Jupiter in 1997

John H. Rogers

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

In the overall patterns of belts and zones, the only significant change since 1996 was the evolution of the NEB following the 1996 NEB expansion event, which followed the standard course: development of dark 'barges' and bright ovals, increased redness, and gradual lightening of the northern extension. Meanwhile there was a new outbreak of dark spots on the NTBs jetstream. All the southern-hemisphere belts were much the same as in 1996. However there were important movements of some long-lived spots, which led to the first observed mergers of large anticyclonic ovals. First, a ten-year-old white oval in the STropZ drifted into contact with the Great Red Spot and slowly disintegrated within it. Then, as the apparition ended in 1998 January, South Temperate ovals BC and DE began to converge closer than ever before.

In an Appendix, we describe the major high-altitude cloud features revealed by methane-band images from 1995 to 1997. These are the polar hoods (which include the visibly dark south polar collar), the major zones (especially the EZ, which has changed since 1995), and some anticyclonic ovals (especially reddish ones).

Introduction

Opposition was on 1997 August 9, at declination 17°S in Capricornus. This report follows on from our previous one for 1996.[1] The *Galileo Orbiter* mission continued during 1997, with imaging and infrared sensing of selected jovian feature(s) at each perijove. Dates and targets of the six perijoves, and BAA observations that related to them, were listed in our interim report.[2]

The first useful data this apparition were Isao Miyazaki's images on April 11, which revealed two long-predicted phenomena that would be of great interest to the *Galileo* team: a dark 'barge' developing in the NEB, and the long-lived STropZ white oval about to collide with the GRS. A third interesting phenomenon was a new outbreak of dark spots on the NTBs jetstream, reported by Yuichi Iga from measurements on Pic du Midi images from May 2 onwards as well as in Japanese visual observations. Further images from May 12 onwards, by Miyazaki and by Don Parker and by the Pic du Midi professional team (on their web site), showed the development of these phenomena in detail.

With the jovian system being roughly edge-on during 1997, some rare multiple satellite phenomena took place. On August 27, the planet was without visible satellites for 14 minutes, as satellite II was invisible in transit, III and IV were occulted, and I disappeared into occultation at 21.38. Then only the shadow of II, moving onto the planet, betrayed the presence of any satellite, until 21.52 when IV began to reappear from eclipse. This was observed by the Director (Figure 8B). The best observed event was the triple transit on September 21, when the shadows of II and IV, and the dark disk of III, were simultaneously transiting across the EZ. This was drawn by Ebdon, McKim, Mettig, and Nikolai (Figure 9), and also imaged by Nikolai. A similar but rarer event occurred on November 10, when the shadows of IV, III, and I transited together; this was observed from the USA, where beautiful false-colour images were taken at New Mexico State University Observatory.[3]

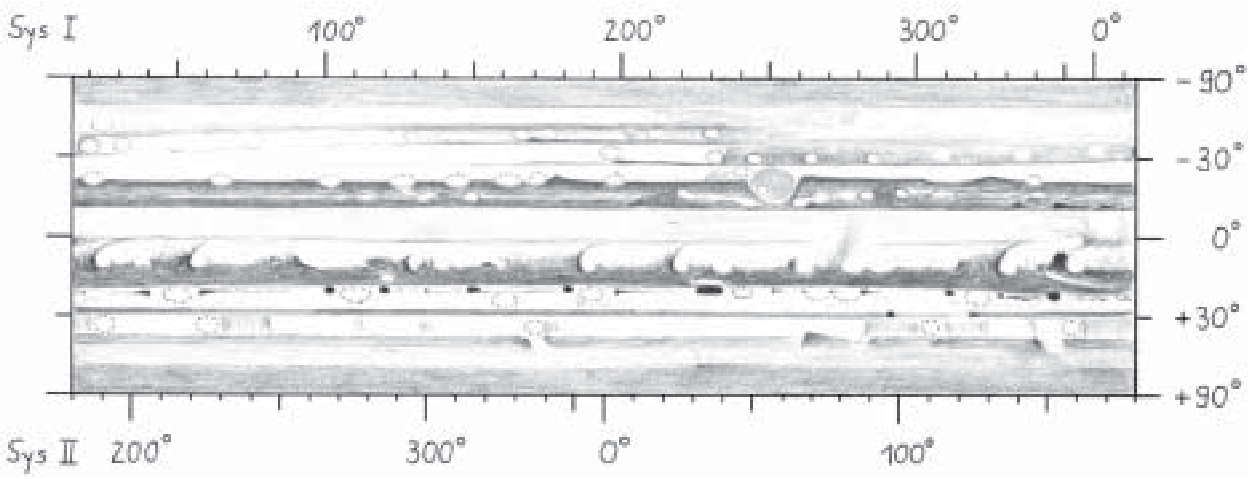


Figure 1. Visual map of the planet, 1997 Aug. 7–11, drawn by Hans–Joerg Mettig. Compiled from 23 of his drawings with 125 transit timings.

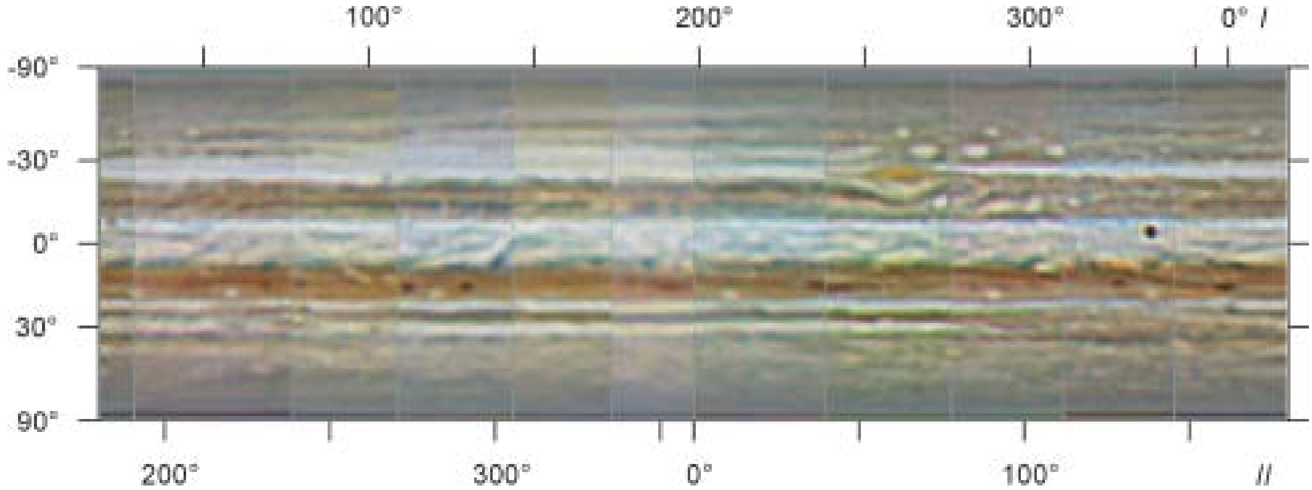


Figure 2. Map of the planet, 1997 July 11–14, from images by Isao Miyazaki, mapped as a photomosaic by Hans–Joerg Mettig, using a program specially written by Grischa Hahn. Longitude scales are for System I above and System II below. The black spot in EZ is a satellite shadow.

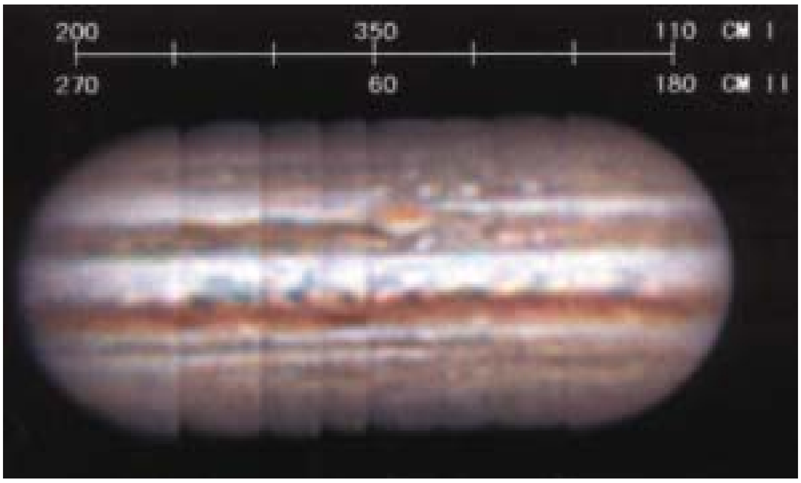
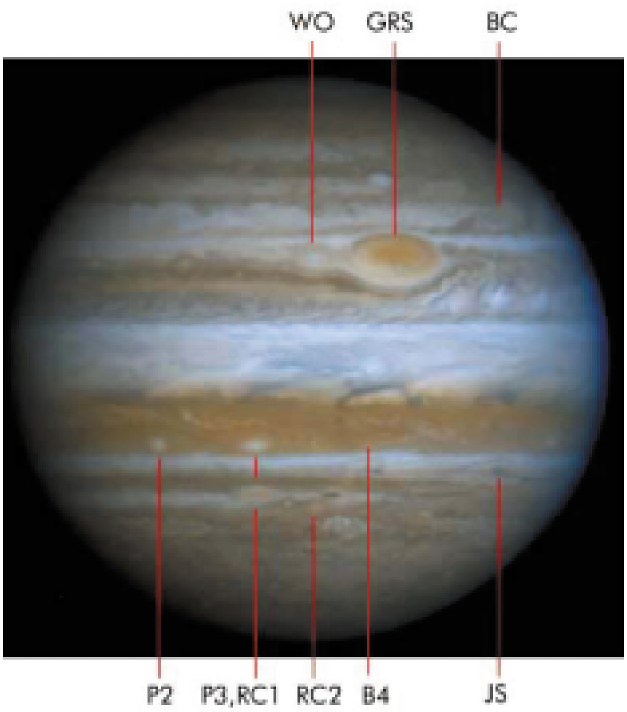


Figure 3 *(left)***.** Map made as a composite of images on 1997 July 7 (Akutsu). Colour is well represented; note orange-brown NEB and chaotic blue projections on its S edge.

