Saturn in 1995–'96

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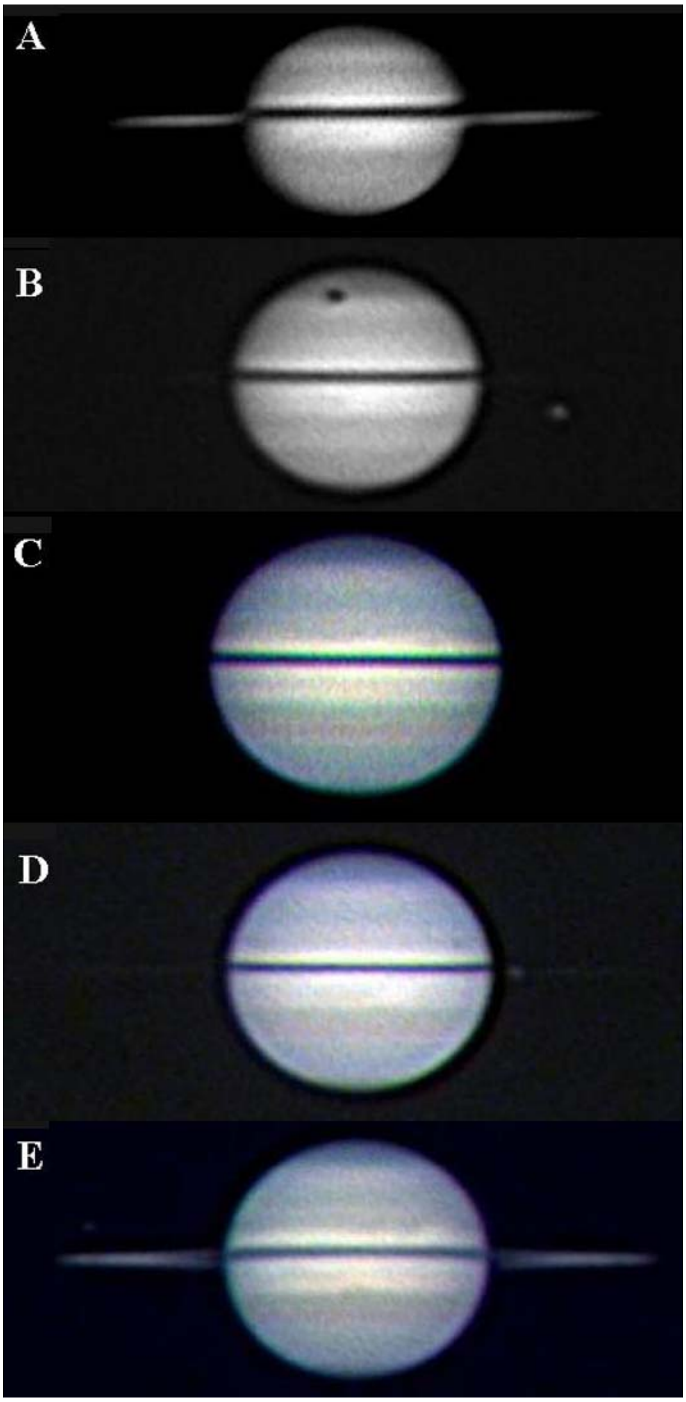
A report of the Saturn Section. Director: M. Foulkes

BAA observations between 1995 April and 1996 February are reviewed. Highlights of the apparition were observations of the phenomena of the triple ring-plane crossings by the Earth and the ring-plane crossing of the Sun, the results of which show that the predicted times were correct to within a few hours. Transits and shadow transits of Titan, Rhea, Dione and Tethys were observed. Several mutual satellite events were also observed, either visually or by means of CCD cameras. White spot activity could again be followed in the planet's northern Equatorial Zone (EZ), though it was much reduced from 1994–'95: the long-enduring white spot (WS1) had survived solar conjunction and continued to move with a rotation period close to 10h 22m, as did another short-lived feature. On the other hand, three other EZ(N) spots showed a considerably faster period. Dark spot activity on the S. edge of the NEB(S) yielded a typical drift rate for the belt, slightly faster then System I, and a similar result was found for white spots in the southern EZ. Rotation periods were also derived for the SEB(N), NEB(N) and NTropZ.



Introduction

Saturn was in opposition to the Sun in Aquarius on 1995 September 14, and during this memorable apparition – as had been the case in 1966 – there was a triple crossing of the ring plane by Earth, in addition to which the Sun passed through the plane on November 19: this is shown graphically in Figure 7.

The planet's northern declination (+5.6° at opposition) was relatively favourable for UK observers, and the added attraction of the edgewise rings drew reports from many contributors (Table 1). Graham had the use of the Lick Observatory's 36-in (91cm) refractor during August 7–14, and Biver the large Cassegrain telescopes of Meudon Observatory for the whole opposition. Gray was able to observe on 57 dates and obtained a good number of Central Meridian Transits (CMT). As in 1994–'95 most observations were visual, but CCD images were made by several observers, with Parker taking his first experimental methane-band images of Saturn (Figure 19). Quarra *et al.* obtained a superb image on one night at Pic du Midi. Miyazaki took an excellent series of 70 CCD images. Observations covered the period 1995 April 20 (Schmude) to 1996 February 21 (Proctor). The limiting solar conjunctions took place on 1995 March 6 and 1996 March 17.

Visual intensity estimates are summarised in Table 2 and belt latitudes in Table 3. It is interesting to compare this apparition with BAA reports for 1966[1] and 1979–'80.[2] This report follows the style of earlier ones, being a continuation of that for 1994–'95, published recently.[3] It may also be compared with those by ALPO and UAI.[4]

Early notes about the apparition appeared in the form of a review of the expected ring phenomena in the *Journal*[5] as well as some preliminary observational reports[6–8] and notes in the *Circulars*.[9–10] The Hubble Space Telescope (HST) took several images of the planet (for example in Figure 23), and these led to the

Figure 1 *(left)*. CCD images with 400mm refl. and Lynxx-PC CCD camera, *I. Miyazaki*.
A. 1995 Apr 28d 20:28 UT, ω_1= 044°, ω_2= 033°. Illuminated rings still bright. EZ(N) white spot activity *p.* and *f.* the CM interrupts the EB.
B. 1995 Jul 5d 16:59 UT, ω_1= 096°, ω_2= 053°, red filter. Titan's shadow on the disk; unilluminated rings very faint.
C. 1995 Aug 10d 15:47 UT, ω_1= 212°, ω_2= 087°, RGB composite. Rings invisible on unilluminated side.
D. 1995 Aug 11d 15:31 UT, ω_1= 327°, ω_2= 170°, RGB composite. Illuminated rings faintly visible again. Rhea is against the *f.* ansa and Rhea's shadow is on the SEBn on the *f.* side. WS5 in the EZ(N) just *f.* the CM.
E. 1995 Sep 30d 13:31 UT, ω_1= 355°, ω_2= 026°, RGB composite. Illuminated rings opened and showing details including ShGR. Note NEBs projection and EZ(S) white oval.

discovery of more new satellites.[11] Of particular interest and importance were the timings of mutual satellite phenomena: several sources of predictions were available,[12–15] and some reliable observations were made. Studies of atmospheric dynamics by Sanchez–Lavega *et al.* were again of relevance to this report.[16] Images around the time of ring-plane crossings by professional observatories were posted on the internet, including some fine work at Pic du Midi.[17]

The writer feels that several valuable BAA results are well worth presenting in this account, despite the regrettable long delay in publication.

Table 1. Observers and observing groups

Observer	*Location(s)*	*Instrument(s)*
P. G. Abel	Burton on Trent, Staffs.	114mm refl.
R. M. Baum	Chester	115mm OG
S. Beaumont	Windermere, Cumbria	300mm refl.
N. D. Biver	Meudon Observatory, France	310mm OG, 600mm & 1m Cass.
A. G. Bowyer	Epsom Downs, Surrey	300mm refl.
D. Bruton	Texas A&M Obsy., USA	355mm SCT
R. Bullen	Bognor Regis, Sussex	216mm refl.
J. S. Chapple	Bristol	254mm SCT
E. Colombo	Milan, Italy	203mm refl.
P. B. Doherty	Selsey, W. Sussex	390mm refl.
E. L. Ellis	St Albans, Herts.	203mm SCT
M. Foulkes	Cleethorpes, S. Humbs.	152mm refl.
	Hatfield, Herts.	203mm SCT & 254mm refl.
	Cambridge Univ. Obsy.	310mm OG
M. Giuntoli	Montecatini Terme, Italy	80mm OG
D. L. Graham	Richmond, N. Yorks.	152mm OG & 406mm refl.
(with T. Dobbins, S. J. O'Meara & W. P. Sheehan)	Lick Obsy., California, USA	36-in (0.91m) OG
D. Gray	Spennymoor, Co. Durham	415mm DK
A. W. Heath	Long Eaton, Notts.	300mm refl.
N. D. James	Chelmsford, Essex	300mm refl.
J. Lancashire	Cambridge Univ. Obsy.	203mm & 310mm OGs
L.T.Macdonald	Newbury, Berks.	222mm refl.
R. J. McKim	Oundle, Northants.	216mm refl.
	Chesterfield, Derbyshire	254mm & 457mm refls.
B. Manning	Kidderminster, Worcs.	260mm refl.
C. E. Meredith	Manchester	215mm refl.
	Salford Observatory	450mm refl.
R. Miles (with A. J. Hollis)	Manley, Cheshire	279mm SCT
I. Miyazaki	Okinawa, Japan	400mm refl.
M.P.Mobberley	Bury St Edmunds, Suffolk	490mm refl.
P. A. Moore	Selsey, Sussex	390mm refl.
S. L. Moore	Fleet, Hants.	355mm refl.
N. Morrison	Crawley, W. Sussex	203mm SCT
D. Niechoy	Göttingen, Germany	203mm SCT
D. C. Parker	Miami, Florida, USA	410mm refl.
I. S. Phelps	Warrington, Cheshire	152mm refl.
T. Platt	Binfield, Berks.	318mm Tri-Schiefspiegler
C. J. Proctor	Torquay, Devon	203mm refl.
G. Quarra (with L.Aerts & P.Tanga)	Pic du Midi Obsy., France	1.08m Cass.
J. H. Rogers	Cambridge Univ. Obsy.	310mm OG
	Linton, Cambs.	254mm refl.
R. W. Schmude	Barnesville, Georgia, USA	90mm OG
	Texas A&M Obsy., USA	355mm SCT
D.Storey	Carterton, Oxon.	254mm refl.
Unione Astrofili Italiani (UAI; 15 observers)	various	various
A. Vincent	Worthing, Sussex	305mm refl.
D. Weldrake	Middlesborough	305mm refl.
J. Youdale	Billingham, Cleveland	305mm Cass.

Abbreviations: refl.= reflector; OG= refractor ('Object Glass'); Cass.= Cassegrain; SCT= Schmidt–Cassegrain; DK= Dall–Kirkham Cassegrain.

The globe

Global colours

Using the Lick refractor Graham (Figure 6) had a fine view of the relative global colours. He saw the SEB and NEB both as greyish brown (sometimes just grey). The STropZ and STeZ were yellowish, and the NTropZ and NTeZ yellowish grey. The SPR was described as steel blue with the NPR grey: a slight difference between the hemispheres had also been witnessed in 1994–'95 but it was less apparent then. Graham saw the SSTeZ, SSTB, EB, NTB and NNTB simply as grey. Observing with Graham, Sheehan & O'Meara recorded the SPR as greenish, which accords with the 'cold' tint seen by Graham. They and many other observers described the EZ as creamy-yellow. Graham's fellow observers[18] described the tint of the main belts as 'butterscotch'. Biver showed the N. and S. hemispheres to have a general warm, yellowish tint.

Gray made systematic colour notes with his large reflector. To him the STeZ was a creamy yellow-green, adjacent to a more greyish or grey-ochre STropZ. The NTropZ varied from deep fawn in the south to yellowish in the north, with a grey or slightly yellowish NTeZ. The SEB was typically brown, with the NEB grey-brown. The EZ(N) was creamy, and lighter than the EZ(S), the latter being greyish-ochre (but with a tinge of pink on Sep 24 and Dec 27). Gray saw the SPR/SPB as olive or greenish brown, but the NPR/NPB as dark slate-blue or blue-grey. CCD filter images tend to show the polar regions and SPB darker in red light, which is consistent with their having a greater blueness than adjacent zones. Filter images also showed the SEB(N) darker in blue, confirming its warm tone, but in red light the SEB(S) was the darker of the two, as shown for example by Parker's RGB series on Jul 4.

With smaller apertures, Foulkes and Heath saw the NEB as brownish-grey, the warm tint being more evident than in the SEB, as Gray had noted. Foulkes and McKim generally saw the EZ(N) as yellowish white and the EZ(S) as greyish white. Heath described the EZ(S) as having an ivory tint. McKim saw the SEB and NEB as 'warm grey', while the STropZ/STeZ and NTropZ/NTeZ were grey with a hint of yellow or yellow-green.

