Jupiter in 2001/2002: Part I

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A report of the Jupiter Section (Director: John H. Rogers)

2001/2002 was the most northerly apparition of the jovian cycle, and it was again very well covered by CCD images from observers around the northern hemisphere. In addition to the usual description of the planet's weather systems in visible light, we give a brief account of features visible in ultraviolet and infrared (methane band) images, which reveal features in the high-altitude haze over Jupiter. The most obvious change on the planet was the breadth and redness of the North Equatorial Belt, following the broadening event in 2000. Together with a pale yellowish shading spread over the northern Equatorial Zone, this comprised the first significant colouration episode for ten years. As another typical consequence of the NEB broadening event, an array of small dark and white ovals developed within the expanded belt. There was also a trapped rifted region of NEB.

In the equatorial jet streams, JUPOS measurements of small spots showed unprecedentedly rapid and varied drifts, reaching the fastest speeds ever observed on both sides of the equator. In the South Equatorial Current, we confirmed that the speed of the jet varies with longitude relative to the South Equatorial Disturbance. In the North Equatorial Current, we found further evidence that the speeds are phase velocities related to the spacing of the projections, as small rapid projections cut across the tracks of the few remaining large dark projections.

High-resolution images enabled observers to track three mergers of pairs of ovals. First, in the NEB, came the merger of two dark 'barges'; then, in the S. S. Temperate region, the merger of two white ovals. The third merger was between smaller white ovals in the N. N. Temperate Zone. These events established characteristic differences between cyclonic and anticyclonic mergers, as we report elsewhere. Two other phenomena now confirmed as recurrent were the formation of a slow-moving anticyclonic ring preceding the GRS, and the tendency for high-latitude dark belt segments to turn red before fading away.

Introduction

Opposition was on 2002 Jan 01 at 06h UT, in Gemini, at declination 23°N. Jupiter (along with Saturn) thus made a fine sight high in the winter sky. Then in late April and May, Jupiter joined the other four naked-eye planets in a very rare conjunction in the evening sky as the apparition ended.

There were two occultations of Jupiter by the Moon, already covered in an interim report.[1] The first was a grazing occultation on 2002 Jan 26. Observers in northern England captured inspiring views of Jupiter looming beyond the lunar impact basins. Then Jupiter underwent a full occultation on 2002 Feb 23, which was also watched by several observers.

Interim reports on the apparition were given in the *Journal*.[2,3] A report on the apparition has also been published by the Association of Lunar and Planetary Observers.[4] Valuable interim reports were also made by the ALPO-Japan at <**http://www.kk-system.co.jp/Alpo/Latest/index.html**>, including whole-planet maps by H. Einaga, and a detailed report on the activity in the NEB.[5]

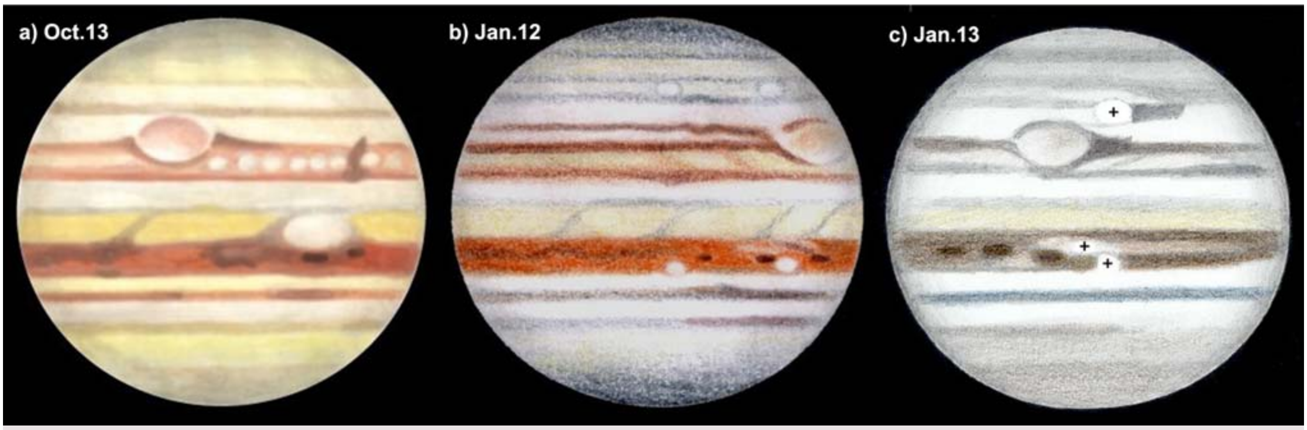

Figure 1. Colour drawings.
(a) 2001 Oct 13, 04h 45m, CM1=43, CM2=95 (Frassati). Note the GRS with the disturbed SEBZ f.; yellowish EZ(N), and broad reddish NEB.
(b) 2002 Jan 12, 22h 55m, CM1=327, CM2=38 (Frassati). Includes STropB, and NEB barges and portholes.
(c) 2002 Jan 13, 20h 15m, CM1=27, CM2=92 (Rogers). Symbol + marks bright white spots, viz. oval BA nearing the GRS, white spot Z in NEBn, and a mid-NEB rift.

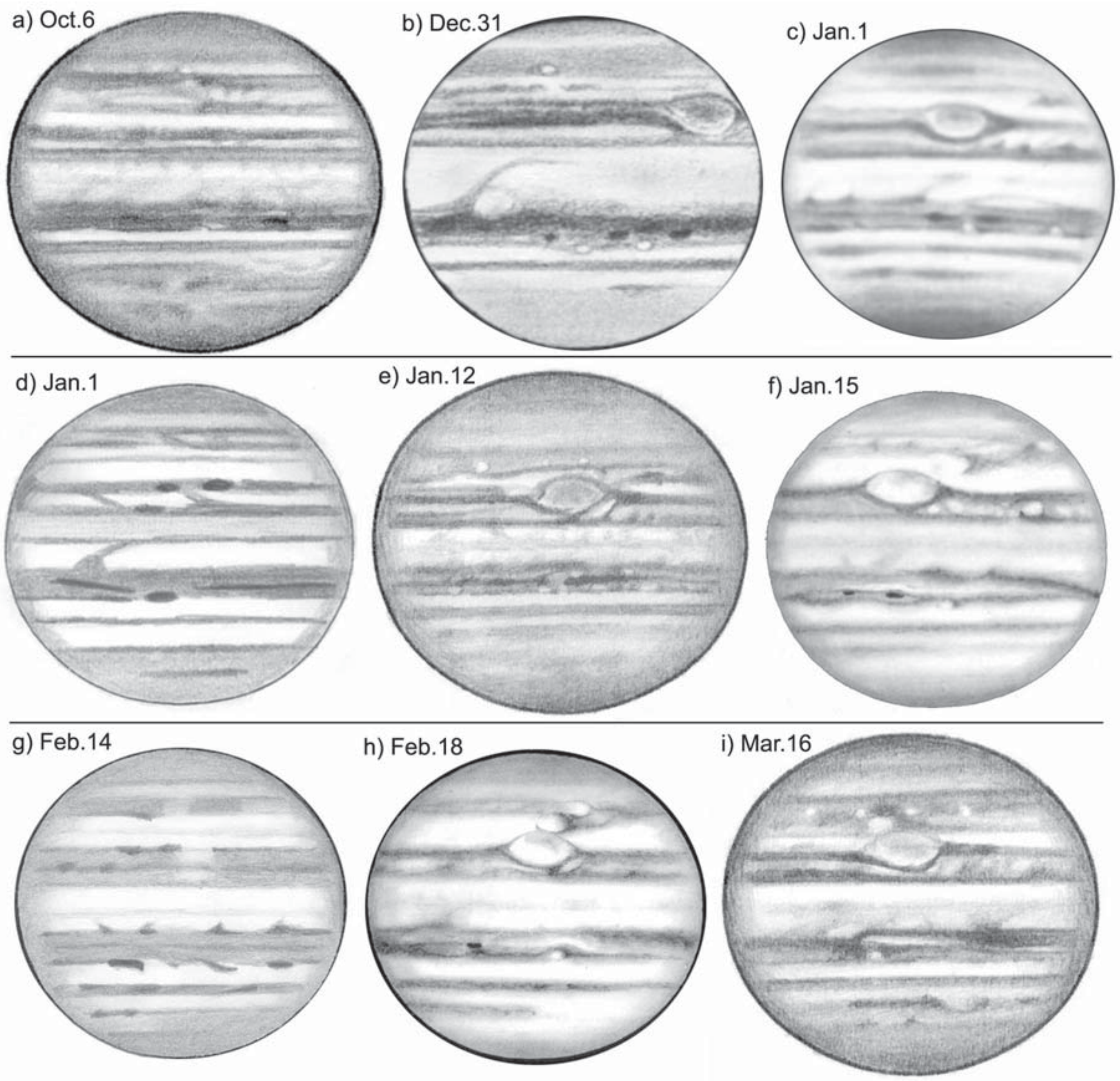

Figure 2. Drawings, 2001/2002.

