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Jupiter's South Temperate Domain, 2018-2024

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Summary

This report, like its predecessors, is based largely on our analysis of amateur ground-based images, but this is now complemented by high-resolution images from NASA's Juno orbiter.

From 1998-2018 the South Temperate domain had shown a consistent cyclic pattern of behaviour. It was whitened around most longitudes, with just one large anticyclonic oval, called BA, and a dark sector of STB following it (STB Segment A). Other structured, cyclonic sectors of STB arose periodically shortly preceding BA, then expanded and prograded until they collided with Segment A and underwent vigorous transformation and merger with it.

Origins of structured sectors, and shift to a new regime: In 2019 there was just one structured sector apart from Segment A: the 'STB Spectre' (Segment F). Unlike previous examples, it grew extremely long, so its following end was no longer approaching BA; and subsequent events changed the typical sequence. When the preceding (p.) end of the Spectre arrived at Segment A, in early 2020, it did not transform internally. Instead, Segment A itself grew more active and longer, and initiated the usual streams of dark spots eastward and westward. (The Spectre itself became unrecognisable.)

Meanwhile, we were expecting one or more new cyclonic spot(s) to arise some way p. BA to initiate the next structured sector. This eventually happened in 2020, when two small pale cyclones developed into two dark spots which we named spots 6 and 7. Spot 7 began as 'Clyde's Spot', when a sudden convective outburst transformed the cyclone into a turbulent feature which darkened and expanded from that time onwards to become the new STB Segment G. A year later, a similar outburst produced dark Spot 8, but that eventually became a pale cyclonic oval which has not expanded greatly. Spot 6, likewise, had changed from dark brown to white, and it was eventually destabilised and merged with Segment G. Thus, the combination of hi-res ground-based and JunoCam images has given much insight into the origins and transformations of STB structured segments.

Following the unique manner of the Spectre's collision with Segment A, the cycle of successive segments was broken, and the domain has moved into a new regime. Oval BA no longer drifted slower than cyclonic features. Instead, Segment A and the new dark Segment G both continued expanding and emitting streams of dark spots on the STBn and STBs jets, re-creating a visibly dark STB around much of the circumference, which had not happened since the mid-1990s.

From mid-2022 through to 2025, there was some kind of dark STB around more than half the planet, comprising Segments G and A and the dusky or spotty space between them. Segment G expanded at an average rate of ~1.75 to 2.0 deg/30d throughout 2022 and 2023. Segment A also continued to lengthen irregularly, with an average rate of ~ 2.0 deg/30d from 2020 to 2023, and developed internal subdivisions with different textures. Following Segment A there was a long dark extension ('Sf. tail') along the STBs jet and STZ.

Oval BA continued to vary in colour. It was strongly reddish in early 2018, then faded to almost white by late 2018, and remained white or almost so throughout 2019 & 2020. In 2021 & 2022 it was off-white with more 'warm' tint, then reddened during 2023 so as to be distinctly reddish throughout 2024. BA's rapid circulation was measured from JunoCam images at PJ17 (2018 Dec.21). A small anticyclonic white oval (AWO-b) existed following Segment A from 2018 March to 2023 Nov. A few even smaller AWOs were tracked but were short-lived.

Drift rates of major features such as BA, AWO-b, and the cyclonic circulations, were largely consistent with previous measurements in relation to their latitudes. From 2020 to 2024, these all had similar drift rates (mean DL2 = -16.2 (±1.0) deg/30d), similar to those of cyclonic sectors in previous decades, defining the S. Temperate Current. We conclude that in this domain, as in others, the slow current is normally determined by the cyclonic features, while anticyclonic ovals can move at the same or different speeds.

Measurements of these and smaller spots by the JUPOS team were used to produce zonal drift profiles (previously unpublished) These showed several very fast retrograding speeds along the south edge of the STB Spectre, even after its p. end had disappeared into Segment A, consistent with the rapid wind speeds around such circulations. Following Segments A and G, retrograding speeds on the STBs were variable; their relationship to the expansion of these segments was unclear, and they became unexpectedly fast f. Segment A in 2023. Anomalous zonal drift profiles that we previously observed f. structured segments were reproduced in some cases but not all, and they have not developed into new large-scale circulations.

A group of spots on the N edge of Segment G in 2023 had particularly rapid speeds, among the fastest ever recorded in the STBn jet, again confirming the rapid speeds around structured sectors. Zonal wind profiles, from Hubble images in 2019 June and from amateur images in 2023/24, were in line with previous data showing frequently faster jet speeds on STBn and STBs alongside structured sectors, viz. the STB Spectre and Segment A.

The STBn jet displayed dark jet spots prograding p. oval BA in 2018 after the STB Ghost collision with Segment A, and again in late 2019/early 2020. Then, despite the reinvigoration of Segment A as the STB Spectre arrived, there was little STBn activity p. BA until 2021, when the situation here was complex; jet spots were probably arising here from mid-2021 until late 2022 when there was little space left p. BA because of DS7 (Segment G) expanding there. Meanwhile, Clyde's Spot (DS7) produced a few STBn jet spots in 2020 and 2021, but from 2021 Sep., when (as STB Segment G) it had erased the remains of the Spectre p. it, it became a major source of STBn spot activity which was intense throughout 2022, 2023 and 2024. Many of the spots drifted north without change of speed, as we have often observed, and even travelled north of the usual STBn jet latitude, decelerating accordingly. JunoCam images suggested a variety of wave patterns on the north sub-peak of the STBn jet, and weak or absent vorticities in the STBn jet spots.

1. Introduction and Overview

Domains on Jupiter are defined as the latitude bands between eastward jets, typically consisting of a belt (cyclonic, low-latitude) and a zone (anticyclonic, high-latitude) separated by a westward flow. For the South Temperate (or S1) domain, the STBn or S1 jet marking the northern boundary is (uniquely) double, with sub-peaks at 26.5°S and (at some longitudes) at 28.7°S. The SSTBn or S2 jet marking the southern boundary is at 36.3°S. (These are average planetographic latitudes from spacecraft: Ref.R1.) They are indicated in Figures 1a & 2.

This domain exhibits large organised structures which evolve over several years, and have long been recorded by amateur observers, now supplemented and clarified by spacecraft imagery. We have previously posted detailed reports on it covering the years 2001 to 2018 (Refs. R1-R3). Some of the major phenomena were first described in Ref.R1, and confirmed and elaborated in subseqent years in Refs.R2, R3 & R4. Here we update this account to 2024, reviewing our already-posted interim reports and adding some new analysis. Much of this is adapted from our interim reports, which contained further details; some of these are referenced in green type by year and report number, or (the more substantial ones) by reference numbers R1, R2, etc. Our reports on individual perijoves (mentioned herein in bold type) also contain further details of JunoCam images. Because some of the phenomena are complex, further background information for some of the following sections is provided in **Appendix A**.

Abbreviations used:
AWO, anticyclonic white oval
F., following = planetary west (right)
Np., north-preceding (north-east)
ZDP, zonal drift profile
FFR, folded filamentary region
STB, South Temperate Belt
STBn, north edge of STB, & associated jet

GRS, Great Red Spot
P., preceding = planetary east (left in images)
Sf., south-following (south-west)
ZWP, zonal wind profile
STC, South Temperate Current
STZ, South Temperate Zone
STBs, south edge of STB, & associated jet

Introduction: The cyclic behaviour (1998-2018) *[Adapted from Ref.R5]*

From 1998-2018 the South Temperate domain showed a consistent cyclic pattern of disturbances (Refs. R1-R3). It was whitened around most longitudes. The merger of three large white ovals in 1998 and 2000 left only a single large anticyclonic oval, called BA. Major cyclonic features are 'structured sectors' of STB, separated by largely undisturbed sectors, and there are always between two and four of them. One is always a dark sector of STB following BA (STB Segment A), of variable length and activity. Others arose in a consistent cyclic pattern during these two decades (Figure 3).

Each additional structured sector arose tens of degrees p. BA, first seen as a small dark spot, then developed in one of two ways: either it would expand as a dark turbulent STB segment, or it would change from dark through reddish to white and then expand as a pale, quiescent loop. In either case, the new structured sector would drift eastward faster than BA and therefore eventually, after several years, having become tens of degrees long, it would collide with Segment A f. BA. This collision caused vigorous activity (including, in two cases, a sudden convective outburst that transformed the formerly quiescent structured segment into a turbulent dark segment); and soon it would merge with Segment A, causing it to become a longer turbulent dark segment, and emitting streams of dark spots p. in the STBn jet and f. in the STBs jet or STZ. The reinvigorated Segment A would then shrink down towards BA again over one or more years.

All this is summarised in Figure 3 & Refs. R1-R3. There were five repeats of this cycle, creating structured segments designated sequentially from B to F. (The three pale quiescent segments also had names: STB Remnant, Ghost, and Spectre.) The last cycle had been completed in 2018, when the STB Ghost collided with Segment A; this was fully described in Ref.R3, and in a joint publication with atmospheric scientists (Ref.P1). When the STB Ghost came into contact with Segment A, a bright white convective plume suddenly erupted inside it, initiating a turbulent transformation of the whole Ghost into a chaotic dark STB segment adjacent to oval BA. This also had all the other effects typical of these collisions, viz., oval BA developed a dark rim and accelerated, and dark spots were emitted eastward on the STBn jet and westward in the STZ.

This was the situation around oval BA at the start of the time period to be covered in this review. Meanwhile, another structured sector had appeared and was expanding: a long pale loop called the 'STB Spectre' (Segment F). We therefore awaited the further evolution of Segment A, the development of Segment F which was converging on Segment A, and probably the appearance of a new structured sector in turn.

Multispectral imaging

While most of our amateur images are in visible light or near-infrared continuum, many observers also take images in the methane (CH4) absorption band at 889 nm, where bright features represent high-level haze or cloud. In CH4 images, zones are generally bright and belts dark, but the long white sectors of STB are lighter: only cyclonic circulations, both small cyclonic spots and long structured sectors like the STB Spectre, appear dark. Conversely AWOs are usually bright in CH4 images, and oval BA is always one of the brightest features on the planet (Figures 2,4,5).

A combination of imaging in the methane band (CH4, 889 nm) and near-ultraviolet (UV) reveals differences among individual features, as shown in various reports (e.g. Refs.R12 & R14a). Typically (e.g. Figures 4 & 5):

--Oval BA is very bright in CH4, and dull in UV, indicating its variable 'warm' tinge.

--Cyclonic white spots, by contrast, are often dark in CH4 but bright in UV. WS6 was very bright in UV, but uneven in CH4 and in RGB. DS7, as a disturbed region, appeared dull in UV, dark and disturbed in CH4.