In summary, there was little evidence for any difference in colour between the two hemispheres, apart from a greater bluish tint in the disappearing NPR compared to the SPR. Support for this colder hue in the N. hemisphere comes from its much greater darkness compared to the S. hemisphere in Parker's methane-band image (Figure 19). It is believed that the implied reduction of atmospheric aerosols and ammonia clouds in the north has allowed the underlying methane to absorb the longer visible wavelengths as well as the IR, as in the case of Uranus and Neptune.

South Polar Region

This emerging region darkened the S. limb, being very foreshortened. Nevertheless it was considerably darker than the NPR. The dusky SPR was bounded by a broad and even darker South Polar Belt (SPB), which was often the darkest marking on the globe. A narrow SSSTeZ was occasionally witnessed between SPR and SPB.

South South Temperate Zone

Very foreshortened, fringing the SPB. A drawing on Aug 10 with the Lick refractor by Dobbins[18] showed the zone unusually light: recall the high latitude white spot of 1994–'95[3] which had been observed to spread in longitude. Intensity estimates and other high resolution

Table 2. Visual intensity estimates, 1995–'96

Feature	*PA*	*SB*	*NB*	*AB*	*RB*	*EC*	*MF*	*DGm*	*DGy*	*AH*	*RM*	*CM*	*SM*	*RS*	*DS*	*UAI*	*DW*	*Ave.*	*No.*
SPR	5.5	4.5	5.7	4.5	4.6	3.3	3.4	5.1	4.3	3.0	4.1	–	–	3.8	5.5	3.3	–	4.3	240
SPB	–	–	5.9	–	–	–	–	5.8	5.2	–	–	–	–	6.8	–	–	–	5.9	71
SSTeZ	–	–	–	–	–	–	–	3.8	3.3	–	3.8	–	–	–	3.0	–	–	3.5	67
SSTB	–	–	–	4.5	–	–	–	5.0	3.9	5.0	–	–	–	–	–	3.5	–	4.4	62
STeZ	2.0	3.3	2.6	3.2	2.5	2.8	3.1	2.3	2.2	3.0	2.8	2.3	3.1	2.5	3.6	2.7	3.6	2.8	347
STB	–	–	4.8	–	–	–	–	4.0	3.8	–	–	–	–	–	–	3.9	–	4.1	99
STropZ	–	3.1	–	3.0	–	–	–	2.7	3.2	–	3.1	–	–	2.5	–	2.6	–	2.7	173
SEB(S)	–	–	4.0	–	–	4.0	–	4.0	4.5	–	4.1	–	–	4.0	–	3.7	–	4.0	156
SEBZ	–	–	–	–	–	3.5	–	3.0	3.8	–	4.0	–	–	3.2	–	2.9	–	3.4	103
SEB(N)	4.7	3.7	4.6	3.7	4.8	3.4	4.4	4.0	4.7	4.1	4.3	3.4	4.1	4.0	4.0	3.6	5.5	4.2	360
EZ(S)	3.0	1.5	1.8	1.3	1.2	1.6	2.2	2.0	2.1	1.8	1.7	1.2	2.8	1.8	3.2	2.0	–	2.0	336
EB	–	–	4.0	–	–	2.7	–	2.6	2.9	–	–	–	–	4.0	–	2.9	–	3.2	81
EZ(N)	3.0	1.5	0.9	1.1	1.2	1.2	1.5	1.5	1.4	1.0	1.3	1.0	1.8	1.5	2.0	1.6	–	1.5	347
NEB(S)	4.2	4.8	5.5	4.9	5.4	4.2	5.2	5.2	5.3	5.0	5.3	5.0	5.1	5.0	4.5	4.3	5.8	5.0	380
NEBZ	–	–	–	–	–	–	–	3.9	3.9	–	4.8	–	–	–	–	3.4	–	4.0	106
NEB(N)	–	–	5.2	4.5	–	–	5.0	4.7	5.7	–	4.9	–	4.0	5.0	–	4.2	–	4.8	166
NTropB	–	–	4.5	–	–	–	–	–	3.7	–	–	–	–	–	–	–	–	4.1	12
NTropZ	–	3.0	3.9	–	–	–	–	2.7	3.3	–	3.3	2.5	–	3.7	4.0	2.9	–	3.3	245
NTB	–	–	5.0	–	–	–	–	3.5	4.0	–	–	–	–	4.8	–	3.6	–	4.2	95
NTeZ	2.0	3.1	3.9	4.0	3.0	3.1	3.3	3.2	3.4	3.5	3.4	3.2	3.5	3.7	4.0	3.0	3.7	3.4	347
NNTB	–	–	–	–	–	–	–	3.8	4.4	–	–	–	–	–	–	3.2	–	3.8	44
NNTeZ	–	–	–	–	–	–	–	3.0	3.3	–	–	–	–	–	–	–	–	3.2	34
NPB	–	–	–	–	–	–	–	–	5.1	–	–	–	–	–	–	–	–	5.1	34
NPR	5.6	4.2	4.8	–	4.0	3.5	3.5	3.7	4.5	–	4.0	5.0	–	4.2	–	3.3	–	4.2	209
NPC	–	–	–	–	–	–	–	–	5.7	–	–	–	–	–	–	–	–	5.7	38
$Rings_m$	–	3.8	–	–	–	–	–	4.0	–	–	–	4.0	–	–	4.5	7.3	–	4.7	27
ShRG	10.0	7.8	9.3	7.8	–	7.9	8.7	8.5	10.0	7.4	8.2	7.8	7.0	6.7	9.2	7.4	8.2	8.2	242
ShGR	–	8.0	–	–	–	–	–	8.0	–	–	–	–	–	–	–	9.6	–	8.5	15
Total used	99	197	100	86	24	97	303	245	1,314	135	256	291	27	45	216	968	33		4,436

Abbreviation: $Rings_m$ denotes the intensity of the rings in general crossing the globe.
Key to observers: PA, Abel; SB, Beaumont; NB, Biver; AB, Bowyer; RB, Bullen; EC, Colombo; MF, Foulkes; DGm, Graham; DGy, Gray; AH, Heath; RM, McKim; CM, Meredith; SM, S. L. Moore; RS, Schmude; DS, Storey; UAI, Unione Astrofili Italiani; DW, Weldrake.

drawings simply record a dusky zone S. of the SSTB.

South South Temperate Belt

The SSTB was normally just a halftone separating the dusky SSTeZ from the light STeZ. Gray habitually found the SPB darker than the SSTB. However, Graham found the SSTB very dark and as dark as the nearby SPB on Aug 12 with the Lick refractor, irregular on both edges with the intervening SSTeZ shaded: next day, at a different longitude, both belts were again resolved, but regular. On Aug 10 and 11 Graham had drawn just one broad belt in these latitudes (Figure 6). To Schmude (on Sep 2) and to Biver (often) the SSTB/SPB complex was the darkest feature of the globe, as the best CCD images confirm. Gray on Dec 27 caught an irregularity on the belt near 280°.[2]

South Temperate Zone

The STeZ was featureless, quite broad, and (atypically) lighter than the STropZ.

South Temperate Belt

The STB was usually fainter and thinner than the SSTB. The average latitude found for its centre (+33.1°, Table 3) was closer to the equator than the BAA 1947–'76 average (+37.5°), but nevertheless the 1995–'96 belt was closer in latitude to the STB than to a S. Tropical Belt.

The STB often seems to have been darker

Table 3. Saturnicentric latitudes, 1995–'96

Feature	*RB*	*DGm*	*DGy*	*RM*	*IM*	*GQ*	*UAI*	*Average*
SPRn	–	–55.0	–58.3	–55.1	–54.8	–61.7	–61.3	–57.7
SPBs	–	–52.4	–58.3	–	–54.8	–	–	–55.2
SPBc	–	–49.7	–56.4	–	–51.8	–51.1	–	–52.2
SPBn	–	–47.0	–54.5	–	–	–	–50.7	–50.2
SSTBs	–	–	–49.3	–	–	–	–46.2	–47.8
SSTBc	–	–	–47.7	–	–	–	–44.2	–46.0
SSTBn	–	–	–46.1	–	–	–43.0	–42.2	–43.8
STBs	–	–	–36.7	–	–31.2	–32.0	–37.1	–34.2
STBc	–	–	–34.7	–	–29.9	–	–34.8	–33.1
STBn	–	–	–32.7	–	–28.6	–	–32.4	–31.2
SEB(S)s	–24.4	–28.1	–26.0	–28.2	–24.7	–	–21.9	–25.5
SEB(S)n	–	–24.9	–22.2	–23.9	–21.4	–	–15.9	–21.7
SEB(N)s	–	–18.9	–16.9	–16.9	–16.1	–14.6	–12.4	–16.0
SEB(N)n	–7.0	–15.8	–13.1	–11.5	–11.8	–10.0	–10.5	–11.4
EBs	–	–	–	–	+4.3	+4.3	+3.9	+4.2
EBc	–	–	+1.9	–	+6.6	+5.6	+4.6	+4.7
EBn	–	–	–	–	+8.8	+6.9	+5.3	+7.0
NEB(S)s	+9.8	+16.3	+11.9	+14.2	+15.0	+15.8	+14.5	+13.9
NEB(S)n	–	+19.7	+15.1	+19.5	+20.3	+20.5	+22.3	+19.6
NEB(N)s	–	+25.4	+19.8	+27.8	+25.0	+23.0	+25.5	+24.4
NEB(N)n	+28.4	+29.8	+22.6	+29.7	+29.0	+28.0	+27.0	+27.8
NTBs	–	–	+34.1	–	+35.7	+33.5	+33.2	+34.1
NTBc	–	–	+36.9	–	+37.7	+36.6	+35.0	+36.6
NTBn	–	–	+39.7	–	+39.7	+39.7	+36.8	+39.0
NNTBs	–	–	–	–	+46.8	+41.8	+47.4	+45.3
NNTBc	–	–	+45.1	–	+49.8	+44.8	+49.4	+47.3
NNTBn	–	–	–	–	+52.7	+47.8	+51.5	+50.7
NPBs	–	–	+52.5	–	–	–	–	+52.5
NPBc	–	–	+55.0	–	–	–	–	+55.0
NPBn	–	–	+57.4	–	–	–	–	+57.4
NPRs	–	+57.3	+56.7	–	+61.2	+65.5	+63.9	+60.9
NPCs	–	–	+69.4	–	–	–	–	+69.4
Total	12	97	279	71	72	21	601	1,153

Key to observers: RB, Bullen; DGm, Graham; DGy, Gray; RM, McKim; IM, Miyazaki (images); GQ, Quarra (image); UAI, Unione Astrofili Italiani.
All observers reduced their own drawings, and all the images were reduced by McKim.

than the SEB(S) early in the apparition, and later this situation persisted at certain central meridian longitudes (CML; ω): this together with a greater darkness of the STropZ at some CML contrived to cause occasional confusion in identity. Gray recorded the STB throughout the apparition, and although to him narrow and faint on the whole it was sometimes seen to rival the SEB(S).

South Tropical Zone

As noted above, the STropZ was darker than the STeZ at most longitudes. Graham’s Aug 9–13 drawings from Lick show that the intensity of the STropZ varied considerably with longitude, and this variation coupled with the relative proximity of the STB gave him the appearance of a triple SEB (Figure 6).[19] Thus on Aug 9 under ω_2= 219° the triple nature was becoming more evident towards the *f.* side, and on Aug 10 under ω_2= 246°, Aug 11 under ω_2= 270° and Aug 12 under ω_2= 47°, the aspect was triple from limb to limb. On Aug 13 under ω_2= 126°, the SEB(S) was darkest on the *p.* side to fade and mix with the central part towards the *f.* side. Thus the effect at that time was weakest from around λ_2~ 160–230°. Biver’s drawings (for instance in Figure 8) confirm this triple appearance over a much longer time period. At lower resolution one sometimes received the impression that the SEB varied considerably in width, as shown by McKim for example on Aug 6 and 17 (Figures 5A, B).

Evidence that the effect persisted throughout the apparition comes from an excellent 830nm image taken at Pic du Midi on Nov 6, where the STropZ was dusky for some way either side of the CM, making the STB and SEB(S) impossible to separate except near the limbs.[17] This appearance was also evident in the Pic du Midi image by Quarra *et al.* (Figure 16) and in several of Miyazaki’s images.

South Equatorial Belt

The occasional apparent triple nature of the SEB has been explained above. In fact the SEB was widely double, with the N. component darkest. Latitudes of the components were perfectly typical. Overall the SEB was fainter than the NEB. The SEB(S) was very regular, but a handful of vaguely darker patches were caught: far too few to derive rotation periods.