Note the detail shown in the SEB and NEB in all drawings, especially dark barges and white 'portholes' in the NEB.

(a) Oct 6d 19h 55m, CM1=214, CM2=314 (Adachi). Shows the p. end of the dark section of STB on the CM, with detail to the south, and faint details in the EZ.

(b) Dec 31d 23h 23m, CM1=246, CM2=49 (Peach). Shows the GRS and the dark STropB emerging p. it.

(c) Jan 01d 00h 00m, CM1=270, CM2=73 (Gray). On the stroke of midnight. Shows the GRS and STropB, and oval BA approaching the GRS.

(d) Jan 01d 22h 20m, CM1=7, CM2=163 (Foulkes). Note the detail in the SEB.

(e) Jan 12d 14h 00m, CM1=0.5, CM2=75 (Adachi). Note the structure of the GRS, with oval BA approaching it. This also shows faint detail in EZ(S).

(f) Jan 15d 21h 51m, CM1=156, CM2=91 (Bullen). Shows oval BA approaching the GRS.

(g) Feb 14d 18h 40m, CM1=344, CM2=165 (McKim). Note the triple SEB and broad SSTB.

(h) Feb 18d 19h 40m, CM1=292, CM2=82 (Bullen). Shows oval BA in conjunction with the GRS, and NEBn white spot Z.

(i) Mar 16d 11h 20m, CM1=184, CM2=85 (Adachi). Shows oval BA passing the GRS with SSTB ovals to the south. Note the structure of the GRS and detail in the NNTB.

Table 1A. Visual observers, 2001/2002

Observer	*Location*	*Telescope*
Adachi, Makoto	Ohtsu City, Japan	310mm Newtonian
Bullen, Robert	Bognor Regis	216mm Newt.
Cicognani, Massimo	Collina (FO), Italy	
Colombo, Emilio	Cambio, Italy	150mm Newt.
Devadas, P.	Madras, India	350mm Newt.
Foulkes, Mike	Hatfield, Herts, UK	254mm Newt., 203mm S-C
	Tewin, Herts, UK	254mm S-C
Frassati, Mario	Crescentino, Italy	200mm S-C
Gray, David	Kirk Merrington, Durham, UK	415mm Dall–Kirkham Cass.
Heath, Alan	Long Eaton, Notts., UK	203mm S-C 250mm Newt.
Hernandez, Carlos	Florida, USA	203mm Klevtzov–Cass.
Horikawa, Kuniaki	Yokohama, Japan	
Macdonald, Lee	Newbury, UK	222mm Newt.
McKim, Richard	Upper Benefield, Northants., UK	410mm Dall–Kirkham Cass.
Mosch, Joerg	Meissen, Germany	Several OGs
Peach, Damian	*See CCD observers list*	
Rogers, John	Linton, Cambs., UK	254mm Newt.
Schmude, Richard	Barnsville, GA, USA	254mm Newt.

(S-C, Schmidt–Cassegrain). Some UAI members also contributed data: see footnote to Table 1B.

This report follows on from our three-part report on the 2000/2001 apparition.[6–8] Part II of the paper will appear in a future *Journal*.

Observations

Visual observations

Although many observers have now switched to digital imaging of the planet, a small but valued number continued to make visual observations in the form of drawings, visual transits, and colour and intensity estimates. Those who contributed visual observations are listed in Table 1A.

Many fine and accurate drawings were received from a few observers including Adachi in Japan and Bullen in the UK. Adachi generated 67 high-quality drawings, which compared very well to the CCD and webcam images taken by other observers. Frassati and Peach generated a number of colour drawings. Gray also experimented in the computer-aided generation of colour drawings, using Corel Draw, so that the digital values used for the drawing form a permanent record of the perceived colour.

Some observers made colour and intensity observations of the belts and zones, as summarised in Tables 3A and 3B. Visual colour observations of specific features are given in the descriptive text below. Heath continued with his long-term programme of visual intensity observations made both in integrated light and with colour filters (Table 3A).

Longitude measurements, by central meridian transit timings, were still made by some observers, especially by Horikawa in Japan (501 transits), and by Cicognani (271 transits) and others in Italy. The records of the Unione Astrofili Italiani were kindly provided for JUPOS analysis by Gianluigi Adamoli, UAI Jupiter Recorder.

Table 1B. CCD imaging observers, 2001/2002

Name	*Location*	*Meas.*	*Telescope*	*Camera*
Akutsu, Tomio	Horishima, Japan	2120	320mm Newt.	Teleris-2
Bernasconi, Andre	Milano, Italy	38	130mm OG	ST-5C
Bryant, Nigel	UK	56	250mm S-C	Starlight Xpress MX7C
Camaiti, Plinio	Torino, Italy (Cerrina Tololo Obs.)	580	280mm S-C	Philips ToUcam Pro
Chevalley, Patrick	Geneva, Switzerland	1315	150mm	Vesta
Cidadao, Antonio	Oeiras, Portugal	10122	254mm S-C & AO-2 adaptive optics	ST-5C
Coelho, Paulo S. A.	Montijo, Portugal	1430	203mm S-C	ToUcam Pro
Colville, Brian	Cambray, Ontario, Canada (Maple Ridge Obs.)	204	300mm S-C	Pixcel 237
Dijon, Jean	Champagnier, France	1269		
Di Sciullo, Maurizio	Coconut Creek, FL, USA	68	258mm Newt.	SL-XP HX-516
Foulkes, Mike & Carter, Paul	Herts., UK	49	254mm S-C	HX516
Grafton, Ed	Houston, TX, USA	1600	360mm S-C	ST6 or ST5c
Haymes, Tim	Reading, UK		310mm Newt.	MX5c
Meyer, Jörg	Gudensberg, Germany	209	360mm S-C	(Frame Grabber board MV-Delta)
Ikemura, Toshihiko	Nagoya , Japan	1154	310mm Newt.	NEC PICONA
Jacquesson, Michel	Sevigny-Wallepe, France	1593	203mm S-C	QuickCam VC
Melillo, Frank J.	Holtsville, NY, USA	64	203mm S-C	Starlight Xpress MX5
Mobberley, Martin	Cockfield, Suffolk, UK	35	360mm	Starlight Xpress MX5c
Moore, David M.	Phoenix, AZ, USA	783	360mm Cass. 254mm Newt.	SLXP HX-5 HX-5
Ng, Eric	Hong Kong, China	900	254mm S-C	ToUcam Pro
Parker, Donald C.	Coral Gables, FL, USA	1260	406mm Newt.	ST9E
Parker, Timothy J.	Los Angeles, CA, USA	14	150mm OG	Starlight Xpress HX516 & 3Com Homeconnect PC webcam
Peach, Damian	King's Lynn, Norfolk, UK & Chatham, Kent, UK	1415	305mm S-C	SBIG ST-5c
Sanchez, Jesus R.	Cordoba, Spain	459	280mm S-C	Audine KAF0401E & QuickCam VC
Sherrod, P. Clay	Arkansas, USA	1419	310 S-C	Olympus C-3000
Testa, Luigi	Parma, Italy	909	*(Measurements supplied by Gianluigi Adamoli)*	
Tan, Wei Leong	Singapore	758	280mm S-C	Philips ToUcam

The column 'Meas.' lists the number of JUPOS measurements made from that observer's images this apparition.
The following also provided images on single dates: Koet, J.; Legault, T.; Platt, T.

Additional records from the following Italian observers were kindly provided to JUPOS by Gianluigi Adamoli, Jupiter Recorder of the UAI:

Visual CM transits: Chiarini, Massimo; Cicognani, Massimo; Frassati, Mario; Giuntoli, Massimo; Maramonte, Emiliano; Siliprandi, Paolo; Tagliaferri, Ugo

CCD images: Carbognani, Albino; Mancini, Riccardo; Nava, Davide; Piazza, Igor; Peltran, Giuseppe; Zattera, Flavio.

Imaging observations

We again received many splendid CCD images for this apparition, from contributors all over the northern hemisphere (Table 1B). The earliest images were by Ikemura on 2001 Aug 12. During the autumn, high resolution images were sporadic, but there were image(s) almost every day in October and November from somewhere in the world. From late October, Clay and Brian Sherrod produced images of Jupiter at the Arkansas Sky Observatory, typically once an hour on clear nights, and archived them in a searchable database at <**http://www.arksky.org/asoimglib.htm**>.

