Jupiter in 2021/22, Report no.10: Final report (Appendix 1)

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Introduction

Opposition was on 2021 Aug.19/20, at 13.5°S.
We have already posted interim reports covering large parts of the planet and the most interesting phenomena during this apparition (2021 reports nos.5-9). Here we fill in the gaps.

This work depends essentially on the images provided by observers around the world, to all of whom we are very grateful. A list of the observers is posted herewith (Report no.11) and also on the JUPOS web site. This report also depends on analysis from the JUPOS team (Gianluigi Adamoli, Rob Bullen, Michel Jacquesson & Hans-Jörg Mettig), who produced a comprehensive set of drift charts, some of which are annotated here. The report is based on amateur ground-based images apart from specific references to JunoCam or Hubble (HST) maps. Further details of the JunoCam images are in our reports on each perijove, on this web site under 'Results from Juno (2021)'.

North is up in all figures, and charts are oriented accordingly. Longitudes and drifts in the equatorial regions are given in System 1 (L1), as always. At other latitudes they are in System 3 (L3), for comparison with spacecraft data; however, drift rates are primarily given in System 2 (DL2 in degrees per 30 days), for comparison with all our previous records. DL3 = DL2 + 8.0 deg.30d.

Some of the best images near opposition in August were posted in Report no.5. Maps of the planet from amateur images have already been posted in some of our interim reports and some of our Juno perijove reports. Here, Figures 1-3 are global maps from Oct.16-17, Dec28—Jan.1, and Jan.9-10. Figure 4 is a map in the methane absorption band at 889 nm. Figure 5 is a map from Hubble (OPAL project) from Sep.4. **Appendix 2** (at the end of this file) gives background info on the major jets.

N3 to N6 domains:

See Report no.9 & ref.1.

N.N. Temperate (N2) domain

Fig.6 is a set of maps covering the main domains of the northern hemisphere. Also see Figure 5, the Hubble map, on which the main features of the N2 domain are more clearly resolved.

NNTZ anticyclonic ovals:

NN-LRS-1: This was strongly methane-bright, as always. In April-May it was a 'warm'-tinted oval with only a weak rim. In June it developed a very dark grey rim, with a distinct orange inner oval, which lasted for months (Figure 7). It suddenly lost its dark rim over Oct.23-27 (Figure 8); this might have been related to an upsurge of activity in the FFR just p. it? Thereafter it was visually very elusive, though the best RGB images showed it as a small pale orange spot. (Only the central oval was orange, as in the PJ39 images) See Report no.9 Figs.13&18.

NN-LRS-1 was partially imaged at close range by JunoCam at PJ38 (2021 Nov.29) and PJ39 (2022 Jan.12): see our PJ39 report. The central part was strongly reddish and bright in methane. Otherwise JunoCam did not get any closeups of major circulations in the N2 domain in 2021.

NN-WS-4 was inconspicuous but could still be tracked. In April-May it was a quite large but dull greyish-white oval; after May it was almost invisible, except in hi-res images which showed it as a small white spot (Fig.6), and it was moderately methane-bright – as confirmed in the Hubble maps on Sep.4 (Fig. 5).

NN-WS-6, throughout the apparition, was a very conspicuous bright white oval, and moderately methane-bright. It had an increasingly dark grey rim. It was shown in Report no.9 Fig.8.

Two small AWOs approached NN-WS-6 from its f. side, close to the N3 jet. First was a very small one seen in Report no.9 Fig.8; it was last seen moving around the N edge of WS-6 on Oct.13-15, and then either merged with it or was torn apart. The second was N3-w1:

N3-w1 was an AWO in the N3 domain which shifted north into the NNTZ in 2021 Sep. after passing NN-LRS-1; see Report no.9. It remained in the NNTZ, ~17° f. WS-6, in Dec-Jan. (It would go on to merge with WS-6, like the one just mentioned, in 2022 May.)

Drifts of the NNTZ ovals are described below.

NNTB sectors:

(i) P. WS-4 (L2 ≈ 340-10 and 10-30; L3(O) ≈ 150-190 and 200-220)*: A very dark distinct segment ~35° long from April to August, lengthening as it extended f. WS-4. In Sep. the short segment f. WS-4 turned light ochre; this persisted thru Dec. The original part p. WS-4 also turned light ochre in Oct. and remained so up to the New Year.