--Although small AWOs are usually methane-bright, a small rimless AWO in the STZ was not greatly so, but was very UV-bright (just S of the F-Spectre in 2021), suggesting that its cloud cover more resembled cyclonic white ovals than other AWOs. (There was a similar, longer-established one in the STZ in 2022.)

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2. Observations and Analysis

Data herein are from amateur imaging unless otherwise stated, but much JunoCam imagery is also included, as it has given unprecedented insights into the nature of the phenomena that ground-based observers record.

The techniques are fully described in our previous reviews, esp.[Refs. R1 & S2], and are only summarised briefly here. Ground-based imaging is done by amateur observers around the world whenever Jupiter is well positioned. (We are deeply indebted to all the observers, who are listed for each apparition on the BAA and JUPOS web pages.) Positional analysis of features, and construction of planet-wide maps, is done regularly by the JUPOS team and by the ALPO-Japan; the JUPOS measurements are presented in this review. **Appendix D** presents JUPOS charts of all measured spots in the domain during this period. **Appendix B** presents maps of the whole S1 domain made by the JUPOS team from amateur images throughout this period. Our interim reports, giving details of the observations and the analysis summarised herein, are posted on the BAA website: https://britastro.org/sections/jupiter.

NASA's Juno spacecraft has been operating in orbit around Jupiter since 2016, with its camera JunoCam returning images near closest approach (perijove) on every orbit, which are released for the public to study. Almost all the images and maps shown in this report were produced by Gerald Eichstädt with further compositing and enhancement by J.R., as also shown in our regular reports on each perijove that are posted on the JunoCam web site (https://www.missionjuno.swri.edu/junocam) and the BAA Jupiter Section web site (https://britastro.org/sections/jupiter). **Appendix C** presents the maps of the S1 domain at every perijove. The complete, unannotated JunoCam cylindrical maps are on our web site at: https://britastro.org/section_information_/jupiter-section-overview/junocam-global-maps. The dates of perijoves are given on the maps (**Appendix C)**. From perijove (PJ) number 1 on 2016 Aug.27, Juno had an orbital period of 53 days (2017-2021) then 43-44 days (2021-22) then 38 days (2022-23). Since PJ47 on 2022 Dec.15, the S1 domain has only been imaged at a resolution comparable to the best ground-based resolution.
In a few cases, blinks or animations of two or more JunoCam images showed wind motions, but these were not done often because with Juno's rapid trajectory over the planet, very precise hi-res map projections over an adequate interval are necessary to reveal even the fastest winds.

In addition to the co-authors of this review, some maps of amateur images were made by Shinji Mizumoto of the ALPO-Japan (a very useful regular series) and by Andy Casely (esp. at Juno perijoves); and some maps of JunoCam data were posted by citizen scientists Björn Jónsson and Kevin Gill.

The Hubble Space Telescope (HST) has also produced at least one pair of global maps per year (Ref.P2), which were sometimes referred to in our interim reports.

This review extends from late 2018 (after Ref.R3) to early 2024, but also includes some later information where relevant. Dates of opposition were as follows: 2018 May 9; 2019 June 10; 2020 July 14; 2021 Aug.19; 2022 Sep.26; 2023 Nov.3; 2024 Dec.7.

Conventions:

Longitudes are here given in System 3 (L3), unless otherwise specified. However, we still use System 2 (L2) for drift rates, given as DL2 in degrees per 30 days, for ease of comparison with all previous data. DL3 = DL2 + 8.0 deg/30d. For jet speeds and ZWPs in the Tables, DL2 is also converted into wind speed in System 3, u_3 (m/s).

Latitudes are planetographic, except on JunoCam maps where they are planetocentric. North is up in all images and maps. (In Refs.R1 & R2, all images and charts were shown with south up, but we changed to the north-up convention in 2015.)

3. Cyclonic features & structured sectors

3.1. The STB Spectre (Structured sector F) *[Largely adapted from Ref.R10]*

The STB Spectre is a cyclonic circulation that began as a small very dark spot ('DS5') in 2014 Dec. From 2016 to 2019 inclusive, it was visually inconspicuous (though always identifiable in v-hi-res amateur images or spacecraft images), consisting of an oblong whitish core surrounded by a pale bluish loop. It often had a slightly darker patch flanking each end, and the whole of it was dark in methane-band images [Ref.R3].

Unlike its predecessors, the Spectre elongated extremely rapidly, by ~7.5 deg/30d throughout 2019 [Ref.R9] (Fig.6). Its ends are plotted on the JUPOS chart (Fig.3). The **f. end** (hereafter **'F-Spectre')** was quite well defined, and JunoCam imaged it closely at PJ21 (2019 July 21) (see Fig.12), PJ22 (Sep.12), and PJ23 (Nov.3) showing a distinct cyclonic hemi-circulation from STBs to STBn. At PJ21 the Spectre was clearly compressed as it was passing the GRS. The **p. end** (hereafter **'P-Spectre')** was not well defined after 2019 April, because it was in a very disturbed region p. the GRS, but it appeared intact and closed in Juno's PJ23 images (2019 Nov.3). The P-Spectre maintained a very rapid average drift rate (DL2 ~ -21 deg/30d in 2019), but seems to have been repeatedly associated with features in the STZ marking the f. end of the 'tail' Sf. Segment A [Ref.R9]. One of these, the small 'AWO-b' that it probably encountered in July, accelerated to the same speed as the Spectre's p. end (Fig. 3) and was still adjacent to the P-Spectre in JunoCam maps up to PJ25 (2020 Feb.17) (Figs. 7 & 9).

From the last quarter of 2019, **the P-Spectre** was only clearly identifiable in JunoCam maps (**Appendix C**; & Fig. 7). The length of the Spectre was 120º at PJ23, 135º at PJ24, and 163º at PJ25. The P-Spectre (and associated AWO-b) had mean DL2 ~ -22 deg/30d (2019 Aug. to 2020 Feb.). They caught up with STB Segment A some time during solar conjunction, possibly just before PJ25 (2020 Feb.17) when they were in contact (Figs.2 & 9), and the p. end of the Spectre was then tapered so it was not clear whether it still maintained cyclonic circulation (Fig. 9).

The effects of this collision were described in [Ref.R10]. Unlike in previous such events, there was no noticeable change in the Spectre itself, which remained invisible to ground-based imaging except at its f. end. However, from early March, Segment A itself was expanding again and remained turbulent, and all the other expected sequels of such a collision occurred: the acceleration of oval BA, the dark collar around BA (which already existed), the outbreak of dark spots Np. BA in the STBn jet (which started in 2019 Dec.), and the outbreak of dark spots Sf. into the 'tail'. (These phenomena are all covered in separate sections below.)

On previous occasions it was suspected that all these phenomena could be due to the turbulence in Segment A, which was renewed each time another structured segment merged with it. In this case in 2020, there was no such merger, but Segment A itself expanded with renewed activity from the time of the collision, producing the same consequences around it.

The F-Spectre persisted with little change, with DL2 = -11.4 deg/30d (2020 Feb-April) (Fig.3). From 2020 Feb-Sep. it had more dark material outlining the f.end (Figs.11 & 12), which later became whiter again. **At PJ28 (2020 July 25), JunoCam** had an excellent view of the F-Spectre, and confirmed that it was still a site of cyclonic recirculation (see **PJ28** report & Fig.11). So did HST OPAL maps on 2021 Sep.4 (Fig.5) & [Ref.R12].

JunoCam and HST images always showed an anticyclonic ring adjacent to it in the STZ (e.g. Fig.12), sometimes white (a small AWO), sometimes visually dark or inconspicuous but still methane-bright (e.g. Fig.11); its reflectivity was peculiar in 2021 Aug-Sep. (Figs.4 & 5).

For much of its life the F-Spectre had a distinct anticyclonic *'recirculation loop'* on its Sf. side, like those of its predecessors the STB Remnant and Ghost, as described in our previous long-term reports [esp. Ref.R3 – see **Appendix A**]. In 2020, motions of some tiny spots and streaks were consistent with this picture although recirculation was not been directly observed [Ref.R11] & (Fig.13). SSTBn jet spots approaching the F-Spectre would be expected to disappear or recirculate here, but in April/ May one disappeared into the dark complex, one passed it then halted, and one passed it unhindered (Fig.13). In 2020 July, another one passed it unhindered (Fig.14), showing that the recirculation loop was no longer operating. Only the small anticyclonic ring/AWO remained in its place.

Another feature of the recirculation loop had been that the retrograding speeds f. the structured sector were sometimes unusually fast and/or southerly [Ref.R3 – see **Appendix A**] [& see Fig.26 below] In 2020, we recorded anticyclonic rings and dark spots adjacent to the F-Spectre, but they fell close to the usual ZWP – not reproducing the previous southward-displaced ZDP [see Fig.27 below].

Thus the F-Spectre appeared to be a well-established structure, of an isolated type not previously studied by spacecraft, and it persisted (though without its recirculation loop) until it arrived at the turbulent DS7 (Segment G) in early Sep., 2021 (see Figs.4 & 5). Its fate then was unclear, as DS7 retained its drift and became larger; but by 2022 July, HST maps coinciding with PJ43 (2022 July 5) showed that the F-Spectre had disappeared, subsumed by the turbulence emanating from DS7 – although the small AWO still existed.

Fast retrograding speeds along the S edge of the Spectre (STBs jet) [New analysis; see **Appendix A** for background, & box below for details; & Fig.27=*ZDPs in section below*]: Hubble images of the pale cyclonic sectors ('STB Remnant', 'Ghost', and 'Spectre') had previously confirmed that they have cyclonic circulation [Ref.R4]; with winds on the S edge of the Ghost reaching DL2 = +77.5 deg/30d at 32.3°S [Ref.R3 Appendix A, & **Table 1**], or even faster [Ref.P1]. On the S edge of the STB Spectre, in 2020, for the first time we recorded dark spots with similar fast-retrograding speeds: DL2 = +69 and +68 (Figs.13 & 14 & 27). Then in 2021 Sep-Oct., a series of dark spots along the S edge of the former Spectre, f. STB segment A (Fig.27) included a burst of three with DL2 = +56 to +63, plus one even faster [Ref.R13]. These fast retrograde speeds in both years had average DL2 = +64.2 (±6.2); lat. 32.45°S; N=6), unprecedented outside structured segments, but approaching the very high wind speeds recorded from Hubble images in 2017.

Below, we will again consider the STBs jet speed (section 4.2) and ZDPs (section 5.1).