Occasional irregularities were observed in the N. component, but more often the SEB(N) also looked smooth and regular. A well-marked dark spot (DS2) was reported by Schmude on Jun 13 and sketched by Bullen on Jul 29. Its drift in decreasing System I longitude is confirmed by a transit of the *f.* end by Gray on Aug 6. Gray’s drawings show slight condensations in the SEB(N) throughout the apparition. The chart indicates negative drifts for a few other features. Tentative periods for two dark spots are quoted below:

Spot	*Limiting dates*	*No. obs.*	*Limiting* λ_1	$\Delta\lambda_1$ *(°/day)*
DS1p	1995 Sep 12–Oct 25	2	177–150	–0.62
DS1c	1995 Aug 12–Sep 12	2	211–194	–0.56
DS2c	1995 Jun 13–Jul 29	2	343–316	–0.59
Average:				–0.59
SEB(N) average period:				10h 13m 34s

Note: Δλ in these reports is the change in (System I or II) longitude on a daily or monthly (30-day) basis.

Equatorial Zone

EZ(S): The EZ(S) differed considerably in brightness from the EZ(N), the difference being striking at first glance with the S. zone much less bright (and also narrower for much of the apparition owing to the angle of presentation and the presence of the rings or their shadow). At high resolution (Biver, Miyazaki, Quarra) the EZ(S) revealed a faint southern component of the Equatorial Band (EB).

The EZ(S) showed little activity in 1995–’96, and even upon Biver’s drawings with large instruments details were rather fugitive: most notable were three bright areas seen by Graham on Aug 12, one or more on the Sep 27 image by Quarra *et al.* (Figure 16), one by Miyazaki on Sep 30 (which indented the SEB N. edge; Figure 1E) and one by Biver on Nov 24. Several different white spots (WS) were identified and all had slight negative drifts in System I. Two were observed often enough to quote tentative periods: though rather few, the observations lie on very good straight lines.

Spot	*Limiting dates*	*No. obs.*	*Limiting* λ_1	$\Delta\lambda_1$ *(°/day)*
WS1c	1995 Aug 11–Dec 28	4	073–033	–0.29
WS2c	1995 Aug 12–Dec 27	5	259–229	–0.22
Average:				–0.25
EZ(S) average period:				10h 13m 49s

At the last edgewise presentation in 1979–’80[2] the EZ(S) had been the brightest part of the EZ.

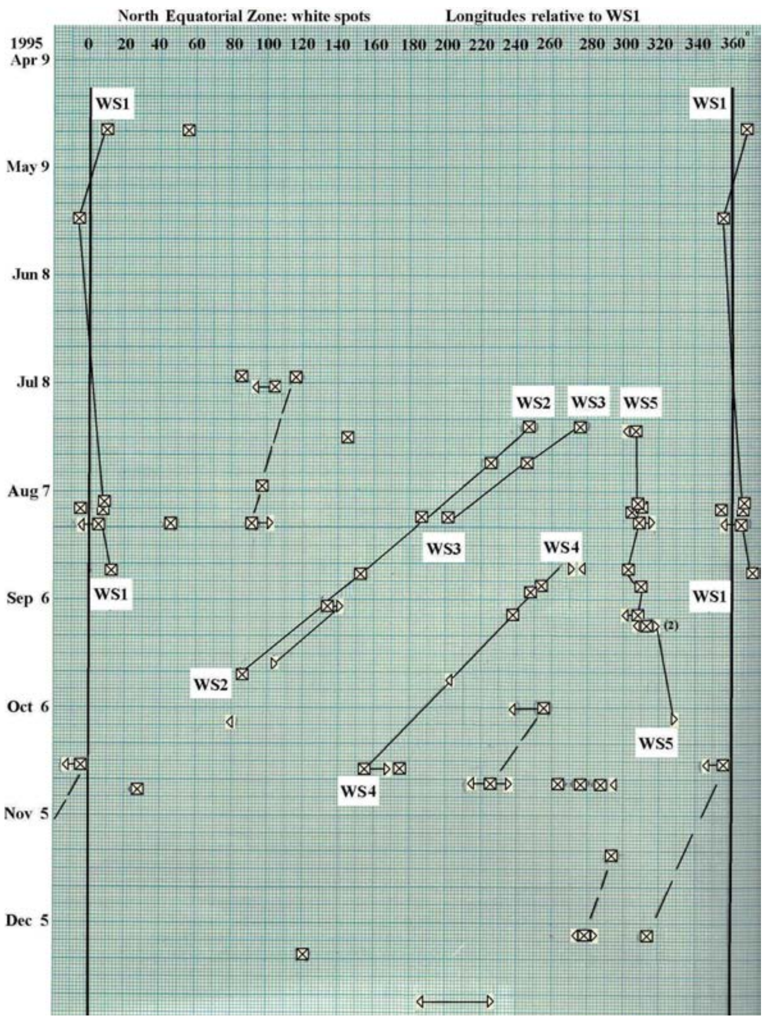


Figure 2. Drift-chart for white spots in the EZ(N), 1995–’96. All longitudes are with reference to a motion increasing by +10.65°/day with respect to System I, this being the average period of the long-enduring white spot, WS1, during 1994–’95. The average track of the long-enduring white spot (WS1) is represented by vertical columns at longitudes 0 and 360°. Tentative identifications are indicated by broken lines.

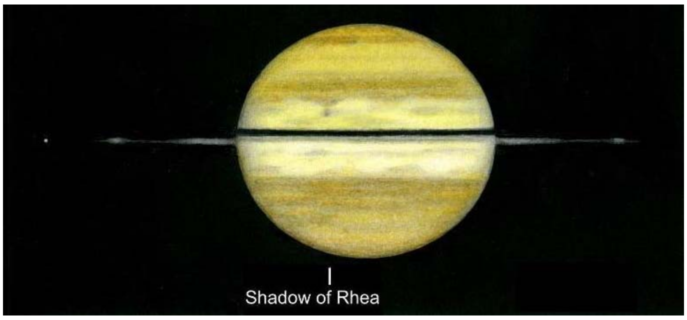


Figure 3. 1995 Jul 20d 03:15 UT, ω_1= 038°, ω_2= 249°, 250mm Cass., ×623, *N. D. Biver*. Pale unilluminated rings. Shadow of Rhea seen as grey dot against the EZ(S).

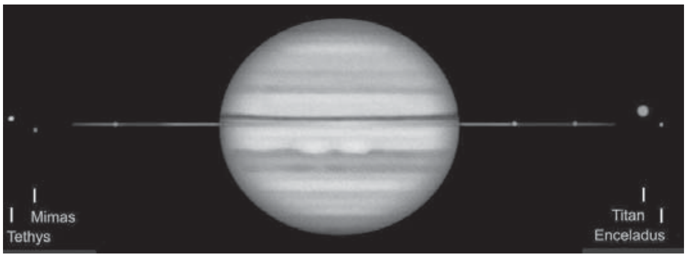


Figure 4. 1995 Jul 30d 01:30 UT, ω_1= 141°, ω_2= 031°, 415mm DK Cass., ×348, *D. Gray*. Pale unilluminated rings. White spots in EZ(N).

EB: The main Equatorial Band was quite dusky, and was located closely north of the rings crossing the globe. With large apertures it was often seen to be irregular, appearing mottled to Graham at Lick. It was interrupted by some EZ(N) white spots. The Pic du Midi image cited earlier – as well as Biver's drawings and images by Miyazaki and Quarra – revealed a further, fragmentary and faint EB close to the NEB S. edge.

EZ(N): The EZ(N) was considerably lighter than the S. part. A number of white spots were seen during the apparition but they were generally less prominent than in the previous one. Several images suggested small-scale activity at the limit of detection: thus Quarra *et al.* on Sep 27 obtained a superb image from Pic du Midi which hinted at many tiny details in the EZ(N) (Figure 16). McKim on Dec 8 (Figure 21) saw a white spot with a double nucleus.

The long-lived EZ white spot from 1994–'95[3] (WS1) survived solar conjunction (as Sanchez–Lavega *et al.*[16] also concluded) but became smaller and fainter. It was recognised upon an image by Miyazaki of 1995 Apr 28.853 (Figure 1A) near the *p.* limb at very roughly longitude 016° (System I), at which time its calculated position (based upon the observed (1994 Aug–Dec) drift of +10.65°/day in System I) should have been 006.3°$_1$. On May 23.405 it was ill-defined but clearly visible upon images by Parker around 262°$_1$: WS1 should have reached 267.7°$_1$ at that time: excellent accord, given that the spot was found to oscillate somewhat in longitude during the last apparition.[3] Few high resolution observations were available for June and July and none covered the appropriate longitudes.

WS1 was subsequently recorded as a rather small white oval by O'Meara at Lick on Aug 10, by Platt's CCD camera on Aug 12, on Aug 16 by Biver (Figure 8D) and Gray as a slightly lighter but well-defined area in the EZ(N), and by Bullen (Figure 12) on Aug 29. All these data are plotted in Figure 2. Platt's Aug 12 image (though only low resolution) appears to show it as two small white spots close together against the NEB, the f. one corresponding to WS1 on the chart.

Other EZ(N) white spots were again observed, but they were fewer and mostly less conspicuous. The only really bright object was a white spot (denoted WS5) whose centre was measured from Jul 21 (Lancashire, visual) to Sep 13 (Mobberley, CCD; Figure 13). Graham (Figure 6A, D) and O'Meara both saw it well on Aug 10 and 13, and it was reported by O'Meara in IAU *Circular* No. 6204, as noted in BAA *Circular* No. 747.[10] WS5 can also be traced upon Miyazaki's Aug 11 images (Figure 1D) and Schmude's Sep 2 photos. The spot seemed quite long to Lancashire on Jul 21, and although reduced in extent by Aug 10 it was at the time larger and more conspicuous than WS1. McKim caught a feature which was probably the *f.* end near the CM on Oct 8.

On Aug 28 Gray reported white spot activity east of WS5, designated WS4 in Figure 2, data from Schmude (Sep 2), Doherty (Sep 3) and Gray (Sep 9) revealing a motion considerably faster than that of WS1. WS4 survived till Oct 23. During October, other regions of spot activity appeared between the courses of WS4 and WS5. On Oct 27 Gray saw a series of inconspicuous white spots stretching over 80° in longitude, but this did not appear to develop further. The chart (Figure 2) also reveals several faster-moving white spots, in particular a pair first observed on Jul 20 by Biver, designated WS2 and WS3. It may be significant that WS1 was in terminal decline as the faster-moving spots originated.

Rotation periods were thus derived as follows, as well as averages for the distinctive slower and faster currents:

Spot	*Limiting dates*	*No. obs.*	*$\Delta\lambda_1$ (°/day)*
WS1(c)	1995 Apr 28-Aug 29	6	+10.67
WS2(c)	1995 Jul 20-Sep 27	7	+ 8.35
WS3(c)	1995 Jul 20-Aug 14	3	+ 7.65
WS4(c)	1995 Sep 2-Oct 23	6	+ 8.76
WS5(c)	1995 Jul 21-Sep 13	11	+10.73
Average (WS1 and WS5):			+10.70
EZ(N) average period (WS1 and WS5):			10h 21m 53s
Average (WS2, WS3 and WS4):			+ 8.25
EZ(N) average period (WS2, WS3 & WS4):			10h 20m 04s

North Equatorial Belt

The dark NEB was easily seen to be double, though the components were less widely spaced than those of the SEB, and more equal in intensity. The S. edge of the NEB was again observed to have several small projections into the EZ(N), particularly by Graham with the Lick refractor in August (Figure 6) and by Biver and Gray (Figure 4, 10B). McKim found the belt delicately mottled in an excellent view on Aug 17.

