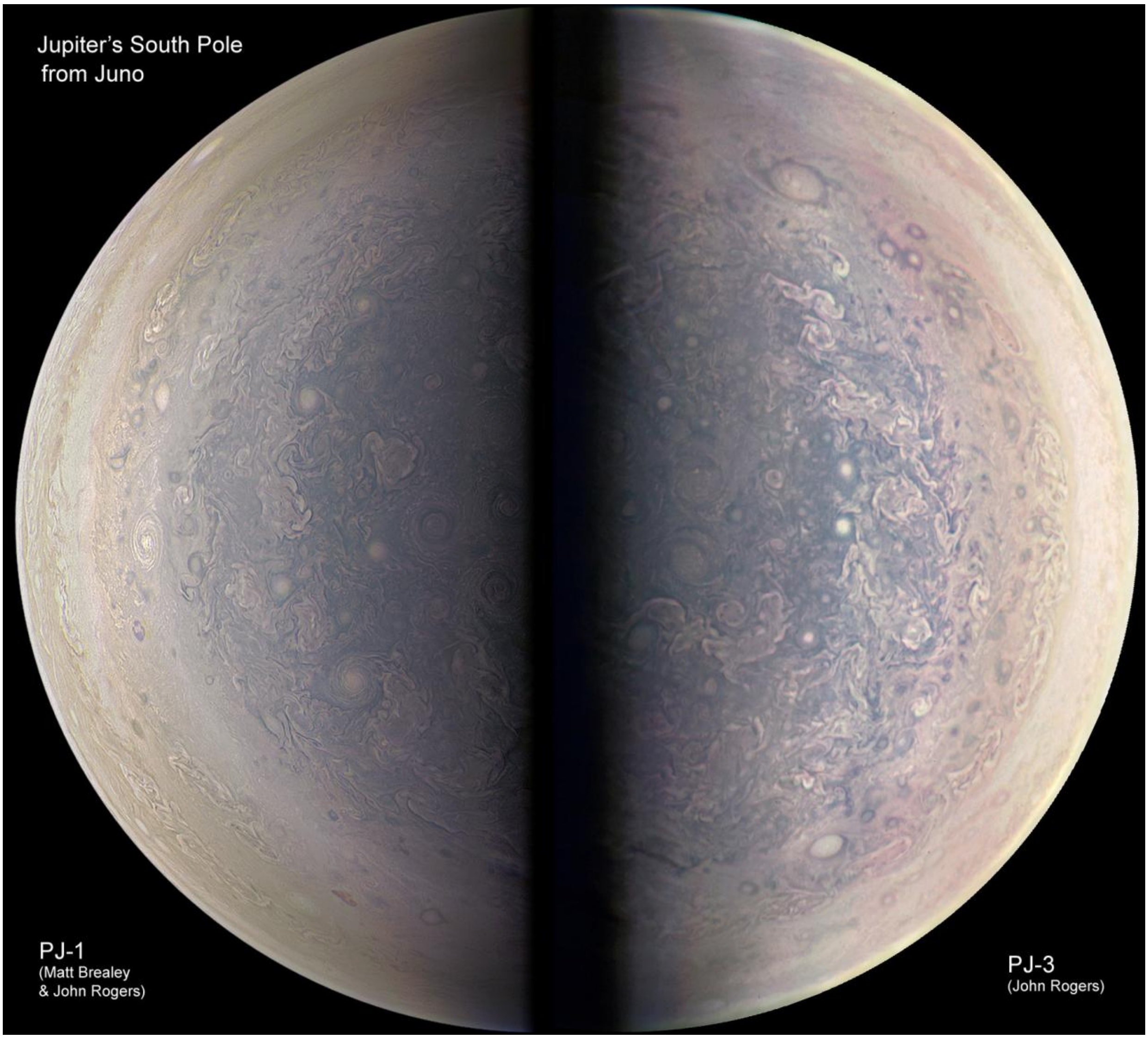


Figure 11.