After Christmas there were images almost every day, often of excellent quality, giving virtually continuous coverage although with decreasing resolution until mid-April, after which coverage was intermittent again. Cidadão produced an especially large number. Peach, Grafton, and Don Parker took images with especially high resolution and fine colour. The last image was by Peach on 2002 June 1.

Table 2. Zenographic latitudes of belts, 2001/2002

Sector A (narrow belt components) Six images by Parker or Cidadao (2002 Jan) CM2 range 16–46		**Sector B** (edges of major belts) Five images by Cidadao (Dec–Jan.) and one by Ng (Feb) CM2 range 260–341	
Band	*Lat.*	*Belt edge*	*Lat.*
S4TB	−54.1	SPRn	−52.7
		(S)SSTBs	−46.7
SSTB	−36.6	(S)SSTBn	−42.4
		STBs	−33.2
STropB	−25.0	STBn	−29.3
SEB(S)	−19.0	SEBs	−20.7
SEB(C)	−13.0	SEB(S)n	−16.9
SEB(N)	−8.9	SEBn	−7.9
		EBs	−2.5
NEB(S)	8.3	NEBs	8.2
NEB(C)	15.2	NEBn	21.3
NEB(N)	19.7	NTBs	25.8
		NTBn	29.7
		NNTBs	37.0

Akutsu and Cidadão also routinely produced many informative sets of images in wavebands from the ultraviolet to the infrared, including the methane absorption band, as discussed in a separate section below.

The PC-*JUPOS* system was again used for all positional measurements, both in latitude and longitude, and for plotting charts of longitudinal drifts in each latitude band.[9–10] Measurements were made by Hans-Jörg Mettig, Damian Peach, Gianluigi Adamoli, and André Nikolai. The final *JUPOS* database for the apparition contained 30,802 measurements, including 911 from transits, the remainder being measurements of features on images.

Table 3A. Visual intensity estimates

	Colombo (Feb 4 and Apr 3)	*Heath (Nov 25–Feb 12)*				*McKim (Dec 29 –Apr 23)*
	No filter	*No filter*	*Red (W25)*	*Blue (W44a)*	*Blue (W47)*	*No filter*
SPR	3.3 (3)	3.0 (21)	2.5 (21)	3.5 (21)	4.0 (21)	3.3 (4)
SSTZ						2.5 (1)
SSTB	3.0 (3)					4.3 (5)
STZ						1.1 (3)
STB	3.2 (3)	3.9 (21)	3.2 (21)	4.0 (20)	4.3 (20)	3.6 (3)
STropZ	2.0 (3)	1.4 (21)	1.2 (21)	1.8 (21)	2.5 (21)	0.9 (5)
GRS		3.5 (3)	1.2 (3)	3.7 (3)	5.5 (3)	
SEB (S)	5.0 (3)	4.7 (21)	4.2 (21)	5.2 (21)	6.3 (21)	5.5 (5)
SEB (N)						5.2 (5)
EZ(S)						1.0 (5)
EB	1.5 (3)					3.0 (3)
EZ (N) (or total EZ)	1.3 (3)	1.3 (21)	1.0 (21)	1.4 (21)	2.1 (21)	1.1 (5)
NEB(S)	5.2 (3)	5.0 (21)	4.5 (21)	5.8 (21)	7.2 (21)	5.6 (6)
NEB(N	5.3 (3)					
NTropZ	1.8 (3)	1.3 (21)	1.2 (21)	1.6 (21)	2.5 (21)	1.2 (5)
NTB	4.2 (3)	5.0 (21)	4.8 (21)	4.9 (21)	4.9 (21)	4.8 (5)
NTZ	2.2 (3)	1.5 (21)	1.3 (21)	1.8 (21)	2.7 (21)	1.2 (5)
NNTB	2.8 (3)					4.0 (3)
NNTZ						3.5 (1)
NPR	3.0 (3)	3.0 (21)	2.5 (21)	3.5 (21)	4.0 (21)	3.4 (5)

Intensity estimates are made on the scale 0: bright white; 10: black. The number of observations is shown in brackets.
Heath made his filter observations with a 250mm Newtonian, equally distributed before and after opposition. He notes little difference in his results before and after opposition.
In addition there were estimates by Schmude and Frassati on two nights each.

Mean latitudes of belts, measured from images, are given in Table 2. All were similar to historical averages[11] except for the NEBn and NTBs edges, which were significantly further north than usual.

General description

Appearance in visual observations

Here we describe the visual appearance of the planet. Some of the best drawings are in Figures 1 and 2. While many observers saw only the major features, Adachi often detected much more detail. Visual colour estimates are shown in Table 3B.

SPR to SSTB: Most visual observers generally described the SPR as grey, sometimes appearing darker than the NPR.

Under good seeing, a dark belt (assumed to be the S^3TB) was often observed to form the northern border to the SPR. Adachi also detected a light zone to the south and a further dark belt, assumed to be the S^4TB. A light SSTZ was generally detected.

The SSTB appeared broad with a number of darker sections or condensations. A few visual observers (especially Adachi) described its structure as complex in good seeing, and succeeded in seeing the chain of small white spots in it near white oval BA and the GRS during spring, 2002.

STB: The STZ appeared as a light zone. Some light spots and small dark condensations were sometimes recorded within it.

The STB showed variations in intensity with longitude, and a dark preceding edge was evident (STC no.6 or 7 in Table 4 below). This p.end was associated with several light and dark spots in STZ (Adachi, Oct to Dec), or with a short narrow band in the centre of the STZ. White oval BA was difficult to detect, but was seen as a pale oval by some visual observers (Adachi, Bullen & McKim).

STropZ: The STropZ appeared as a bright zone and was generally featureless. Adachi detected the p. end of the S.Tropical Band from Dec 2 to Feb 24.

GRS: The GRS appeared as a faint oval within a well-defined Red Spot Hollow (RSH). The southern rim was dark and was often seen to extend p. and f. connecting with the ends of the RSH. However the southern rim was not connected to the p. end of the RSH on Dec 31 (Peach), Jan 15 and Feb 22 (McKim), nor during April (Peach), concomitant with the detachment of the S. Tropical Band.

The northern half of the GRS was sometimes lighter than the southern half. Indeed some observers sometimes only detected the dark southern rim, giving the GRS the appearance of a light oval embedded within the SEB. Both Adachi and Peach occasionally recorded a GRS oval separated from this dark southern rim. They and Gray also sometimes recorded a dark elongated centre to the GRS.

Visual colour estimates are shown in Table 3B. Adachi also recorded the GRS as faint red or faint orange. Heath's intensity observations with colour filters show a strong red colour (Table 3A).

SEB: Dark spots extending into the STropZ from the SEBs were recorded by some observers, usually from L2 ~200 up to the p. end of the GRS (Adachi,

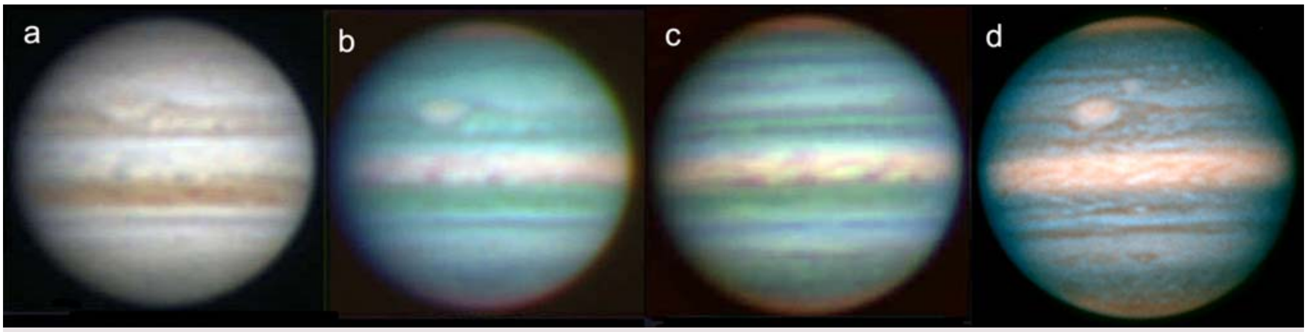

Figure 3. False-colour images, highlighting the relative altitudes of the clouds, with a true-colour image **(a)** for comparison. In each case the red channel is the methane band (0.89 microns), so red or pink areas are high haze, especially the polar hoods and the EZ.
(a) 2001 Oct 19, (Akutsu): true colour.
(b) 2001 Oct 19, (Akutsu): blue = white light, green = I-band, red = methane.
(c) 2001 Oct 31, (Akutsu): blue = UV, green = I-band, red = methane.
(d) 2002 Feb 25, (Cidadão): blue = I-band, red = methane. (Also see Part II of this paper. Oval BA is methane-bright in its centre; the GRS oval is methane-bright throughout.)