*[NNTB segments are slow-moving in L2; in L3 they are retrograding so L3 is given at opposition, Aug.20, i.e. L3(O).]

(ii) F. WS-4 (L2 ≈ 10-100; L3(O) ≈ 190-290): Mostly almost white up to July. In August the FFR p. WS-6 expanded and this sector became disturbed and darker. It was a dark NNTB segment in Sep.-Nov., but then faded from the p. side, until it was all pale ochre in mid-Dec. apart from one tiny dark spot.

(iii) FFR p. WS-6 (L2 ≈ 100-140, L3(O) ≈ 290-320): This FFR was visible from April onwards, growing longer up to August, shorter again in Nov. It may have contributed to the NNTBs jet spot outbreak (see below).

(iv) From WS-6 to LRS-1 (L2 ≈ 150-240, L3(O) ≈ 330-40): This sector turned dark in August, except for a FFR of variable darkness immediately p. LRS-1. This FFR is probably the same one that developed in 2020 Aug. and was the ultimate source of NNTBs jet spots in 2020 (see our 2020 final report) and 2021 (see below).

Drift rates:

Figure 9 is the JUPOS chart of L3 vs time for the N2 domain (plus the AWO translocating from the N3 domain). Figure 10 is a zonal drift profile (ZDP) from the JUPOS data.

LRS-1 showed a gradual irregular deceleration from DL2 ≈ -12 deg/30d (April) to 0 (Dec.)

WS-6 was oscillating with a period of ~3½ months, observed over nearly 3 cycles, with DL2 ranging between ~-14 and +5 (DL3 ~-6 and +13).

WS-4 had an irregular drift with mean DL2 ≈ -4 (DL3 ≈ +4) from April to Sep., and then steady DL2 = -10 (DL3 = -2) from Oct. to Jan.

The zonal drift profile (ZDP) (Figure 10) shows that these ovals all followed gradients roughly parallel to the reference zonal wind profile (ZWP) derived from Cassini imagery, but with small offsets such that LRS-1 < WS-6 < others in latitude, as we have reported previously [ref. 2].

While NNTZ AWOs had drift rates ranging from positive to negative DL3, NNTB dark segments had positive DL3 and near-zero L2, as usual. Several dark spots at 39-41°N were retrograding: mean DL2 = +12.7 deg/30d (DL3 = +20.7 deg/30d) (±5.4; n = 6).

NNTBs (N2) jet:

There were many dark spots on this jet throughout the apparition, but more and larger from July onwards. They mostly appeared on JUPOS charts around L2 ≈ 180 (L3 ≈ 0), i.e. downstream of the FFR p. LRS-1; but on maps and charts they were much more prominent p. L2 ≈ 70 (L3 ≈ 280), i.e. downstream of the FFR p. WS-6. They had DL2 ≈ -72 to -92 deg/30d (DL3 ≈ -64 to -84 deg/30d).

N. Temperate (N1) domain

Following the great NTB Revival in 2020. the NTB had two contrasting components: the grey NTB(N) (up to 31°N), and the narrow reddish featureless NTB(S) (at ~25°N), both of which were fading (Fig.6). Initially, the NTB(N) was very dark grey for >200° f. the NTZ AWO, and moderately dark elsewhere,, but all this faded during the year until in Dec. it was almost all greyish white north of 27°N. So in Dec., the NTB consisted of just a narrow dark grey component at 26°N with a faint reddish southern fringe.

As in late 2020, the domain was divided by an oblique boundary in the NTB(N) with a very small but bright AWO just N of it (with DL2 ≈ +22, DL3 ≈ +30 deg/30d). F. it was the very dark grey NTB(N), with prominent waves on its N edge moving more slowly (DL3 = +32, DL3 = +40 ±2). This faded away in July-August. P. it there were just a few short well-defined dark grey streaks (mini-barges) at 30°N, moving faster; from June to Sep. there were four of these, but in Oct. two small ones merged into the longer one f. them. This left just one short dark streak (with DL2 = +5.7, DL3 = +13.7), slightly oscillating with a period of 2 months.

The AWO disappeared in Sep. The Hubble maps on Sep.4 (Fig.5) confirm that there was no longer any rifted region adjacent to it. JunoCam at PJ36 (Sep.2) imaged a pale orange cyclonic oblong within the fading NTB(N), and a smaller, darker mini-barge at PJ38 (Nov.29).