5. North Polar Region

Figure 12 (Images 092 & 104) These two images show the north polar region from opposite sides as Juno flew over the pole. They confirm features shown at PJ-1, including white haze streaks near the terminator, and ubiquitous FFRs. Several AWOs are marked at lower latitudes.

Figure 13 (Image 099 & 100): This is the image taken directly above the north pole – plus a methane-band image for comparison. Whereas most AWOs are methane-bright, one AWO in the N5 domain is only weakly so and another is not methane-bright at all.

The FFRs are interrupted by a bland zone at ~64-68ºN (planetographic latitudes; i.e., approximately matching the N6 domain, bounded by the N6 and N7 prograde jets), within which is a narrow dark line. This dark line is not continuous and not fixed in latitude, and it appears brown; in the methane image (Figure 13) it is dark. It is adjacent to some of the high-altitude haze streaks, which are methane-bright. I suggest it is a thinning of the diffuse bright haze overlying the bland zone [see footnote below].

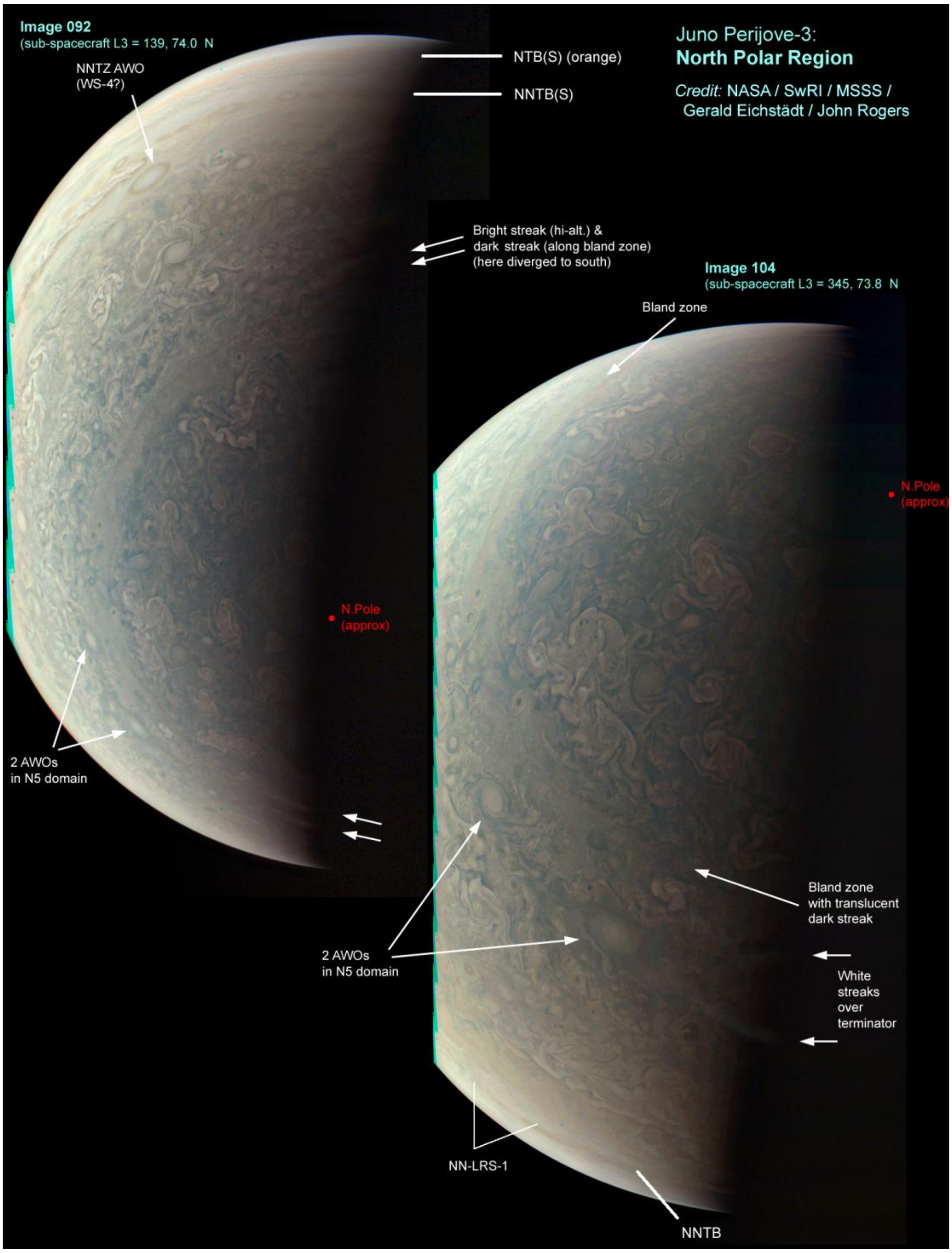


Figure 12.

Streaks of white haze seen at or even beyond the terminator must be at high altitude, which is confirmed for some as they are methane-bright. Those at high latitudes may be thickenings of the bluish-white haze of the South Polar Hood (see above) and North Polar Hood (which is more diffuse), while those at lower latitudes, in the S4 domain and across the NNTB (see above), must be separate haze bands.

[*Footnote*: Often these haze streaks seem to have 'shadows', which commonly appear brown, as noted above for those in the SPH and the NNTB and the N6 bland zone. Accurate calibration and photometry of the images will be needed to validate this impression, and interpretation will depend on physical modelling, but I can offer some speculative interpretations of the 'brown shadows'. Where they are seen under full sun (as in the N6 bland zone), the 'shadow' may be a band of thinner haze adjacent to the thicker white band, perhaps cause by vertical waves in the upper atmosphere (as we sometimes see on Earth). The brown colour may be due to contrast with the surrounding haze which is actually bluish, and/or to viewing deeper brown clouds through the gap in the haze. However, this seems unlikely to account for some conspicuous examples of white bands with 'brown shadows' seen near the terminator: (i) because the N. Polar Hood haze does not extend down as far as the band across the

NNTB (see above); and (ii) because the large <-shaped haze band in the SPH is only weakly detected in the methane image (see inset in Figure 9). These may be true shadows lit by a reddish sunset glow, due to the thicker haze bands scattering light like a stratospheric volcanic aerosol on Earth.]