Foulkes, Frassati, Gray, McKim & Peach). Light spots were sometimes detected between the dark spots and both types were observed between the latitudes of the SEBs and the STropB.

The SEB generally appeared double with well defined SEB(S) and SEB(N). The SEB(S) often appeared darker than the SEB(N) p. the GRS. However f. the GRS the SEB(N) was often the darker component. Although most observers thought the two components had similar colour (Table 3B), Adachi sometimes recorded the SEB(N) as bluish.

F. the GRS, the SEBZ was disturbed as usual with white spots and darker bridges. At other longitudes, the SEBZ appeared either bright or shaded with some lighter spots.

Table 3B. Colour estimates

	Colombo Feb 10 to Apr 3 (3 nights)	Devadas Dec 13 to Mar 31 (18 nights)	Foulkes Oct 18 to May 31 (25 nights)	Frassati Oct 11 to 12 Jan (3 nights)	McKim Dec 29 to Feb 28 (6 nights)	Rogers Oct 3 to Apr 6 (5 nights)	*CCD images Oct to Mar. (assessed by JHR)*
SPR	Grey	Light grey or brown	Grey	Grey		Grey	*Grey & grey-brown*
SSSTB				Grey			*Grey*
SSTZ	Grey		Light grey	Yellowish grey			
SSTB	Grey		Greyish brown or brown	Grey			*Grey*
STZ	Grey		Yellow or light grey	Light yellow	White		*Light grey or fawn*
STB	Grey		Grey	Grey		Grey	*Dark grey*
STropZ	Yellowish		Yellowish white or white	White	White	White	*White*
GRS		Light red or light pink	Pale pink	Salmon pink or white	Grey	Warm grey	*Orange (+/– grey & white)*
SEB (S)	Red	Yellowish grey	Greyish brown	Greyish brown	Slightly brown	Grey or brownish grey	*Dark brownish-grey*
SEB(Z)			White or shaded	Yellowish	White or shaded		*Light fawn*
SEB(N)	Red	Light red	Greyish brown	Greyish brown or brown	Slightly brown	Grey, dark grey or brown	*(C) Blue-grey; (N) Grey-brown*
EZ(S)	White or pale yellow		Light grey, white or yellowish white	White		White or bluish white	*Bright white*
EB	Pale grey		Faint grey	Grey	Warm grey		*Dull*
EZ (N) (or total EZ)	White or pale yellow	Light bluish. White. Light yellow	Grey or yellowish	Yellowish or ochre yellow	Yellowish	Grey or yellowish grey or white	*yellowish*
NEB	Brick red	Deep red or brick red	Brown, dark brown or choc-olate brown	Red or brown	Orange or reddish brown	Strong reddish brown	*Strong reddish brown*
NTropZ	Yellowish white		Yellowish white or white	Grey or white	White	Yellowish white or white	*White*
NTB	Red		Greyish brown	Greyish brown	Warm grey	Grey, bluish grey or cold grey	*Dark grey*
NTZ	Yellowish		Light grey	Yellowish grey	White	White	*White*
NNTB	Grey		Grey	Grey		Grey or brownish	*Grey (& pale reddish sectors)*
NNTZ	Grey		Light grey	Yellowish grey			*Fawn*
NPR	Grey	Light grey	Grey	Grey		Grey or brownish	*Grey & fawn*

Adachi and Heath also made intermittent colour observations of a few belts and zones.

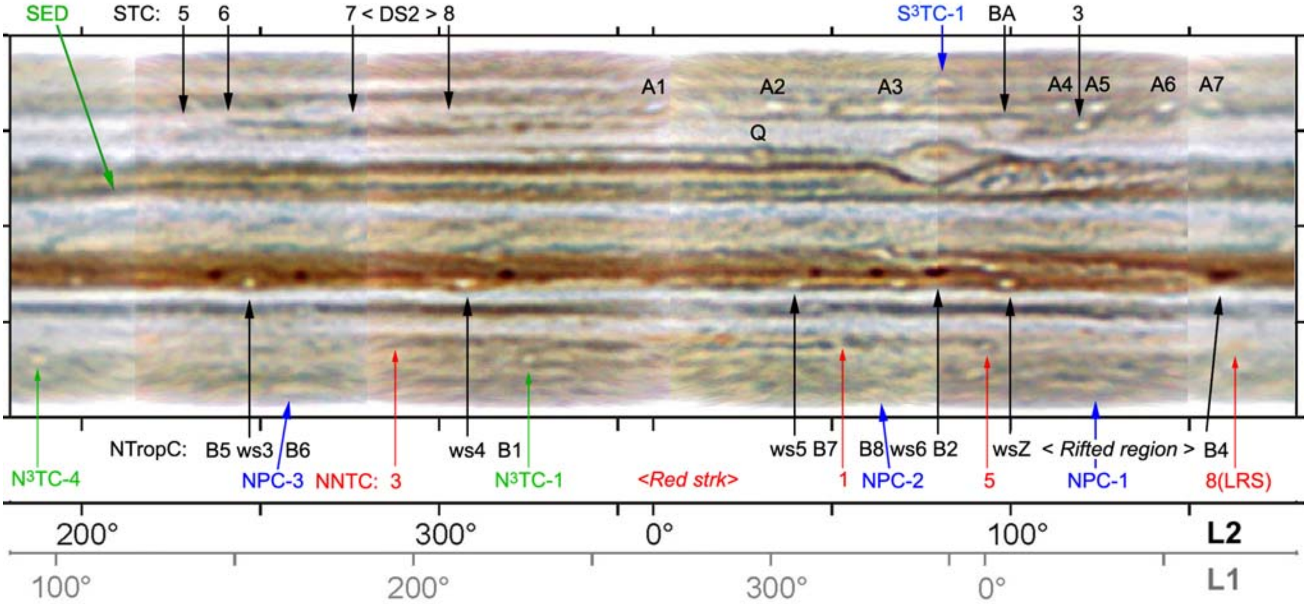

Figure 4. Map of the planet, 2002 Jan 8.9 to 11.0, shortly after opposition, from images by Cidadão, compiled by Mettig. Features are labelled, coloured according to their current.

Equatorial region: The EZ(S) appeared brighter and narrower than the EZ(N), and generally white and featureless. The Equatorial Band was faint or absent.

The EZ(N) often appeared shaded, usually with a noticeable yellowish colour (Table 3B). Although the yellow tint was quite weak, it was the first EZ colouration for ten years.

Some of the usual projections/festoons from the NEBs were seen (sometimes with white plumes f. them), but they were faint, and often difficult to see in poor seeing. The festoons/projections were often described as grey or light blue.

NEB: The NEB was a dark belt, and broad following the NEB expansion in 2000. Three components were sometimes recorded under good seeing although the appearance varied with longitude, the central component being darkest. Bright rifts were sometimes seen to cross the belt.

Many visual observers commented on the strong reddish-brown colouration of the belt in contrast to the SEB (Table 3B). This was first noted by Adachi in his first observation on August 15, and he soon notified observers that 'the NEB was broad and orange-tinted', more so than the previous apparition. The reddish colouration is also shown in Heath's colour filter intensity observations (Table 3A), and in Peach's and Frassati's colour drawings (Figure 1). Some very dark spots ('barges') were seen embedded in the NEB(C)n edge, and were generally recorded as dark brown (Foulkes and Rogers). Heath usually scored these as intensity 7 to 8. Further north, some small white ovals were detected on the NEB(N) extending slightly into the NTropZ.

NTropZ, NTB, NTZ: The NTropZ appeared bright and featureless. The NTB was dark. Some darker sections were occasionally recorded.

The NTZ appeared shaded. A faint NTZB was detected by Adachi who also, on occasions, recorded isolated light spots.

NNTB to NPR: The NNTB appeared variable in width and intensity. It was sometimes recorded as double with some darker sections or bars.

Adachi detected a light NNTZ and sometimes a broken N^{3}TB, an N^{4}TB, plus a belt further to the north. He also occasionally recorded large light diffuse areas north of the NNTB (reminiscent of those recorded by *Cassini*).[7]

The NPR was generally recorded as grey.

Appearance in CCD images

In this section, and in the right-hand column of Table 3B, we give a description of the belt structures and colours that appeared in CCD images. This is a visual interpretation of images which had good colour range but not strong sharpening, such as those of Cidadão. (Other images, with stronger sharpening, showed local features more distinctly but may have masked large scale contrasts.)

The reader may wonder why this 'analysis' of colour images consists merely of subjective impressions, in the same manner as direct visual observations. Obviously the raw images do contain objective colour information, of which we are not yet making full use, and during this apparition we had a detailed discussion with all the leading imagers about how objective colour values might be extracted. It became apparent that this is a very complex problem and a satisfactory method has not yet been worked out.