Figure 4 *(below left)***.** Image from the Hubble Space Telescope, 1997 May 4, CM2 ~45. In the south this includes: the GRS; STropZ white oval (WO) approaching its p. edge; and oval BC. In the north it includes: NEBn 'portholes' nos. 2 and 3 (P2, P3), and the big barge no.4 (B4), though this is not well shown (see text); two reddish clouds in NTZ (RC1, RC2; see text); and a NTBs jetstream spot (JS). The N. Temperate Disturbance is on the f. side. Compare with Figure 3A in ref.2.

Figure 5 *(below)***.** Enhanced-contrast image, 1997 Aug.5, 05.58 UT, CM1 213, CM2 58 (Parker). This shows the spectacle of the STB white ovals (BC, DE, FA, from left to right), passing the GRS. It also shows the two light orange ovals in N. Polar region, no.11 (orange, cyclonic) p. CM, no.9 (former Little Red Spot but now paler, anticyclonic) just f. CM.



Observations

The contributors are listed in Table 1. Foremost was Isao Miyazaki (Japan) who sent approximately 400 CCD images, usually in triptychs comprising a white-light image, a colour image, and a methane image. Don Parker (Florida) also sent many superb images, and other sets of excellent images came from Tomio Akutsu (Japan) and Jean Dijon (France). We have also measured some professional images from the Pic du Midi observatory,[4] at the start of the apparition and to fill some gaps.

The most prolific visual observer was Hans–Joerg Mettig (Germany), who made 120 drawings and about 650 transits. He also sent his own charts, plotted using the JUPOS computer system written by Grischa Hahn and himself.[5] These charts tracked most of the spots listed in our tables, and Mettig's whole-planet map is presented as Figure 1. Other visual observers deserving special mention were Makoto Adachi (Japan), who sent 104 drawings including many of excellent quality, and David Lehman (California) who sent many drawings and transits, tracking many spots in precise agreement with image measurements.

Table 1. Observers of Jupiter, 1997

Visual observers		
M. Adachi	Otsu, Japan	310mm refl.
M. Bosselaers	Berchem, Belgium	255mm refl.;
	Bredasdorp, S. Africa	130mm Kutter 3-mirror
J. Chapple	Bristol	250mm SCT
E. Colombo	Milano, Italy	152mm refl.
W. Cuppens	Gruitrode, Belgium	355mm refl.
P. Devadas	Madras, India	355mm refl.
T. Dobbins	Coshocton, Ohio, USA	346mm refl.
C. Ebdon	London	250mm refl.
D. Fisher	Sittingbourne, Kent	215mm refl.
M. Foulkes	Hatfield, Herts.	203mm SCT & 254mm refl.
D. Graham	Coshocton, Ohio, USA	355mm refl.
H. Gross	Hagen, Germany	250mm refl.
A. Heath	Long Eaton, Notts.	200mm SCT
D. Lehman	Fresno, Ca., USA	250mm refl.
L. Macdonald	Newbury, Berks.	222mm refl.
R. McKim	Oundle, Northants.	216mm refl.
H-J. Mettig	Radebeul, Dresden, Germany	150mm coudé OG
D. Niechoy	Göttingen, Germany	200mm refl.
A. Nikolai	Berlin, Germany	130mm OG & 150mm OG
J. Olivarez	Oakland, Ca., USA	200mm refl. etc.
J. Rogers	Linton, Cambs.	250mm refl.
R. Schmude	Barnesville, Ga., USA	510mm refl.
J. Stellas	Athens, Greece	102mm OG
D. Storey	Carterton, Oxon.	250mm refl.
R. Stoyan	Erlangen, Germany	356mm refl. etc.
R. Tatum	Richmond, Va., USA	250mm refl.
G. Teichert	Hattstatt, France	280mm SCT
D. Ward	Portland, Vict., Australia	150mm refl.
S. Whitby	Hopewell, Va., USA	152mm refl.
CCD images, mostly via internet:		
T. Akutsu	Nasu-gun, Japan	320mm refl.
B. Colville	Maple Ridge, Ont., Canada	250mm SCT
J. Dijon	Sillans, France	200–500mm refl.
	Champagnier, France	520mm refl.
M. Gavin	Worcester Park, Surrey	300mm refl.
J. Manteca & A. Sanchez Caso	Gualba, Barcelona, Spain	200mm & 250mm refl.
I. Miyazaki	Okinawa, Japan	400mm refl.
D. Parker	Coral Gables, Florida, USA	410mm refl.
T. Platt	Binfield, Berks.	318mm Quad-Schief-spiegler
T. Richards	Eltham, Vict., Australia	180mm OG
Summaries of other national reports forwarded by:		
M. Bosselaers & W. Cuppens	Belgium	
Y. Iga	Japan	
W. Wacker	USA	

In addition to the individual observers, several recorders from different countries sent compilations of data and analyses including charts. Yuichi Iga (Japan) reported and analysed the NTBs jetstream outbreak, from Pic du Midi images and Japanese observations.[6] Dr Wynn Wacker (USA) e-mailed selected ALPO images and drawings showing the North Polar region's 'dark mottling'.[7] Dr Tom Richards and Barry Adcock (Australia) sent observations by members of the Astronomical Society of Victoria, and a paper analysing them, which included many images and strip-map drawings by Richards, and drawings by Don Ward.[8] Mark Bosselaers and Wim Cuppens sent visual data and charts from Belgian observers in the VvS. An interim report has also been published by American observers.[10]

In the past we have plotted all reliable longitude measurements on common charts, but with the recent increase in high-quality CCD imaging, this is no longer necessary nor time-efficient. This report is mainly compiled from the best CCD image data, unless otherwise stated. However visual data were also plotted for some regions, and the charts sent by recorders from other countries were used to confirm and extend the results from images. Visual data will still be invaluable when there are rapid changes to be recorded, or when CCD images are not available.

Preliminary assessment of longitudes for the GRS suggests that our drift rates derived from images are overestimated by about +0.3°/month during oppositions, due to the phase effect. This is half of the phase effect found in earlier reports using photographs or transits.

Intensities and colours of belts and zones, according to visual estimates, are listed in Table 2. Zenographic latitudes of belts are in Table 3; latitudes of spots are included in Table 9.

Longitudes are given, as usual, in Systems I and II (L1, L2, formerly λ_1, λ_2), and drift rates in degrees per 30 days (DL1, DL2, formerly $\Delta\lambda_1$, $\Delta\lambda_2$).

South Polar and Temperate Regions

South Polar Region

As in 1995 and 1996, contrast-enhanced CCD images showed a bright South Polar Hood (SPH) bordered by a very dark, broad 'collar' all around the pole (SPB; 63–69°S). However these features were much enhanced by the image processing. They are discussed in the Appendix.

There was a bright reddish spot at 60°S, with irregular motion, slowly retrograding then slowly prograding at up to –16°/mth. In its latitude and motion it was very similar to several other white or yellow spots imaged in the past [p.83 of ref.11], including one in 1996,[1] which could be the same

Table 2. Intensities and colours, 1997 (visual estimates)

	Colombo Aug–Oct		*Devadas June–Oct*	*Foulkes Aug–Nov*	*McKim Sep–Nov*	*Rogers Aug–Sep*		*Heath Sep–Oct*	*(B–V)*	
N=	*8*		*1–6*		*6*	*5*		*10*		
SPR	3.5	grey	Brownish grey	Grey	3.3	2.6	grey	3.0	1.1, 1.7	greyish
SSTB*	3.5	grey	–	Warm grey or g-b.	4.2	3.0				
STZ	2.6	grey or yelh.	–	Light grey	–	–				
STB*	3.3	grey or brown	(Neutral)	Grey or g-b.	4.4	4.0	grey	4.0	0.8, 1.2	grey
STropZ	1.6	yelh.	–	Yelh-w. or w.	0.5	0.3	off-white	1.0	1.8, 2.6	yelh.
GRS	3.0	rosy	–	Grey	–	1.8	pinkish grey	3.0	1.8, 3.0	pinkish
SEB(S&N)	5.0	brown	Yel-brown	Warm brown or g-b.	4.8	5.7	dark grey	5.0	1.0, 2.1	fawn
EZ	1.0	yellow	Bluish-white (NEBs/festoons: Bluish)	Yelh-w. or w. (Festoons/EB: Grey)	0.7 (EB: 2.5)	0.1 (EZ(N): 0.7	white off-white)	0.5	1.1, 2.0	off-white
NEB	5.1	brown	Reddish; deep red (NEBn)	Cold brown or g-b.	5.0	5.9	reddish-brown	5.0	1.3, 2.6	brown
NTropZ	1.9	yelh.	–	Dull yel. or dull w.	1.1	1.1	yelh.	2.3	1.1, 1.7	greyish
NTB	5.0	brown	Reddish	Light grey (early), darker brown (late)	3.8	4.4	grey	3.2	0.7, 1.1	grey
NTZ	1.7	yelh.	–	Light grey	1.1	0.8	off-white	2.3	1.0, 1.9	greyish
NNTB	3.5	grey	Reddish	Dark grey	3.6	4.2	grey			
NPR	3.5	grey	Grey	Grey or pink	3.2	3.0	grey	3.0	1.0, 1.7	greyish

w., white; yel., yellow; yelh., yellowish; g-b., greyish-brown. *Not prominent at all longitudes.
N, number of observations. Number for SSTB, STB and GRS was smaller.
Heath's 'B–V' column is the difference between his estimates in red (W25) and blue (W44a, W47) filters.

spot if it underwent another fast spurt during solar conjunction (Table 4).