Box: *Rapid jet speeds on S. edge of STB Spectre.*

Hubble images of the pale cyclonic sectors ('STB Remnant', 'Ghost', and 'Spectre') had previously confirmed that they have cyclonic circulation [Ref.R4]; as measured along the S edge of the Ghost in 2017, the winds reached DL2 = +77.5 (±5.3) (u_3 = -35.4 (±2.2) m/s) at 32.3°S [Ref.R3 Appendix A, & **Table 1**]; or DL2 = -86 and -110 (u_3 = -39 and -49 (±10) m/s) [Ref.P1].

In 2020, two dark spots were observed with unprecedented fast-retrograding speeds along the S edge of the Spectre. [Others, above 33°S, had more normal speeds, e.g. DL2 = +12 (2020 March-April).] One, in 2020 April, was gradually decelerating as it drifted south, with a mean speed of DL2 = +69 at 32.5°S to +7 at 33.6°S (Fig.13). The other, in 2020 July, had a mean DL2 = +68 at 32.9°S until it passed the f. end of the Spectre on July 15, then it rapidly decelerated to +24 at 32.7°S, [Fig.14; & Fig.27=ZDP, below], which is more typical of the STBs retrograding current (its mean peak from spacecraft is DL2 = +31). Then in 2021 Sep-Oct., a series of dark spots along the S edge of the former Spectre, f. STB segment A [Fig.27], included three with DL2 = +56, +58 and +63 (at 32.1—32.2°S; plus one short imprecise track with DL2 ~ +71 at 32.8°S) [Ref.R13]. These exceptionally fast retrograde speeds may have been a short-lived burst, as there were slower spots here in 2021 May-Aug. in about the same latitude. Nevertheless, these speeds (average DL2 = +64.2 (±6.2); lat. 32.45 (±0.34)°S; N=6) are unprecedented outside structured segments, but approaching the very high wind speeds measured from Hubble images around the STB Ghost.

By 2021 Sep. the former Spectre encompassed most longitudes and was no longer a closed circulation, but these speeds suggest that its fast winds still operated. Indeed, a few spots with greater-than-usual speeds were still seen in this sector thereafter: one with DL2 = +45 (31.9°S) in 2022 (in the Sf. tail of Segment A); and two with DL2 = +43 (31.5 and 32.1°S) p. Segment G in 2023. It is not clear whether they represent a consistent current, or were just occasional exceptions.

3.2. New cyclonic features, DS6 & DS7 (Clyde's Spot)

[A summary was presented in Ref.R5.]

Since 2018, we were expecting one or more new cyclonic spot(s) to arise some way preceding BA to initiate the next structured sector [Ref.R3]. This eventually happened in 2020, with appearance of two dark spots which we named spots 6 and 7. Spot 6, very dark and compact, appeared to be typical of the dark spots that have initiated new structured sectors in the past. But in fact it was Spot 7 that did so: it originated with a sudden convective outburst creating "Clyde's Spot", a turbulent feature which expanded continually from that time to become the new dark STB Segment G [Refs. R6, R7, P3]. Then a similar outburst in 2021 produced Spot 8, which conversely ended up as a quiescent, modest-sized pale spot. Spots 6, 7, and 8 were well monitored by amateurs during their eventful lifetimes, and intermittently observed close up by JunoCam and HST. These phenomena were particularly covered in our reports cited below, and were analysed and modelled in detail, from the same and additional obs'ns, by R. Hueso *et al.* [refs. P3 & P4].

Even before 2020, JunoCam had revealed several small, pale cyclones in the whitened STB latitudes p. BA, and spots 6, 7, and 8 developed by transformation of these cyclones [ref.P3] (Fig.15). Subsequent images show how they changed between three canonical types of cyclonic circulation (Fig.16): dark oval ("mini-barge"); white oval (which may expand); and turbulent patch ("mini-FFR", i.e. folded filamentary region). Two mini-FFRs also expanded, to become dark STB segments.

The initial pale cyclones

In the region of interest spanning tens of degrees p. BA, in 2019, JunoCam images showed several small, low-contrast cyclones, which were also tracked in amateur data as small pale streaks. The first sighting was a pair of small vortices seen by JunoCam at **PJ17** (2018 Dec.21). Then in 2019 from mid-Feb. onwards, amateur observers noticed a faint oblique streak across the whitened S. Temp. domain, spanning 28-33°S, methane-dark and stable, with typical STC drift, and two other such streaks, even fainter, further p. [Reports 2019 nos.3&4]. As would become apparent later, this appearance is typical of a pale cyclone with a light grey border that tapers to Np. and Sf. with the zonal wind gradient. Two of these were tracked by JUPOS as pale grey streaks in 2019: the DS6 precursor at 30.3°S, and the DS7 precursor at 30.0°S, close to the Cassini ZWP. (Examples are indicated on our 2019 chart and maps in **Appendices B,C,D**.)

This region was captured again by JunoCam at **PJ19** (2019 April 6), revealing the streak(s) to be 2 or 3 contiguous cyclonic vortices, and another further p. was captured at **PJ20**; all were methane-dark (Fig.2). **PJ24** (2019 Dec.26) gave the best view of one of these little cyclonic vortices (Figs.8 & 16). Hueso et al. [Ref.P3] tracked them using Hubble and ground-based images, and showed that (after some mergers between them) they were indeed the precursors of spots 6 and 7 (Fig.15).

Spot 6

This was first observed as a dark spot ~42º p. BA (named **DS6**), from the start of the apparition on 2020 Jan.31. In Feb. and March it was sometimes variable in shape and intensity, but it was a very dark compact spot by March 25, and it remained so throughout 2020. JunoCam obtained hi-res images of it at **PJ26** (2020 April 10) (Figs.10 & 16) revealing its fine cloud structure and the winds in and around it.

But in 2021 it would turn orange then white, becoming white oval **WS6** (see below). In early 2023, having become destabilised as it approached the expanding STB Segment G, it merged into it (see below).

Spot 7 (Clyde's Spot / DS7 / STB Segment G)

DS7 was particularly interesting. A small pale streak, tracked in amateur images, ~80º p. BA, had been identified as a probable cyclone of interest. On 2020 May 31, just after it passed the GRS, Clyde Foster noticed a new, very methane-bright spot at that location, so it became known as ***'Clyde's spot'***. By great good fortune, it was imaged close-up by JunoCam on June 2 at **PJ27**, showing that it was a methane-bright high-altitude cloud that had erupted within a well-formed cyclonic vortex, showing evidence of expansion. The methane-bright plume was short-lived, and never conspicuous in visible light, but images still showed variable tiny spots at the same site, increasingly dominated by a dark spot (**DS7**) which was conspicuous throughout July, with continuing signs of small-scale disturbance.

In 2021, DS7 appeared as a short turbulent dark streak in amateur images, and it was emitting disturbance around it. JunoCam got excellent views of the sector from BA to DS7 at **PJ33** (2021 April 15), **PJ34** (2021 June 8), and **PJ35** (2021 July 21) (Fig.17); also see the HST OPAL maps on 2021 Sep.4 (Fig.5). The images at PJ33 and PJ34 revealed DS7 as a beautiful miniature FFR (Figures 16 & 17), apparently emitting disturbance to Np.and Sf.

Thus, this single plume eruption in the pre-existing cyclonic vortex initiated continuing, growing disturbance at this point, in the form of an irregular, variable dark spot. It retained convective and turbulent activity ever since its first eruption, and was still expanding. [For more details see: Refs. R6, R7, R11; our PJ27 & PJ34 reports; & Ref.P3]. So Clyde Foster had observed (for the first time) a convective outbreak that initiated an expanding turbulent sector that would soon form the next structured sector, to be called (in historical sequence) STB segment G.

In 2021 [Ref.R12], with DS7 being very active, the whole sector from oval BA to the F-Spectre was darkened and disturbed (see below). Many small spots were tracked retrograding out of DS7, and some of them merged to create a dark spot designated d1. This was very dark in July and August, converging on WS6 then remaining adjacent to it.

We did a detailed analysis of the sector around DS7 from amateur images [Ref.R12]. DS7 was emitting much small-scale disturbance and distinct dark spots f. it with mean DL2 = +27.3 (±5.0) at 31.9 (±0.4)°S (**Table 1**, & Fig.27 below). These values are similar to the STBs jet peak in the Cassini ZWP, and to the spots that sometimes appear f. segment A when it has been reinvigorated [see sections 4.2 & 5.1 below]. Otherwise, such speeds are rarely observed in ground-based data, so they confirm the overall impression of DS7 as a particularly energetic STB Sector. These motions can be seen in more detail by blinking Hubble maps from 2021 Sep.4 (see Fig.5) [Ref.R12]

On reaching d1, these spots either disappeared or merged with it; no recirculation was recorded. No more retrograding spots were seen after Sep. Then in Nov., d1 recirculated to the SSTBn, shifting south to 34°S and prograding.

Meanwhile p. DS7, the shaded STB was generally quiescent up to 2021 August, apart from several spots prograding from DS7 [Ref.R12]. In early Sep. (2021), DS7 caught up with the F-Spectre p. it, which did not survive. Subsequently, DS7 retained its consistent drift rate, and probably continued growing (~17° long in Nov.), although its boundaries were unclear in ground-based images. From Sep. onwards, intense disturbance was emitted p. from it on STBn, but the activity f. it subsided [Ref.R13].

Spot 6 (continued) *[See: Refs.R12 & 14b]*

After solar conjunction in early 2021, we expected to see ***DS6*** again, but when JunoCam imaged the region close-up at **PJ33** (2021 April 15), DS6 had turned into an orange cyclonic oval adjacent to oval BA (Fig. 17). The colour was somewhat weaker at **PJ34** (2021 June 8), and even weaker at **PJ35** (2021 July 21) (Fig. 17) and in the HST images on Sep.4 (Fig.5). In amateur images it was recorded as a bright white oval, hence renamed ***WS6***. However, the very best amateur images close to opposition (e.g. Fig.4) did resolve the slightly redder inner oval from the bluer outer annulus. (Reddish colours always appear stronger in JunoCam images.)

WS6 was in contact with oval BA in 2021 March-April, then its relative position oscillated over several months. These changes in drift rate corresponded to changes in its latitude, in accordance with the ZWP, as shown in the JUPOS chart (Appendix D) and ZDP (Fig.27, below). It continued as a white oval shortly p. BA throughout 2021 and 2022. JunoCam's next close-up view of it was at **PJ44 (2022 Aug.17)** (Fig. 17). WS6 had a striking 'yin-yang' pattern internally, and an animation showed the cyclonic circulation within both WS6 and the adjacent segment G, as well as FFRs.