SPR to SSTB: As usual, there was a sharp edge to the SPR (or S^{4}TBn) at 53°S, and from there to the STB, belts tended to form regularly spaced patterns that did not coincide with the jetstreams. In one sector (sector B in Table 2), where there was a substantial STB, there were distinct broad zones and belts: STZ, (S)SSTB, and S^{3}TZ, all from Oct to Feb, though less distinct in March.

In other sectors, there were no prominent STB and no prominent high-latitude zones, but narrow bands including a true SSTB, and also many anticyclonic white ovals (AWOs).

STB: There were still two sectors of prominent dark full-width STB, with associated long-lived spots, whereas elsewhere the belt was absent or was merely a faint STB(N). The most obvious sector, ~80–100° long, was constructed around the long-lived dark streak once known as DS2 (STC no. 7–8 in Table 4), following which it dwindled into a line of more southerly streaks and spots. The second sector of dark STB was only 15° long, between AWOs no.1 (BA) and no.3 (Table 4), with only inconstant streaks f. no.3.

STropZ: This was bright white as usual. A dark S. Tropical Band appeared from the p. end of the GRS in Nov (described below),

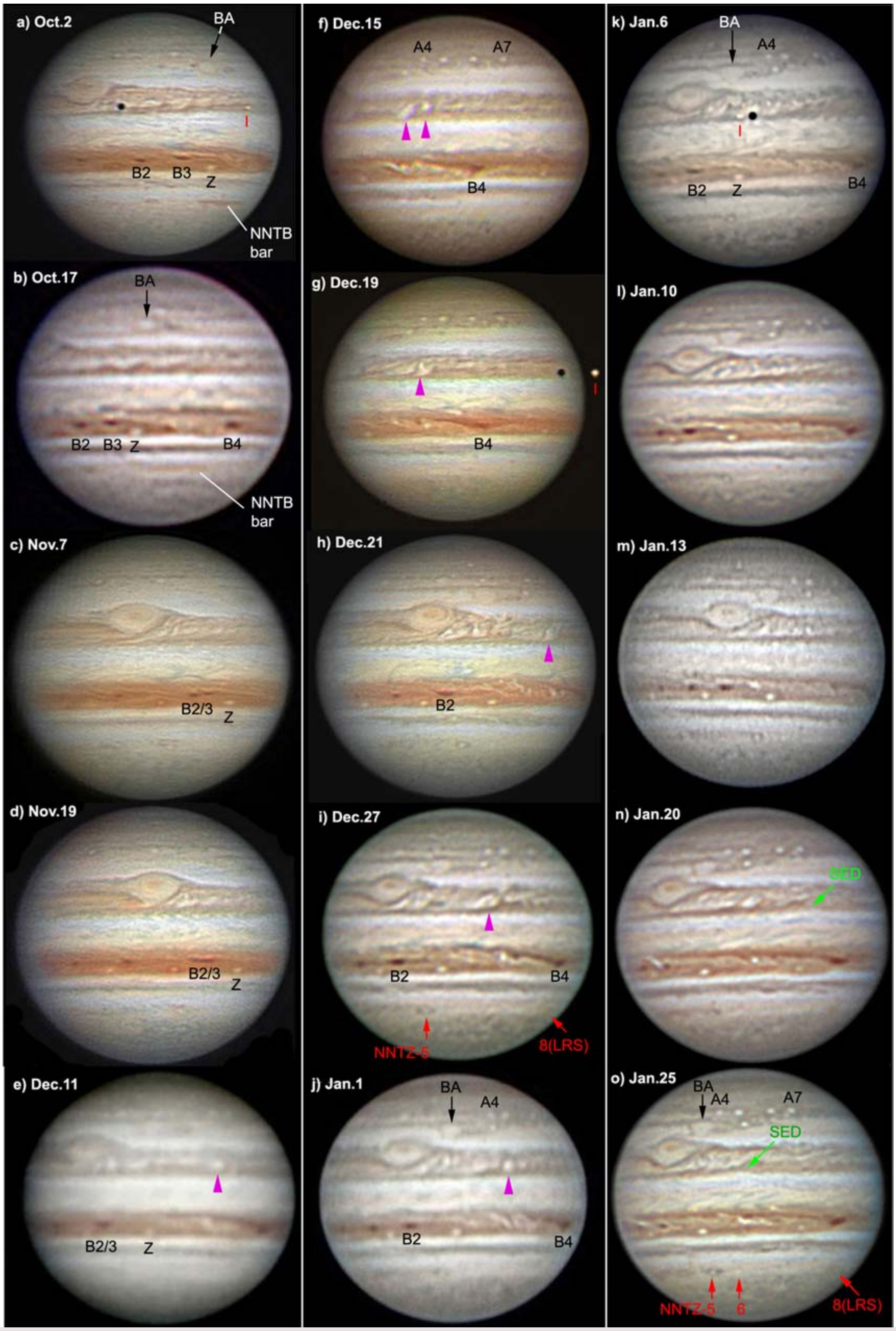

Figure 5. Colour images, showing the GRS and region f. it, 2001 Oct to 2002 Jan.
Features of interest are labelled, including: S.S. Temperate AWOs A4 and A7; Io in transit (red bar below); new white spots in SEB (purple arrowheads); main complex of the SED; NEB barges B2 and B3 (merging) and B4, and white spot Z.
(a) Oct 2, 10h 58m (Grafton).
(b) Oct 17, 09h 11m (Parker), CM1=117, CM2=136.
(c) Nov 7, 10h 01m (Grafton), CM1=212, CM2=72.
(d) Nov 19, 09h 42m (Grafton), CM1=306, CM2=77.
(e) Dec 11, 08h 47m (Sherrod), CM1=152, CM2=112.
(f) Dec 15, 03h 17m (Parker), CM1=223, CM2=155.
(g) Dec 19, 06h 28m (Grafton), CM1=252, CM2=152.
(h) Dec 21, 06h 25m (Grafton), CM1=206, CM2=91.
(i) Dec 27, 01h 57m (Cidadão), CM1=271, CM2=111.
(j) Jan 01, 00h 49m (Chevalley), CM1=299, CM2=102.
(k) Jan 06, ~00h 10m (Legault).
(l) Jan 10, 23h 15m (Cidadão), CM1=23, CM2=110.
(m) Jan 13, 00h 21m (Chevalley), CM1=19, CM2=90.
(n) Jan 20, 01h 53m (Cidadão), CM1=101, CM2=118.
(o) Jan 25, 00h 57m (Cidadão), CM1=137, CM2=116.

