<u>JunoCam at Perijove-8: What the images show</u>

--John Rogers, 2017 Oct.16

Summary

At PJ8 (2017 Sep.1), JunoCam produced a complete swathe of hi-res images from pole to pole, displaying fantastical cloudscapes in all the high latitudes, and confirming now-familiar features of the polar regions and the small bright shadow-casting clouds. The long-lived FFR in the NNTB displayed beautiful cloud patterns. Newly formed ovals and barges were imaged in the northern NEB. The highlight was the STB Ghost, whose circulations can be detected in a preliminary animation. In the SSTB, hi-res images support our view that anticyclonic vortices develop from a large FFR and merge into the developing AWO-A5a, while outbound images suggest that two long-lived AWOs are likely to merge at any time.

As another bonus at PJ8, Io and Europa were imaged for the first time, and the shadow of Amalthea was fortuitously captured on the EZ (Supplementary Figure S1).

Introduction

Perijove-8, on 2017 Sep.1, was the last perijove within the 2016/17 apparition. So there were few ground-based images to provide context; however a few observers managed to obtain suitable images, notably Clyde Foster (Figure 1). We have also made a useful context map from the JunoCam inbound and outbound images as projected by Gerald Eichstädt (Figure 2).

Since orbital insertion more than a year ago, Juno's orbit has been evolving. Due to perturbations, the orbit is no longer strictly polar (inclination at PJ8 is 87.3º), and perijove has lowered and gradually shifted to the north (altitude is now 3431 km at 9ºN). (At PJ1, the values were 89.9º, 4147 km, 3.8ºN.) Due to Jupiter's orbit round the Sun, the spacecraft no longer flies over the terminator as it did at PJ1; the plane of Juno's orbit is more-or-less fixed, but as Jupiter has moved ~10% of the way round the Sun, the spacecraft now flies over the sunlit side at perijove. This has unfortunate consequences for the pointing instruments including JunoCam, which was originally not expected to be operating more than a year after orbital insertion. Around perijove the spacecraft is usually oriented so that its spin axis and solar panels and main antenna point approximately towards the Sun and Earth, and at the start of the mission, the pointing instruments would thus scan the planet along the sub-spacecraft track below. But the changing angle of Juno's spin axis relative to its orbital plane means that, from now onwards, the pointing instruments will progressively miss the planet: first to be lost will be the inbound images (already incomplete at PJ8), then the outbound images, then the closeup images, until only the polar regions will be imaged.

On the other hand, at PJ8 JunoCam was able to return more images than usual; not only was this a 'Gravity' orbit in which the antenna transmits most directly to Earth so that a high real-time data rate is possible, but also the data allocation for JunoCam was increased. Therefore the hi-res images comprised a continuous swathe from pole to pole, and this report will not show all the individual images. Instead, we have compiled Gerald's small cylindrical map projections into a map on which individual images can be located (Figure 6; see below). Gerald has also projected the images into an astonishing movie of the fly-over, shown here:

https://www.youtube.com/watch?v=sb8WvC0kDqI

and here is an equally wonderful movie of those images, by Seán Doran:

https://www.youtube.com/watch?v=2eijI0gueFY&t=3

North polar region

Figure 3 is a north polar projection map compiled from the inbound and over-the-north-pole images.

(The curved 'spokes' are where data are missing due to the aforementioned orbital evolution). Figure 4 compares the over-the-north-pole image (105) with the accompanying methane-band image (106), in the projections by the JunoCam team.

These images show the now-familiar features of the north polar region. These include the 'bland zone', and the long linear brown-and-white haze bands that are always seen to lie obliquely along it and to its south. As usual, the darker (brown) bands are also dark in the methane image. Two short sections of these (Figure 5) show rainbow-like colours (brown on one side, bluish on the other side), such as we noticed in a few haze bands at PJ4. This (PJ8) is the first time that some have shown up in two successive images, confirming their reality, as previous images were not taken close enough in time to catch the bands twice under similar lighting conditions.

These two 'rainbow bands' are close to two anticyclonic white ovals (AWOs) of the N5 domain, which are well shown in closeup images (Fig.5); another broad haze band runs directly across one of these AWOs.