N. Tropical domain

The most notable development of the apparition was the fading and quiescence of the NEB. It had undergone a typical expansion event in 2020, and by 2021 April it was still fully broadened, although the northern extension was beginning to fade. It contained a series of AWOs and barges, a classic appearance at this stage after the expansion event. By mid-June, the northern extension of the NEB had faded almost completely, and the mid-latitudes of the NEB had also begun to fade rapidly [see Report no.2]. From August onwards, most of the belt was exceptionally faint, leaving only a narrow, very dark brown NEB(S), and the barges which were also very dark brown.

The belt was also completely calm, with none of the normal convective or turbulent 'rifts', and from August onwards all the usual NEBs dark formations had disappeared. Instead, the NEBs carried elusive small features moving with 'super-fast' speed. The appearance was very similar to 2011-12, which preceded the NEB Revival in 2012 [see Report no.2, & ref.3].

Early in the apparition, a few tiny white spots appeared, but did not last long nor expand across the belt. Two of these were associated with a barge-like feature just Sf. WSZ (on April 19 and May 12: see PJ33 report). On two occasions in May, similar bright spots appeared in the NEB(S); these were the precursors of more extensive disturbance later in the year, as were described in Reports nos.6 & 7.

Barges and ovals in northern NEB:

In April there were 9 barges and 9 AWOs of various sizes (tracked in the JUPOS chart in Fig.11); by late Sep., after some mergers of barges and fading of AWOs, there were 8 barges and 6 AWOs. The barges remained very dark brown, although some became small. The AWOs (which we here designate White Spots A to G, in addition to WS-Z) became difficult to see, with irregular pale grey shadings having low contrast with their surroundings. WS-Z became largely grey after July, as did WS-B after Sep., and the other AWOs after Oct. However, amateur and JunoCam images in 2022 would show that six of them did persist into the next apparition. Moreover, most of them were methane-bright, to varying degrees, throughout the 2021 apparition, esp. WS-B, E & Z (see Figure 7, & figures in Reports nos.5 & 7). WS-B, E & Z were among the larger AWOs, but notably they remained methane-bright in Oct-Dec. even after they were no longer visibly white.

Some of these ovals appeared white only in a small southerly spot at 20°N; our JunoCam reports in previous years (as well as PJ37, see below) have shown evidence that this is due to clusters of bright white clouds which form over the northern part of the large anticyclonic oval, which remains centred near 19°N although much of it is no longer bright.

WS-B often showed unusually distinct anticyclonic spiral streaks, as well as a white streak extending Sp. from it into the NEB (Figure 7; see caption for discussion). The reason for this disturbance is unknown. WS-B was viewed close up by JunoCam at PJ37 (Oct.16); our PJ37 report showed and described the JunoCam and amateur images at that time, including a small dark spot orbiting anticyclonically around its periphery.

The drift rates of these barges and ovals can be obtained from the JUPOS chart (Figure 11). From March to June, there was a wide range of speeds, including rapidly prograding ones for some barges [DL2 ranging up to -22.6 deg/30d; mean DL2 = -13.8 (±6.0) deg/30d at latitude 15.0 (±0.2)°N, for 6 barges], whereas two smaller barges were retrograding [DL2 = +4 to +19 deg/30d at 15.8 (±0.2)°N]. From Oct. to Jan., the remaining 8 barges had more stable tracks, although faster than in most recent years [mean DL2 = -7.3 (±3.4) deg/30d at 15.4 (±0.4)°N], and the AWOs all had roughly the same speed.

These diverse speeds are all consistent with the usual ZDP (Figure 12). The diverse speeds early on have also been recorded after previous NEB expansion events (including the Revival in 2012; ref.4); as new barges and ovals form, they have different latitudes and speeds, but with some mergers and some adjustments they form a more stable array. The rapid speeds late in the apparition are faster than in most recent years, but essentially the same as in 2011/12 during the previous NEB Fade; in both apparitions, this is because the barges lie slightly further south than usual. Presumably this is an aspect of the fading process. Specifically, from our recent reports:

Apparition	*No.of barges*	*Mean DL2 (±SD)*	*Mean lat.(±SD)*
2011/12	6	-6.6 (3.1)	15.3 (0.3)
2015/16	5	+0.5 (3.0)	16.0 (0.45)
2018	2	+0.3 (~1)	
2020	8	+2.4 (6.5)	15.9 (0.32)
2021 (late)	8	-7.3 (3.4)	15.4 (0.36)

This apparition's speeds are also quite typical within the historical record: the mean speed for the N. Tropical Current from 1887 to 1991 was DL2 = = -9 (±7) deg/30d [ref.5], with particularly fast speeds in the 1970s.