South South Temperate Region

The general impression of the southern hemisphere was much as in 1996. There were several narrow dark belts in the S.S. Temperate region (Table 3), and seven of the tiny long-lived anticyclonic white ovals at 41°S (Table 4).

South Temperate Region

As in 1996, the STB was substantial on one side of the planet (from the cluster of ovals, to a f. end or 'step-up'), but weak on the other side.

Long-lived ovals BC, DE, FA formed a tight cluster, and were passing the GRS during 1997 (Figures 1–9). They were closer together than last year, and most of the ovals that were between them had disappeared. However there was still a cyclonic spot between DE and FA, wandering slightly in relative longitude; it was vivid red and so it may well be the 'morphing spot' that had been notable for several years. By October 5 it had become a very small red spot in contact with oval DE (Figure 7A). It then backed off from oval DE, as imaged on Oct.12, but was a mere fragment when last imaged on Oct.17 and 19.

The most important event did not begin until the last months of the apparition, and was not recognised until after solar conjunction, when the Pic du Midi Observatory reported that ovals BC and DE had merged. During 1997, ovals BC and DE had maintained almost steady drift of –12°/ month, their centres 17–18° apart, until late October when they had just passed the GRS. Then BC decelerated and DE accelerated, bringing them only 11° apart in December (Parker, Dec.11; Miyazaki, Dec.28; Figure xC). In 1998 January both ovals were smoothly accelerating but continuing to converge (10° apart; Pic du Midi, Jan.7 and 17).[4] After solar conjunction, from 1998 March 27 onwards, there was only a single white oval moving at about –16°/month, to be described in our next report.

Another interesting new spot appeared in 1997 October: a very small dark bluish spot on the STBs. It emerged from a region of STBs that was slightly darker on September 10 (alongside a brighter patch of STZ) and comprised a faint bluish-grey smudge on Sep.20. It was first imaged as a spot, very small and faint, at L2 = 318 on October 4; it was slightly more conspicuous on Oct.12, and notably dark on Oct.18, prograding with typical STC drift. This became an exceedingly dark and compact spot that attracted attention in the 1998 apparition.

South Tropical Region

South Tropical Zone and Great Red Spot

An important and unprecedented collision occurred between the Great Red Spot and a long-lived white oval in the STropZ.

Table 3. Latitudes of belts, 1997.

SPBs*	–69.2		
SPBn	–62.8		
Narrow belts:			
S^4TB	–55.3		
(anon.)	–49.4		
S^3TB	–44.2	NNTBn	+36.7
SSTB	–38.3	NNTBs	+33.4
STB (p. BC)	–29.0	NTBn	+28.3
STBn (f. GRS)	–27.6	NTBs	+25.1
SEBs	–22.5	NEBn	+21.4
SEB(S)	–20.5	NEB(N)	+20.5
SEB(C)	–13.7	NEB(C)	+15.5
SEB(N)	–8.8	NEB(S)	+9.8
SEBn	–7.8	NEBs	+8.2
EBs	–4.4		

Zenographic latitudes were measured by the Director from four images by Miyazaki, 1997 July to September.
*SPBs, S. edge of S. Polar Belt or 'collar', = N. edge of S. Polar Hood. In methane images, N. edge of S. Polar Hood was at –61.6.

Figure 6. Some late images by Miyazaki, showing the gradual clearing of the yellow-ochre expanded northern NEB, but residual colour contrast with bluish-white NTropZ.

(A, *top***)** Sep.2, 14.54 UT, CM1 284, CM2 273. Shows the NEB triplet of two intense barges with a porthole; also a NTBs jetstream spot, and the NTB rift on the p. side. (A second, transient, NTB rift is on the CM). Also shows the SPR bright spot.

(B, *centre***)** Nov.12, 11.17 UT, CM1 197.5, CM2 5.5.

(C, *bottom***)** Dec.28, 09.14 UT, CM1 176, CM2 354.

(B) and **(C)** both include NEB barges and porthole, including the long barge no.4 still persisting. They also show ovals BC and DE (on f. side), which have suddenly moved closer on Dec.28.

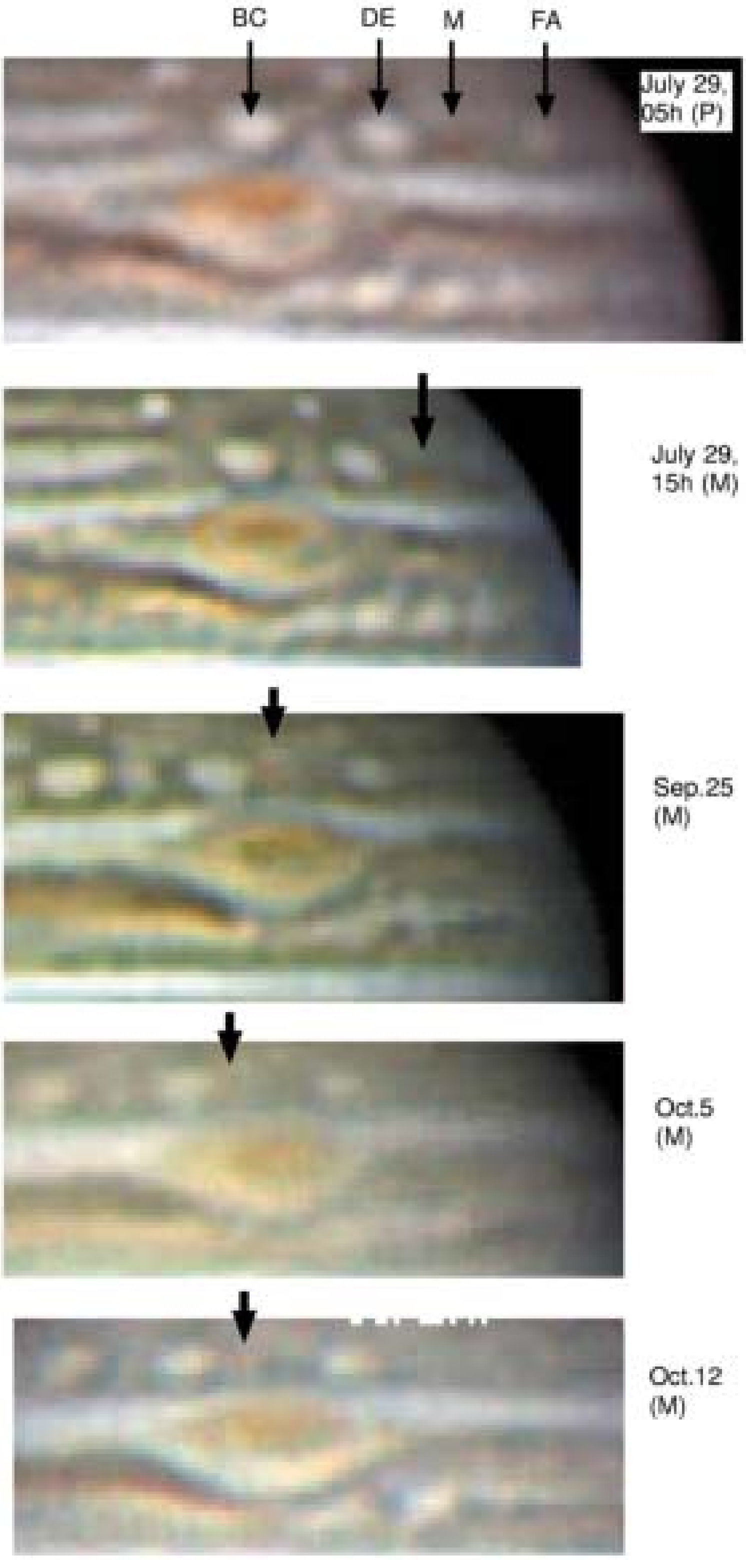


Figure 7. The GRS after it consumed the STropZ white oval, with the S. Temperate white ovals passing it.

(A, *above***)** Details from images by Parker (P) and Miyazaki (M), July 29–Oct.12. This follows on from the earlier series of images in the interim report [ref. 2]. In the GRS, a dark bluish patch or streak is always present, and it shows anticlockwise motion over one rotation on July 29, trailing behind a light spot (see text). The S. Temperate ovals include anticyclonic white ovals BC, DE, FA, and also the red, cyclonic 'Morphing Spot' between them. The Morphing Spot approached to contact the f. edge of oval DE by Oct.5, then recoiled on Oct.12. (The alignment of colours in the Oct.12 image is inexact.)

(B, *opposite page***)** Image of the GRS from *Galileo* at the C9 encounter; 1997 June 26, 01.34 UT. South is up (sic). The GRS appears distorted as it was near the p.

The event was predicted in our 1996 reports, detected by Miyazaki in 1997 May,[2] and imaged by *Galileo* in June following a last-minute revision of the targetting of the GRS region (Figure 7B). This was important for understanding the atmosphere as it was the first time two such large anticyclonic ovals had been seen to collide on Jupiter. Would the white oval rebound, dissipate, or merge, on its encounter with the GRS? In the event it merged, but over about 2 months, not one week as some models predicted.