In 1994–'95 it was considered that the slow-moving EZ(N) white spots must have disrupted any NEBs projections into the zone, but in 1995–'96 the white spots were much less active and HST images showed a very tranquil zone even at high resolution. Transits by Gray were supplemented by some from the UAI, and by measures off good drawings. All spots drifted in decreasing System I longitude, and nearly every observation could be fitted to a line on the chart. The number of observations was just adequate to make firm identifications, and the similarity in the derived drift-rates increases confidence in the results. Periods may be given for some dark spots (DS):

Spot	*Limiting dates*	*No. obs.*	*Limiting λ_1*	*$\Delta\lambda_1$ (°/day)*
DS1p	1995 Aug 21–Dec 10	3	009–316	–0.48
DS1c	1995 Aug 21–Dec 10	5	016–323	–0.48

DS1f	1995 Aug 15–Sep 30	6	030–011	–0.40
DS2c	1995 Aug 15–Oct 24	3	048–021	–0.38
DS3c	1995 Jul 1–Nov 9	5	185–124	–0.47
DS4c	1995 Aug 10–Oct 26	6	329–271	–0.75
Average:				–0.49
NEB(S) average period:				10h 13m 38s

The NEB(N) again contained a small number of elongated 'bars' or dark sections, as portrayed by Biver, Ellis, Graham (Figure 6), Gray (Figures 4, 22), Heath, McKim and Weldrake. On Sep 16 Graham, Gray & Heath (Figure 14) all observed with Gray's telescope and recorded a small northward projection from the NEBn into the NTropZ. Periods could be derived for some of the dark sections (DS), some of which were quite long. Several other short-lived features (not listed below) appeared to show the same average drift. These results (tentative for DS3c and DS4p) were comparable with 1994-95:

Spot	*Limiting dates*	*No. obs.*	*Limiting λ_1*	*$\Delta\lambda_1$ (°/day)*
DS1c	1995 Aug 12–Nov 25	4	058–329	–0.85
DS2c	1995 Aug 12–Dec 23	4	077–341	–0.72
DS3p	1995 Jul 8–Sep 24	4	154–089	–0.83
DS3c	1995 Jul 8–Sep 16	3	165–106	–0.84
DS4p	1995 Sep 29–Nov 27	2	202–134	–1.15
DS4c	1995 Aug 5–Nov 27	5	259–156	–0.90
DS4f	1995 Aug 5–Dec 25	4	282–165	–0.82
Average:				–0.87
NEB(N) average period:				10h 37m 44s

North Tropical Zone

The NTropZ showed little of interest. A NTropB was seen occasionally (Biver and Gray), especially early in the apparition: a high resolution Pic du Midi image of Nov 6 does not show it. Gray found the NTropZ darker to the S. of it than to the N., and transited the *p.* end of a lighter section of NTropZ on two dates. If these were the same feature (which appears likely from past experience), its tentative period is typical of recent years:

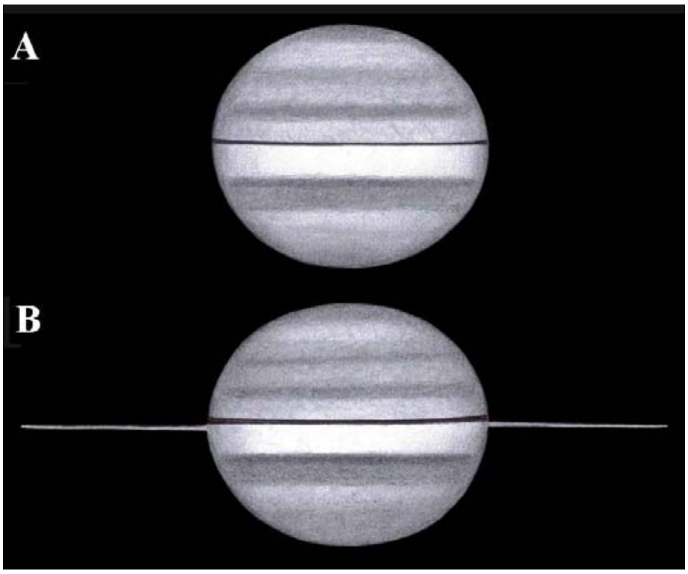


Figure 5. Observations from the UK before and after the 1995 Aug 10 ring-plane crossing by the Earth; 216mm refl., ×232, *R. J. McKim*.
A. 1995 Aug 6d 00:20 UT, ω_1= 250°, ω_2= 276°. Unilluminated rings not seen with this aperture.
B. 1995 Aug 17d 23:00 UT, ω_1= 258°, ω_2= 256°. Sunlit rings easy, evenly illuminated; wide double SEB, shaded STropZ.

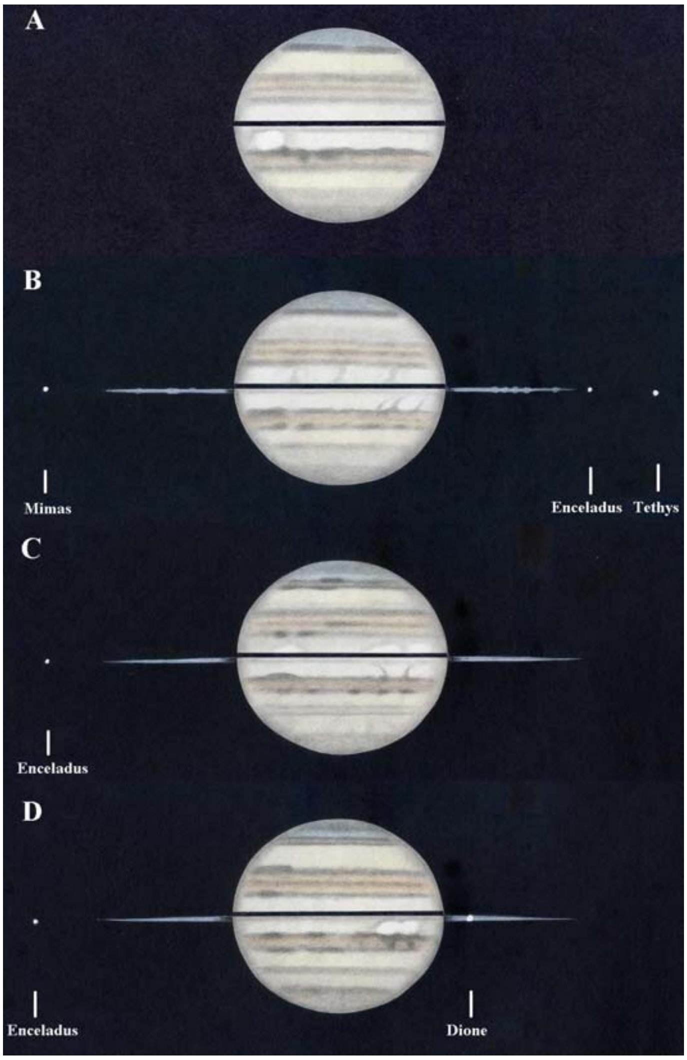


Figure 6. Observations from Lick Observatory during the 1995 Aug 10 ring-plane crossing by the Earth; 0.91m OG, ×588, *D. L. Graham*.
A. 1995 Aug 10d 09:50 UT, ω_1= 002°, ω_2= 246°. WS5 in EZ(N) near *p.* limb.
B. 1995 Aug 11d 07:50 UT, ω_1= 056°, ω_2= 270°. The rings are again visible, appearing as a string of starlike points, especially on the *f.* side.
C. 1995 Aug 12d 09:10 UT, ω_1= 228°, ω_2= 048°. The ring appears to stop short of the limbs of the planet. Note the detail on the dark SPB and SSTB.
D. 1995 Aug 13d 08:45 UT, ω_1= 337°, ω_2= 126°. The ring appears as on Aug 12.WS5 in EZ(N) on *f.* side.

Limiting dates	*No. obs.*	*Limiting λ_1*	*$\Delta\lambda_1$ (°/day)*
1995 Aug 14–Dec 26	2	292–231	–0.46
NTropZ period:			10h 38m 04s

North Temperate Belt

The NTB was neither broad nor very dark; occasional irregularities were seen with large instruments, and Graham saw it closely double on Aug 12 (Figure 6C).

North Temperate Zone

The dusky NTeZ revealed no irregularities.

North North Temperate Belt

The NNTB was similar to the NTB. The NNTB was not visible on every date to the Lick team in August, and most BAA observers could not see it at all. It was fainter than the NTB on the Pic du Midi Nov 6 (830nm) image.

North North Temperate Zone

The NNTeZ was reported by Gray simply as a dull zone.

North Polar Region

Seen obliquely as a dusky zone along the N. limb, being less dark than the SPR. Gray reported a darker edge (the North Polar Belt (NPB)), as well as a dark cap within the NPR.

The ring-plane crossings

The circumstances of the triple ring-plane crossings were as follows, according to predictions (said to be accurate to ±2 hours) published on the Jet Propulsion Laboratory website and quoted in BAA *Circular* No. 745:[9]

1995 May 22	05:18 UT	1st crossing by the Earth, from N. to S. (duration: 24 min)
1995 Aug 10	20:54 UT	2nd crossing by the Earth, from S. to N. (28 min)
1995 Nov 19	15:09 UT	Sun crossing the ring plane, from N. to S. (3.8 days)
1996 Feb 11	23:34 UT	3rd crossing by the Earth, from N. to S. (12 min)

These phenomena were illustrated graphically by Graham[5] in a very useful paper describing what could be seen at each stage: his illustration is reproduced again here (Figure 7). Here D_e and D_s are the elevations of the Earth and Sun respectively above the ring plane, positive to the north and negative to the south. Graham himself was at Lick Observatory at the time of the 2nd Earth crossing and Sheehan & O'Meara[18] have described the impressions of the observing team. Tables showing how the visibility of the rings depended upon aperture were given by Heath for 1966[1] and by Benton[4] for the current opposition.

As in previous observations of the unilluminated rings, there were frequent reports of asymmetry between the two ansae, now interpreted in terms of a slight warping of the ring plane. Bright spots then marked the locations of sparse ring particle density, particularly in the positions of the Cassini division and ring C.

In the following notes, the *p.* ansa is called the W. ansa, for it is to the W. of Saturn in the sky. (On the disk of the planet itself, the *p.* side of any marking is always to the E. under the IAU convention.)

The observations thus fall into a number of time periods.

Early observations, 1995 April-May

Refer to letter A in Figure 7.

Few observations were made so early in the apparition. However, with their CCD cameras Miyazaki on Apr 28 (Figure 1A) and Parker on May 15 captured the illuminated rings, and Schmude sketched them on Apr 20. On May 20, two days before the Earth's ring-plane crossing, Biver could still see the rings well, as would have been expected. On May 21 at 10:00 UT Bruton saw the rings as a dim line only 19 hours before the crossing.

Observations during the 1995 May 22 ring-plane crossing by the Earth

Refer to letter B in Figure 7.

Observing from Meudon less than two hours prior to the ring-plane crossing, Biver was already unable to see the rings on May 22 at 03:35 UT. Nor could Bruton at 09:30 UT, some 4 hours after the event. Schmude observed on May 23 around 10:10 UT, 29 hours after the 1st ring plane crossing by the Earth and found the rings quite invisible, as did Parker (CCD) at 09:36 UT. Lancashire (after a

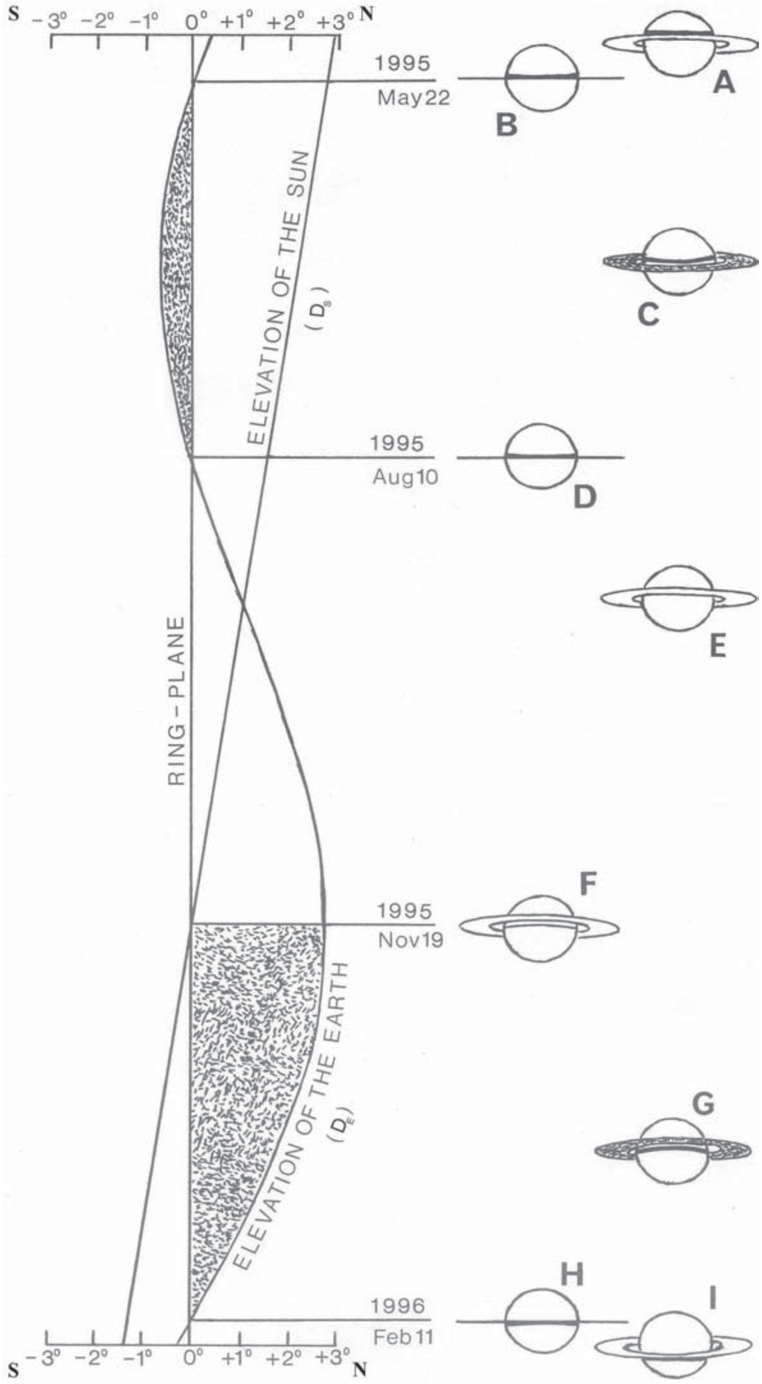


Figure 7. Diagrammatic representation of the ring-plane crossings (also see text). The angle of opening of the rings has been exaggerated for clarity. D_e and D_s are the elevations of the Earth and Sun respectively above the ring plane, positive to the north and negative to the south. Originally drawn by *D. L. Graham*.

run of cloudy mornings and abortive earlier attempts) failed to see the rings on May 24, but twilight interfered with all these early observations. Biver on May 26 failed likewise.