The NEB(S) and EZ:

See Reports nos.6 & 7, & ref.6.

Major jets

Our interim reports have not included systematic measurements of jet speeds, so we have measured spot tracks on the JUPOS charts to give the mean speeds in **Table 1** (all in deg/30d). Histograms of the data are in Figure 13, and background information about these jets is in **Appendix 2**.

NEBs (Nov-Dec.): At this time the 'super-fast' speed had entirely taken over the NEBs and was no longer accelerating. Nevertheless, the 8 definite tracks fall into two groups:
(i) Mean DL1 = -47.9 deg/30d (±4.8; N=6)(range -40 to -54); (ii) Two tracks with DL1 = -72 and -79.
Discussion (see Appendix 2): The super-fast range spans DL1 ≈ -45 to -95. Of our tracks in 2021, two fall centrally in this range, while the others are near the lower end of it.

SEBn (July-Dec.): The entire chart is filled with fast tracks or hints of them, but almost all are short (< 2 weeks), especially the faster ones (mostly <1 week), as the 'chevron' features were ephemeral. There was a wide range of speeds, interspersed without obvious pattern. The histogram (Fig.13) shows that they fall into two groups, with mean DL1 = -82.2 (±6.1) and -42.3 (±11.3).
Discussion (see Appendix 2): The speeds are reminiscent of 2010 in falling into two spatially interspersed groups, but they are slower than previously observed, given that there is no S. Equatorial Disturbance now.

SEBs (June-Oct.): There was a very large number of spots retrograding in this jet, many of them being distinct rings (see maps in Fig.1 of our Report no.5). The chart by Shinji Mizumoto (see our Report no.8) shows 35 of them from mid-March to mid-Oct. They were long-lived, most surviving to reach the Red Spot Hollow. We measured well-established tracks, including a few spots that merged, but omitting decelerations of a few spots as they approached the GRS. They had a continuous range from DL2 = +113 to +130, strongly peaked at +124, plus three outliers with DL2 = +106, +108, +138. The mean DL2 was +122.6 (±6.6).

Discussion (see Appendix 2): This speed range is very close to the usual range, which spans DL2 ~+108 to +133. We believe that +133 is the peak speed of the jet.

The last of these spots arose in mid-August and approached the GRS in mid-Oct. Thereafter, only three more were recorded, arising up to late Oct., and had lesser retrograding speeds: DL2 = +112, +104, +92.

STBn: We measured spots in four groups:
Lat.<26°S (an unusual activity so far north; imprecise measurements), mean DL2 = -89.3.
Lat.>26°S: (i) P. spot 8 (emitted from this new outbreak – omitting early accelerations from slower speeds), Sep-Oct: mean DL2 = -94.0. (ii) P. WS6 in Aug-Sep: mean DL2 = -84.3.
(iii) P. DS7 in Oct-Jan. (a major outbreak of STBn jet spots, with quite long straight tracks): mean DL2 = -79.2.

Discussion (see Appendix 2): This complex jet is double and variable. In 2021, the fast speeds for the low-latitude spots and those from spot 8 are unusual, but are typical of the northern sub-peak. The somewhat slower speeds p. WS6 (which is p. BA) and p. DS7 (now another turbulent STB segment) are typical of the early stages of such outbreaks.