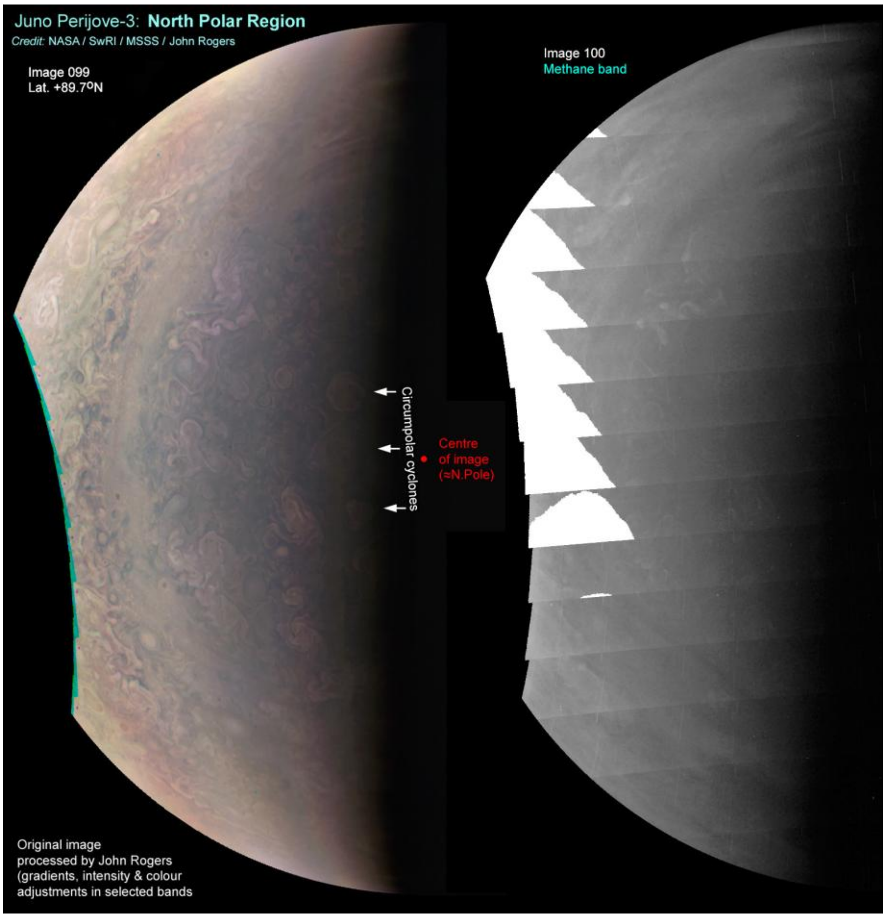
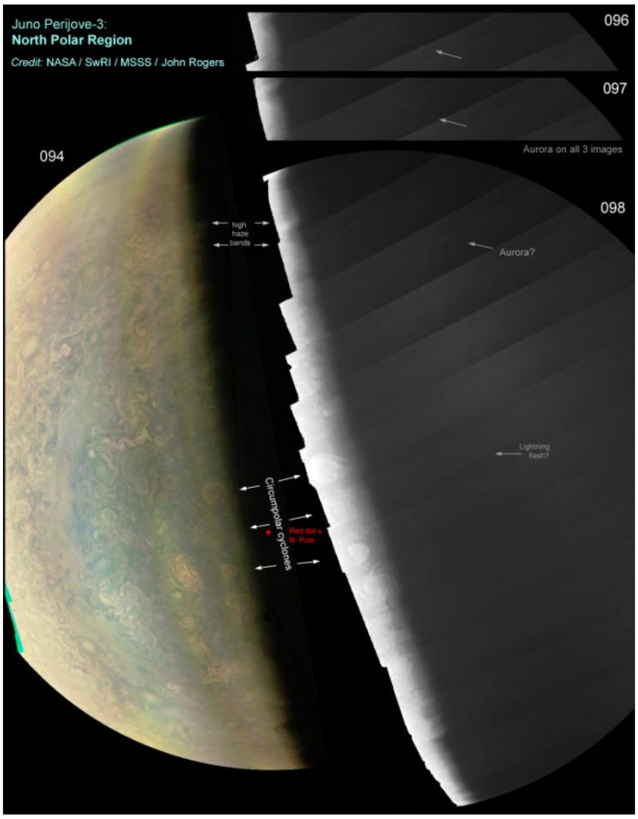


Figure 13; Figure 14.

Figure 14 (Images 094-098): JunoCam took a series of images of the north polar region, some with long exposures to search for lightning or aurora on the dark side. Here we see a possible lightning flash on one image, and a possible auroral streak on all 3 images. (However the JunoCam team warn that they still need to exclude cosmic ray hits and scattered light.)



Around the pole itself, we see a cluster of three circumpolar cyclones (CPCs), as at PJ-1. The pole itself is in darkness so we cannot see if the cluster has a central CPC as at the south pole.

Figure 15: Here are two images taken directly over the north pole, from PJ-1 and PJ-3.

[*Footnote*: Examples of the best polar-projection maps from amateur images are in our major on-line reports for recent years. Imagers like Chris Go and Damian can sometimes resolve FFRs up to ~60ºN/S, and can detect pale patches up to ~75ºN which are probably unresolved FFRs; their outlines change quite rapidly (within weeks). We posted sequences of hi-res north polar projection maps showing these changes in:

2010/11 Report no.9 (Fig.23); 2011/12 Final Report = no.9 (Fig.35); 2014/15 Final Report = no.12 (Fig.18).]