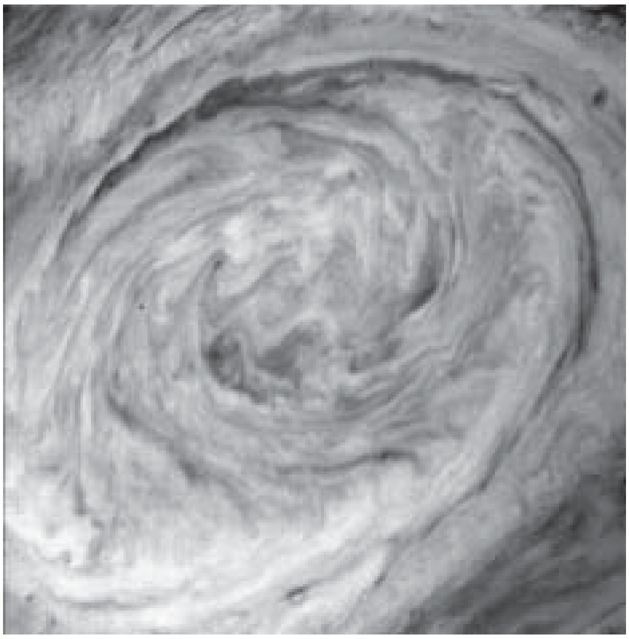
This conspicuous STropZ white oval had been tracked since 1987. (For its history to 1992, see pp.197–198 of ref.11, and ref.13.) When the SEB whitened before the SEB Revivals in 1990 and again in 1993, the white oval turned into a little red spot. After the 1993 SEB Revival, the spot reverted to a white oval, which was conspicuous and stationary near the longitude of impact site G in 1994, but it then recommenced the slow increase in longitude which brought it to the GRS in early 1997. The encounter was summarised and illustrated in our interim report.[2]

Miyazaki's images on April 11 revealed the long-lived STropZ white oval about to collide with the GRS, just 8° edge-to-edge. The convergence rate between the white oval and the GRS, which was 4°/month last year, had been only 3°/month during conjunction. However the next image on May 12 showed the white oval poised on the p. end of the Red Spot Hollow. On May 20 and 21 it seemed to be moving into the Hollow, and on May 22 (Parker and others) it seemed to be a bright white streak within the north or north-preceding (Np.) part of the GRS itself, as if caught up in the rapid circulation within the GRS. Then it apparently stalled just Np. the middle of the GRS, and broke up. On May 24 and 29 (Miyazaki), the main sign of it was a bright notch in the Red Spot Hollow just p. its northernmost point, and there was no distinct sign of it on June 3 (Parker).

However, the white clouds at the visible surface may have taken a different course than the deeper circulation of the white oval. Images on June 5 (Scott Murrell, 755 nm)[9] and June 6 (Miyazaki; Figure 10A)[2] showed a striking bright spot with a dark rim, just Nf. the middle of the GRS; this could well be the revived white oval, still proceeding slowly round the GRS. For the remainder of June, only Pic du Midi images were available,[4] mostly at the near-infrared wavelength of 780nm so not revealing much in the GRS. There was no obvious disruption, though the GRS had a variable dark rim. This was when *Galileo* imaged the GRS (Figure 7B).

Then, from July to September, images often showed an unusual and variable blue-grey streak within the GRS, which may well have been a relic of the collision. Comparing images on July 12 (Miyazaki) and July 14 (Parker),[2] this curved blue-grey streak in the GRS appeared to have shifted radially outwards over 2 days! However this would be most peculiar; rather, the blue-grey streak(s) may have been a variable border to a white strip, orbiting within the GRS, just like a white strip which had a 6-day orbital period during the *Voyager* encounters [pp.195–196 of ref.11]. On July 29, two images 10 hours apart showed a white spot moving anticlockwise in the f. part of the GRS with a dark bluish spot trailing behind it (Figure 7A). Over the next 2–3 months, the appearances resembled those seen in July (Figure 7A). In or near the middle of GRS was an unusual dark grey bar, oriented east–west, which was probably dark material from the white spot rim concentrated into the centre of the GRS vortex. The detailed appearance changed frequently, alternating between a simple dark grey bar, and a more red-and-grey complex with a fainter blue-grey streak curving somewhere in the f. part of the GRS.

This collision did not change the large-scale appearance of the GRS, which was the same as in the *Voyager* era. Even in hi-res images, most of the orange-pink oval GRS was undisturbed. Visual observers as usual saw some pinkish or rosy colour under favourable conditions (Colombo, Devadas, Rogers). The GRS was 19° long.



limb. Taken in the near-infrared continuum (756nm). This single image does not show obvious differences from earlier *Galileo* and *Voyager* close-ups of the GRS, but in combination with a multicolour set of half-images that was taken one rotation later, it should show how the GRS was disturbed following the white oval merger. NASA image, taken by the *Galileo* SSI team, leader Dr M. J. S. Belton, and obtained from the Planetary Data System web site [ref.12].

South Equatorial Belt

The SEB was unchanged since 1996. The belt had three grey components, with light brown material between them. SEB(S) was broader than usual to the south, without evident jetstream spots. SEB(C) was narrow and very dark though fragmentary in places. SEB(N) was tenuous. The usual bright rifting continued f. the GRS.

Equatorial Region

As usual for the past few years, there was a narrow white strip in the south part of the EZ, whereas the central and northern parts were occupied by a complex subtle mixture of shadings with subdued tints.

NEBs features were often irregular and very rapidly varying. Many were long bluish-grey plateaux; some were shorter projections, and some were very dark. There were many transient small spots, both dark and bright. White spots sometimes formed plumes at the f. ends of dark features. Stable dark projections were rare (Table 5). Rather, the shapes of the long dark features, and the patterns of small spots, changed radically over a few days.

For example, conspicuous dark bluish spots suddenly appeared or intensified, according to Miyazaki and/or Mettig, as follows: L1= 87 and 125 (July 20; both immediately f. bright plumes); L1= 350 (Aug.11); L1= 37 (Aug.16–29; no.2 in Table 5; remained very dark and compact with D L1= –8°/mth till early Oct., then reversed drift and changed form); L1= 322 (Sep.22; no.7 in Table 5; a very dark stable wedge in October, but absent in November). No factors to cause these changes could be seen.

Drifts were also diverse, and the pattern had changed since 1996. Drifts in System I were generally negative at L1 < 30 and positive at L1 > 40, with the new dark block (no.2) drifting to and fro in the middle. Table 5 lists only the more coherent features; many others were too inconstant to be listed.

North Tropical Region

North Equatorial Belt

In 1996 the NEB underwent a classical NEB expansion event, its north edge shifting to 21°N. Such events occur irregularly (the previous one was in 1993) and are typically followed by reddish colour and the appearance of dark 'barges' and white 'portholes' in the expanded north half [pp.118f of ref.11]. These sequels indeed appeared in 1997.

The NEB was broad, and rich reddish-brown overall – strikingly redder than the SEB. It was partially triple like the SEB,

Table 4. Longitudes and drifts, 1997: southern hemisphere

1997: No.	*Description*	*L2(O)*	*DL2*	*Dates*	*N*	*1996: No.*	*L2(O)*	*DL2*	*O–O DL2*
SPC									
1	Pinkish light spot SPBn	264	(~0 to –16)	July 12–Oct 13	13	?	344	(~–27 to 0)	–6.0
SSTC									
Anticyclonic white ovals (AWO) at 41°S									
2	AWO (bright)	338	–27.5	April 11–Aug 9	17#	10	330	–24	–26.3
			–> –25.3	Aug 9–Nov 2	10#				
3	AWO (bright)	42	–23.9	May 22–July 22	7	3	20	–33; –21	–25.3
			–> –26.7	July 22–Nov 14	19#				
4*	AWO (bright)	66	–28.0	June 6–Oct 24	21	4	42	–25	–25.1
5	AWO (tiny, new)	(86)	–26.1	Aug 25–Nov 12	5				
6	AWO	146	–28.0	June 21–Nov 3	16	6	113	–21	–24.4
7	AWO	163	–26.4	July 12–Oct 17	10	7	150	–28; –24	–26.0
8	AWO (at p. end dark SSTB)	183	–26.2	July 11–Oct 25	14	8	187	–29; –24	–27.4
9	F. end dark SSTB	248	(–27.5)	May 31–Nov 13	19				
Average			–26.6		10				
STC									
10*	AWO-BC	59	–12.1	May 15–Oct 24	30#	BC	215	–11.2	–11.7
11*	AWO-DE	76	–11.0	May 15–Nov 12	32#	DE	237	–12.0	–12.0
12	Dark red spot ('Morphing Spot'?)	86	–12.5	May 22–Oct 5	11	17	263	(var.)	–13.2
13*	AWO-FA	100	–11.9	June 6–Nov 10	24#	FA	275	–12.6	–13.1
14*	AWO (small)	136	–16.5	Aug 13–Oct 17	8	?19	291	–12.0	–11.6
15	F. end of main STB	240	(–11)	July 13–Oct 25	11	...	358	–13.4	–8.8
Average			–12.5		6				
STropC									
16*	Great Red Spot	64	+0.7	May 12–Nov 10	28#	GRS	59	+1.0	+0.4
17*	White bay STropZ/SEBs	10	+7.1	July 2–Sep 21	11#	–			
18	White spot in SEBZ(S)	308	+3.8	May 31–July 31	5				
			–> +13.0	Aug 7–Nov 14	12#				
Average			+6.1		4				

The columns are as follows: *Number*; *Description*;
L2(O), System II longitude at opposition on 1997 August 9 (for System III, add 9°);
DL2, System II drift in degrees per 30 days (for DL3, add +8.0°/month);
Dates of observation or drift measurement;
N, Number of rotations on which longitude was measured from images. (#: These spots were also measured, on a similar number of occasions, by visual transits by Mettig, and by some other visual observers.)
The remaining columns give data from the 1996 apparition, followed by *DL2 (O–O)*, the average drift rate between oppositions in 1996 and 1997. The lines marked *Average* give the average drift rate for each current, and the number of values from which it was derived.