In 2022 Dec., WS6, which was close to the turbulent Segment G, became disrupted with dark spots inside, and then appeared to merge with Segment G [Ref.R12]. The transformation began gradually around Dec.12, and the white oval became darkened and chaotic. By Dec.28, it was almost continuous with Segment G, but was still comparatively blue and strongly methane-dark. By 2023 Feb. the merger was complete (Fig. 16).

This was the first observation of a large cyclonic white oval being transformed and incorporated into an adjacent turbulent sector, which may have destabilised it (although comparable to the transformation of the much larger STB Ghost in 2018). There was no methane-bright plume outbreak.

The space between segments G and A comprised a stretch of dusky STB in 2022, which became lighter in 2023 although still bordered by small dark spots along the STBn and STBs, and shortening until 2025 when G and A were separated only by oval BA. ***Segment G*** has remained dark and turbulent and continued to grow longer, from 30-35° long in 2022 June to 55-60° long in 2023 Nov. [see JUPOS chart, **Appendix D**]. Measurements of its length are scattered, as the ends were sometimes indistinct, especially when much dark material was spreading p. it, so; but often it could be made out in hi-res images as an FFR-like segment. The mean growth rate from 2022 June to 2023 Dec. was between 1.75 and 2.0 deg/30d (Fig.6). This was similar to that of Segment A since 2020 (see section 4.1 below), and slightly greater than the growth rates of previous dark turbulent segments B (0.6 --> 1.0 deg/30d) and D (1.1 --> 1.6 deg/30d) [Ref.R1].

[See sections below for ZDPs of spots emitted p. and f. Segment G.]

3.3. Spot 8

STB Spot 8 appeared on 2021 Aug.7 as a bright convective outbreak in a small pale cyclone that had just passed the GRS, exactly like Spot 7 (Clyde's spot) a year earlier. But unlike that one, it did not appear in the sector p. BA, and it has not expanded as a structured sector. It likewise became a turbulent spot, but this was not sustained and in 2022 Jan. it turned into a quiescent dark brown oval. In early 2023 it reddened then faded, as Spot 6 had done, becoming a whitish spot in a pale bluish envelope (just like previous features such as DS5 in 2016 which became the STB Spectre) (Fig.16).

Details were given in [Ref.R12]:

The first sign of spot 8 as a suspected cyclonic feature was a grey streak, from 2021 May onwards. It was adjacent to the f. end of the STZB throughout this time, suggesting that it was part of a bigger dynamical feature. Within this grey streak a small white spot brightened noticeably as it passed the GRS from 2021 June to early August. On Aug.7, Eric Sussenbach produced a remarkable image sequence over 100 minutes, showing mysterious changes in its internal structure.

The start of the convective outbreak was recorded one rotation later on Aug.7, by Christopher Go and others: a very small white spot in RGB, and very bright in CH4. It faded rapidly in CH4, and was never conspicuous in visible light, but initiated continuing disturbance at that site (Fig.16), & HST image in Fig.5) – all this was exactly like Clyde's Spot in 2020. By late August, it was enlarged, with vigorous smallscale activity internally, and disturbance from it was spreading in the Np. and Sf. directions on the STBn and STBs jets. JunoCam got a good view of it at **PJ36** (Sep.2) (Fig.18), which showed white cloud lobes reminiscent of those in Clyde's spot at PJ27 (Fig.16), as well as a long series of eddies and spots prograding from the outbreak on the STBn jet. This volley of 7 or 8 STBn jet spots that arose Np. it in late August persisted through October, and a few spots were tracked retrograding Sf. it.

In 2021 Sep., spot 8 became less active and less conspicuous visibly, although JunoCam's closeups of it at **PJ38** (Nov.29) showed that it was still a turbulent little feature (Fig.18). Then in Dec. [Ref.R13], it changed into a distinct, very dark little oval (Fig.16). JunoCam closeups confirmed that it was a quiescent, dark brown cyclonic oval at **PJ39** (2022 Jan.12) and **PJ41** (2022 April 9) and **PJ46** (2022 Nov.6), very like the former DS6.

Curiously, there has always been a smaller white cyclone 20-30° p. Spot 8, likewise methane-dark, at least from PJ43 (2022 July 5), and tracked in amateur images from 2022 July until 2024 and beyond [see JUPOS chart, **Appendix D**] [e.g. Ref.R14b] It was shown to be a cyclone in PJ43 and PJ46 near-limb images. Around 2022 Dec.1 it was passing the GRS, and was very bright white (and still methane-dark), just like the cyclones which produced the convective outbreaks of Spots 7 and 8, but this one did not do likewise; it continued unchanged.

Spot 8 underwent a further transformation in early 2023, fading and reddening before becoming a white oval, still enclosed in a blue-grey streak. This is a typical behaviour of quiescent dark cyclonic spots in many domains [Refs. S2 & S3 (p.215)]. Ground-based images showed that this very dark spot faded suddenly just after it passed the GRS at the end of 2023 Jan. The **PJ49** (2023 March 1) map, although also lo-res, confirmed what we suspected: that spot 8 had become a light, slightly reddish oval flanked by blue-grey patches, just like previous examples of fading spots such as the one that evolved into the STB Spectre in 2016. It remained very methane-dark.
In ground-based images it was then a white oval in an oblique, pale bluish-grey sheath, just like previous quiescent cyclonic circulations such as the STB Spectre. It has persisted like this up to 2025, without noticeable expansion (Fig.20) The tiny cyclone has remained ~20° p. it in JunoCam maps, though only resolved in the best amateur images. Both spot 8 and this cyclone are still methane-dark (e.g. Fig.20).

3.4. Discussion: Life histories of cyclonic circulations

[Adapted from Ref.R5; also see Ref.P3]

Most domains on Jupiter exhibit cyclonic circulations ('spots') that belong to a limited range of types [Ref. S1]: dark ovals or oblongs (called 'barges' in the NEB, with smaller versions elsewhere); pale ovals or oblongs (white in the SSTB, light ochre in some domains); and FFRs ('folded filamentary regions', i.e. chaotic cyclonic regions, sometimes with bright convective spots, and with disturbance spilling p. and f. in the zonal winds). These have long been recognised in the STB. Now, spots 6, 7 and 8 provide well-studied typical examples; with the thorough ground-based coverage, and intermittent hi-res coverage from JunoCam and HST, we can clearly see their dynamical structure and define their origins, transformations, and life histories. They also give new insights into the origin of STB structured sectors.

An important discovery is that each of them originated from a small, pale cyclone in the whitened STB [Ref.P3]. From previous ground-based studies, we knew that structured sectors originate in the sector tens of degrees p. oval BA, usually as a dark spot (sometimes very dark); sometimes some circulation or interaction of tiny spots was recorded [Refs.R1-R3], but never any convective outbreak. It seemed possible that perturbation of the jets east of oval BA altered the dynamics of the region, but no specific mechanism was known. Now we know that small pale cyclones were most common in this sector p. BA, and the three dark spots all originated from them -- in at least two cases, by an intense, but small and short-lived, convective outbreak. One of these (Clyde's Spot, DS7) indeed became the next structured sector. The other (DS8) did not, perhaps because it did not arise p. BA. The third dark spot (DS6) originated during solar conjunction in 2020 Jan., so we cannot exclude the possibility of a similar convective outbreak in that case, although the cyclone could have converted to become a dark spot more calmly as seen by 2020 Feb.-March.

Did earlier structured segments arise with convective outbreaks like Clyde's Spot? We looked for their origins as thoroughly as possible and no such outbreaks were noticed, but they might have been missed, since the plume in Clyde's Spot was very methane-bright for only a few days, and it was not conspicuous in visible light.

Subsequently spots 6, 7 and 8 all changed between three canonical types of cyclonic circulation: dark oval, white oval, and turbulent patch ("mini-FFR") (Figs. 16 & 21). White ovals and mini-FFRs can also expand, as freely-moving cyclonic sectors typically do, to become structured sectors of the STB.

Thus the JunoCam images have identified hitherto-poorly-resolved "spots" as distinct types of cyclonic circulation. The same types are also common in other domains, with minor variations in form, as noted above. In the S2 domain, where they are often longer oblongs, we have recently documented how each type can change into any other type [Ref.S2]. Fig.21 summarises the metamorphoses of these three types in both domains.

Some of the transformations occurred just after the spot passed the GRS, which may have destabilised it: viz. the convective outbreaks that initiated Spots 7 & 8, and the whitening of Spot 8. Likewise, some transformations of circulations in the S2 domain occurred just after they passed oval BA [Ref.S2]. Other changes might depend on variations in the supply of convective energy to sustain a turbulent region.

3.5. Addendum: Convective outbreaks in 2025 Sep-Oct. [Ref.R17]

A pair of unusual bright eruptions in the STB & SSTB in 2025 Sep-Oct. deserve mention, as they appear to be initiating new FFRs in the S1 and S2 domains respectively, even though they were subsequent to the period covered in this review (Fig.22).
Two outbreaks of small white spots have appeared, one in the STB and one nearby in the SSTB, approaching the GRS. Each began with a small bright spot, also very bright in the methane band, in pre-existing cyclonic structures. The first appeared in the STB on Sep.22, in a small red cyclonic oval ('mini-barge' oval) which had existed at least since early August within the dark belt. This was similar to the few previous convective outbreaks observed in the STB (Clyde's Spot and Spot 8 in small pale cyclones, and earlier eruptions in the STB Remnant and Ghost as they collided with Segment A), but was the first one to occur without any apparent triggering factor. Then a similar outbreak appeared in the SSTB on Oct.4, in a pale whitish oblong – the first intensely methane-bright outbreak that we have observed in the S2 domain [Ref.R4]. It may be significant that both occurred as these regions were approaching the GRS, and their proximity also suggests that one might have triggered the other. They have rapidly expanded into chaotic regions (FFRs), and we wait to see if they will persist. Further details and images are in our Report no.2 [Ref.R17].

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4. STB Segment A and slow-moving features in STZ (Sf. extension or 'Sf. tail')

(after the STB Spectre arrived in 2020 Feb.) (See **Appendix A** for background.)

4.1. Descriptions of Segment A & its Sf. tail

After the dramatic arrival of the STB Ghost in 2018 Feb., transforming into a turbulent sector and merging with Segment A, it generated a very dark STZB f. it (not resolved into individual spots), and several dark spots retrograded even further f. it [with DL2 ~ +19] (up to 2018 May). But the length and apparent activity of this rejuvenated Segment A dwindled rapidly; the STZB Sf. it broke up into dark streaks late in 2018, and the STB segment ceased emitting spots Sf and Np. by early 2019. During 2019, small scale turbulence resumed inside it, and it remained ~20-22° long from 2019 March to Sep., not showing its expected shrinkage [Ref.R3]. [See maps in **Appendix B & C**, & Fig.1b, & Figs.7-10].