It appears that the JPL predictions were very accurate: according to Biver, HST data gave an observed time of May 22 05:38 UT ±3 min.

Observations, 1995 June–August

Refer to letter C in Figure 7.

The unilluminated rings were open to their maximum extent upon the south face on Jul 1 (–0.6°) and this helped their positive observation. On Jun 1 (03:00 UT) ring stubs were suspected on each side by Biver (1m Cass.), and on Jun 5 and 9 the whole length of

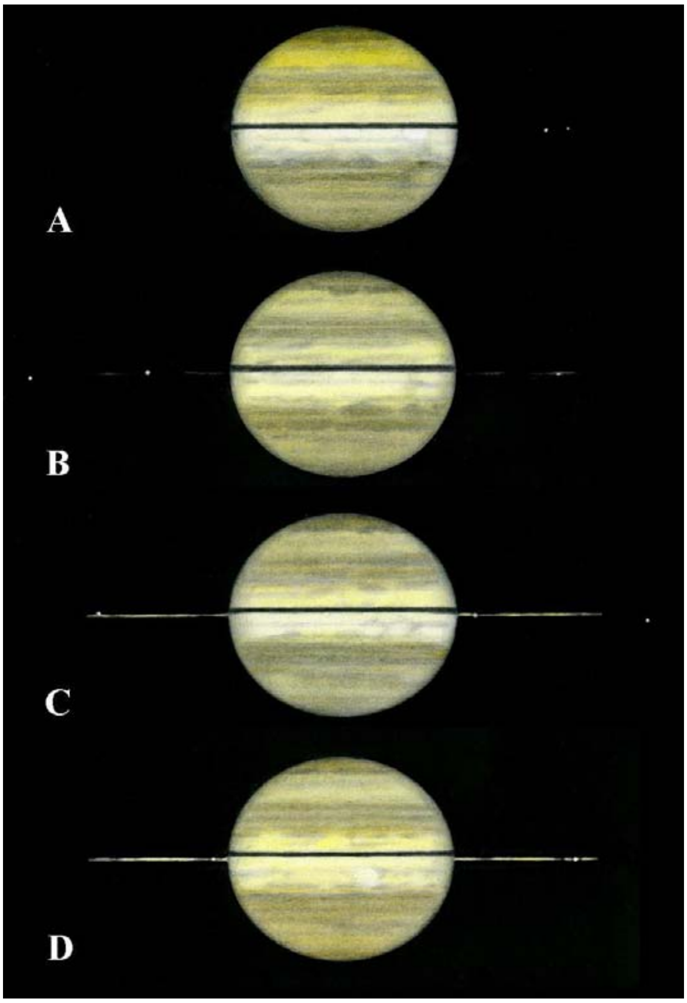


Figure 8. Observations from Meudon during the 1995 Aug 10 ring-plane crossing by the Earth; 600mm Cass., ×520, *N. D. Biver.*
A. 1995 Aug 10d 01:20 UT, ω_1= 063°, ω_2= 318°. No sign of the rings. Tethys and Mimas (right) are shown on the *f.* side.
B. 1995 Aug 11d 00:10 UT, ω_1= 147°, ω_2= 011°. The newly illuminated rings have very faintly reappeared. Enceladus (left) and Tethys are *p.* the globe and Mimas is *f.* it.
C. 1995 Aug 14d 02:15 UT, ω_1= 233°, ω_2= 358°. Rings are now very well seen, with Tethys on the *p.* ring tip and Rhea just *f.* the globe, and Enceladus beyond the *f.* ring tip.
D. 1995 Aug 16d 00:55 UT, ω_1= 075°, ω_2= 137°. Enceladus is near the globe on the *p.* ansa and Dione near the tip of the *f.* one. (Rhea, *f.* Dione, is not shown.) Long-enduring EZ(N) WS1 just *f.* the CM. Notice the apparent triple aspect of the SEB, and several belts within the EZ, in **A–D.**

the rings could be made out. Gray on Jun 8 and 18 persistently suspected a ring stub on the *f.* side, and Niechoy drew both stubs on Jun 9. The unlit rings were again just visible to Schmude on Jun 13 (with the *f.* ansa brighter), to Lancashire as faint stubs on Jun 15 (which quickly vanished into the twilit sky background) and to Bullen on Jun 19, with the latter finding the *f.* ansa a little easier to glimpse. However, the rings were not always visible with smaller telescopes: Ellis could not see them with 20cm on Jun 30 and on several dates in July.

Biver on Jun 9 and 25 could already see a brighter spot at the Cassini Division and a widening of the ring at the place of ring C. On Jul 2 Gray could definitely see the faint 'rays' in the position of ring A and 'stubs' in the position of ring C; again the *f.* side was slightly brighter. A further small condensation in ring B around the B2/B3 boundary appeared to Gray on Jul 8 and 16. On Jul 4 Parker caught the rings by CCD camera: in a long exposure ring C was very bright, ring B dull, Cassini's division was a small light patch and ring A was seen but dull. Miyazaki also imaged the rings on Jul 5 (Figure 1B). Biver had the advantage of a large aperture, and his drawings of Jul 6 to 30 (for example, as in Figure 3) all show the foregoing features upon the unlit rings.

On Jul 7 Lancashire was again at the eyepiece of the 30cm Northumberland refractor: 'Fantastic view of gossamer-thin rings extending nearly a Saturn diameter on either side (*f.* brighter than *p.*); *f.* side showed two 'knots' which I take to be faint satellites.' Using the same instrument on Jul 15 Rogers caught the ring stubs on each side. On Jul 21 Lancashire found the *p.* side brighter and more extended than the *f.* side, and this was also the case on Jul 28, but both extensions were shorter. Contrarily, on Jul 29 the *p.* side was reduced to a mere stub, but the *f.* side showed its normal extent, threaded by three faint satellites. On Jul 23 (01:00 UT) S. L. Moore had also seen the *f.* ansa only, but Proctor had suspected both ring stubs 20 minutes earlier. Lancashire's last observation prior to the ring-plane passage on Jul 31 showed just the *p.* ansa, faintly.

By this time it was exceptionally difficult to see any trace of the rings. Miyazaki's camera caught the unlit rings on Jul 28 but it did not capture them with a short exposure on Aug 2. On several dates from Aug 2–9 McKim (Figure 5A), Meredith and Storey likewise failed to see the rings with 22–25cm apertures, but on the morning of Aug 5 (at 02:15 UT) Morrison succeeded in seeing both ansae as a 'smoke-grey' line.

On the morning of Aug 6 with the advantage of a large aperture Gray again succeeded in catching the unlit rings. They were again symmetrically brighter in two places, but excessively faint, much more so than during his last view on Jul 30 (Figure 4). This was to be the last BAA observation of the unlit rings prior to the ring-plane passage.

The HST imaged Saturn on Aug 6 (Figure 23A), at a different hour to Gray, revealing the faint rings in some detail as well as several of the smallest satellites. Graham could not see the rings from Lick on Aug 8 at 10:30 UT nor on Aug 9 at 09:05–11.45 UT. Indeed it is thought that no ground-based observers observed the rings during Aug 7–10, with Miyazaki taking many images on the latter date between 15:22 and 15:59 UT (Figure 1C), providing a useful limit in the timings to be discussed below.

Observations during the 1995 Aug 10 ring-plane crossing by the Earth

Refer to letter D in Figure 7.

Observation of the second ring-plane passage was inhibited by the presence of the Full Moon on Aug 10 (18:16 UT), which had risen several hours in advance of Saturn. From around Aug 16 it would no longer pose a problem.

With newly coated optics on the 60cm Cassegrain at Meudon, Biver failed to see any sign of the rings on Aug 10 at 00:50–01:35

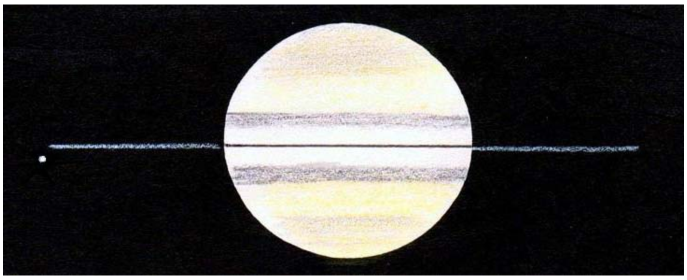


Figure 9. 1995 Aug 11d 23:30 UT, ω_1= 248°, ω_2= 080°, 390mm refl., ×400, *P. A. Moore*. Newly illuminated rings well seen.

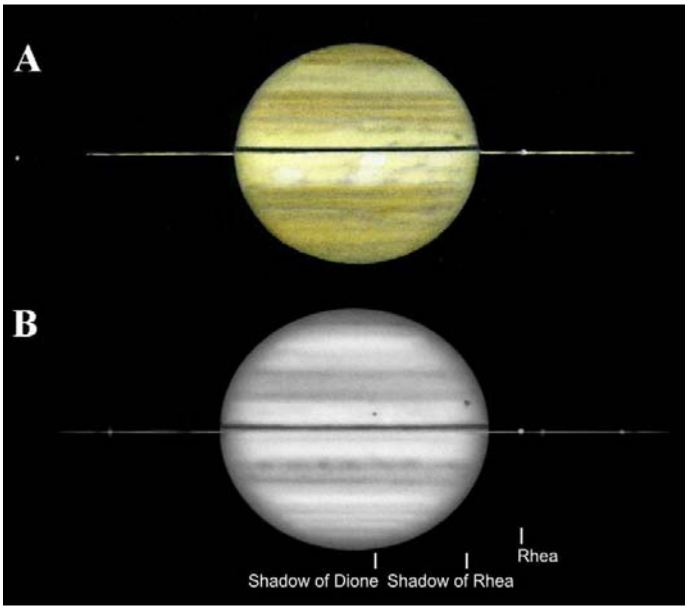


Figure 10. Two near-simultaneous drawings of satellite transits by different observers.
A. 1995 Aug 16d 03:30 UT, ω_1= 166°, ω_2= 224°, 600mm Cass., ×520, *N. D. Biver*. Shadow transit of Rhea observed; shadow transit of Dione glimpsed.
B. 1995 Aug 16d 03:40 UT, ω_1= 172°, ω_2= 230°, 415mm DK Cass., ×348, *D. Gray*. Shadows of both Rhea and Dione seen. Details on NEBs. Compare with **A**.

UT (Figure 8A), and nor could any UK observer. Graham & Dobbins at Lick on Aug 10 at 09:50 UT had no success as yet. Also observing from Lick,[18] O'Meara & Sheehan had felt the rings to have been glimpsed on Aug 9 and 10, but their colleagues could not confirm this: there is always a great tendency for eye and brain to prolong the line of the ShRG and EZ out towards the nearby satellites. The writer experiences the same illusion by looking at suitable CCD images.

On Aug 10 23:45 UT–Aug 11 00:35 UT Biver (Figure 8B) could just make out the newly illuminated rings, particularly on the *f.* side (near the position of Mimas), an impression shared by Weldrake on Aug 11 at 02:12 UT. Despite his small aperture, Baum could also see them by averted vision from 23:15 UT on Aug 10 as stubby extensions, while McKim occasionally glimpsed very faint stubs at 23:50 UT. From the USA Graham succeeded in seeing the rings easily on Aug 11 (Figure 6B), and at 07:25 UT he noted: '...in best moments the ring appears as a string of starlit points, especially the *f.* ansa. Magnificent – a delicate thread-like apparition, a soft haunting glow in the dark.' The Lick observers found the tapering rings to have a coppery tinge, and now witnessed them brightening with time with the *f.* side still the brighter according to Graham. Dobbins[18] at 10:05 UT saw a very faint extension of ring material on the *p.* side beyond ring A as far as Mimas. Some of Biver's drawings occasionally suggest faint extensions, too.

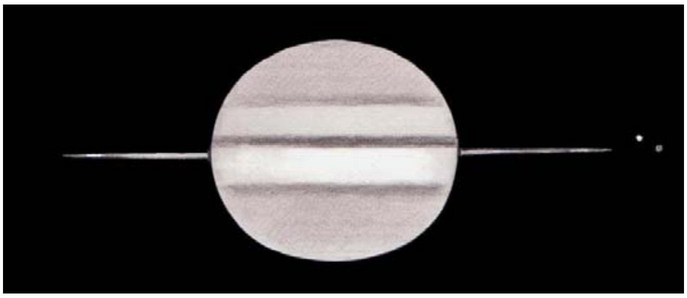


Figure 11. 1995 Aug 25d 01:00 UT, ω_1= 118°, ω_2= 248°, 300mm refl., ×190–318, *A. W. Heath*. Brightening at the position of ring B1 upon both ansae. Two satellites in conjunction off tip of E. ansa.