*Notes on individual objects:
No.4 Still visible to Nov 14 but apparently accelerating towards No.3. Between nos. 4 and 5 was a cyclonic white oval, passing ovals BC-DE-FA.
No.9 SSTB splits or veers south into S^{3}TB; p. end bright SSTZ sector; variable speed.
Nos.10–13 Ovals BC and DE changed speeds from October onwards and converged; see text. Oval FA then gradually accelerated, following DE. No.14 was observed with slower drift before August.
No.16 (GRS) was 2–3° f. the quoted track in June–July, probably because of the impact of the STropZ white oval (which is not listed).
No.17 A very bright bay tracked by Mettig; apparently a junior version of the one which had merged with the GRS. It was visible on images, but not measured from images as the SEBs was complicated here.

Table 5. Longitudes and drifts, 1997: Equatorial region

No.	Description	L1(O)	DL1	Dates	N_p, N_v	Notes
N Equatorial Current						
1	Dark proj.	(20)	(var.) (0 to −7)	Aug 13–Nov 13	15, 11	Small dark proj., –> F. end of large dark proj. (with w.s. f. it)
2	Large dark proj.	(38)	(var.)	Aug 28–Oct 24	14, 13	Appeared suddenly at end of August
3	F. edge plateau	(48)	+11	Sep 8–Nov 29	13, 5	F. edge of long dark proj. or plateau
4	F. edge plateau	183	(var.) +6	July 11–Sep 5	15, 1	F. end of dark plateau, sometimes with plume
5	Dark proj.	(296)	−12	Aug 13–Nov 3	11, 10	Dark proj. or f. edge thereof (with w.s. f. it)
6	Dark proj.	320	−18	Aug 4–Sep 19	7, 10	Dark proj. or plume
7	V. dark proj.	(322)	0	Sep 19–Oct 25	9, 5	Wedge-shaped, very dark proj.
8a	Dark proj.	356	−17	July 19–Aug 28	6, 8	
8b	F. edge dark proj.	(356)	−4	Sep 1–Oct 19	9, 6	Same proj., changed shape
Average			−4.9		4	

N, Number of rotations on which longitudes was measured from images (N_p) and from transits by selected visual observers (N_v).
Proj., projection on NEBs; var., variable; w.s., white spot.

but the components were more fragmentary and the background reddish-brown colour was stronger. This colour was noted by several visual observers (Devadas, Heath, Rogers, Tatum) (Table 2) although other observers saw NEB and SEB as equally brown (Colombo, Foulkes). The NEB was clearly the reddest belt in tricolour CCD images, especially Akutsu's which seem to display colours most faithfully (Figure 3). The dark barges, which were very conspicuous visually as they were so dark, shared the reddish-brown colour of the belt according to images and some visual observers (Heath, Rogers).

NEB(S) comprised the irregular string of dark blue-grey NEBs plateaux and projections. NEB(C) was a tenuous and incomplete brown line connecting some of the dark barges (and thus marking the canonical NEBn). NEB(N) was a narrow purplish (!) line marking the limit of the expanded belt. The space between the C and N components progressively faded during the apparition, initially following the longest barge, and then elsewhere, so that the NEB was gradually reverting to its normal width, leaving the N component as a narrow purplish 'N.Tropical Band' at 21°N. By late November, the expanded northern strip (19–20°N) had cleared completely, except that it still had a 'warm' tint, in contrast to the 'cold' tint at 22–23°N. These two nearly-white zones formed the reconstituted NTropZ, with the very tenuous N.Tropical Band at 21°N in the middle (Figure 6).

Once again several visual observers (Foulkes, Graham, Rogers) saw the NTropZ as yellowish, even though it was almost white in images. Overlap of colour from the warm-tinted northern NEB may have contributed to this impression.

'Barges and portholes'

'Barges' are dark cyclonic oblongs at 16°N, and 'portholes' are anticyclonic white ovals at 19°N, both in the NEBn edge; arrays of them typically develop after a NEB expansion event [pp.118f of ref.11]. As predicted by the Director, a classical array of both types appeared in 1997. Some were visible in the earliest images from April–May, and they were very impressive by May 31. Although most of the barges were small, they were intensely dark and brown, and visual observers were struck by their intensity. In spring there were six barges and seven portholes; after two portholes

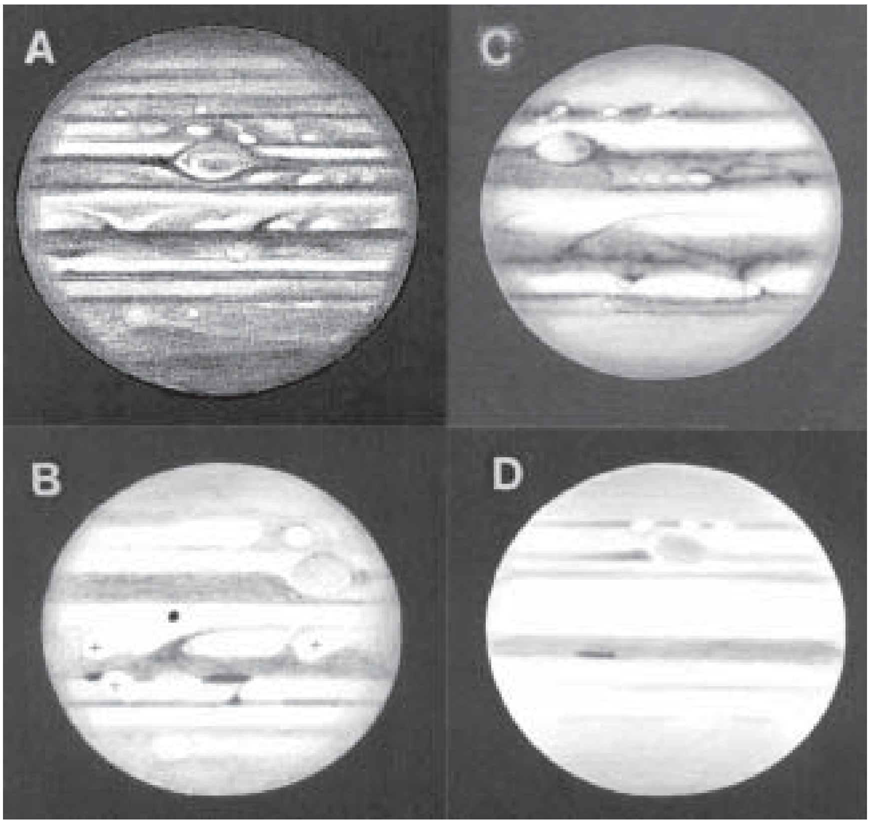


Figure 8. Four drawings which show the GRS with the ovals to S, and NEBn dark barge(s); also NTBs jetstream spots in two of the drawings.

(A) Aug.20, 13.31 UT, CM1 340, CM2 68 (Adachi).

(B) Aug.27, 23.10 UT, CM1 359, CM2 30 (Rogers). The NTropZ appeared yellowish-grey, possibly because the white zone was blurred with the yellowish-brown NEBn extension. This was made 1.5 hours after the planet was without visible satellites; the shadow of Europa is still on the EZ.

(C) Sep.1, 00.02 UT, CM1 100, CM2 93.5 (Bullen).

(D) Sep.4, 20.20 UT, CM1 79, CM2 50 (Heath).

Table 6. Longitudes and drifts, 1997: North Tropical region

No.	Description	L2(O)	DL2	Dates	N_p, N_v
NtropC					
1	DS (small)	352	−1.4	May 12–Oct 19	32, 28
2	WS	(17)	+1.6	May 12–June 9	7, 0
3*	WS	(20)	(−5)	May 12–June 9	7, 0
3b	WS	3	(−5)	June 25–Nov 14	32, 18
4*	DS	38	−5.6	Apr 11–Nov 12	36, 28
5	WS	86	−4.8	Apr 11–Aug 9	18, 0
			−1.7	Aug 13–Nov 10	13, 12
6*	VDS (small)	119	−11.8	May 28–Oct 14	16, 18
7	WS	130	−10.5	June 11–Oct 17	20, 15
8	VDS	157	−4.0	May 28–Sep 19	16, 22
			−1.5	Sep 19–Nov 23	10, 9
9	WS	189	−0.6	June 21–Sep 2	10, 1
			−4.4	Sep 2–Oct 25	7, 0
10	WS	218	−1.5	June 24–Oct 29	23, 18
11*	DS	(226)	−0.6	Aug 12–Nov 2	17, 19
12*	VDS (small)	270	−2.4	May 31–Nov 22	27, 30
13*	WS	280	−2.1	May 31–Nov 22	28, 13
14*	VDS (small)	290	−1.2	May 31–Nov 22	28, 26
15	DS (growing)	(318)	(−5.0)	Sep 10–Nov 2	7, 3
Average			−3.5		19

The columns are as follows: *Number*.
Description: DS, dark spot ('barge') at 16°N; VDS, very dark 'barge'; WS, white spot ('porthole') at 19°N.
L2(O): System II longitude at opposition on 1997 August 9.
DL2: System II drift in degrees per 30 days (for DL3, add +8.0°/month). Most showed slight variations of a few deg./month.
Dates of observation or drift measurement.
Number of rotations on which longitude was measured from images (N_p) including Pic du Midi images, and from transits by selected visual observers (N_v). About half of the latter were by Mettig.

*Notes on individual spots:
Nos. 2 and 3 merged and move p. in June, forming No. 3b, whose drift varied −10 –> −1 –> −6.
No. 4 was the largest (12° long) and best-observed dark barge. It was first recorded on 1996 Oct 30 at L2= 68.
No. 6 was gradually accelerating; became tiny in September, then disappeared.
No. 11 formed from two tiny spots present at L2 230 and 240 in July, and gradually intensified.
Nos. 12–14 formed a striking triplet, and were again observed on 1998 January 9 by Cuppens.

merged (Figure 3 of ref.2), and a new barge evolved from merger of two 'pinprick' dark spots, by the autumn there were seven barges and six portholes. After each merger, the new spot, whether dark or bright, moved faster for a few weeks. Four of the portholes had a barge 10° away, either p. or f. or (in one case) both p. and f. (Figure 6A). The latter triplet arrangement has been seen before (p.119 of ref.11), but the other barges and portholes did not show any tendency to arrange themselves as triplets. The largest and best-observed barge was no.4, just p. the longitude of the GRS, shown in many of the figures. It was 12° long, and conspicuous and dark in Earth-based images from April 11 to Dec.28 (Figure 6), at all wavelengths from red to blue. (It was still present in the 1998 apparition.)