By early 2020, the structures f. oval BA were as follows, in order of increasing longitude [Refs.R9 & R10]:

(i) STB segment A. There is a short dark turbulent segment of STB f. BA, which presumably generates the dark rim around BA, the dark spotty STB(N) p. it, and the dark spotty 'tail' Sf. it. At PJ24 (2019 Dec.26) it was only 16º long, having resumed shrinking, and at PJ25 (2020 Feb.17), only 10º long. This was its minimum: since early March, 2020, after the arrival of the Spectre, it has grown again, expanding to 17º long by April 12. The intense turbulence in segment A is visible in an animation (Ref.R10 Fig. 5).

(ii) The dark 'tail' in the STZ, Sf. segment A. This 'Sf. tail' was variable in 2019, largely consisting of a narrow dark band in the STZ. The f. end of this STZB repeatedly remained roughly stationary in L2 for several weeks in 2019 (including, in May, when it was due S of the GRS). Then it was virtually absent during solar conjunction (PJ24, PJ25), except for one or two dark spots. In early March, 2020, more small dark spots retrograded to repopulate this tail (see below).

(iii) Small AWO(s) in STZ (see section 4.3 below). One small AWO (AWO-b) existed from 2018 March to 2023 Oct., initially embedded in the STZB. It probably encountered the P-Spectre in 2019 July, and remained coupled to it up to PJ25 (2020 Feb.17), when it reached its minimum distance f. BA. Thereafter it remained in contact with the f. end of segment A, and moved away from BA.

Segment A was reinvigorated after the Spectre arrived, in or around 2020 Feb.:

After the Spectre arrived around 2020 Feb., dark Segment A expanded and remained turbulent, and emitted dark spots Np. it on the STBn jet and Sf. it on the STBs jet [Ref. R11]. Segment A continued to grow longer until it reached a maximum of ~25º around mid-May. F. Segment A, from early March, dark spots and streaks extended west in an expanding 'Sf. tail'. The best-tracked of them had DL2 = +12 deg/mth (March-April). They were thus travelling along the S edge of the Spectre, and by early June had reached its f. end, forming a dark STZB all along the STBs retrograding jet. One of these spots had the remarkable speed of DL2 ~ +69, which could be typical of the westward spread of this dark material along the STB S edge (see section 3.1 above).

JunoCam had excellent views of Segment A at **PJ26** (2020 April 10) & **PJ32** (2021 Feb.21) & **PJ45** (2022 Sep.29) (Figs. 9, 10, 23, 24). It was obviously turbulent throughout; at **PJ26**, hi-res animated maps showed its cyclonic circulation (Fig.10). By **PJ32**, Segment A had grown to 45° long (Fig.23). Its continuing expansion, its turbulence, and the rapid drift rate of oval BA since 2020 Nov., all indicated that it remained highly active since the STB Spectre collided with it a year earlier. Its p. half still looked like a FFR, with several bright white patches suggesting convection. Its f. half looked different: browner, less chaotic, but with vivid examples of orange patches over cyclonic eddies, up to the now-well-established AWO-b at its f. end. This appearance persisted in lower-resolution images throughout 2021 (e.g. Fig.17) & [Ref.R12] and 2022 (PJ41 to PJ49).

In 2021, Segment A continued to lengthen (with a few fluctuations) (Figs.3 & 6) & [Ref.R12]. In 2021 May, its expansion stalled, as oval BA was slow-moving during May; also BA lost its dark rim then, and all these changes suggest that Segment A had reduced activity in early May. But thereafter, BA accelerated again and Segment A slowly lengthened, reaching 60° long in November. At its f. end was AWO-b. The 'Sf. tail', f. AWO-b, was variable: largely a dark STZ Band (STZB), that had emerged from segment A in 2020, but in 2021 was largely undisturbed. Two tiny AWOs developed within it; with oval BA and AWO-b, they made a series of 4 ovals with spacings of ~55-65° (section 4.3 below). Later in 2021, the STZB developed numerous prominent dark spots (section 4.2 below).

In 2022, JunoCam's best resolution was at **PJ45** (2022 Sep.29) (Fig.24). This showed that there was dense small-scale turbulence in both p. and f. parts, with a typical pattern of streaks and orange eddies displaying its strong cyclonic gradient. This view was spectacular because there was also a dark grey S. Tropical Band alongside the STB, and the space between them was filled with a chaotic tangle of cloud structures (Fig.24, bottom), probably between the two components of the STBn jet.

Segment A had continued to lengthen so it was 80-85° long in 2022 June, but thereafter it remained ~80° long until Dec., when it expanded to ~90°. By 2023 Nov. it was 105° long, and it reached 110° in 2024 March. The average growth rate was ~2.0 deg/30d from 2020 to 2023. The best amateur maps throughout these years distinguished the visibly disturbed p. part near BA, and the more quiescent, dark brown f. part. (See Figs.1b & 25; & **Appendices B *(maps)* & D** (JUPOS chart.) The structure therefore reverted to how some STB segments had appeared in Voyager maps, with a turbulent p. part just f. the large AWOs (resembling the 'wake' f. the GRS). In 2023 the p. part sometimes appeared as a distinct FFR-like structure, and the f. part was also spotty on the smallest scale, though even this ceased in 2024.

There was a Sf. tail f. Segment A throughout these years, though variable in appearance. In 2022 it was still a long, dark, quite narrow STZB, extending f. past Spot 8 – somewhat irregular though few spots were tracked on it. In 2022 Dec., as the STZB moved on p. the GRS, it broke up into distinct dark spots. During 2023 (July onwards), the Sf. tail was much reduced; there was a short 'linker' spanning ~20° from Segment A to AWO-b, and a longer Sf. tail proper consisting now of faint wisps and small spots – which had surprisingly rapid-retrograding drifts (see below).

4.2. Speeds on the retrograding current following STB segment A

[Note: In this section, speeds are westward (retrograding) rather than eastward (prograding) as elsewhere. We usually specify 'rapidly retrograding' to make this clear.]

Background is given in **Appendix A**. This record is now continued from 2019 to 2023, speeds are listed in **Table 1** and zonal drift profiles are charted in Fig.27 [*dark blue-black squares*].

After the dramatic arrival and transformation of the STB Ghost in 2018 Feb., it generated a very dark STZB f. the regenerated Segment A (not resolved into individual spots), and several dark spots retrograded even further f. it with DL2 ~ +19 deg/30d (up to 2018 May). But it shrank rapidly and ceased emitting spots by early 2019. We did not find particularly fast-retrograding spots after this collision, from 2018 to 2020.

The next reinvigoration of Segment A occurred in early 2020 with the arrival of the STB Spectre, as described in Section 3.1 above. But as most spots f. Segment A from 2020 to 2022 had modest speeds, DL2 < +20, they did not provide clear evidence for an effect of this reinvigoration. In 2020 and 2021 there were a few spots with unprecedented fast-retrograding speeds here (though most spots had modest speeds, DL2 < +20), but they could be due to the residual STBs jet of the STB Spectre along which they ran. One spot in 2020 had DL2 = +69 (decelerating), and another further f. had DL2 = +68 alongside the Spectre then rapidly slowed down to +24 as it passed the f. end. Several very fast-retrograding spots f. Segment A in 2021 had DL2 up to at least +63. [See section 3.1 above, inc. Box.] In 2022 there was one with DL2 = +45 (31.9°S) in the Sf. tail of Segment A.

Only in 2023 did numerous fast-retrograding spots reappear in the Sf. tail, although by this time Segment A was very long and did not appear to be specially active. The numerous scattered points in the ZDP include spots in the 'linker' between Segment A and the Sf. tail, and some spots did run continuously through both, past AWO-b; but most spots can be resolved into two ZDP curves, sketched by shading in the chart (Fig.27). One curve is typically blunt with peak speed DL2 ~ +12, mainly spots in the linker; the other is faster-retrograding with peak speed ~+30, similar to the Cassini ZWP although slightly broader, for spots in the Sf. tail proper.

The reason for the variable speed of the STBs retrograding jet thus remains unclear. Rapidly-retrograding spots have appeared several years after some reinvigorations of Segment A, but it is not clear whether the reinvigoration from 2020 onwards produced them, as the few rapidly-retrograding spots seen from 2020 to 2022 may have had other causes, or some may have been unusual outliers. Moreover, when few spots were recorded by JUPOS, this may not always represent a low level of activity, as it could be due to variations in their visibility. We wonder whether the well-populated fast-retrograding ZDP in 2023 could represent a new normal state f. long STB segments in the new regime that has developed since 2020 – but it has not been repeated in 2024/25.

4.3. Small AWOs in STZ

One small AWO, here designated 'AWO-b', existed from 2018 March to 2023 Nov.
It formed in 2018 March at the f. end of the chaotically transforming STB Ghost, probably derived from the Ghost's recirculation loop and mergers of various small dark spots (vortices?) [2018 Report no.6, Figs.11 & 12]. [It was not the same as one seen at the f. end of the small Segment A before the Ghost collided with it in 2018 Feb; this apparently did not survive the transformation. See Ref.R3, esp. Figs.3&4.]
For the rest of 2018 this very small AWO was methane-bright and embedded in the dark STB Band f. the rejuvenated Segment A, and it was very likely the same as a well-tracked AWO in 2019 (methane-bright, with dark rim, near the f. end of the STZ Band). In 2019 it merged with AWO-c and AWO-d (see below). It encountered the P-Spectre some time around 2019 July, and accelerated to the same speed. It was still adjacent to the P-Spectre in JunoCam maps at PJ23 (2019 Nov.3), PJ24 (2019 Dec.26), and PJ25 (2020 Feb.17) (Figs.7,9,10). It reached its minimum distance f. BA at PJ25, and remained in contact with the f. end of Segment A thereafter. Thus its arrival at Segment A reduced its DL2 from -22.3 (mean, 2019 Aug. to 2020 Feb.) to -9 (2020 Feb.-April), and it moved away from BA, having grown larger in Feb. and very bright.
AWO-b is shown close up in JunoCam Figs. 9 & 10 & 23 ('STZ AWO'). In mid-2020 it had lost its dark rim and was only weakly methane-bright, and although both aspects recovered later in that year, during 2021 and 2022 it had no dark rim and was only weakly methane-bright. It remained at the f. end of Segment A until early 2023, then it became separated from the main Segment A by a short 'linker'. In 2023 it was not methane-bright [e.g. PJ50 map]. It disappeared in 2023 Nov. (in amateur images) but was still present (though not methane-bright) in HST images on 2024 Jan.6.