Table 1

Major jets: Drift rates from JUPOS charts (JHR)													
(All in deg/30d)													
	NEBs		**SEBn**				**STBn**						
	DL1			**DL1**	**DL1**			**DL2**	**DL3**			**DL2**	**DL3**
	Nov-Dec		Jul-Dec	(all)	(sorted)		***All:***			***Lat.26-30S:***			
Mean	-54.8		Mean	-55.6	-82.2		Mean	-84.9	-76.9	(i) P.DS8	Mean	-94.0	-86.0
SD	13.5		SD	21.4	6.1		SD	8.8	8.8	Sep-Oct	SD	3.9	3.9
N	8		N	39	13		N	32	32		N	6	6
					-42.3								
					11.3					(ii) P.WS6	Mean	-84.3	-76.3
SEBs					26					Aug-Sep	SD	3.9	3.9
June-Sep	**DL2**	**DL3**									N	8	8
							Lat.<26S:						
Mean	122.6	130.6					Mean	-85.8	-77.8	(iii) P.DS7	Mean	-79.2	-71.2
SD	6.6	6.6					SD	13.4	13.4	Oct-Jan	SD	4.1	4.1
N	28	28					N	8	8		N	10	10

In addition, the STBn spots were fully analysed from the JUPOS database by G.A., including more, shorter track segments, and assigning latitudes. The ZDP is included in Fig.15. At <26°S, these more precise measurements included the shorter, slower parts of tracks which were even further north, and followed a ZDP parallel to the Cassini ZWP, but ~0.8° north of it. At >26°S, the speeds had similar ranges to those given in **Table 1**; the ZDP chart shows large, random scatter from 26.0 to 28.3°S (and no significant differences between longitude sectors were found). The scatter is probably due mainly to the tendency of these spots to drift northward without change of speed, and also to their tendency to veer southwards while passing the GRS.

South Tropical domain (SEB, GRS, & STropZ):

See Report no.8.

South Temperate domain

See Report no.5

While Report no.5 gave full description and illustration of the phenomena of this domain, it contained only a limited analysis of the speeds and latitudes of spots. Here we supply this analysis of the JUPOS data for the whole apparition, and also describe the evolution of features in the closing months. The STBn jet was dealt with above.

In Report no.5 we presented a series of maps up to late Nov., and a set of v-hi-res images in Oct. We specially investigated the dynamics in the crowded space between DS7 and oval BA, which included the cyclonic white oval WS6, and the anticyclonic dark ring d1. Up to Sep. there were many small dark spots retrograding Sf. DS7, which terminated at spot d1. These retrograding spots ceased after Sep.; instead, DS7 began to emit copious spots on the STBn jet, running up to and then past the GRS. Maps since Sep. are in Figures 1-3.

A summary of the drifts of the major features was Table 1 in Report no.5. The results of the JUPOS analysis are summarised in Fig.14 (chart) and Fig.15 (ZDP). In most respects the ZDP is typical; most points are close to the reference ZWP. Oval BA lies on the reference ZWP like other, smaller AWOs.

The most notable results are for the 'South-following tails' Sf. all three potential structured sectors. They all contain strongly retrograding dark spots, with speeds rarely observed in ground-based data, mostly at 31.7—32.6°S, i.e. at the peak of the retrograde STBs jet in the reference ZWP.

--*The spots f. STB segment A* [dark blue squares in Fig.15] are widely scattered in speed (DL2 = +4 to +63) but very constrained in latitude (32.1—32.5°S) (except for one short imprecise track). They include exceptionally fast retrograde speeds but show no gradient at all! The slower spots were in May-Aug.; the faster ones were in Sep-Oct., possibly a short-lived burst.

> *Discussion*: It might be relevant that these tracks were all along the S edge of the former STB Spectre; very high wind speeds were measured from Hubble images around a similar circulation, the STB Ghost [refs 9 & 10]. The former Spectre now encompasses most longitudes and is no longer a closed circulation, but could it still distort the ZWP? This might also explain the anomalously fast and northerly spots in the STBn jet. Sectoral ZWPs from the Hubble OPAL data might elucidate this issue.

--*The spots f. DS7 (STB segment G)* [magenta diamonds] are nicely clustered near the peak of the reference ZWP. (Mean DL2 = +27.3 (±5.0) at 31.9 (±0.4)°S; fastest = +34 at 31.7°S.)

> *Discussion*: These values are similar to the peak of the Cassini ZWP, and to the spots that appeared in the Sf. tail of STB segment A after it merged with other STB structured segments that had collided with it: in 2005-2007 after the collision in 2003-04, and in 2014-2016 after the collision in 2013 [ref.7-9]. Otherwise, such speeds have been rarely observed in ground-based data. So it is now clear that such speeds are typical in the Sf. tail of segment A for a few years after it is reinvigorated, and we now find similar speeds in the Sf. tail of the newly developing STB segment G.