Hubble Space Telescope images (e.g. Figure 4) did not show the barges prominently, but this was because they used near-infrared wavelengths. The NEB barges were not much darker than the NEB in near-infrared images, e.g. most of the images from the Pic du Midi[4] and by Scott Murrell.[9] More puzzling is the invisibility of the large barge no.4 in Figure 4; however it shows a small bright 'rift' draped around the position of the barge, so perhaps the barge was temporarily veiled

Table 7. NTBs jetstream spots

No.	Description	L1(O)	DL1	Dates	N_p, N_v
NTC-C					
Small dark spots on NTBs					
1	DS	41	−62.2	May 2–Nov 12	25, 6
2	DS	85	−58.8	Apr 13–Nov 10	45, 24
3*	DS	(148)	−63.6	July 1–July 29	10, 1
4	DS	181	−59.2	June 28–Nov 14	34, 14
5*	DS	241	−63.2	Apr 3–Nov 10	22, 6
6	DS	297	−62.0	Apr 9–Nov 23	30, 14
7	DS	324	−61.0	Apr 9–Nov 3	25, 13
Average			−61.4		7
NTC-B					
P. end of rift in NTB			+68	July 22–Nov 13	18, –

N_p, N_v: as in Table 6.
*No.3 reappeared in September, as observed three times by Tatum.
*No.5 was absent in May-June and in August.

by haze associated with the passage of this rift. It was also indistinct a few days later (Figure 3 of ref.2).

The drift rates of the barges and portholes were quite diverse, which presented a challenge in predicting their positions months in advance for the *Galileo*-E11 encounter.

Three of the white portholes were included, by chance, in *Galileo* imagery: one at the E4 encounter, one at G7 (no.5 in Table 4; ref.2), and one at E11. However, it seems that no barges were imaged, as the relevant longitudes could not be fitted into the targeting schedule.

North Temperate Region to North Polar Region

NTBs jetstream outbreak

On the NTBs edge were seven small, very dark bluish spots, constituing a typical NTBs jetstream outbreak, moving at –10° per *day* in System II (Table 7). They were first reported by Yuichi Iga (Japan) from measurements on Pic du Midi images,[4,6] as well as in Japanese visual observations; some were later identified in Pic du Midi images from early April. They were well tracked by images, and also well observed visually by Lehman, Mettig, and Tatum. By June/July there were seven of these spots. Although they were so similar, they had slightly different appearances and speeds; in most cases their individual speeds remained absolutely constant throughout the apparition.

No.2 was the biggest and/or darkest. Nos.3 and 5 were long streaks rather than spots in their first month of existence, and each had 1–2 months of visibility alternating with 1–2 months of invisibility. Nos. 1,6, and 7 were typical spots; and no.4, the last to appear in early July, became diffuse in September but was very dark again in October. These spots were sometimes exceptionally large and dark when alongside NEBn 'portholes', but were unaffected when passing lighter sectors of NTB.

These spots were analysed by Iga[6] who determined mean D L1 = –60.0°/mth, mean period 9h 49m 9.5s. Our own chart, using mostly the same data, gives mean D L1 = –61.4°/mth, mean period 9h 49m 7.6s (Table 7). This is almost exactly the same speed as the NTBs spots have shown in most years since 1991, typical of the NTC-C. The constancy both of the mean speed and of the individual spot speeds are remarkable since the NTC-C does not represent the full speed of the NTBs jetstream [chapter 7.4 of ref.11].

Some hi-res images showed the jetstream spots as detached from the NTBs edge. This apparent NTBs edge was slightly further north than usual, and some images showed a faint yellowish-brown fringe which represented the canonical NTBs edge, alongside the much darker grey belt.

North Temperate Belt

The NTB was a solid, very dark, grey belt at most longitudes.

However there was a rather faint sector of NTB, initially noted from May to mid-July lying alongside the N. Temperate Disturbance (NTD; see below; DL2~ +19°/mth, = NTC-A). But from mid-July onwards it detached from the NTD and moved much faster (D L1 = +68°/mth, DL2 = –161°/mth, = NTC-B). This faint sector or rift varied from ~4° to ≥50° long. It often appeared as an oblique (Sp.–>Nf.) rift in the NTB, probably similar to the cyclonic turbulent rifts in the NEB which also move at speeds intermediate between Systems I and II. Historically it is typical for NTC-B features like this to appear following NTC-C spot outbreaks (chapter 7.4 of ref.11).

North Temperate Disturbance and North Temperate Zone

The North Temperate Disturbance (NTD) was a sector starting at L2 ~ 65–90, in which the darkest 'belt' was not the NTB but a variable oblique streak spanning the NTZ. (See pp.103–104 of ref.11 for a description of NTD's, especially of the previous NTD of 1988–1992; this resembled the present one in many details, including the appearance of bright cyclonic ovals and a Little Red Spot in the NTZ flanking it.) The NTD developed from a darkened sector of NTZ that was recorded in 1996, first with a distinct NTB(N) and then with general shading. When the *Galileo* G7 images were taken in early April, 1997, the NTB was still very prominent and dark along here (Miyazaki and Pic du Midi images) – but the G7 images showed that something was odd, because the NTB seemed very diffuse except for an intensely dark narrow straight line along the middle of it.[2] Then in 1997 May–June this had become a classic NTD, i.e. a great dark belt segment spanning the canonical NTZ, while the NTB proper was rather faint. But it evolved rapidly. In mid-July the main feature was a very narrow, orange-brown, oblique band trending northwards through lightly shaded NTZ. In late July only a short streak was left, with NTB and NNTB restored intact alongside it. This well-defined dark grey streak (NTC-A nos. 1–2 in Table 8), 16–20° long, was at 29°N. so it was a normal NTB(N) streak; it persisted till October then faded.

One or more bright white ovals were sometimes imaged just p. or f. the p. end of the NTD, but they were short-lived; no.6 was one longer-lived one which survived. Although they appeared to be in NTZ, their latitude is typical of the NTB so they were actually cyclonic (Table 9). True NTZ anticyclonic white ovals are rare.

An even more remarkable spot (no.7) also appeared near the p. end of the NTD. It was a Little Red Spot prograding on NNTBs, which developed from a diffuse reddish cloud in the NTZ in May, which probably developed from interaction between two reddish clouds shown in the HST image *circa* May 4 (Figure 4). These two clouds were at L2 = 34, on NTBn so probably retrograding, and L2 = 47, on NNTBs so probably prograding; the NTZ reddish cloud was imaged at L2 = 39 on May 12-24, when it seemed to diffusely overlie both NTZ and NNTB (Figure 3A of ref.2). The LRS as imaged from May 31 onwards was orange-grey and became, more and more, a compact oval embedded in NNTBs, with gradual acceleration (Figure 3C of ref.2). However the 'NNTBs' was further south than usual so the spot was well within the canonical NTZ. It was bright in methane images, remarkably so given its small size (see Appendix). Its drift of –26°/mth was almost unprecedented, except for NNTBs dark spots in 1942–1945 and 1989 [pp.97–98 of ref.11]. Probably these were all dark anticyclonic spots only partially entrained by the prograding NNTBs jetstream. (There was no detectable activity on the NNTBs jetstream itself this year, except in *Galileo* images.)

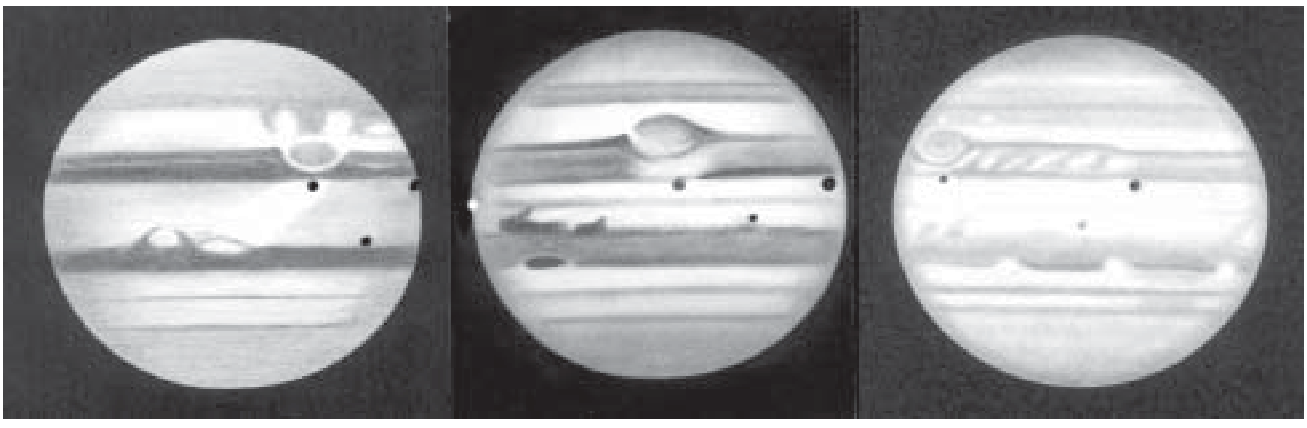


Figure 9. The triple transit on Sep.21. From left to right, transiting across the EZ, are the shadow of II (moving fastest), the dark disk of III (northerly, appearing smaller, presumably because only parts of it are very dark), and the shadow of IV. Also note the GRS, with white ovals south of it.