Other small AWOs were short-lived, as follows:
(c) 2019 March only. On 2019 April 1 this tiny oval merged with AWO-b, due S of the GRS; the merger can be seen in the GRS animations [2019 report no.4] (& in the PJ19 map).
(d) 2018 Oct. to 2019 Sep., ~30-->40 deg. f. BA, at f. end of Segment A (JunoCam maps; not visible on JUPOS chart until 2019 May, when it acquired a dark rim). It was near the irregular p. end of the STZ Band. It probably merged with AWO-b on 2019 Sep.20, at the p. end of the STB Spectre.
(e) 2021 May-Oct.
(f) 2021 April to 2023 Oct. First recorded alongside the GRS. From 2021 Nov. it remained near the Sp. edge of Spot 8, trapped between Spot 8 and the smaller cyclone p. it.
(g) 2022 June to 2023 Jan. Between BA and WS6, a small dark spot in the STZ latitude developed a bright centre in 2022 May, turning into a small, dark-ringed AWO. It gradually became methane-bright from July onwards, and was notably so since Sep. [Ref.14a].

There was also the small anticyclonic oval at the f. end of the STB Spectre in 2019-2021, sometimes seen as an AWO (see section 3.1 above).

5. Zonal slow current, Zonal drift profiles (ZDPs) & Zonal wind profiles (ZWPs)

5.1. South Temperate Current (STC)

The STC is the zonal slow current for the domain, i.e. the speed range that is typical for substantial features within it. From the 1950s to the 1980s, the mean STC speed was dominated by three large AWOs and other features tended to have similar speeds [Ref.S1]. In recent decades, oval BA typically moved more slowly than the cyclonic structured sectors that repeatedly arose and caught up with it [Refs.R1-R3], so there were multiple speed ranges within the STC, and this was still the case with the diverse drift rates up to 2019. But from 2020 March onwards, after the P-Spectre contacted Segment A, the drift rates have been more steady and similar.

We have measured the drift rates for the main features from the JUPOS charts, as listed in **Table 2**. The means across the whole time-span 2020-2024 are given below. They are calculated in two ways: (i) as the average of mean speeds measured within and between apparitions, over intervals of several months; (ii) as the overall rate over several years. From (ii), the average of the different features is DL2 = -16.3 (±1.0, SD) deg/30d, or -16.2 when time-weighted, which we take as the best average. The values are similar for BA (-17.2) and the cyclonic structured segments (-15.4 to -17.3); only the f. end of Segment A (expanding rather than contracting as previously), and AWO-b which was associated with it, are slightly slower with DL2 ~ -15. (Notably, the f. end of Segment A has the most stable drift of any feature, since the P-Spectre contacted it: -14.5 (±0.5, SD) apart from just two intervals of ~2 months each, when it moved 3 deg/30d faster for no obvious reason.)

Mean speeds (DL2, deg/30d), 2020-2024			
	Method:	(i)	(ii)
BA		-17.4	-17.15
AWO-b		-14.4	-14.75
F-Segment A*		-14.5	-15.2
Spot 6		-17.4	-17.15
Spot 7		-15.6	-16.3
P-Segment G*		-17.6	-17.3
F-Segment G		-16.3	-15.4
Spot 8*		-14.7	-17.0
Mean		**-16.0**	**16.3**
SD		1.0	1.0
*omitting some extreme values			
Overall (time-weighted) mean:			**-16.20**

*omitting some extreme values with method (i)

This mean DL2 -16.2 is similar to that of the STC from 1880-1940 (range of apparition means -11 to -19) [Ref.S1], and the f. end of dark turbulent STB when it revived from 1994 to 2000 (-15.5 --> -14.5: Ref.R4) and STB structured sectors from 2001 to 2018 (mean for 2001-2012 was -16.7) [Refs.R1-R3] (see **Appendix A**). So this seems to be the most consistent speed for the STC. The epochs when the major anticyclonic ovals typically drifted faster (1940s to 1960s) or slower (1980s to 2010s) [Ref.S1 & Refs.R1-R4] may have ceased, as BA has aged. From 2020 to 2024, oval BA has been moving with the same STC speed as the cyclonic structured spots and segments. This long-term behaviour is consistent with our findings for northern domains, where the cyclonic circulations control the zonal slow current, while the AWOs move sometimes at the same speed or sometimes differently [Refs. R4a&b] – although in those domains the AWOs tend to move faster, whereas in the S. Temperate domain BA has usually moved slower.

5.2. Zonal drift profiles (ZDPs)

The ZDP is the relationship between longitudinal drift rate and latitude for coherent spots. For the smallest spots, it converges with the ZWP, which refers to the smallest cloud features as measured by spacecraft; but for larger spots it can be different. In many domains, while small prograde spots follow a ZDP indistinguishable from the ZWP, retrograde spots follow a 'blunter' ZDP, i.e. their retrograde speeds are less than those of the ZWP. We previously observed this for some features in the S. Temperate domain.

Also, we previously showed from spacecraft ZWPs that the STBn jet and often the STBs jet were faster in structured sectors [Refs. R1&R3]. Distortions of the ZWP were suspected in some sectors where we found altered ZDPs, viz. f. Segment A [see above] and f. pale circulations such as the STB Remnant & Ghost & Spectre [see above].

For the five apparitions considered in this review, a full JUPOS analysis of this domain had previously been done only for 2021 [Ref. R13]. Now, co-author G.A. has analysed the JUPOS data for all these apparitions, taking drift rates and latitudes over shorter intervals than in **Table 2** for greater precision, and the resulting ZDPs are presented in Figure 27. The Cassini ZWP [Ref. P5] is shown for reference. Results pertaining to particular features have been summarised above, and here we give a more complete overview.

Cyclonic circulations: The pale cyclonic precursors of DS6 and DS7, in 2019, were close to the ZWP, as were some other small cyclonic white spots. But once the larger circulations had developed, their tracks were generally S of the ZWP, fitting a typical blunt ZDP: DS6 and DS7 (2020), Spot 8, the p. and f. ends of Segment G (the former DS7), and the f. end of Segment A. There was one exception: WS6 in 2021, which usually fell on or even slightly N of the ZWP, for unknown reason. At the f. end of the STB Spectre, in 2020, there were several rings and dark spots on the anticyclonic side, and they all fell close to the ZWP. (They did not reproduce the southerly displacement of the ZDP that was observed for spots Sf. the STB Remnant in 2004-07 [see section 3.1 above])

Oval BA and smaller AWOs [see section 6 below]: Oval BA previously followed a ZDP blunter and N of the Cassini ZWP, which shifted closer to the ZWP as BA shrank [Refs.R1 & R2]. In 2019-2023, it was usually on a similar ZDP, although sometimes actually on the ZWP; see Fig.28. The ZDP for oval BA is significantly closer to the Cassini ZWP in 2019-2023 than it was in 2011-2015 (see Section 6).

The next-largest oval, AWO-b, sometimes followed a similar blunt ZDP to oval BA, but otherwise, smaller AWOs fell on the ZWP. In 2022/23 [Ref.R14], the three small AWOs all oscillated, apparently being trapped by adjacent features, and they oscillated in latitude as well as in drift rate.

Next we give an overview of the ZDPs for smaller spots all around the domain, with reference to the major sectors present in 2021-2023, in order of increasing longitude; compare with the maps (**Appendices**). The STBn jet is deferred to Section 7. (Some preliminary results were discussed in [Ref.R13].)

i) Segment A

We had not previously recorded spots moving along the edges of Segment A except when it was being reinforced by transformation of a colliding sector. But in 2022 and 2023 we recorded dark spots on its S edge [*purple points in Figs.27 & 28B*], following a ZDP S of the Cassini ZWP; and some on the N edge, which travelled slightly faster than others in those latitudes (27-28°S).

ii) Sf. tail of Segment A (dark spots)

[*Dark blue-black squares in Figs.27 & 28B*] These spots gave complex results and were discussed in sections 3.1 (including Box) and 4.2 above. The ZDPs since 2018 do not correlate clearly with the reactivations of Segment A by collisions. Although the fast-retrograding speeds in 2021 and 2022 could be caused thus, they could also be due to the residual STB Spectre current. And the abundant fast speeds in 2023 do not seem to have any visible explanation.

iii) Spot 8 and undisturbed surroundings

Spot 8 followed the blunt ZDP as noted above [*ringed blue points in Fig.27*]. A few southward-displaced spots were observed Sf. the new Spot 8 (2021, 2022), suggesting similarity to the altered ZDP previously seen Sf. some quiescent structured sectors [see Box in section 3.1, or Ref.R3].

iv) Segment G

Speeds are not usually measured within turbulent STB segments, but in 2023 Sep-Nov. we recorded extremely fast speeds on the STBn jet along the N edge of Segment G (see Section 7 below).

v) Sf. tail of Segment G (dark spots)

[*Green diamonds in Fig.27*] Three consecutive apparitions gave puzzlingly different profiles. In 2021, there were many retrograding spots and they followed the ZWP, clustering at its peak. (Previously, such fast-retrograding speeds only appeared in the Sf. tail of Segment A, when it was visibly disturbed, so it is notable that the STBs jet behaves in the same way in this newly developing structured segment.) In 2022 there were two spots, well S of the ZWP. But in 2023. there were many more spots and they had more modest speeds fitting a blunt ZDP.

The SSTBn (S2) jet:

This jet was covered in our long-term S2 domain report up to 2023 [Ref. S2]. It was still a strong jet according to ZWPs, but had only a few spots on it during these years (including one in 2020 July mentioned in section 3.1 above). But more were tracked in late 2023 and 2024.

In late 2023 we recorded many SSTBn jet spots with a well-defined ZDP [Fig.27]. The mean peak speed was DL2 = -123.4 (±8.9; N=19), u_3 = +45.8 (±3.6) m/s, at 35.8 (±0.3)°S, with individual tracks ranging up to DL2 = -136; all consistent with the recent acceleration of this jet reported in [Ref. S2].