We have noticed haze bands running across northern AWOs at previous perijove(s), and there is another example near the south pole at PJ8 [see below]. These examples suggest that the circulations of these AWOs do not extend to the altitude of the haze bands.

Like other N5-AWOs imaged by Juno, but unlike AWOs in other latitudes, these AWOs are not methane-bright (Fig.4).

Mid/high northern latitudes

All the images show glorious patterns of swirling chaos, all the way down to the NNTB. Two full-size images are labelled in Figures 7 and 8, with latitudes of the prograde jets marked approximately. Small anticyclonic ovals can be identified amid the chaos, including: several of them scattered through the middle of the N4 domain; a sharply bounded ring in the N3 domain; and a dark spot on the N2 jet.

A highlight of these two images is the long-lived cyclonic folded filamentary region (FFR) in the NNTB, which was deliberately targeted. Although it does not show any very bright outbreaks here, it does show an amazing kaleidoscopic mixture of swirling multicoloured streaks and vortices, haze bands cutting across them at different angles, and rows of tiny shadow-casting white clouds only ~15-30 km across.

These tiny shadow-casting white clouds, measuring just tens of km, seem to lie at the top of the main cloud deck, and have been seen scattered but widespread in closeup images since PJ5. At PJ8 we see them on many areas of white cloud, including: several AWOs; large FFRs in the N5 and N2 domains; the turbulent NNTZ and NTZ; the STropZ and STZ; and large FFRs in the S2 and S3 domains.

We have suggested that turbulence from the NNTB-FFR is responsible for the numerous dark spots on the N2 (NNTBs) jet which form some way to the east (downstream). In the global maps (Figs.2&3), a jumble of these spots can indeed be seen in this sector of the NNTBs, passing the AWO WS-6. They become more distinct as they travel east, and some may continue all the way round the domain. The well-defined N2 jet spot seen in closeups alongside the NNTB-FFR (Fig.8) is probably one of these.

North Tropical & Equatorial region

Juno passed over a very interesting sector of the NEB, where new barges and AWOs have been forming this year, and the images captured several of them as we hoped. Figure 9 shows a cylindrical map compiled from Gerald's map projections, and Figure 10 shows the JunoCam team's perspective projections. Both are at reduced resolution, but the original images did not show much detail at the smallest scale; most of the NEB clouds are genuinely diffuse.

By comparison with Figure 1 and our previous posts of ground-based data, we identify an AWO (WS-d) and a barge on each side of it. One of these barges formed in April; the other is newly forming at PJ8, as we had suggested would happen. WS-d has a rather loose and diffuse appearance compared to long-established AWOs in other domains, though not so loose and diffuse as WS-b imaged at PJ7.

A white rift stretches sinuously along the NEB south of these circulations, with an apparently new white spot eruption adjacent to it, which does show sharp-edged clouds.

On the NEBs edge is a NEBs dark formation (labelled 'NEDF'; i.e. an infrared 'hot spot') – probably the clearest example that Juno has yet flown over, although the images did not cover it well and it seems to be diffuse.

In the EZ south of the hot spot, there are large expanses of white clouds with mesoscale waves, but this image (116) is of low quality.

South Tropical region

The closeup images show a quiet stretch of the SEB, but nevertheless there are beautiful swirls and red eddies near its southern edge.

Ground-based images suggested that the large-scale convective activity in other sectors of the SEB might be declining in August, and the PJ8 lo-res images (Figure 2) did not show any of the usual 'rifts' following the GRS on Sep.1, but they were distant images with the region near the limb. An image by Clyde Foster on Sep.15, does show two rifts following the GRS, so the activity has not (yet) ceased.

In the hi-res-imaged sector, there are waves along the SEB south edge, and a dark S. Tropical Band which has prograded from the GRS in recent months.

South Temperate region: the STB Ghost

The highlight of PJ8 was the complete hi-res imaging of the STB Ghost, a long-lived cyclonic circulation. Two of the images are shown (at reduced resolution) in Figure 11, with key features and currents marked. Beautiful circulation patterns are seen in and around the STB Ghost. As exepcted, these patterns are very similar to those seen around the (smaller) STB Spectre at PJ5. The structure is also the same as that of the (much larger) STB Fade during the Voyager flybys in 1979 (Figure 12), particularly the two-tone braided border. Although that formed in a completely different way (by whitening of a long STB sector between AWOs, rather than by growth of a small cyclonic oval), all these structures had matured into closed cyclonic circulations with the same appearance.