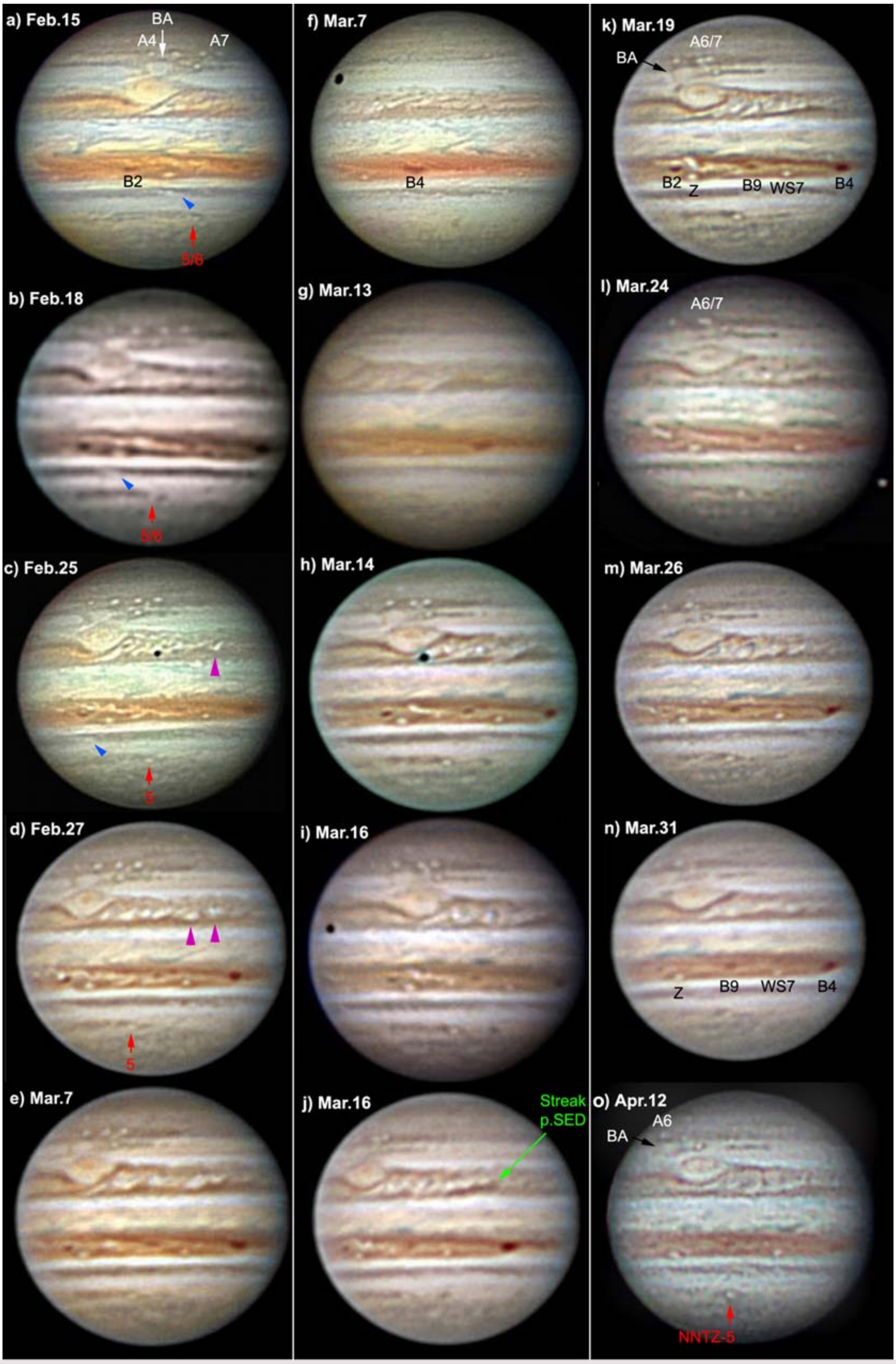

Figure 6. Colour images, showing the GRS and region f. it, 2002 February to April.
Features of interest are labelled, including: S.S. Temperate AWOs A6 and A7 (merging); new white spots in SEB (purple arrowheads); NEB barges B2 (merged), B9 (new), and B4, with white spots Z and 9 (new); prograding bright rift in NTB (blue arrowhead); and NNTZ white ovals 5 and 6 (merging).
(a) Feb 15, 02h 19m (Grafton), CM1=264, CM2=82.
(b) Feb 18, 00h 22m (Sherrod), CM1=305, CM2=101.
(c) Feb 25, 01h 11m (Grafton), CM1=0, CM2=103.
(d) Feb 27, 22h 55m (Cidadão), CM1=31, CM2=111.
(e) Mar 7, 19h 32 (Cidadão), CM1=90, CM2=110.
(f) Mar 7, 01h 09m (Grafton), CM1=138, CM2=164.
(g) Mar 13, 15h 10m (Tan), CM1=156, CM2=133.
(h) Mar 14, 19h 57m (Cidadão). CM1=129, CM2=96.
(i) Mar 16, 01h 40m (Parker), CM1=137, CM2=95.
(j) Mar 16, 22h 16m (Cidadão) CM1=170, CM2=121.
(k) Mar 19, 19h 16m (Cidadão). CM1=173, CM2=102.
(l) Mar 24, 18h 18m (Peach), CM1=207, CM2=98.
(m) Mar 26, 20h 08m (Cidadão). CM1=229, CM2=104.
(n) Mar 31, 19h 14m (Cidadão), CM1=265, CM2=103.
(o) Apr 12, 19h 07m (Peach), CM1=353, CM2=99.

and was ~100° long in Jan, when it began to detach from the GRS. In Feb it broke up and faded away. The whole evolution is shown in strip-maps compiled by Y. Iga, to be published in Part II of this report.

SEB: F. the GRS was the usual disturbed region. At most other longitudes the SEB had three components. SEB(S) was very dark brown with some dark spots, SEB(C) was dark blue, and SEB(N) was narrow and brown.

EZ: The southern EZ was very bright white though narrow, having recovered from the South Equatorial Disturbance.

The central and northern parts of the EZ appeared darker and yellower than in recent years, sufficient to be considered a mild yellowish colouration event. Akutsu's and Cidadão's UV images confirmed that the EZ(N) was darker than the previous apparition (Figures 7 & 9a).

The NEBs projections were merely long low bluish or grey plateaux, with only weak or fragmentary festoons, and there were usually no really bright or white spots.

NEB: The NEB was very broad, following the expansion event of 2000, and strikingly reddish brown. Both orange NEB and yellowish EZ were recorded in the first images by Ikemura in 2001 August, and confirmed by the first images by Cidadão and Akutsu in September. At some longitudes three components could be distinguished:

- NEB(S), variably grey as the NEBs 'plateau' material merged with the brown belt;
- NEB(C), reddish brown, in line with the very dark barges;
- NEB(N), grey-brown and narrow, marking the limit of expansion.

(As another typical consequence of the NEB broadening event, an array of small dark and white ovals developed within the expanded belt: see 'Local features and drifts' in Part II.)

The expanded NEBn had some bright strips in it from early in the apparition, gradually extending, and in the spring these progressed into a general brightening (clearing) of the expanded NEBn. In March, the dark NEBn material notably cleared between barges B4 and B6, and there was also some clearing further f. By the end of the apparition in May, the NEB was largely back to its normal width except for the sector of ~100° p. barge B4.

Discussion: The reddening of NEB and EZ(N)

The striking redness of the North Equatorial Belt was presumably a consequence of the broadening event in 2000. The reddish colour is a common sequel to NEB expansion events. The weak yellowish shading in the northern EZ was probably part of the same episode, as colour often does not