5.3. Zonal wind profiles (ZWPs)

(1) Zonal wind profile (ZWP) from Hubble data, 2019 June 26-27

Marco Vedovato produced ZWPs from the Hubble OPAL images on 2019 June 26-27 [Ref.R9], covering two overlapping sectors of interest:

Sector 1: L3 = 205-305 (p. GRS, inc. part of STB Spectre)

Sector 2: L3 = 130-240 (further p. inc. Segment A and oval BA)

Both sectors included the S.Tropical Band, visibly disturbed at the time, but there was no perturbation of the ZWP there. Both also included the short Sf. tail of STB Segment A. The ZWPs covering relevant latitudes have been replotted for the present review (Fig.29). The jet speeds are as follows:

ZWPs from HST images on 2019 June 26-27, by Marco Vedovato: Peak speeds of jets																
He did ZWPs separately from 2 rotation pairs in Sector 1, & one rotation pair in Sector 2, all in R & G & B.																
The red channels did not give results at all latitudes so are not used here.																
(A)	**Mean peak values from all sets (table below):**															
		S2 jet				**STBs retro jet**				**STBs jet (S comp.)**				**STBs jet (N comp.)**		
		Lat.(g)	u3	DL2		Lat.(g)	u3	DL2		Lat.(g)	u3	DL2		Lat.(g)	u3	DL2
Sector 1	Mean	35.6	44.7	-119.6		32.2	-30.9	66.4		29.2	36.0	-92.2		25.4	32.3	-82.4
										(but absent on 2nd rotation)						
Sector 2	Mean	35.7	44.1	-118.2		31.6	-18.0	35.0		28.4	29.4	-76.4		26.1	38.3	-95.5

This was a complex region, and more granular analysis would be needed to assign exact speeds to particular features. The variability of the S. Temperate currents contrasts with the constancy of the S2 jet (analysed in Ref.S2). The STBs retrograding jet was exceptionally strong in Sector 1, possibly representing the strong flow around the STB Spectre; the STBn jet (S. component) was also strong there, although only on one of two rotations. Both these jets were only moderately strong in Sector 2, covering STB Segment A, though still faster than previously recorded in quiet unstructured sectors.

(2) ZWP from amateur images, 2023 Nov. to 2024 Jan.

Grischa Hahn produced ZWPs from four image pairs taken ~10 hours apart from Eric Sussenbach and Chris Go [Ref.R16]. These were on 2023 Nov.26, covering the sparse Sf. tail of Segment A but not the structured sector itself; and on 2023 Nov. 27, Dec.10, and 2024 Jan.10, all of which included part of Segment A. Because ground-based wind speeds are highly sensitive to timing errors, the zero-speed baselines were adjusted to give the best fit globally to an earlier Hubble profile. The ZWPs covering relevant latitudes have been replotted for the present review (Fig.30). The results are all in line with previous data showing faster jet speeds alongside structured sectors, as follows.

STBs jet: This retrograde jet was fast in two of the three ZWPs which covered STB segment A, especially on Dec.10 (DL2 = +76 deg/30d ; u_3 = -34 m/s; 32ºS), but moderate on Nov.26 from an unstructured sector (DL2 = +41; u_3 = -19 m/s).

STBn jet: The Nov.26 ZWP, which does not cover a structured sector, shows only the northern sub-peak, at u_3 = +35 m/s. The other three ZWPs all include part or all of STB segment A, and show both sub-peaks, averaging +39 m/s for the northern and +43 m/s for the southern.

ZWPs from images by E. Sussenbach & C. Go, 2023/24: ZWPs by G. Hahn
Latitudes and speeds of jet peaks

	S2 jet			**STBs retro jet**			**STBs jet (S comp.)**			**STBs jet (N comp.)**		
	Lat.(g) (deg.Sg)	u3 (m/s)	DL2 (deg/30d)	Lat.(g) (deg.Sg)	u3 (m/s)	DL2 (deg/30d)	Lat.(g) (deg.Sg)	u3 (m/s)	DL2 (deg/30d)	Lat.(g) (deg.Sg)	u3 (m/s)	DL2 (deg/30d)
Nov.26	**35.9**	45.0	-115.7	31.3	-19.4	41.1		*none*		26.2	35.4	-88.2
Nov.27	**35.6**	47.3	-124.6	32.3	-18.4	37.5	29.1	38.6	-97.7	***26.1***	40.3	-99.7
Dec.10	**35.7**	42.3	-112.3	32.0	-34.4	75.8	***28.5***	45.0	-112.2	27.0	36.0	-90.4
Jan.10	**35.6**	46.5	-124.4	32.2	-27.0	57.3	28.1	45.7	-113.6	***26.6***	39.7	-98.6
Mean	**35.6**	**45.4**	**-120.4**	**32.2**	**-26.6**	**56.9**	**28.6**	**43.1**	**-107.8**	**26.6**	**38.7**	**-96.2**
SD (n=3)	0.1	2.7	7.0	0.2	8.0	19.2	0.5	3.9	8.8	0.5	2.3	5.1

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6. Oval BA

(i) Drift rate:

From 2001-2015 [Refs.R1 && R2; see **Appendix A**], BA alternated between typical drift rates in a slow range when Segment A was quiet (DL2 = -10.4 to -11.8 deg/30d), and a fast range when Segment A was dark and turbulent STB (DL2 = -14.2 to -16.5). From mid 2016 to early 2018, before the impact of the STB Ghost, oval BA had a mean speed in the slow range: DL2 ~ -12.0 (2016 June – 2018 March), with an oscillation of period ~2-3 months [Ref.R3].

Its drift rate from 2018 onwards is shown in Fig.31 and listed in **Table 2**. It underwent a modest acceleration into the fast range in 2018 following the impact of the STB Ghost, then much greater acceleration in 2020 following the impact of the STB Ghost, which has been sustained up to 2024.

In 2018 April, as the STB Ghost transformed into an expanded turbulent STB Segment A, oval BA began a series of progressive though irregular accelerations, beginning with DL2 ~ -12.8 (2018 April-June), and continuing into the fast range, reaching a maximum speed of -17.1 (2019 Jan.-March) , even faster than usual in these circumstances. It suddenly decelerated again in 2019 March, and then had mean speed of -14.2 (2019 March-Aug.), slackening to a mean of -13.6 over solar conjunction (2019 Oct.—2020 Feb.).

Then in 2020 March, soon after the arrival of the STB Spectre, it accelerated suddenly and dramatically – within less than 3 weeks – to DL2 = -18.7 (2020 March-April). This was the initial fast phase of an oscillating track, starting with a period of 2-3 months, with a mean DL2 = -17.3 (2020 March-Dec.). This continued for several years, with the period generally lengthening to as much as ~6 months, including several rather long fast phases with DL2 = -18.6 to -18.8 (2020 Aug-Sep.*; 2021 July-Sep.; 2022 Jan-Apr.*; 2022 Nov-2023 Feb.) [*these were while BA was passing the GRS]. *The overall mean speed was DL2 ~ -17.2 (2020 April—2023 July).* Since 2023 Feb., the average speeds have been less extreme (though still within the fast range), and a 2-3-month oscillation has again often occurred. Mean DL2 has been -16.2 (2023 May—2024 Feb.), -16.4 (2024 Sep.—2025 March).

Throughout this period of fast speeds (2020-2025), Segment A has been dark and expanding and visibly turbulent, at least in the sector immediately f. BA.

On the JUPOS summary chart, note that oval BA travelled particularly fast on 3 of its 4 passages past the GRS, as is usual, but quite slowly on the fourth. (We do not see any changes in activity of Segment A that might explain the discrepancy. It may be that BA's oscillation in speed could override any local influence.)

BA's latitude varied with its speed, as usual, following a consistent ZDP as described in the previous section. BA's ZDP has continued to migrate southwards ever since it formed in 2000, getting ever closer to the spacecraft ZWP [Ref.R1]; the separation was 0.4-0.5° in 2011-2015 [Ref.R2], ~0.4° in 2016-2018 [Ref.R3], and 0.2-0.3° in 2019-2023 [see Fig.28].

(ii) Appearance:

Views of Oval BA are in the maps in **Appendices B & C,** and in Figs. 7 & 25 (amateur), Figs. 8-10 & 17 (JunoCam), and Fig.5 (HST).

Oval BA was orange in early 2018, then fading in July & August, and almost white in Oct. The fading was also shown by JunoCam at **PJ17** on 2018 Dec.21. Throughout 2019 & 2020 it appeared white or almost white, although the best images showed a slight residual fawn tint, & it had a narrow dark rim.

In 2021 (at least from April onwards) it had recovered slight colour; it was 'off-white', with a slight warm tinge throughout the apparition (stronger in JunoCam and Hubble images). Its dark rim faded away in May but reappeared during June. Throughout 2022, it was still off-white with a 'warm' tint due to a slightly reddish internal annulus. It still had a modestly dark grey-brown rim.

In 2023, from June to early August, BA was conspicuous, white with a dark rim; but then it became duller and lost its rim, so from late Sep. onwards it had virtually no contrast.However, v-hi-res images still revealed the reddish internal oval contrasting with a bluish-grey outer part, esp. in Nov. as it was passing the GRS (Fig.25). In Dec. the red colour intensified further. It was then moderately strong reddish throughout 2024, before & after solar conjunction.

Size: The dimensions of Oval BA have been measured from Hubble maps by J.R. (Fig.32), giving a mean of 7.6° (±0.3°) x 5.5° (±0.4°) from 2015-2022. In some years there was a distinct inner reddish oval, with mean size 6.1° (±0.4°) x 4.5° (±0.5°) from 2016 to 2024. So it has not shrunk further since 2012 when the mean length was 6.8° [Ref.R1, Table 3].

(iii) Circulation from JunoCam:

Oval BA was well imaged by JunoCam at **PJ17** (2018 Dec.21), enabling us to measure its internal rotation [see our PJ17 report Appendix 1]. The central part had the fastest angular rotation (9.9 deg/hr), as the spiral streaks suggest. The fastest winds were in the formerly-orange annulus, averaging 109 (±8) m/s in the north and 142 (±8) m/s in the south. The speeds could be up to 18% higher at the outer edge of this annulus.

JunoCam also got close-up views of oval BA at **PJ24** (2019 Dec.26: Fig.8; similar to PJ17), **PJ26** (2020 April 10; Fig.10; also with animation), and **PJ47** (2022 Dec.14-15: emerging from the terminator).

7. The STBn jet

(See the **Appendices** for background information, sets of ground-based and JunoCam maps, and synoptic JUPOS charts, & **Table** 3 for jet speed measurements.

(i) Chronicle of jet spot activity

In 2018 March, after the STB Ghost transformed into a newly turbulent Segment A, STBn jet spots again appeared p. BA as expected. Although the disturbance on STB(N) was dense, only a few distinct spots could be tracked within it, in 2018 May-July, DL2 = -87 (n=3) and -74 (n=2), at 29 --> 28°S [Ref.R3]. Few were tracked as the new STB(N) was a continuous dark band, up to 2018 Dec. In early 2019, mainly in March, it faded so the outbreak had declined. There was only faint spottiness on STB(N) p. BA from 2019 April to Sep.