Miyazaki's images of Aug 11 from 15:17 UT onwards captured the rings faintly and equally with Rhea against the following ansa (Figure 1D). On Aug 11 at 23:20 UT McKim saw the rings to their full extent. At the same time Bullen saw both ansae, the *p.* one most prominent, being brighter at its inner and outer edges, but the *f.* ansa 'seemed to be in many small segments'. Patrick Moore's drawing of Aug 11 (Figure 9) at 23:30 UT also shows the *p.* ansa to have been slightly the brighter of the two. On Aug 12 at 01:15 UT Ellis agreed, and saw a string of starry points along both ansae. On the same morning Heath also found the *p.* ansa slightly brighter: two bright spots were seen in the approximate place of ring B by Heath, the *f.* one confirmed by Morrison.

On Aug 12 around 09:10 UT and on Aug 13 at 08:45 UT Graham was again at the eyepiece of the Lick refractor, and the rings then appeared silvery grey, appearing to stop short of the globe on each side, perhaps due to glare from the planet (Figure 6C). McKim saw the rings well on the evening of Aug 12, when they appeared brighter nearer the globe. Ellis on Aug 14 at 02:20 UT and Bowyer at 03:30 UT found the *p.* ansa longer than the *f.* one, the former again seeing lots of tiny points of light. Proctor on Aug 14 at 23:15 UT saw the ansae of equal length but the *p.* one only looked brighter in the position of ring B.

On the evenings of Aug 15 and 16 Baum also found that the rings appeared to twinkle, and he generally found the *p.* ansa to be the brighter of the two on Aug 10–19. However, the combined work of Biver, Ellis, Lancashire, McKim (Figure 5B), Meredith, S. L. Moore, Phelps, Rogers, Storey and Weldrake on the nights of Aug 14/15–18/19 showed the ansae equal. This was also S. L. Moore's impression on Aug 15 and 16: with his large aperture he also noticed a slight break between the globe and the start of the *p.* ansa. Youdale likewise found the rings weakened near the planet on Aug 17–26. Most observations continued to show the ansae as identical. By Aug 15–16 Gray was able to see brightenings in the position of ring A as well: see Figure 10B.

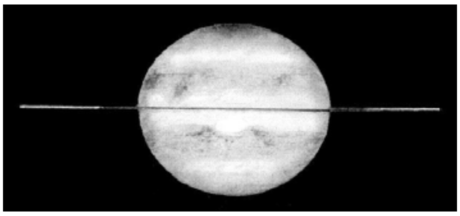


Figure 12. 1995 Aug 29d 00:23 UT, ω_1= 233°, ω_2= 236°, 216mm refl., ×216, *R. Bullen*. White spot in EZ(N).

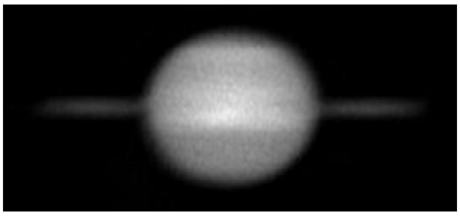


Figure 13. 1995 Sep 13d 22:06 UT, ω_1= 343°, ω_2= 192°, 490mm refl., CCD image, *M. P. Mobberley*. WS5 in EZ(N) *p.* CM.

We conclude that the rings reappeared between 16h and 23h on Aug 10, in perfect agreement with predictions. The inequality between the *p.* and *f.* ansae seemed to gradually disappear as the viewing angle of the sunlit rings increased over the next week or so.

Another superb image by the HST on Aug 10 was published in the *Journal*.[20]

Observations 1995 August to November

Refer to letter E in Figure 7.

By late August the rings had opened somewhat, and there were more consistent reports of their being equal on each side and with a brightness maximum at the position of ring B (Figures 11, 12).

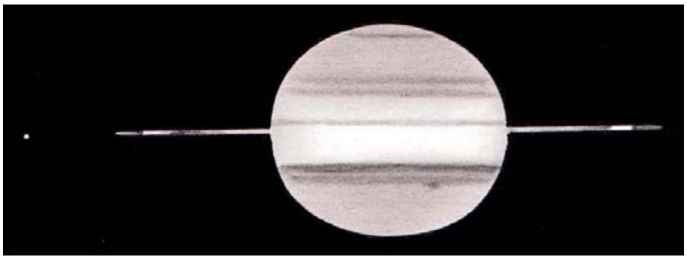


Figure 14. 1995 Sep 16d 21:20 UT, ω_1= 329°, ω_2= 082°, 415mm DK Cass., ×262–348, *A. W. Heath*. NEBn projection into NTropZ.

More and more detail could be made out with each passing week until late October when they began to fade without closing as the next ring-plane crossing approached.

On Sep 10, four days before opposition, the Earth and Sun attained precisely the same elevation north of the ring-plane, so no shadow of the rings on the globe (ShRG) could be seen. In practice the shadow was absent for longer: for example, between Sep 7 and 14 D_e and D_s differed by 0.2° or less. On Sep 9 Gray saw the rings crossing the globe as a dusky halftone. McKim on Sep 11,

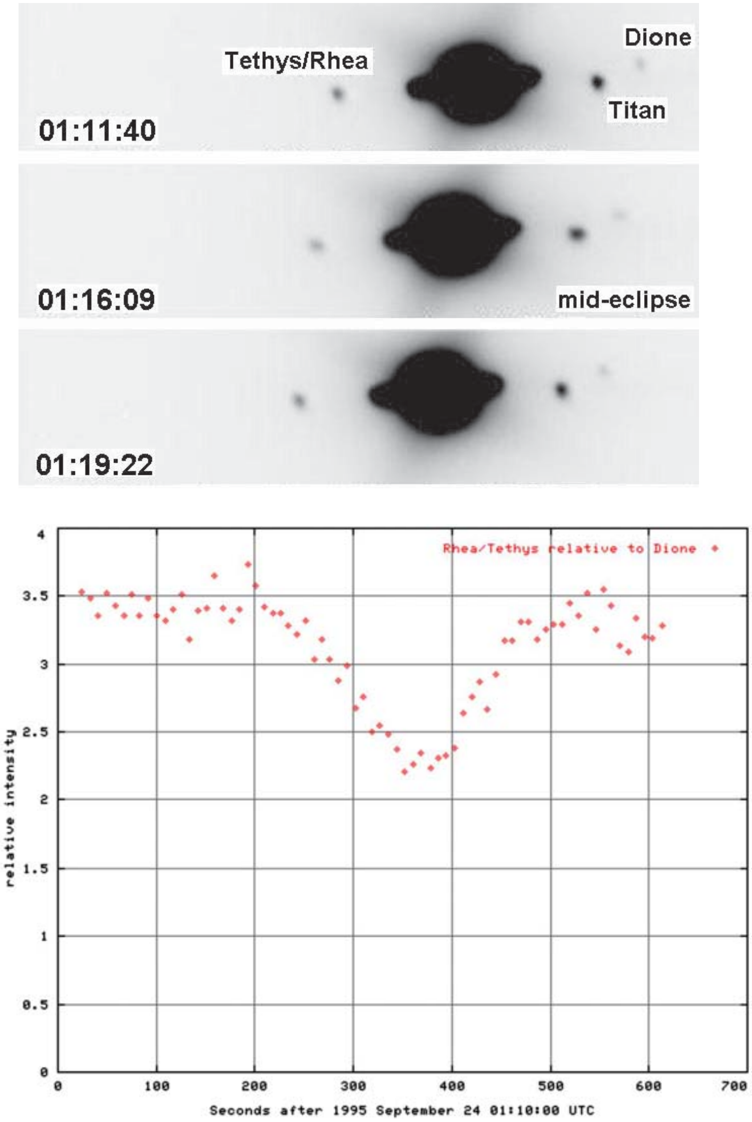


Figure 15. 1995 Sep 24d, 300mm refl., CCD camera, *N. D. James*.
A. Images showing eclipse of Rhea by Tethys (the two satellites were not resolved).
B. Lightcurve showing eclipse of Rhea by Tethys; ratio of the two satellites’ combined light relative to Dione.

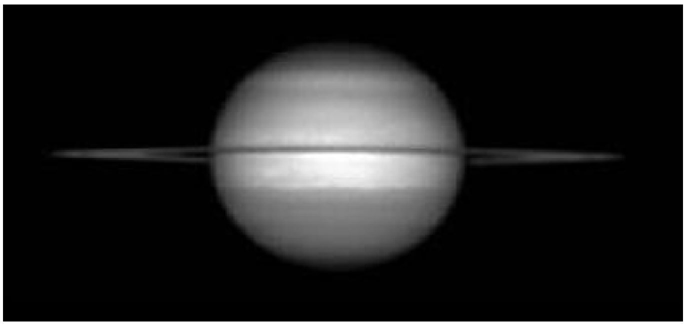


Figure 16. 1995 Sep 27d 22h 30m, ω_1= 298°, ω_2= 054°, 1.08m Cass., 780nm IR filter, ISIS CCD800 camera, *G.Quarra et al*. Detail in EZ(N) including WS2 *p.* the CM, and many belts.

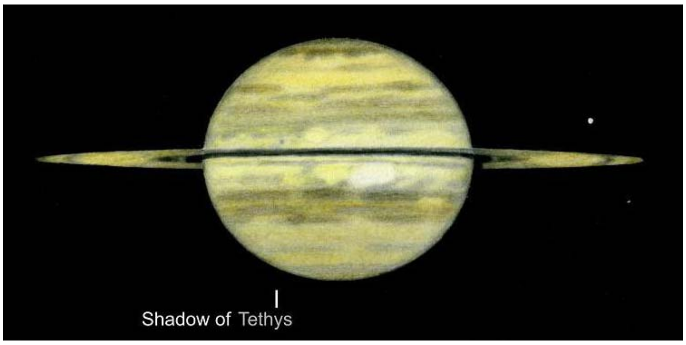


Figure 17. 1995 Oct 22d 19:35 UT, ω_1= 063°, ω_2= 096°, 600mm Cass., ×520, *N. D. Biver*. Shadow transit of Tethys seen against EZ(S) *p.* the CM. White spot and other activity in EZ(N).

Mobberley on Sep 13 (Figure 13) and Heath on Sep 16 (Figure 14) found a similar situation. From the last week of September, ShRG began to appear conspicuously dark once more, and now to the N. of the rings crossing the disk (Figures 16, 17). The fading and recovery of the ShRG was analysed graphically by the writer in the 1979–’80 BAA Saturn report.[2]

During this period the rings were very well seen and the traditional details observed, albeit much foreshortened. On Oct 17 for example McKim could see that ring B1 was obviously crescent-shaped and that the *p.* ansa was slightly brighter than the *f.* one. It required a moderate aperture to glimpse the Cassini division. Gray could already make out its location on Aug 28 and Sep 8. Graham had a good view of it on Sep 16 and 28: it appeared darker on the *f.* side on the earlier date. It was impossible to use ring B1 as a bright reference for the intensity scale during the apparition, but it was still clearly the brightest part of the sunlit rings.

At such a low angle of opening ring C was relatively bright when seen at all. A moderate aperture was required to separate it from ring B, or ring C from the globe. A superb image by Miyazaki on Sep 30 showed the gap between ring C and the globe very clearly (Figure 1E). Gray could just see it on Sep 9, and it became progressively easier to spot until the rings were fading by early November.

On Sep 3 Doherty managed to record the ShGR visually, Quarra *et al*. imaged it on Sep 27 (Figure 16), Graham caught it on Sep 24–Oct 10, Miyazaki imaged it on Sep 30 (Figure 1E) and Macdonald noted it on Oct 30 and Nov 15. This was of course a difficult feature throughout the apparition, and even more so upon the unlit rings.

Parker secured a good image showing the ghostly rings on Nov 12 including one through a methane band filter alone (Figure 19), and the HST acquired an image on Nov 17 (Figure 23B) just prior to the Sun’s crossing of the ring-plane.