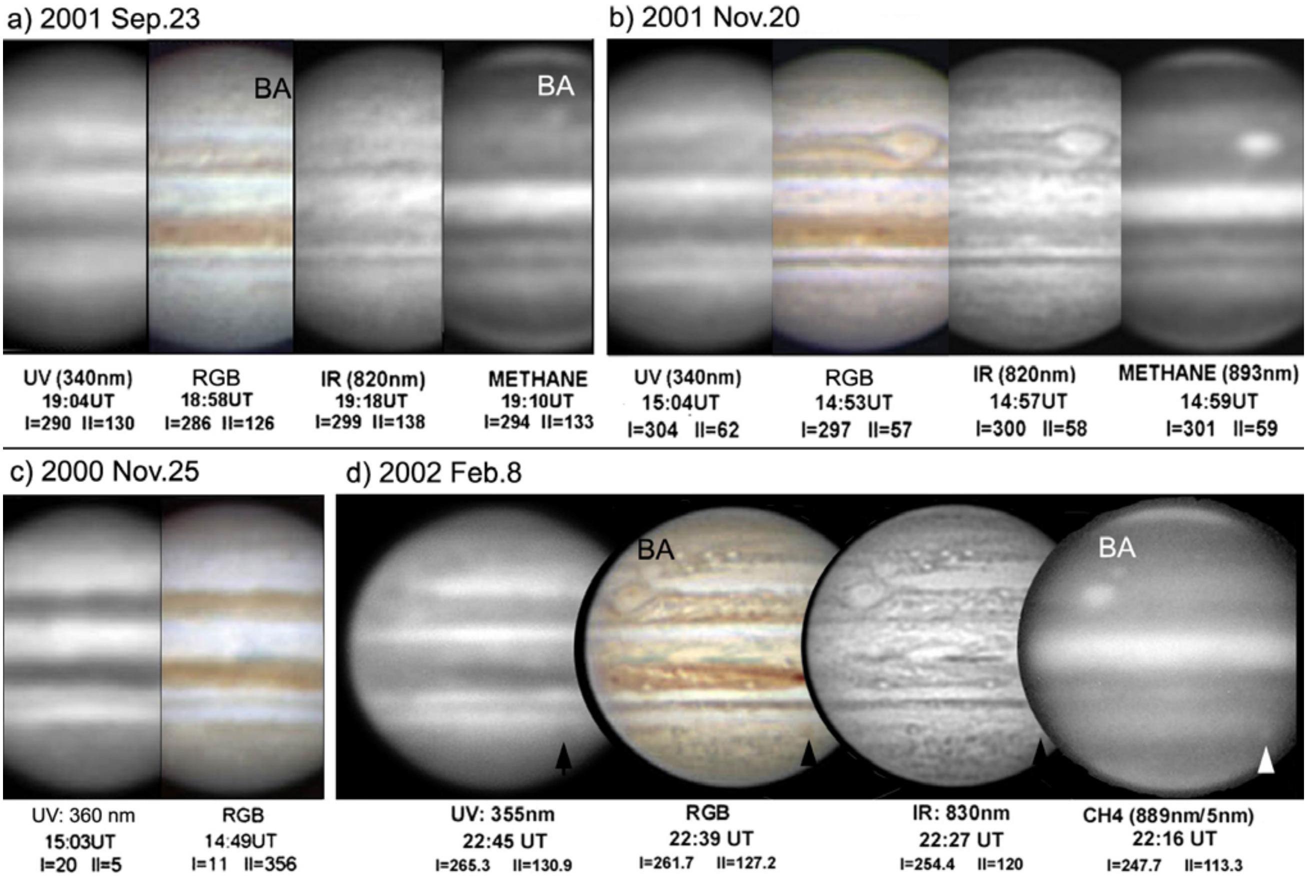

Figure 7. Alignment of the belts in different wavebands: (from left to right) Ultraviolet, visible, I-band (near-infrared continuum), methane band (890nm). Central wavelengths of UV and IR filters are labelled. All images are by Akutsu except set (d). Note the yellowish (UV-dark) EZ(N). (c) is from the previous apparition for comparison.
(a) 2001 Sep 23 (Akutsu). Includes oval BA, and a methane-dark patch on SEB(S).
(b) 2001 Nov 20 (Akutsu). Includes the GRS (methane-bright), and S. Tropical Band p. it (dark in UV and methane).
(c) 2000 Nov 25 (Akutsu). One year earlier: for other examples see Refs.7 & 8. Includes the S. Equatorial Disturbance main complex. Note that the EZ is fairly clear in UV, in contrast to the darkness in subsequent images which represents the yellowish colour in 2001/2002.
(d) 2002 Feb 8 (Cidadão). Filters: U-355 (range 320-390nm), RGB (white light), IR-830 (range 830 to ~1000nm, limited by detector sensitivity), CH_4-889 (5nm width). At left are the GRS and oval BA (both methane-bright), and white spot Z (in NEBn, N of f.end of GRS) with a UV-dark, methane-dark cloud around it. At lower right is the NNTZ LRS (arrowhead; see also figures in Part II).

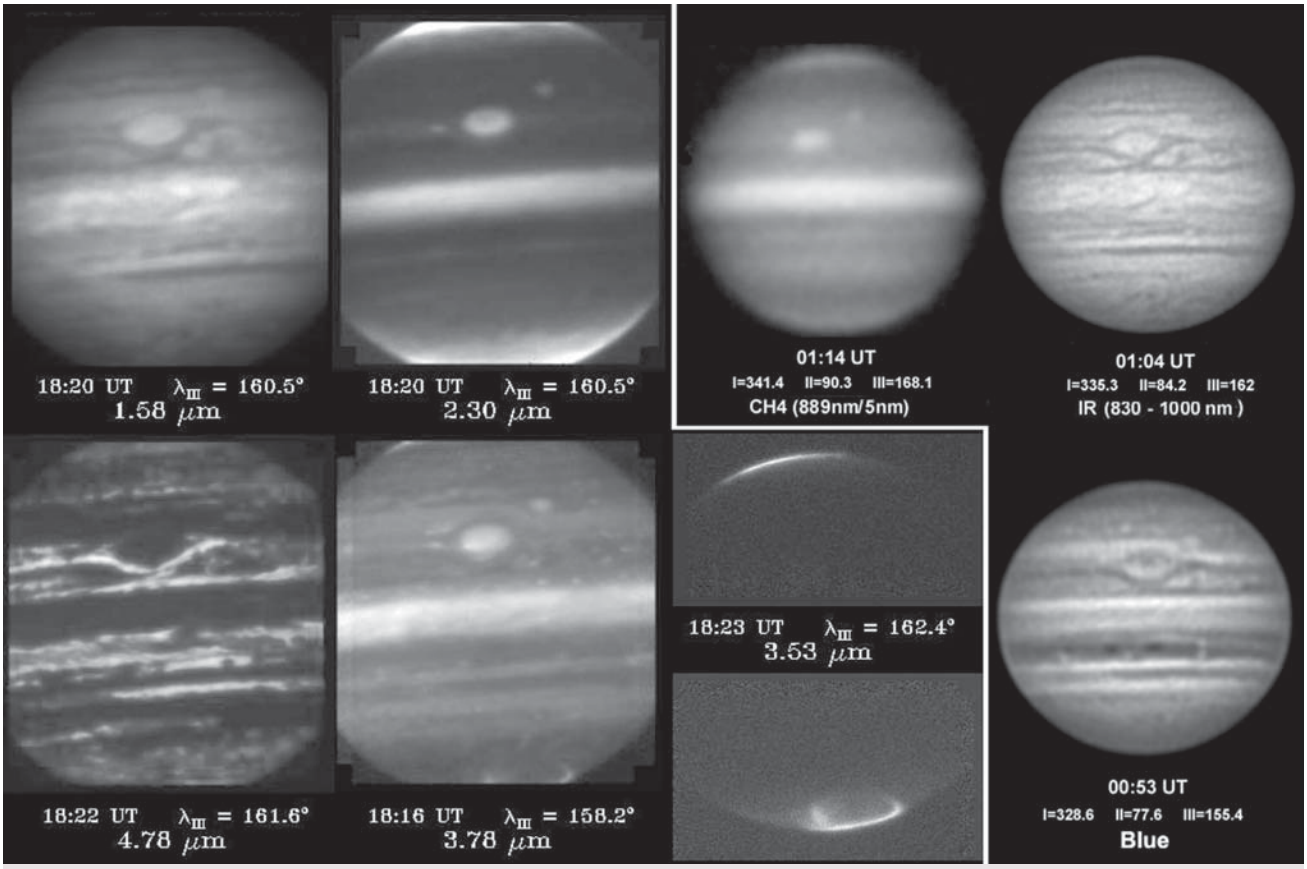

Figure 8. Images at many infrared wavelengths on 2002 January 8. *Left:* Set of images from the NASA Infrared Telescope Facility, by courtesy of Dr Glenn Orton (for explanation see Ref.7). *Right:* Set of three images by Cidadão on the same date. Includes the GRS and oval BA. (Also see Figure 7d.)

respect belt/zone boundaries.[11] These comprised the first significant colouration episode for ten years, and indeed, the first since amateur digital imaging became widespread. In ultraviolet images, the EZ(N) was clearly darkened, confirming the increased absorption of short wavelengths. In methane-band images, there were no obvious changes related to the colouration, suggesting that it resulted from a reddening rather than a thickening of the high-altitude haze.

NTropZ to NTZ: NTropZ was narrow but still white. NTB was a substantial, very dark grey belt, except for short paler sectors which were shown to be oblique rifts in v-hi-res images (see 'Local features and drifts' in Part II). NTZ was clear and white.

NNTB: NNTB was fragmentary. There were some distinct dark grey segments, with strips of fairly clear narrow NNTZ alongside, but at other longitudes there was just pale fawn-coloured shading over the whole N.N. Temperate domain. Two dark brown bars of NNTB separately turned into red streaks before fading away (see 'Local features and drifts' in Part II).

NNTB to NPR: Many dark grey streaks in a lighter brownish background occupied this region up to high latitudes, with no coherent belt structures, merging into dark grey shading near the pole.

Appearance in infrared (methane band) and ultraviolet

Imaging in the infrared methane band (890nm) and the ultraviolet (<390nm) reveal the high-altitude haze, which reflects in the IR but absorbs to a variable degree in UV.[12,7] Here we only give a brief overview of the methane-band images, emphasising the minor differences from the state that we reviewed in 2000/2001.[7] In contrast, images in the near-infrared continuum (I-band: ≥750nm) probe deeper than visible light, and these look like exaggerated versions of red images; we will not comment on them here. Examples are shown in Figure 7.

Multispectral image sets were taken by Akutsu, Cidadão, and Colville: see Ref. 12 for details of their methane filters. Akutsu took methane-band images (893nm filter, width 6.5nm) on most dates from Sep 22 to Nov 24, and on five dates in Feb and March. These images were always accompanied by I-band images and usually by UV images (filter centred at 340nm). Cidadão took methane-band images (889nm filter, width 5nm) on many dates from Dec 26 to April 15, plus one on May 3. These images were usually accompanied by I-band images and on seven dates also by UV images (filter centred at 355nm, spanning 320–390nm). Colville took methane-band images (filter width 18nm) on Aug 25, Jan 27, and Feb 10.

The discrete methane-bright features were, as usual, the major anticyclonic ovals and a few transient rifts, as follows:

1 The GRS and oval BA: imaged frequently by Cidadão as they passed in Feb–March; see Figures 3, 7, and Part II.

2 Oval Q (p. the GRS): occasionally just detected.

3 The NNTZ Little Red Spot: see separate section below.

4 Occasional white spots in the post-GRS disturbance in the SEB (however most of these are not methane-bright).

5 One rift in the NEB, which was also very bright in white light on that date.

Belt/zone structure in methane images was as follows. It was generally as in 2000/2001, and the following description emphasises the minor changes. As usual, the only bright bands were the polar hoods and the very bright 'EZ', which was further N than the visible EZ.

SPR to SSTB: Uniformly dark, outside the usual bright polar hood.

STB: Absent where it was faint visually, but the visible sectors of dark STB were also dark in methane, especially in Akutsu's images.