For the Ghost, a sequence of 6 images (117-123) was obtained, which should enable its dynamics to be measured, when the maps have been perfected. A preliminary animation covering just images 118-121 over a span of 8.0 minutes is posted as Figure S2. It uses hi-res cylindrical maps from Gerald, with some empirical re-alignment. The circulation and the adjacent jets are perceptible, although comparable to the residual distortions of the map projections. (By comparison, the animation of the GRS at PJ7 detected ~50% faster winds over a ~50% longer timespan at ~50% higher resolution, and was still not quantitative.) The most striking motions appear to be south of the f.(W) half of the Ghost, where winds diverge rapidly along the oblique boundary between the prograde S2 (SSTBn) jet and the retrograde circulation which curves north around the f. end of the Ghost.

On the Sf. side of this boundary, the STZ is strikingly orange, with a well-formed grey anticyclonic vortex (Figure 6 & 11 & S2). This vortex appears to be the point of recirculation* from the prograde SSTBn jet to the slow or retrograde drift in the STZ, and the orange STZ is probably a recirculation loop, as was also seen for the STB Spectre at PJ5 -- although the speeds of recirculating spots are not fast enough to trace in these maps. The JUPOS charts showed evidence for recirculation here up to July. There are not enough later hi-res observations to track recirculation up to the time of PJ8, but the latest JUPOS chart shows that a dark spot or complex was fixed at the f. end of the Ghost during late August; it probably included the prominent vortex in the PJ8 images.

*For our accounts of the recirculation phenomenon, see:

1. Rogers JH (2015) 'Jupiter's South Temperate Domain, 2012-2015'. http://www.britastro.org/jupiter/2014_15report08.htm
2. Rogers J & Adamoli G (2016) 'Jupiter in 2015/16: Final report.' https://www.britastro.org/node/8263

Mid/high southern latitudes

S2 domain: The same sequence of images (e.g. Figures 6 & 11 & S2) shows the sector of SSTB f. the giant FFR f. AWO-A5. [The PJ8 global map (Fig.2) suggests that this may have now split up and separated from A5, although the lo-res and uneven nature of the map precludes a definite conclusion.] The f. end of the giant FFR is in view, and the beautiful patterns f. it support what we have inferred from ground-based observations: that small anticyclonic vortices arise from the turbulence of the FFR, and drift gradually westwards relative to it, eventually merging into the recently developed AWO-A5a [see our recent reports esp. 2016/17 Report no.8].

The global map (Fig.2) also shows that AWOs A1 and A2 are now only 9º apart, so they are likely to merge soon, possibly before PJ9.

S3 domain: The same series of images (Figures 6 & 11) shows the whole of the giant FFR in the S3 domain, and the images closer to the pole (Fig.2) show a jumble of small dark rings (vortices) f. this FFR, consistent with our hypothesis that many of these spots are generated from the FFR, as in the S2 domain.

S4 domain: Here too there is a very long FFR, and many small dark rings (all around the domain), and S4-AWO-3 (which has an orange annulus around a white core). This can be compared with S4-LRS-1 in the over-the-pole image (126), which is almost entirely orange, and is more methane-bright (Figure 13).

South polar region

Figure 13 compares the over-the-south-pole image (126) with the accompanying methane-band image (127), in the projections by the JunoCam team. These images show the now-familiar features of the south polar region, including:

--The methane-bright South Polar Hood (SPH), and the very methane-dark South Polar Band between the S5 and S6 jets. Blinking two south polar projection maps shows the motion of the S6 jet clearly [not shown].

--Large waves on the S5 & S6 jets coinciding with the edges of the SPH and South Polar Band.

--All AWOs are methane-bright, including S4-AWO-3 and (even more so) S4-LRS-1, and one at 72ºS.

--Bright strips in FFRs are methane-bright.

--Haze bands, including a very long bow-shaped dark one (possibly a clear lane in the SPH?) that spans almost the whole width of the SPH, with one branch running across the AWO at 72ºS.