A different, atypical form of STBn jet spot activity developed from 2019 April when a very dark S. Tropical Band (STropB) emerged on the p. side of the GRS, elongating rapidly. On its S side, there were sometimes striking chains of dark spots in May and June – looking like wave-trains, with spacings ranging from 4.0 to 6.6°, though perhaps just chains of disturbances [Report 2019 no.6]. They were centred at 26.4°S, with mean DL2 ranging from -79 to -104 deg/30d, not correlated with the spacing of spots. So the speed and latitude were typical for the north component of the STBn jet, but this was an unusual outbreak unconnected with STB activity. The dark spots may have been formed by instability on the STBn jet where it squeezes past the GRS, enhanced by concurrent 'flaking' disturbances on the periphery of the GRS, and by the STB Spectre alongside.

Returning to the chronicle of typical STBn activity, p. BA, in 2019 Sep., a volley of dark jet spots appeared; a similar chain was present at PJ24 (2019 Dec.) (Fig.8), and after solar conjunction, this outbreak was well under way at the start of 2020 Feb. But it faded in late March, and ceased in April [Ref.R10] & (Fig.7). From PJ26 (2020 April) up to mid-Oct. there was no significant STBn activity p. BA, and only a few spots were tracked, although BA was moving fast throughout this period. In late Oct. and on Nov.6-9 there were volleys of spots just p. BA, but none before nor after.

In 2021 (April-July), there was an extensive dark STropB which streamed past BA, and spots and shading p. BA due to the expanding Clyde's Spot (DS7) (see below), but WS6 just p. BA potentially blocked any STBn jet activity, so the situation was complex (see Fig.17). It remained so from 2021 Sep. onwards, into 2022, but the STropB and other features there were less dark, and JunoCam did not view the region closely. The JUPOS chart shows STBn jet spots arising just p. BA from 2021 July-Sep. and from 2022 June-Aug., so the activity was probably continuous until late 2022 when there was little space left between BA and DS7.

Meanwhile, **Clyde's Spot (DS7)** produced a few STBn jet spots in 2020, and again from 2021 April onwards. From 2021 Sep., when (as **STB Segment G**) it had subsumed the F-Spectre, it became a major source of spots with more and more of them being tracked by JUPOS. This activity was intense throughout 2022, 2023 and 2024 (e.g. Fig.20). On the JUPOS chart (**Appendix D**) and in Fig.20, note that they were not blocked at Spot 8, but many of them terminated at the GRS.

In 2022, they were emerging p. STB segment G, at ≤~27.2°S, but then drifting north even across the usual latitude of the STBn jet, and mostly travelling at 25.6°S, which is an unusually low latitude (seen at PJ42 & PJ43). In 2022 Oct-Nov. this sector changed as the STropB extended around the planet, masking STBn jet spots in a dusky, streaky band; but JunoCam's PJ46 images confirmed that jet spots were still present within the dusky shading. In late Dec. (as the STropB faded away) and thereafter, dark jet spots reappeared p. Segment G like before.

Another source of STBn jet spots was within Segment A itself, in 2023 August onwards and extensively in 2024, at 27.4 (±0.5)°S. Few if any of these emerged p. BA.

(ii) Correlation with activity of Segment A?

On timescales of half a year or more, the period 2018-2023 has sustained the correlation between the turbulence of Segment A, the speed of BA, and activity on the STBn jet p. BA. Most notable was the absence of STBn jet activity for most of the time from 2019 March to

2020 Feb. when BA was travelling rather slowly, up to the arrival of the STB Spectre in 2020 Feb. But then, despite the reinvigoration of Segment A, STBn activity p. BA did not revive thoroughly for at least a year. From 2020 onwards, while Segment A was continually turbulent and BA always had a very rapid drift with oscillations, there did not seem to be month-by-month correlation with the waxing and waning of STBn jet activity. From 2023 onwards, it is difficult to assess STBn jet activity because of Segment G closely p. it. (The very rapid STBn jet spots alongside Segment G in 2023 did not come from Segment A, in view of their high latitude.)

(iii) Speeds of spots and jet, & ZDPs

The speeds and latitudes of the STBn jet spots are shown in **Table 3** and Figure 27 (right-hand side). The results are generally consistent with the previous trends (**Appendix A**). They do not follow the average ZWP, and seldom move with the peak speeds of the jet as seen in ZWPs. Across all five apparitions, most jet spots have DL2 between ~-70 and -90, between ~25.5°S and 28°S. They always span a large latitude range between the two sub-peaks of the jet, partly attributable to their habit of drifting northwards between the jet components without change of speed, which we often observed. Speeds close to the spacecraft jet peaks were only observed for exceptional groups of spots, viz: some of the STropB 'waves' in 2019, and some of the very scattered spots in 2021 (some of them likewise N of the northern sub-peak, others being p. the new Spot 8); and a group of spots on the N edge of Segment G in 2023.

Within the bulk of the spot populations, there were some variations. **In 2021**, average speeds of DL2 ~ -84 and -79 p. BA/WS6 and p. DS7 (Segment G) were typical of the early stages of such outbreaks, though with large, random scatter from 26.0 to 28.3°S (and no significant differences in ZDP between longitude sectors) [Refs.R12 & R13]**.** **In 2022,** the massive outbreak of dark spots on the STBn jet continued, emerging p. Segment G, still with comparatively slow speeds close to DL2 = -77 (±5), despite drifting a long way north to ~25.6°S.

In 2023/24, these numerous spots p. Segment G had changed their behaviour [Ref.R15]: as shown in the colour-coded tracks in the JUPOS charts (**Appendix D**) and in the ZDPs (Fig.27). They appeared at 28.1 (±0.4) °S, at the p. end of segment G, with rather slow speeds averaging DL2 = -62 (±9.6) (N=27), and then accelerated and drifted north. At medium latitudes (26.7 to -27.6°S), most were moving with DL2 ~ -80 to -90 (significantly faster than in 2022, consistent with the accelerations seen in previous spot outbreaks). They typically moved N in the range from ~28°S down to 26°S, without further change of speed, as is common. But the fastest speeds were attained at the N edge of the jet (25.8 to 26.6°S), with DL2 ~ -89 (**Table 3**). And exceptionally this year, many of these spots then crossed the north component of the jet and decelerated while moving down into the 24-25°S range. This far northward drift had not been common in other apparitions, but had occurred in 2021 and 2022 to some extent. As they drifted north in the STropZ, their ZDP largely paralleled the Cassini ZWP; they ran ~0.4° north of it (as in 2022), but this does not seem to indicate any fundamental change to the ZWP as similar divergences have been seen elsewhere.

Also in 2023/24 [Ref.R15], there were other distinct classes of STBn jet spots, alongside the N edges of segments A and G, rather than p. them as usual. Along the N edge of segment A, they had an unremarkable mean DL2 = -86 deg/30d, at 27.4°S (**Table 3**). But along the N edge of Segment G in 2023 Sep-Nov, very remarkably, they had mean DL2 = -120.3 (±10.5) deg/30d, at 29.4°S, and the fastest pair had DL2 = -132.7 and -143.3 deg/30d [*not shown in JUPOS chart*]. These confirm that the S component of the STBn jet is strong alongside STB structured sectors, and the value of -143 deg/30d (u_3 = 58 m/s) is equal to the mean speed on the N fringe of the quiescent STB Ghost measured from Hubble maps in 2017, which is the fastest speed ever recorded in the STBn jet [Ref.R3 Appendix A].

(iv) JunoCam images of the STBn

The N component of the jet, around 26.5°S, normally shows high-amplitude wave patterns in JunoCam images – visible in most of the JunoCam maps presented herein (e.g. Figs.8-12 & 33). An undisturbed sector of the STBn jet was viewed at **PJ28** (2020 July 25) (Fig.12), and an animation from hi-res maps of these images around the F-Spectre gave the impression that the northern division of the jet does not run straight, but deviates along the waves. At **PJ32** and **PJ45**, JunoCam viewed a sector flanked by the long turbulent Segment A and a long dark STropB, and the narrow whitish space between them was particularly chaotic (Figs.23 & 24).

JunoCam had many good views of STBn jet spots from 2018-2022. Similar spots had been viewed by Voyager 2 (1979) and by Hubble (2014 April 21), and did not show significant vorticity. But some of the JunoCam images have suggested weak vorticity, which may be variable in keeping with the variable ZWP across this complex jet. Certainly they never show the strong anticyclonic structure of spots on other strong jets as revealed by Voyager [Ref. S1].

At **PJ24** (2020 Feb.2) (Fig.8), the STB(N) p. BA consisted largely of dark spots, showing weak anticyclonic structure. This is surprising as such spots generally fall on a weakly cyclonic gradient – possibly because this was only a short distance p. BA, so the spots were emitted as anticyclonic vortices, and their vortex strength could weaken as they prograde.

PJ36 (2021 Sep.2) showed a long series of STBn jet eddies and spots prograding from the new Spot 8 outbreak (Fig.18). **PJ38** (2021 Nov.29) & **PJ39** (2022 Jan.12) again showed Spot 8 (now a mini-FFR transforming into a dark oval), with STBn jet spots streaming past it (Fig.18), but these had come from the region of DS7/Segment G, now very active. These spots were brown, rather diffuse, and with only slight signs of vorticity. **PJ41** (2022 April 9) likewise showed Spot 8 with an ongoing outbreak of STBn dark spots that had come from Segment G, here with streaks suggesting weak anticyclonic vorticity (Fig. 19).

PJ37 (2021 Oct.) again showed a series of six roughly circular spots that developed where the jet was disturbed by the new Spot 8 outbreak in August. They all appear to consist of translucent brown haze, overlying the tangled white streaks that are seen along this latitude, with no evident vorticity (Fig.33).

PJ42 (2022 May 23) viewed in close-up some of the many jet spots from STB segment G, travelling to an unusually low latitude. Here we see narrow streaks curving around them for the first time (Fig.19, right). Most of these streaks (esp. on the left of the figure) could represent waves on the flank of the jet, perhaps entraining the spots, rather than intrinsic vorticity, whereas one on the right does contain narrow concentric arcs (indicated by red arrows), probably lines of pop-up clouds.

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Those starting 'P' are to professional papers. Those starting 'R' are to our reports on the S. Temperate domain, posted on our web site, including EPSC abstracts. Those starting 'S' are to other substantial reports of ours.

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