STropZ: The S.Trop.Band was methane-dark in Nov and faintly so in Jan. Later, oval Q was associated with a barely detectable methane-bright spot.

SEB: SEB(S) was particularly dark. In Akutsu's images, dark patches were common on it (Figure 7a); in Cidadão's, the SEB(S) was more well-defined relative to the rest of the belt, but less disturbed – probably reflecting the different depths probed by their filters. Otherwise the SEB was uniformly grey, apart from rare methane-bright spots in the post-GRS disturbance, and slight irregularity along SEBn as it was still affected by the SED.

EZ: The main complex of the S. Equatorial Disturbance[8] was still detectable in methane, though very stretched out. Preceding it, the 'SEBn' was still displaced northwards into the EZ.

In northern EZ, as in previous apparitions,[7] the methane-bright haze extended some way over the visible-light NEBs edge, including the latitudes of the NEBs projections. These dark projections were visible in Akutsu's images – indeed, they appeared large because of the contrast with the methane-bright haze – but usually not in Cidadão's images, due to the relative widths of the filters. However they became more visible in Cidadão's images in

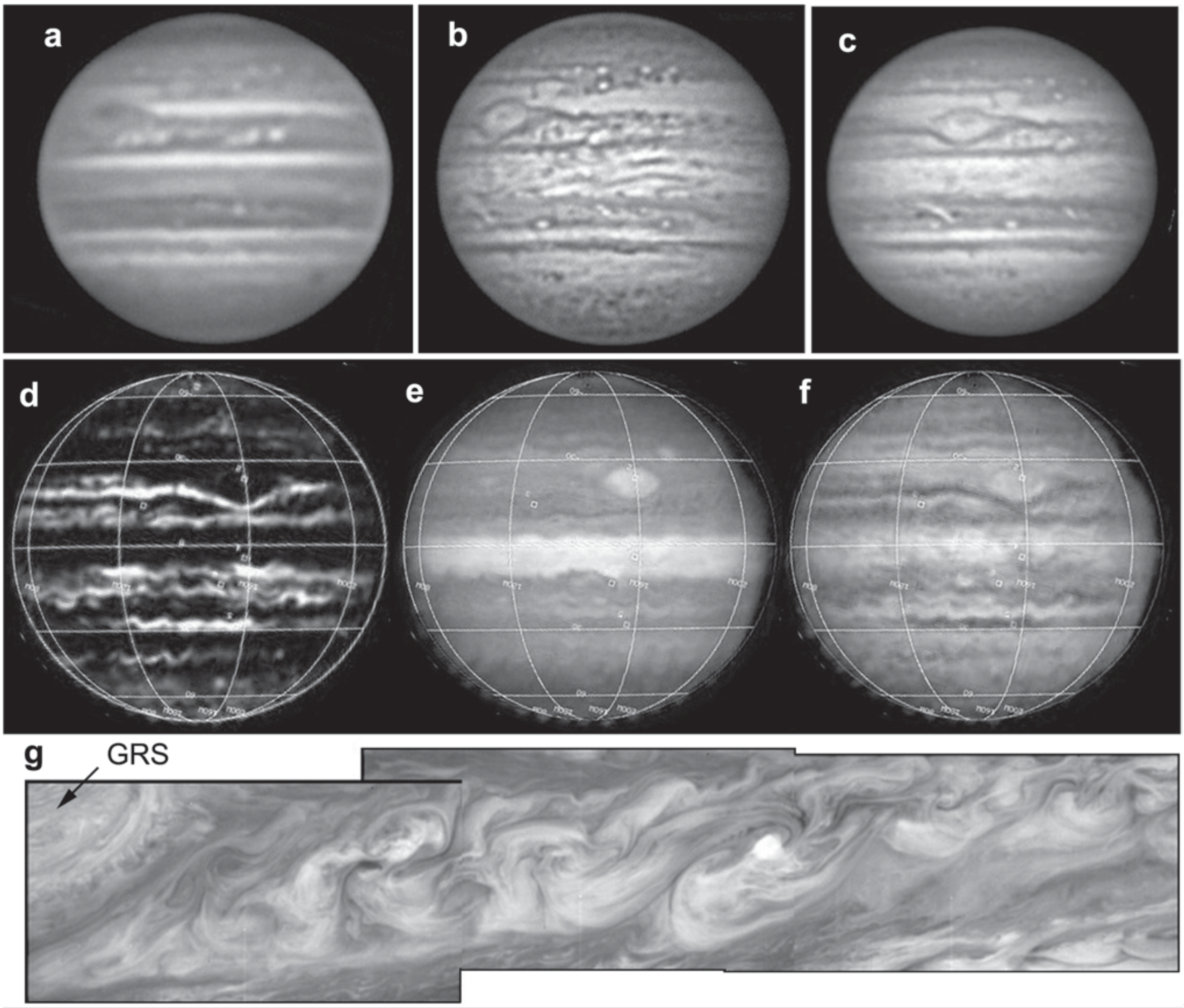

Figure 9. Images from the Observatoire du Pic du Midi, and from the *Galileo* Orbiter during its final imaging flyby on 2002 Jan 20–21, with an amateur image **(c)** for comparison.
a) Pic du Midi (by courtesy of Dr Eric Frappa), in UV: 2001 Dec 17. Notably dark features include the EZ(N), GRS (top left), and NNTZ-LRS (bottom right).
b) Pic du Midi (by courtesy of Dr Jean Lecacheux), in I-band (with high contrast enhancement): 2002 Jan 20, 21h 48.5m UT, CM1=110, CM2=117. Bright features include the EZ, GRS, oval BA, and NNTZ-LRS (bottom right).
c) Don Parker, in white light, Jan 21, 06h 53m UT.
d,e,f) Synthetic images from the final set produced by *Galileo*'s NIMS on Jan 20. These preliminary 'index images' were constructed from scans; the waviness of the belts appears to be an instrumental effect that had not yet been corrected. Many wavelengths were recorded; these appear to be (d) in thermal IR around 5 microns, (e) in a methane band, and (f) in I-band. (Credit: NASA and the *Galileo* NIMS team, obtained from the NASA Planetary Data System.)
g) Part of the final sequence from *Galileo*'s camera on Jan 21, showing the turbulent SEBZ f. the GRS. (A small part of the GRS appears at left.) (Images from NASA and the *Galileo* SSI team, obtained from the NASA JPL Planetary Image Atlas, composited by JHR.)

March and April. This variability has also been noted in HST methane-band images: the dark projections were strongly visible in 1994[12] but not in 1996.[13]

NEB: The NEB was very dark, but narrower than in visible light, both on the S side, as methane-bright EZ haze covered the NEBs, and on the N side, as the NEBn had not expanded in methane (as was also seen during previous expansion events). The prominent NEB wave pattern of 2000/2001 had disappeared, but there was still some unevenness over NEB/NTropZ.

AWOs (portholes) in NEBn were generally not methane-bright, though they were occasionally just detectable. In particular, white spot Z was usually not methane-bright: instead, in Feb, it was embedded in a methane-dark bulge (Figure 7d) similar to the large dark waves of 2000/2001.[7] (These dark waves had generally formed over anticyclonic circulations, but previously not over WSZ itself; however WSZ was quite small in 2002.)

NTB: NTB was a very dark belt.

NNTB to NPR: No NNTB was visible in methane. NTZ graded diffusely into the dark circumpolar region, which graded diffusely into the bright polar hood as usual.

Appearance from spacecraft and professional observatories

For comparison with our multispectral images, we show hi-res professional images at different wavelengths, kindly provided on the Web by the scientists responsible. See Ref. 7 for an explanation of these images. Figure 8 shows a set of infrared images from the NASA Infrared Telescope Facility, with Cidadão's multispectral images on the same date, including the GRS and oval BA. Figures 9a,b show two images from the Observatoire du Pic du Midi, in UV and in I-band.

The *Galileo* spacecraft was still orbiting Jupiter and had two perijoves during the apparition, from which some data were returned, although repeated radiation-induced events sometimes caused the spacecraft to switch off at critical times. At the I32 encounter around 2001 Oct 16, some data were returned from the Near-Infrared Mapping Spectrometer (NIMS).

At the I33 encounter around 2002 Jan 17, although most images were lost, the spacecraft was revived in time to take the very last images of the mission, on Jan 19–21 (Figure 9). These were a set of full-disk infrared scans of Jupiter by NIMS, and a set of hi-res camera images targeted at the turbulent SEBZ f. the GRS. Examples of the NIMS 'index' images are shown in Figures 9d,e,f. Part of the final sequence from the camera is shown in Figure 9g .

The ageing spacecraft was then targeted for a final (non-imaging) perijove named A34 on 2002 November 5, and incineration in Jupiter's atmosphere on 2003 September 22.

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