(A, *left***)** Sep.21, 19.25 UT, CM1 210, CM2 52 (Ebdon).

(B, *centre***)** Sep.21, 19.34 UT, CM1 215.5, CM2 57.5 (McKim); II is on p. limb at end of its transit.

(C, *right***)** Sep.21, 20.39 UT, CM1 255, CM2 97 (Nikolai).

Table 8. Longitudes and drifts, 1997: Northern hemisphere

No.	Description	L2(O)	DL2	Dates	N
NTC-A					
1*	P. end of NTD	{ 93	(+5)	May 15–July 25	7
	then of grey streak in NTZ	{ 90	+12	Aug 6–Oct 17	7#
2	F. end of grey streak in NTZ	106	+13	Aug 6–Oct 17	6#
3	W.s. in NTZ (v.bright)	194	+15.5	July 13–Oct 25	15#
4	W.s. in NTZ (at p. end of shading)	226	+14.5	July 16–Oct 25	13#
5	W.s. in NTZ	(249)	+11	Aug 31–Oct 6	7#
6	W.s. in NTZ	68	+12.5	July 20–Oct 17	8#
Average			+13.1		6
7	Little red spot on NNTBs	348	−25.6	July 12–Oct 6	13
NNTC & N^3TC					
8	Whitish oval on NNTBn	152	+3.7	June 21–Nov 23	18#
9*	Whitish oval	67	(var, −10)	May 15–Nov 10	26
10	White oval in NPR	309	−13	July 26–Oct 19	12
11	Orangey oval in NPR	29	−20	July 14–Sep 12	8

Columns and annotations are as in Table 4 (Southern hemisphere). See text and Table 9 for more details of these spots.
*These features were tracked since 1996:
No.1: P. end of dark NTB(N): 1996, L2(O) 254, DL2 +16; DL2(O–O)= +12.2.
No.9: Little Red Spot: 1996, L2(O) 186, DL2 −10; DL2(O–O)= −8.9.

The NTZ, apart from the NTD, was bright white at most other longitudes through most of the apparition. However there was a cluster of two or three small transient dark spots at L2 ~ 220–270 (July), 270–290 (Sep.) (not listed in the table but moving with the NTC; one of them was orange-brown). In September the sector containing these spots showed increasing patchy shading – grey veils flanked by bright but cyclonic white ovals like those near the NTD (NTC-A nos.3,4,5 in Table 8).

Other northern spots

The various ovals in the northern hemisphere in 1997 were of considerable interest, in respect of (i) their colours in visible light and their reflectivity in methane images (see Appendix); (ii) their drifts and latitudes; (iii) their appearance in *Galileo* images during the G7 encounter in 1997 April (Figure 2 of ref.2). They are listed in Tables 8 and 9.

In addition to the North Tropical and Temperate ovals just described, the well-defined ovals were as follows.

–No.8: Small white oval north of NNTB, not visible in methane, moving with the normal NNTC; its latitude is cyclonic.

–No.9: NNTZ Little Red Spot, bright in methane. Evidently it is the one tracked since 1995, which we called LRS-1 in 1996; it was prograding then but slipped behind by >20° during solar conjunction, according to infrared data from Dr Glenn Orton (pers. com.). It was targeted for the *Galileo* G7 images in 1997 April and just half of it was imaged, after its changes in drift.[2] It had a steady prograding motion of DL2 = −12°/mth which was typical of the N^3TC, not the NNTC; but then it had another hiatus in September, slipping 8° behind its previous track. Evidently it was one of those NNTZ features influenced by the N^3TC, but to a variable extent. It was dark reddish in images in May, but in Miyazaki's images from July onwards, it was merely creamy or white, not reddish – though it remained methane-bright as before. (Parker's more enhanced images still showed some colour; Figures 5 and 10.)

–No.10: Small white oval north of NNTB, just visible in methane though never red, moving like no.9 in the same latitude.

–No.11: In contrast, 35° preceding no.9, there was another oval which was reddish but not methane-bright (Figure 5). This was slightly further north, in a cyclonic latitude.

The correlation or otherwise between colours in visible light and brightness in methane images is discussed in the Appendix. Initially there seemed to be surprisingly little correlation. But when latitudes were established, it turned out that some of these white or red ovals were (unusually) in canonically cyclonic latitudes, and therefore were cyclones. These cyclonic ovals were not methane-bright, regardless of how white or red they were. White or reddish ovals are more usually anticyclonic, and these included all the methane-bright ones, especially any anticyclonic ovals which were or had been reddish.

The correlation between drifts and latitudes also accords with previous records, in spite of the great variety of drifts. Most spots adhered to the normal drifts for their domain (NTC-A, NNTC, N^3TC), except for faster-moving spots in the NTZ and NNTZ as described above, which also have historical precedents.[11]

The *Galileo* G7 imaging in 1997 April was targeted to the North Temperate region (L2 ~ 106), and it included an excellent sample of interesting spots.[2] They included a NEBn 'porthole'; part of the North Temperate Disturbance; a pair of NNTBs

Table 9. Bright ovals and dark barges, 1997

Name	Apparent position	Lat. ß″	Domain	Sense	DL2	Current	Redness	Methane brightness
–	SPR	−60.1	SPR	A	−8	SPC	+	[nr]
AWOs	SSTB	−40.8	SSTZ	A	−27	SSTC	–	[nr]
BC, DE, FA	STBs	−33.5	STZ	A	−12	STC	–	++
Morphing spot	STB	(−31)	STB	C	−12.5	STC	++	–
GRS	SEBs	−22.6	STropZ	A	+0.7	STropC	++	+++
Dark barges	NEB	+15.9	NEB	C	−3.5	NTropC	+	–
Portholes	NEBn	+18.9	NTropZ	A	−3.5	NTropC	–	–
Nos.3–6	NTZ	+29.5	NTB	C	+13	NTC-A	–	–
No.7 (LRS)	NNTBs	+34.3	NTZ	A	−26	–	++	+
No.8	NNTBn	+38.4	NNTB	C	+4	NNTC	–	–
No.9 (former LRS)	NNTZ/NPR	+42.0	NNTZ	A	−10	NNTC/ N^3TC	(±)	++
No.10	NNTZ/NPR	+42.0	NNTZ	A	−13	N^3TC	–	(+)
No.11	NPR	+44.5	N^3TB	C	−20	N^3TC	+	–

All these were light ovals (red or white), except for the dark red 'morphing spot' and the 'barges'.
The zenographic latitude (ß″) determines in which domain the spot lies, and so whether it is anticyclonic (A) or cyclonic (C). The observed drift rates in degrees per month are typical of the normal currents for the domains. [nr], not resolvable.

jetstream spots (light reddish anticyclonic ovals, also bright in methane, but too small to be recorded in our images); part of the NNTZ LRS; as well as other characteristic spots of these latitudes.

N.N.Temperate Belt to North Polar Region

NNTB was a solid, fairly narrow, dark belt at most longitudes, with intensity varying from moderate to very dark grey; however latitudes indicate that it actually lay across the canonical NNTBs latitude.

Further north, at most longitudes there were no distinct zones or belts, though there were many short faint sectors, and some small very dark flecks. There were several well-defined bright ovals, and innumerable smaller fainter spots in the highest-resolution images.

There was some correspondence about 'high latitude mottling' shown in images of the north polar region, first in high-quality CCD images by Brian Colville of Canada. The dark patches were most conspicuous in near-infrared images, and as such images had not often been taken before the last few years, it is not clear if these features are unusual. The ALPO web site gives more details.[7] Possibly the north polar region was entering one of its episodes when more detail is visible, perhaps because the haze is thinner.

Address: 10 The Woodlands, Linton, Cambs. CB1 6UF. [JR@mole.bio.cam.ac.uk]

References

1 Rogers J. H. & Foulkes M., 'Jupiter in 1996', *J. Brit. Astron. Assoc.*, **111**(2), 67 (2001)
2 Rogers J. H., interim report, *J. Brit. Astron. Assoc.*, **107**(6), 333–335 (1997)
3 Karkoschka E. & Murrell S., *Sky & Telesc.*, **95**(5), 106 (1998 May)
4 Lecacheux J. *et al.* (Observatoire du Pic du Midi), http://megasn.obspm.fr/gll_pdm.html
5 Mettig H-J., http://www.t-online.de/home/h.j.mettig/
6 Iga Y. *et al.* (ALPO-Japan), http://www.kk-system.co.jp/Alpo/Intro_Jupiter.htm
7 Hill R. (Association of Lunar and Planetary Observers), http://www.lpl.arizona.edu/alpo
8 Richards T. J. (Astronomical Society of Victoria, Australia), http://www.qsr.com.au/User-Pages/Tom.html
9 Beebe R. (International Jupiter Watch, Atmospheres), http://atmos.nmsu.edu/ijw/ijw.html
10 Olivarez J., *J. Assoc. Lunar Planet. Obs,*. **40**(3), 129–133 (1998)
11 Rogers J. H., *The Giant Planet Jupiter*, Cambridge University Press, 1995
12 NASA, http:///www-pdsimage.jpl.nasa.gov/cgi-bin/Nav/GLL_search.pl
13 Rogers J. H. & Foulkes M., 'Jupiter in 1991/92', *J. Brit. Astron. Assoc.*, **104**(4), 167–178 (1994)
14 Rogers J., interim report, *J. Brit. Astron. Assoc.*, **105**(3), 109–111 (1995)
15 Minton R. B., *Commun. Lunar & Plan. Lab.* 9 (no.176), 339–351 (1972)
16 West R. A. *et al., J. Geophys. Res.*, **86**(A10), 8783–8792 (1981)
17 McDonald G. D. *et al*., *Icarus,* **99**, 131–142 (1992)
18 Moreno F. *et al.*, *J. Geophys. Res.*, **98**(E10), 18837–18845 (1993)
19 Hubble Space Telescope images taken in 1994 July during comet impact week. Examples in:
Space Telescope Science Institute, http://oposite.stsci.edu/pubinfo/index.html
Rogers J. H., Miyazaki I. & Limaye S. S., *J. Brit. Astron. Assoc.*, **106**(3), 151–154 (1996)

Appendix

Methane band images of Jupiter, 1995–1997

John Rogers, Michael Foulkes & Isao Miyazaki

At the near-infrared wavelength of 0.89μm, a strong methane absorption band allows images to reveal the heights of the uppermost clouds and hazes in Jupiter's atmosphere [chapter 4 of ref.11]. Methane is uniformly distributed in Jupiter's atmosphere, so the planet is very dark in this waveband; but high-altitude clouds and hazes, lying above much of the methane, appear brighter. Since early studies at the University of Arizona,[15] it has been known that the major methane-bright features of the atmosphere are the polar hoods, the major zones (especially when coloured reddish), and anticyclonic ovals.