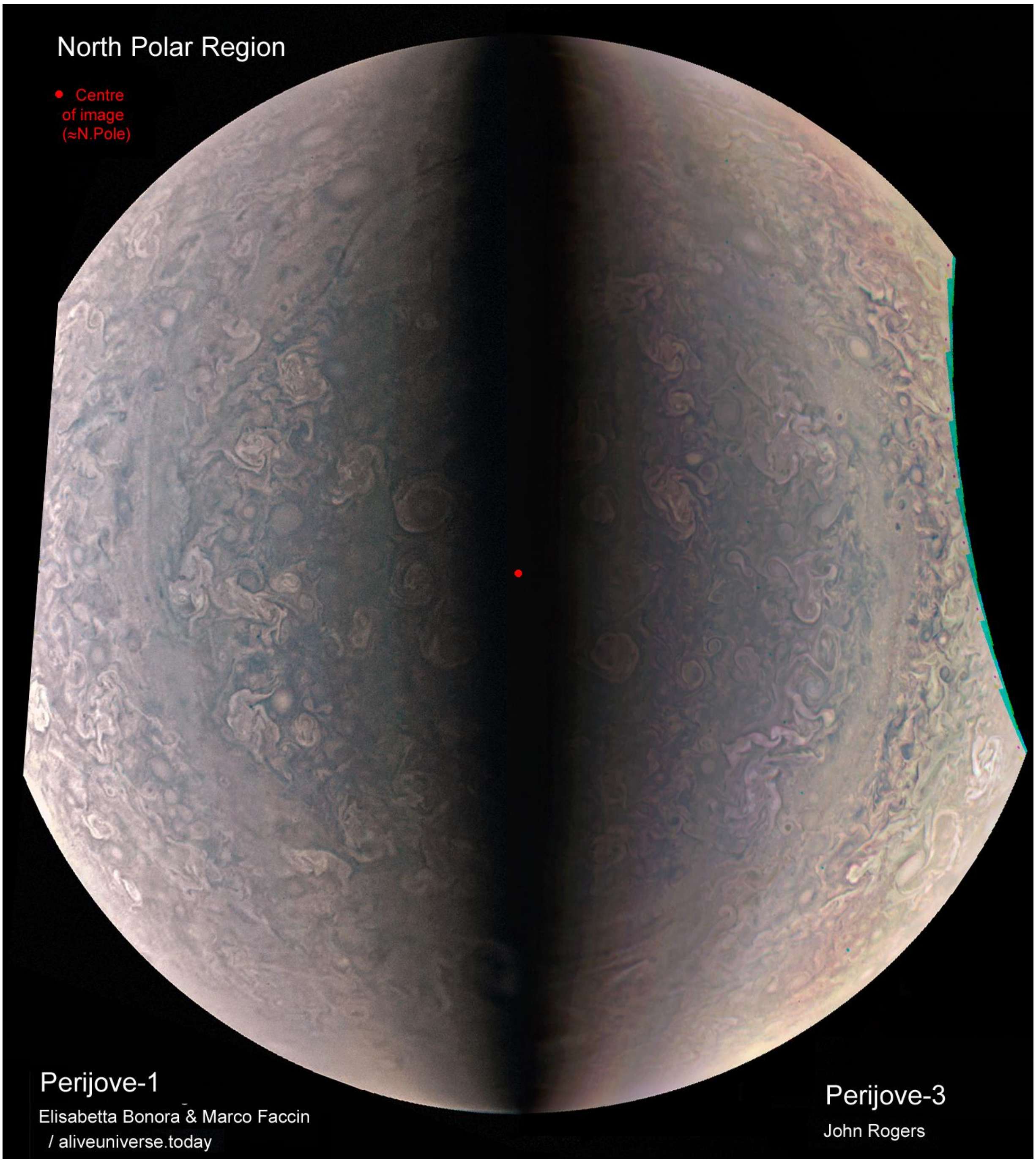

North Polar Region
Centre
of image
(≈N.Pole)
Perijove-1
Elisabetta Bonora & Marco Faccin
/ aliveuniverse.today
Perijove-3
John Rogers

Figure 15.