--*The spots f. Spot 8*: Only two could be measured [d17, d25], which had DL2 = +17 and +18, but widely different latitudes, so there is no evident pattern here.

Spot 8 showed only weak continuing activity, and in Dec. it changed from a small irregular spot into a distinct, very dark little oval (Figs.1-3 & Fig.16C). JunoCam closeups confirmed that it was still a turbulent little feature at PJ38 (Nov.29) but a quiescent, dark brown cyclonic oval at PJ39 (2022 Jan.12) (see our reports). In future this may be called DS8.

The initial convective outbreak of spot 8 in 2021 August was essentially identical to that of Clyde's spot in 2020 (which generated DS7); both have been analysed thoroughly in a paper from Ricardo Hueso's group, in collaboration with the amateur community [ref.11]. But by early 2022, the evolution of the two features has diverged: DS7 is still very active and expanding as STB segment G, while spot 8 has subsided to become a a small dark oval.

The region between BA and DS7 was less disturbed after Sep, as no more retrograding spots were seen (Fig.14); this sector appeared calm and lightly shaded, with a narrow dark band through it

(Figs.1-3 & 16). Spot d1 moved S to 34°S and prograded on the SSTBn (Fig.14). So in 2021 Dec. and 2022 Jan., the structures here were fairly stable: in order, oval BA (off-white with a slight 'warm' tint); WS6 (white oval, now stably centred 16° p. BA); d1, a small dark spot on SSTBn; DS7, now a disturbed region of ill-defined extent, passing the GRS; and then a long oblique band packed with turbulence and dark spots, embodying the disturbance streaming from DS7 into the STBn jet. South of this band is a small white spot that could be related to the former F-Spectre. (Figs.1-3 & 16)

S.S. Temperate (S2) domain

Maps from April to Nov. were presented in Fig.1 of our Report no.5. Maps in Dec.-Jan. are in Figs.2 & 3; images of the chain A1-A5 in Dec. are in Fig.16. Fig.17 is a collection of all the JunoCam maps from 2021. Fig.18 is the JUPOS chart of the domain.

Anticyclonic ovals:

There are still seven stable AWOs in this domain. At the start of the apparition, AWOs A1 to A5 had closed up together to form a single chain, mostly separated by FFRs. The other two (A7 & A8) were widely separated. Their drifts ranged from DL2 = -27 to -32 deg/30d, with A3 (the steadiest) having DL2 = -28.7.

A much smaller AWO, referred to here as A0, was tracked 20-30° p. A1 from August onwards. It is also shown in the JunoCam map at PJ36 (Sep.2) and the Hubble OPAL maps (Sep.4) (Fig.5). It seems likely that A0 was created or sustained by mergers of smaller anticyclonic vortices emerging from a large FFR just p. it, just as we reported for a small AWO known as A5a from 2015-2019 [see our 2016/17 Report no.8]. Blinking of the OPAL maps (posted with 2021 Report no.5 as Animation-2) reveals a row of three such vortices leading from the cyclonic FFR to the AWO A0; also, at PJ38 (2021 Nov.29), we noted a chain of four anticyclonic vortices likewise (Fig.17). But by PJ39 (2022 Jan.12), the FFR had moved closer to A1 and the chain of vortices had diminished, while A0 had disappeared; the JUPOS chart suggests it merged with A1.

Cyclonic features:

FFRs were all documented in the JunoCam maps (Fig.17) and most of them also in the amateur maps. An isolated FFR was present ~40-60° p. A1 at least from April to Oct. (and later still in JunoCam maps), although it may have been weaker in June. There was also a large FFR p. A7 and another p. A8, although their level of disturbance may also have varied. AWOs A1,A2,A3,A4 were initially all separated by small FFRs (PJ32 & PJ33, Feb. & April), but the one between A1-A2 became less turbulent at PJ34 (June), leaving only the other two.

A white oblong developed between A4 and A5 at the start of the apparition. This was a small FFR at PJ29, then a dull grey-brown oval in JunoCam images at PJ31 & PJ32 (2021 Feb.21) during solar conjunction, and slightly lighter at PJ33 (April 15). Amateur images from March 14 to April 9 showed it very light, slightly reddish, and by May it was fully white. It remained bright white thereafter, but did not expand: it was 9° long in June-July, and only 7-8° long in Nov.-Dec.