Recent advances in CCD technology have enabled advanced amateurs to take useful images in this waveband. Isao Miyazaki routinely takes methane-band images, along with his visible-light images. He uses a filter centred at 893nm with a width of 5nm, and exposures are typically 90 seconds. After some preliminary images in 1994, before and during the comet crash,[14] he began taking them regularly in 1995.

This report summarises what has been revealed by Miyazaki's methane-band images in 1995, 1996, and 1997. (Images from 1998 have shown the same patterns as in 1997). Typical 1997 images are in Figure 10. The galilean satellites all appear very bright because they are not subject to methane absorption. Here we discuss the major high-altitude cloud features that are visible: the polar hoods, the major zones, and some anticyclonic ovals.

Polar hoods

The brightest features are the hazes or 'hoods' that lie over both poles. The north polar hood is diffuse, but the south polar hood is brighter and has a sharper edge. Both hoods show some limb-brightening, especially the northern hood, consistent with their high altitude. These high-altitude hazes may be produced by some reactions involving the downward flux of auroral particles,[16,17] and their asymmetry could be due to the asymmetry of the jovian magnetic field, in that the northern auroral zone is offset from the rotational pole, whereas the southern auroral zone is more centred on the pole and so produces a more well-defined hood.

When first studied, at the University of Arizona in 1968-1972, the methane-bright South Polar Hood extended down to 68-70°S (4-5% of the planet's polar diameter).[15] The latitude of the apparent edge varied slightly, along with the tilt of the planet, such that the apparent width of the hood was constant, and this still seems to be the case. However, more recent images show the methane-bright hood extending down to 65°S (6% diameter) in 1992[18] and 1994 [images by Miyazaki and Hubble Space Telescope][19]; and to 63°S (7% diameter) in 1995-1997 [this report].

The south polar hood can also be detected in the best visible-light images, though only in blue or violet light until the advent of digital unsharp-masking. In 1968-1972, the methane-bright hood and the visible hood coincided, extending down to ~69°S, and the visible

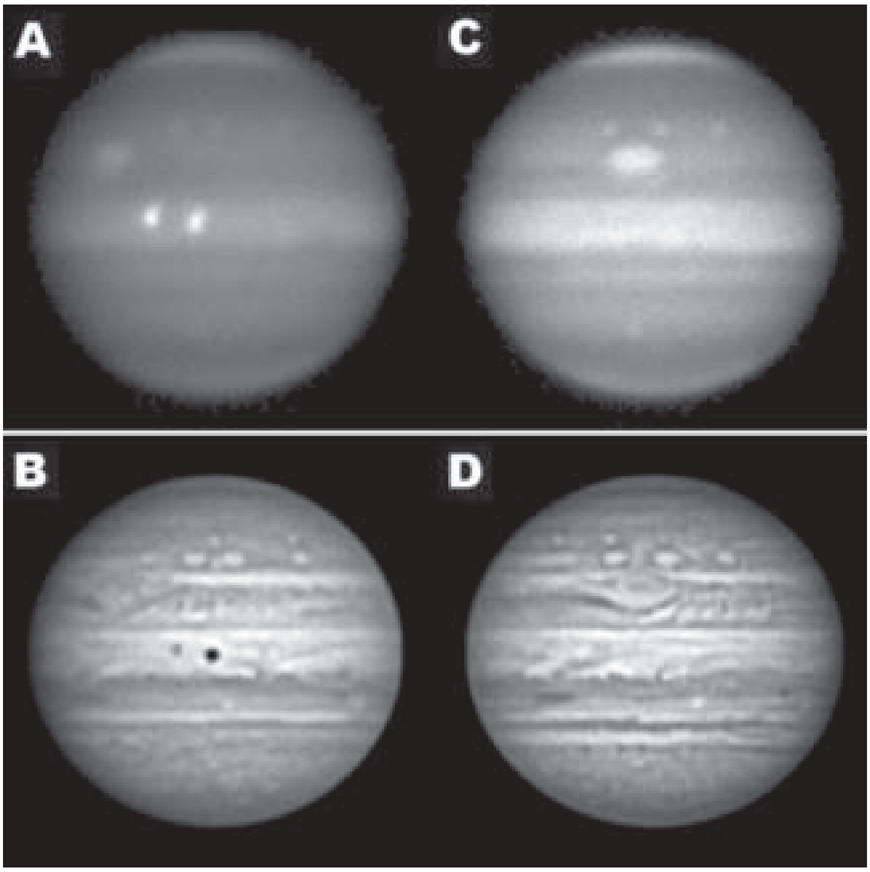


Figure 10. Images in methane band (A, C) and white light (B, D) by Miyazaki.
(A, B) 1997 June 6 (shows GRS; BC, DE, FA; I & III in transit; SEBZ rift not bright).
(C, D) 1997 Aug.25 (shows GRS; BC, DE, FA; NNTZ WO; SEBZ rift not bright).

hood was surrounded by a dark collar down to ~61-63°S.[15] Miyazaki's visible-light images from 1994-1997 (after digital unsharp-masking) show that the visible hood and dark collar are in the same latitudes as before, even though the methane-bright hood now covers the collar as well as the visible hood. Thus the visible hood still extends only to 69-70°S (3-5% diameter), and the collar to 63-66°S (6-7% diameter). The latitudes were the same in far-red images taken in 1992 at Calar Alto.[18] We should also note that, although the visible bright hood appears much more prominent and white (rather than blue) in Miyazaki's post-1994 colour images, this is attributable to the digital image processing rather than to any change in the hood itself.

As the visibly dark collar reflects brightly in the methane band, this implies that it lies at high altitude, perhaps in the stratosphere. Therefore it is probably made of molecules formed from above by auroral chemistry, possibly hydrocarbons. In contrast, in 1968-1972 the dark collar was not methane-bright, so it presumably lay at deeper, tropospheric levels like other belts. The cause of this change is unknown. It was not caused by the comet crash because 1992 (pre-crash) and 1994 (impact week) images showed the same pattern as the 1995-1997 images.

Major zones

In general, methane images show a similar pattern of belts and zones as in visible light, because the cloud-tops in zones are higher. However there are some interesting discrepancies and changes.

The STropZ is always methane-bright and the SEB methane-dark, especially SEB(S). In 1995, when there was conspicuous SEBs jetstream activity and a visibly bright SEBZ, methane images showed very dark patches on SEB(S), and a perceptible SEBZ. In 1996-1998, when SEB was quieter and darker visibly, it was more uniformly dark in methane. The SEBs jetstream activity (which largely consisted of anticyclonic dark spots) is the only local disturbance to have shown up prominently in methane images. In contrast, cyclonic rifts or white spots in the SEB (following the GRS, and in the 1998 mid-SEB outbreak) are not bright in methane.

The EZ has changed little in visible light in these years, but in 1995 the methane images showed a broad dark Equatorial Band, and this was much reduced in 1996-1998. The NEBs projections and plumes are rarely detectable in methane images, except for diffuse methane-brighter patches over some visibly bright plume areas.

The NTropZ is always methane-light and the NEB methane-dark. When the NEB was visibly broader in 1996 and 1997, there was surprisingly little change in the methane images.

Anticyclonic ovals

The Great Red Spot is the most obvious methane-bright spot. The South Temperate anticyclonic white ovals are also always methane-bright.

In contrast, in the North Tropical region, the anticylonic white 'portholes' are not methane-bright; not in Miyazaki's images in 1997, nor in *Galileo* images in 1997,[2] nor in a Hubble Space Telescope image in 1994.[19] Presumably the portholes, embedded in expanded NEBn in each of these years, had lower cloud-tops, in contrast to smaller anticyclonic white ovals in other domains which were strongly methane-bright in the same image sets.

In higher northern latitudes, anticyclonic ovals are smaller and less conspicuous visibly, but methane images in 1994, 1995, and 1996 revealed two methane-bright spots in NNTZ latitudes; close inspection of hi-res colour images showed that these coincided with anticyclonic Little Red Spots.[1]

In 1997, the picture in the northern hemisphere initially seemed more complex, with little correlation between colour and methane-brightness. However, analysis confirmed that anticyclonic ovals are methane-bright if they are red (or even have a tendency to redness); white anticyclonic ovals are sometimes methane-bright (though those on NEBn are not); and cyclonic ovals are not methane-bright, regardless of how white or red they are. These visibly-bright ovals of 1997 are listed in Table 9. They included a prograding 'Little Red Spot' in NNTZ (tracked since 1995 but no longer red), and another Little Red Spot prograding on NNTBs. When latitudes were established, some of the ovals which were not methane-bright turned out to be in canonically cyclonic latitudes, and so they were cyclonic rather than anticyclonic, which is more usual for white or reddish ovals. Thus the high-altitude haze that appears methane-bright is only formed over anticyclonic ovals, and particularly so if they are red.

Received 1999 August 31; accepted 2000 February 26