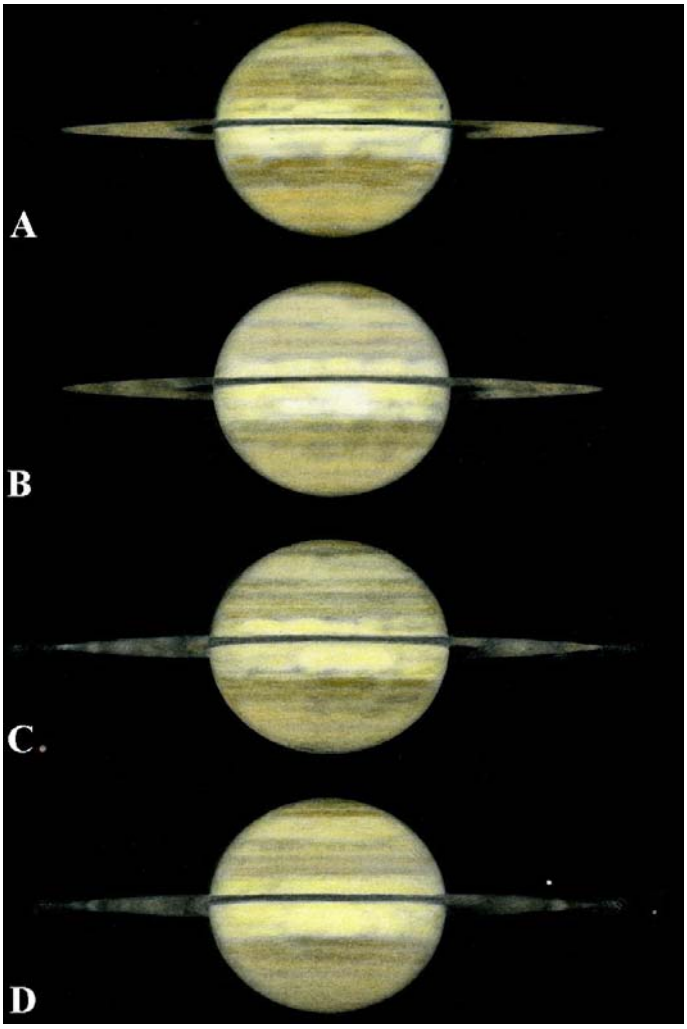


Figure 18. Observations from Meudon during the 1995 Nov 19 ring-plane crossing by the Sun. **A–C**, 600mm Cass., ×520; **D** 1m Cass., ×735, *N. D. Biver*.
A. 1995 Nov 6d 20:10 UT, ω_1= 148°, ω_2= 056°. Sunlit rings fading; shadow of Tethys against EZ(S) near the following limb.
B. 1995 Nov 16d 19:10UT ω_1= 275°, ω_2= 22°. Sunlit rings very faint.
C. 1995 Nov 17d 19:10 UT, ω_1= 040°, ω_2= 313°. Fading rings now mottled.
D. 1995 Nov 19d 19:20 UT, ω_1= 294°, ω_2= 142°. Typical aspect of the unilluminated side of the rings.

Observations during the 1995 Nov 19 ring-plane crossing by the Sun

Refer to letter F in Figure 7.

A particularly fine series of visual observations was made by Biver at Meudon at the critical time. To him the rings visibly dimmed between Oct 22 (Figure 17) and his next observation on Nov 4. Having witnessed the normal sunlit appearance on Nov 6 (Figure 18A), Biver found the rings very faint (though still showing detail) on Nov 16 at 19:10 UT (Figure 18B). On Nov 17 he found the fading rings mottled (Figure 18C), as though reverting to the dark side aspect, and brighter on the *f.* side on both Nov 16 and 17. On Nov 19 (19:20 UT; Figure 18D) the rings had faded and their mottled surface now showed the typical dark side aspect, with the *p.* ansa still the brighter of the two.

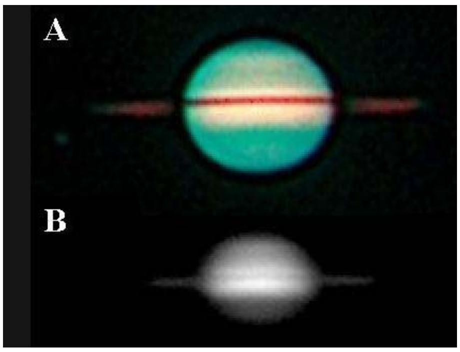


Figure 19. 1995 Nov 12d 01:03-01:20UT UT, ω_1= 221-231°, ω_2= 320-330°, 400mm refl., Lynxx-PC cooled CCD camera at f/19, *D. C. Parker.*
A. False colour composite made from single frame Methane band (890nm), red and green filter images (exposure times 4.3s for red, 6.7s for green, and 5 min (!) for Methane band).
B. Methane band (890nm) filter image.

Other observers could not see so much detail on the rings. Abel could still see them with a small reflector on Nov 17 but they had vanished completely to him on Nov 19. To Beaumont they faded greatly during Nov 16–18. To Colombo the dimmed rings on Nov 14 looked dark brown. With a 30cm aperture on Nov 19 at 20:52 UT, some 5 hours after the ring-plane crossing, Weldrake confirmed Biver in seeing the typical dark side aspect with a brighter part of the ring near the planet (ring C), a gap, and then a tiny faint spot in the position of Cassini's division/ring A. Gray's near-simultaneous observation and drawing showed these points and some other subtleties.

Once again the prediction for the transition from the lit to the unlit rings seems to have been correct to within a few hours.

Observations 1995 Nov to 1996 Feb

Refer to letter G in Figure 7.

On Nov 20 the rings were already open to their maximum extent on the newly unilluminated face, at an angle of +2.7°. This made their observation much easier than during the previous unlit phase when the maximum angle of opening had been just 0.6°. From Nov 19 onwards Biver would continue to draw much the same pattern on the rings until the viewing angle became too low, after 1996 mid-Jan. During Nov 19 till Dec 28 he considered the *p.* ansa slightly brighter than the *f.* one. Biver described the change in the rings as follows. Ring B seemed the brightest until Nov 17 or 19, whereas the locations of ring C and of ring A/Cassini's division became almost as bright from Nov 19. From Nov 30 the situation had become more obvious with ring C brightest from 1.15 to 1.5 Saturn radii (with two bright parts), then another (but slightly lower) brightness peak occurred at 1.9 Saturn radii (Cassini's division and the beginning of the A ring). Another faint patch was noticed in the mid-A ring at 2.1 Saturn radii and another between ring C and the Cassini division. The ShGR could just be perceived upon the brighter ring C on some dates, a point confirmed by Gray on Nov 19.

With smaller apertures the rings remained invisible, but those with larger telescopes mostly continued to see them faintly. Meredith saw the ansae faintly on Nov 26 (22cm refl.) with the *p.*

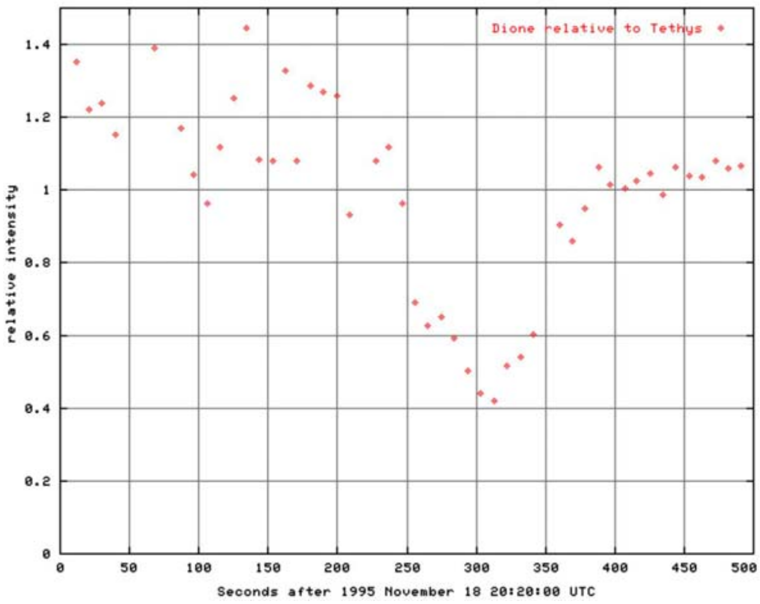


Figure 20. 1995 Nov 18d, 300mm refl., CCD camera, *N. D. James*. Lightcurve showing eclipse of Dione by Rhea; ratio of Dione's brightness relative to Tethys.

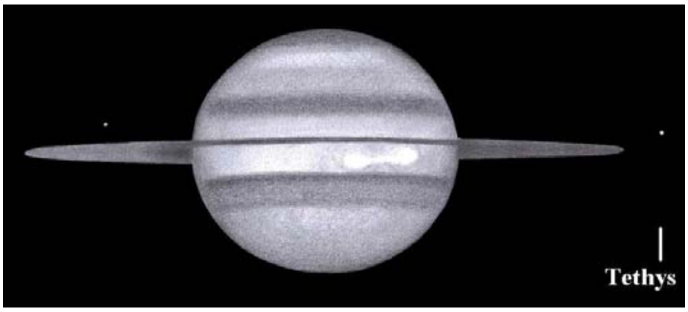


Figure 21. 1995 Dec 8d 19:30 UT, ω_1= 140°, ù$_2$= 095°, 457mm refl., ×200 (approx.), *R. J. McKim*. Dark side of rings well visible, and brighter on the *p.* side; double white spot in the EZ(N).

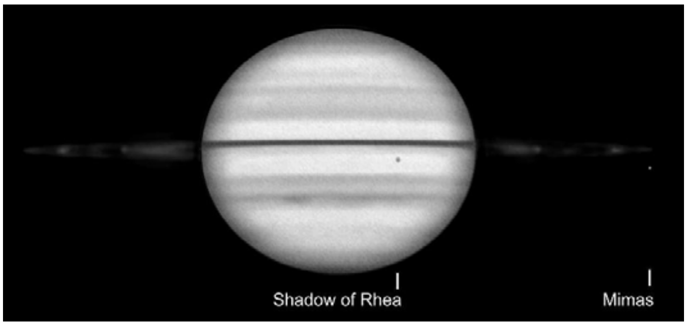


Figure 22. 1995 Dec 20d 17:00 UT, ω_1= 102°, ω_2= 033°, 415mm DK Cass., ×262, *D. Gray*. Detail in unilluminated rings. Shadow transit of Rhea.

side the easier to see. McKim saw the ansae well on Nov 27 (22cm refl.) and the brightening at the place of ring C, but they did not seem quite to extend up to the disk. On Dec 8 he saw the unilluminated rings very well with a 46cm refl. and had the same impression, as well as noting they were brighter on the *p.* side (Figure 21), a point confirmed by Rogers and Graham (the latter catching the *p.* side only). On Dec 9 with a 25cm telescope he could trace only the *p.* ansa. Foulkes on Dec 9 (25cm reflector) also only caught the *p.* ansa. Heath caught both sides as stubs on the same date. Meredith on Dec 14 and McKim on Dec 20 saw both ansae with the *p.* one the easier to see. Macdonald and Meredith saw both ansae on Dec 24–27 and (like Biver during this time interval) considered the *p.* ansa a bit brighter. On Dec 25 Proctor could see both ansae, and noticed brightenings at the positions of ring C and the Cassini division/ring A; at the same time Gray caught some additional smaller bright areas and found the *p.* ansa to be the brighter one. On Dec 27 Graham (40cm refl.) caught the brightenings at ring C. To Meredith on Dec 28 and Giuntoli on Jan 2 only the *p.* side of the steadily narrowing unlit rings could be detected, but Graham on Dec 28 saw both sides. After having caught the unlit rings occasionally in November, Niechoy sketched faint ring stubs on Dec 12, 29 and Jan 5.

It will be seen that the observations of the unlit rings consistently point to their being brighter on the *p.* side.

By the time of his final observation on 1996 Jan 31 (with the Meudon 60cm Cassegrain), Biver could see only undifferentiated pale streaks in the place of ring A/Cassini's division and ring C.

Observations during and after the 1996 Feb 11 ring-plane crossing by the Earth

Refer to letters H and I in Figure 7.

On Feb 3 McKim could see the ShRG but not the rings: likewise Proctor on Feb 4 and Foulkes on Feb 8, but poor weather and twilight hindered the observations now. The ring-plane crossing was on the night of Feb 11/12. Fortunately Beaumont was able to observe just after the critical time. On Feb 13 18:15 UT faint streaks of light were glimpsed on both sides, more prominently on the *f.* one. On Feb 14 18:00 UT (but through light haze) she saw stubs of rings on both sides, and ShRG was glimpsed. On Feb 16 at 18:15 UT Graham & McKim observed with the latter's 216mm refl. and saw the rings easily to their full length; ShRG was not seen. Heath, Macdonald and Proctor all had a similar view and found the *p.* and *f.* sides identical. On Feb 18 in twilight McKim repeated the observation of the illuminated rings as well as seeing the thin ShRG. On Feb 19 and 20 Beaumont again saw the rings well. Finally on Feb 21 Proctor found the outer parts of the rings (rings A/B) brighter, and the *f.* side brighter than the other.

Bicoloured aspect of the rings

The difference in brightness between the *p.* (W) and *f.* (E) ansae in white light has been recounted above. Heath continued his observations of comparative red (Wratten 25) and blue (W44A and W47) filter intensity estimates upon the sunlit rings. On Aug 16, 25 and Sep 3 he found no difference between the W. and E. ansae in white light or with colour filters. Schmude on Sep 2 (*ca.* 04.30 UT) found the ansae equal in white light but the *p.* side was the brighter with both W25 and W47.