A very small, very dark spot was first seen just Nf. A7 in June, drifting f. from it. In August it turned brown and faded, then was lost as it encountered a FFR p. A8.

Slow-moving dark spots and streaks were present 20-50° f. A8 from July onwards, some with DL2 = -20.1 (±1.9), others with DL2 = -13.3 (±1.4).

S3 & S4 domains

Figure 19 shows the JUPOS charts for these domains. In each domain there are two well-tracked AWOs, with very variable speeds from DL2 ≈ +4 to -40 deg/30d or even faster. (One of these is S4-LRS-1, which maintained DL2 = -40 from Sep. until late Nov., when it suddenly halted.)
Each domain also shows many retrograding tracks for small dark spots. In S3, these are mostly from DL2 ≈ +10 to +20, though up to +42. In S4, they are more consistent, with mean DL2 = +9.4 (±1.6;

N=7). These retrograding speeds probably represent small dark spots just S of the FFRs, as they differ from the usual zonal slow current in S3 (DL3 ≈ 0) and the prograding speed of FFRs in S4 as suggested by JunoCam maps in 2021 (not shown).

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Figures

Figure 1. Global map from 2021 Oct.16-17 (previously posted in our PJ37 report).
Figure 2. Global map from Dec28—Jan.1.
Figure 3. Global map from 2022 Jan.9-10 (previously posted in our PJ39 report).

Figure 4. Global map in the methane absorption band at 889 nm, by Andy Casely.

Figure 5. Global map from Hubble OPAL RGB images, 2021 Sep.4.
[Two maps were made ~10 hours apart. Part of the map from the NNTB northwards was Fig.6 of Report no.9, and a blink of part of the southern hemisphere was Animation-2 in Report no.5.]
The Hubble Space Telescope (HST) takes comprehensive sets of images once a year in the OPAL project [NASA / ESA / STScI / A. Simon, G. Orton & M. Wong]. "This work used data acquired from the NASA/ESA HST Space Telescope, associated with OPAL program (PI: Simon, GO13937), and archived by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. All maps are available at http://dx.doi.org/10.17909/T9G593."
The maps are also posted here: https://archive.stsci.edu/prepds/opal/.

Figure 6. Set of maps covering the main domains of the northern hemisphere.

Figure 7. Sets of RGB & CH4 images showing NN-LRS-1 and NEBn WS-B. (A) In May & June (top row) & August (remainder). (B) In late August & Sep. NNLRS1 is a prominent red oval with very dark rim. This also shows N3-w1 passing NN-LRS-1 (A) and subsequently moving S (B) [see Report no.9], and a very methane-bright patch on the EZ (B) [see Report no.7]. In NEBn WS-B, the white streaky spiral pattern changes from night to night, but not in an obviously circulatory way; the appearance could be due to bands of bright clouds, esp. in the northern part of the oval, which form and circulate and dissipate quite rapidly. See our PJ37 report for further images of WS-B in Oct. and JunoCam's closeups, which are consistent with this view, although taken after the oval had lost much of its brightness.

Figure 8. NN-LRS-1 in late Oct., with its dark rim rapidly breaking up; the fragmenting dark rim moves clockwise (anticyclonically). This also shows N3-w1 after translocation into the NNTZ.

Figure 9. JUPOS chart of L3 vs time for the N2 domain, plus N3-w1 as it translocated from the N3 domain.

Figure 10. Zonal drift profile (ZDP) from JUPOS data for the N2 domain.

Figure 11. JUPOS chart for the N. Tropical domain.

Figure 12. ZDP from JUPOS data for the N. Tropical domain. (Values for AWOs are imprecise because their outlines were ill-defined.)

Figure 13. Histograms of speed measurements for spots in the major jets, from the 2021 JUPOS charts.

Figure 14. JUPOS chart for the S. Temperate domain.

Figure 15. ZDP from JUPOS data for the S. Temperate domain including the STBn jet.

Figure 16. Images showing important features in the S. Temperate domain:
(A) Oct., including the region from oval BA to DS7. (B) Dec-Jan., ditto. (C) Late Dec., showing STB spot 8 after it turned into a dark oval.

Figure 17. The JunoCam maps of the S2 domain in 2021, aligned on AWO-A3 in the centre of the chain of five.

Figure 18. JUPOS chart of the S2 domain, from 2020 to 2022.

Figure 19. JUPOS charts of the southern halves of the S3 & S4 domains in 2021.

Appendix 2: Summary of previous data on the rapid jets

NEBs (super-fast current):

[Ref: Rogers (2019) JBAA 129, 94-102 (NEB Paper II), Table 1: https://britastro.org/node/15628]

As well as the familiar NEDFs with small DL1, smaller NEBs features sometimes drift with a fast current (commonly) or a super-fast current (where NEDFs are absent). The super-fast range, observed for some months in 2008 and 2010 along with some slower speeds, and more completely and durably in 2011, spans DL1 ~ -45 to -95 deg/30d (u_3 ~ 127-151 m/s) [mean DL1 around -70, u_3 ~140 m/s].

SEBn:

[Ref: Rogers & Mettig, 2008, JBAA 118, 326; Simon-Miller et al., 2012, Icarus 218, 817; both are our SED papers. *Also*: Adamoli G & Rogers J (2012), Report 2010 no.26: 'The SEBn in 2010: The dual motion of the chevrons in the rapid jetstream', https://britastro.org/jupiter/2010report26.htm]

[from R&M 2008:] When the SED is present and active, as it was during the Voyager and Cassini flybys, the observed jet speed is slow p. it (~116-128 m/s, DL1 ~-22 to -47 deg/30d) but rapid f. it (~142-162 m/s, DL1 ~ -77 to -119). When the SED is absent or weak, it no longer modulates the observed speeds: a rapid jet speed of ~155 m/s (-104) is observed at all longitudes, but some individual features move more slowly over shorter intervals.

[from S-M et al. 2012:] In 2008 (conspicuous SED), our data showed mean speeds increasing from 120 m/s (-30.5) p. SED to 140 m/s (-72) f. SED. In 2010 (no SED), our data showed mean speeds of 156 m/s (-107 ±8) for fast spots, 140 m/s (-71 ±10; range ~-55 to -80) for slow spots. Hubble data found ~140-160 m/s (-72 to -114) throughout. Cassini data from 2000 showed the chevrons had a true mean speed of 147 m/s (-87), while oscillating in latitude.

SEBs (retrograde):

[Refs: Rogers et al., 2016, Icarus 277, 354 (SEBs waves); Rogers, 2017, JBAA 127, 264 (SEB Rev.)]

This jet usually carries anticyclonic vortices (often distinct rings) on the S edge of the jet peak, retrograding with DL2 ranging from ~+108 to ~+133. We believe that +133 is the peak speed of the jet, although most spacecraft ZWPs give a lower value which may be dominated by the vortices themselves, and the ZDP is systematically broader than the ZWP.

STBn (double, variable jet).

[Refs. 8&9 above: Rogers & Adamoli, 2015, 2019 (S.Temp. domain, 2001-2012 & 2012-2015).]

This jet is double and variable. In ZWPs it has two sub-peaks, at ~26.5°S and 29°S. The northern peak is present all around the planet, with mean DL2 ~ -94 to -114 in recent decades. The southern (29°S) peak is mainly present alongside STB structured sectors, where it has DL2 ~-111 or sometimes faster.

Dark spots on the STBn are mainly produced in either of two circumstances: (i) Np. a dark turbulent segment of STB, esp. the segment f. oval BA when it has been reinvigorated by events f. it; (ii) during an incipient STB Fade (as in 2010). Images from Hubble and Juno confirm that these spots have little if any vorticity. They tend to drift northwards during their lives, between the latitudes of the two sub-peaks, usually without change of speed as the southern sub-peak disappears as the spots prograde from their origin.

An outbreak is initiated by a collision of STB segments f. oval BA. Initially the jet spots drift comparatively slowly (mean DL2 ~ -75 to -83 deg/30d), but later they drift faster (~-90 to -100 deg/30d). The spots p. a different STB segment in 2010 also had comparatively slow drift (mean DL2 ~ -76 deg/30d at 28.0°S). In 2020 July-August, p. Clyde's Spot/DS7 (another incipient STB segment), just 3 spots were tracked, with mean DL2 = -83.4 ±2.3, at lat.27.2 ±0.4 [JUPOS analysis by G.A., unpublished].