The satellites

In addition to the much improved chance of observing Saturn's faint, inner moons without the distracting presence of the rings, many satellite phenomena (including numerous mutual events) occurred. Predictions of mutual phenomena observable from the

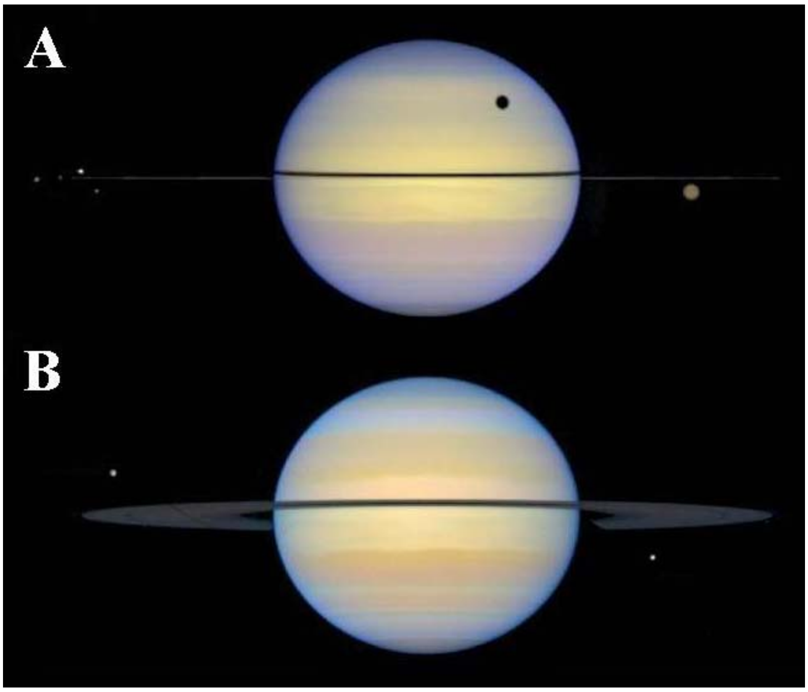


Figure 23. HST images (*E. Karkoschka [LPL] and NASA.*)
A. 1995 Aug 6d. A shadow transit of Titan is in progress. From W. to E. the satellites are Enceladus, Janus, Tethys, Mimas (W. ansa) and Titan (E. ansa).
B. 1995 Nov 17d. Dione is S. of the W. ansa and Tethys N. of the E. one. According to WINJUPOS the image must have been taken around 08:25 UT, and (remarkably) the streak crossing the *p.* ansa is actually the shadow of Dione rather than an image fault. As ever, the composite colours in **A** and **B** are only an approximation.

UK were highlighted by Asteroids & Remote Planets Section Director R. Miles in several BAA *Circulars*,[10] while the *Handbook* carried predictions of occultations, eclipses, transits and shadow transits for Tethys, Dione, Rhea and Titan as well as eclipses of Dione and Rhea by Titan.[12]

Longer sets of mutual event predictions were published by Arlot & Thuillot,[13] and by Asknes & Dorneau.[14] These predictions[13,14] were partly summarised by Nicholson in *Sky & Telescope*.[15]

Both the BAA[12] and the UAI[21] published details of planned observing campaigns for mutual phenomena. R. Miles summarised some of the successful observations at a BAA meeting.[22] The UAI intended to follow up the previous PHEMU campaign

Table 4. Observations of satellite phenomena

Date	*UT*	*Observer*	*Remarks*
1995			
Jul 2		Gray	Enceladus well seen.
Jul 5		Miyazaki	Shadow of Titan imaged in transit. (Figure 1B)
Jul 6	03:10	Biver	Dione's shadow suspected in transit (250mm Cass.)
Jul 8	01:10	Gray	Enceladus seen on E. side.
Jul 16		Gray	Annular eclipse of Dione by Tethys predicted at 01:02.2–01:14.5UT. Dione fade began 01:04 UT; Dione invisible by 01:09 UT; Dione= Tethys by 01:14:40 UT; Dione brighter than Tethys by 01:15:05 UT.
Jul 16	03:14	James	Dione and Tethys still very close after the above event, appearing as short streak on CCD image (300mm refl.)
Jul 16	03:00	Gray	Mimas glimpsed midway along W. ansa.
Jul 16	02:15	Ellis	Tethys and Dione in conjunction E. of the planet, too close to resolve (203mm SCT).
Jul 19		Gray	Enceladus well seen near E. Elongation.
Jul 20	01:45–03:15	Biver	Shadow of Rhea seen as grey dot against the EZ(S) (250mm Cass.)
Jul 21	24:00	Proctor	Titan hanging upon *p.* limb against EZ(N) just leaving transit. (mid-Egress predicted at 23:38 UT in the *Handbook*).
Jul 30	01:30	Gray	Mimas seen off the W. ansa with Enceladus off the E. one.
Aug 2	15:35–15.41	Miyazaki	Rhea's shadow imaged in transit.
Aug 4	00:00	Foulkes	Enceladus seen W. of the rings (203mm SCT).
Aug 5		Foulkes	Reappearance of Rhea from occultation predicted at 01:15 UT but satellite not visible even by 01:30 UT despite transparent sky and use of occulting bar.
Aug 5	23:15	Foulkes	Enceladus near E. Elongation (254mm refl.)
Aug 6	01:50	Gray	Mimas seen off the E. ansa.
Aug 10	00:00	Meredith	Mimas and Enceladus appear as an unresolved point to the E. of the rings (215mm refl.).
Aug 10	01:30	Ellis	Enceladus glimpsed near E. Elongation (203mm SCT).
Aug 10	23:30	Foulkes	Tethys and Dione too close to separate (254mm refl.).
Aug 11	00:05	S.L.Moore	Mimas seen on E. side.
Aug 11	15:17–15.46	Miyazaki	Rhea's shadow imaged in transit (Figure 1D).
Aug 12	03:17	Platt	CCD image shows Mimas and Tethys too close to be resolved to W. of rings.
Aug 15	04:00	Gray	Enceladus at the tip of the W. ansa.
Aug 16	03:30	Biver	Shadow transit of Rhea seen; shadow transit of Dione suspected (600mm Cass; Figure 10A).
Aug 16	03:40	Gray	Shadow of Dione as a tiny grey dot in EZ(S) near CM, with Rhea's shadow as a larger grey dot on the following side at the SEB N. edge. Rhea seen upon E. ansa. (Figure 10B)
Aug 16	23:15	S.L.Moore	Mimas seen on W. side.
Aug 19	00:05	Foulkes	Transit of Dione not visible (254mm refl.)
Aug 23	23:00	Foulkes & Rogers	Enceladus visible near E. elongation (310mm OG).
Sep 3		Doherty	Total of 8 satellites visible (390mm refl.).
Sep 9	23:30	Gray	Mimas off tip of E. ansa.
Sep 16	21:20	Graham, Gray & Heath	Enceladus seen off the W. ansa (410mm DK)
Sep 24		James	Partial (annular) eclipse of Rhea by Tethys predicted for 01:13.4–01:19.4 UT. An event definitely occurred between about 01:13:40–01:17:40 UT (Figure 15). The observations were previously published in BAA *Circular* No. 751[10]
Oct 15	21:30	Ellis	Tethys very close to Rhea off the W. ansa.
Oct 22	19:35	Biver	Shadow transit of Tethys against EZ(S) followed up to 5 min before its egress at the *p.* limb. (600mm Cass.)
Nov 2		Chapple	Predicted partial eclipse of Enceladus by Tethys 22:34:37–22:36:03UT. Observer did not detect fall in light of Enceladus due to unsteady seeing.
Nov 6	20:10	Biver	Shadow of Tethys just off *f.* limb (600mm Cass.).
Nov 9	21:55	Meredith	Glimpses of Enceladus on the E. side, but its eclipse by Titan not observable due to sky conditions.
Nov 9		Miles & Hollis	Total eclipse of Enceladus by Titan predicted for 21:54:08–22:08:14 UT. Observed eclipse (lightcurve from Starlight Xpress CCD, with unfiltered 10s exposures) from 21h 54m 00+5s to 22h 09m 10+5s. Predicted mid-eclipse at 21h 01m 11s; observed at 21h 01m 35s.
Nov 18		Foulkes	Eclipse of Titan by Rhea predicted at 18:43.018.53.7 UT, but no noticeable brightness drop by end of observation at 19:00 UT (254mm refl.) due to poor seeing. Enceladus seen to W. of rings.
Nov 18		Rogers	Partial eclipse of Dione by Rhea predicted for 20:23.0–20:26.7 UT (and thus minimum brightness at 20:24.85UT). Observing began at 20.10 UT; Dione seen to disappear but timings affected by bad seeing and thickening cloud. Rhea was always too close to the planet to be visible.
Nov 18		James	Partial eclipse of Dione by Rhea predicted for 20:23.0–20:26.7 UT (and thus minimum brightness at 20:24.85UT). Imaging commenced at 20:20UT; notable drop in brightness of Dione (relative to Tethys) began at 20h24m02±5s, reached a minimum at 20h25m08±5s (thus within 20s of the predicted mid-event time), and returned to normal brightness at 20h26m23±5s (Figure 20).
Nov 19	20:50	Gray	Mimas against the rings near the E. ring-tip.
Nov 26		Foulkes	Tethys eclipse reappearance predicted at 18:55 UT; not seen, even with occulting bar, until 19:25 UT. Mimas seen W. of the rings (254mm refl.)
Nov 27		Manning	Total eclipse of Enceladus by Rhea predicted at 20:14:50–20:25:10 UT. Notes from selected cooled CCD camera frames, not precise limiting timings: Enceladus 1st fade 20:15:54 T; gone at 20:17:55 UT; 1st reappearance 20:23:43 UT.
Dec 20	17:00	Gray	Shadow of Rhea seen against EZ(N). Mimas near tip of E. ansa (Figure 22).
Dec 27	19:30	Foulkes	Titan and Rhea too close to be resolved (152mm refl.)
Dec 27	17:05	Meredith	Enceladus on E. side.

(for 'phénomène mutuels', organised by the Bureau des Longitudes of Paris Observatory) for Jupiter's satellites.[23]

In contrast to 1979–'80, transits and shadow transits of Titan were not favourably timed for observation from the longitude of the UK, but Proctor just caught the end of a Titan transit at midnight on Jul 21. Miyazaki imaged Titan's large shadow on Jul 5 (Figure 1B): was this the first time it had been captured by a CCD camera? On Aug 2 Miyazaki caught Rhea's shadow in transit, but not certainly that of Tethys. On Aug 11 (Figure 1D) he again imaged the shadow of Rhea. The HST image of Aug 6 (Figure 23A) beautifully shows Titan's shadow in transit, while on Nov 17 it caught Dione's shadow against the *p.* ansa (Figure 23B). Benton[4] notes positive observations of Titan's shadow by Walter Haas from the USA in 1995 December.[24]

The reported phenomena are listed in Table 4, together with some rare sightings of the inner moons with ordinary instruments. Mimas and Enceladus were naturally easy objects at Lick.

As far as the usefulness of these timings go, it is clear that there are slight differences (from a few seconds to a few tens of seconds) between some of our results and the predictions, and the CCD data for 1995 Nov 9, 18 and 27, involving eclipses by Rhea and Titan, may be significant.

Foulkes remarked upon Titan's orange colour on Aug 19 and Oct 8, and Youdale resolved its disk on Aug 26. On Oct 22 using the 600mm Cassegrain at Meudon (×520) Biver saw Titan with a large orange disk, much larger than that of Rhea (whose disk was also resolved). Graham from Lick in August (×1175) also distinctly saw Titan's orange disk.

Conjunctions

Beaumont supplied photographs of the attractive conjunction of Saturn with Venus, whose closest approach (1°) was on 1996 Feb 2.

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3 R. J. McKim, *ibid.*, **124**(3), 142–150 (2014)
4 For the ALPO report see J. L. Benton, *J. Assoc. Lunar Planet. Obs.*, **41**(1), 1–23 (1999), and for a UAI one see L. Testa, *Astronomia*, 1997, no. 4, pp 11–27. (Rotation periods derived by the UAI for NEBs projections are spurious, being based upon too few observations.)
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6 D. L. Graham, *ibid.*, **106**, 274 (1996). This provisional analysis of EZ(N) white spots (also stated in Ref. 7) has been superseded by the present report. (Graham's white spot A is identical to WS5, though its suggested post-August acceleration has not been confirmed; B is WS1 and C is WS4.)
7 D. L. Graham, *ibid.*, **106**, 306–307 (1996)
8 D. L. Graham, *ibid.*, **107**, 291–292 (1997)
9 BAA *Circular* No. 745 (1995 May 24) contained predictions of the times of the ring-plane crossings. The next triple ring plane crossings will occur in 2038.
10 BAA *Circulars* No. 746 (1995 Jul 14), 747 (1995 Sep 1), 750 (1995 Oct 25) & 751 (1995 Dec 21) contained predictions of mutual satellite events, some actual observations, and some news of ring-plane crossing and spot observations.
11 HST discoveries of new satellites were cited (for instance) in IAU *Circulars* Nos. 6192 (1995 Jul) & 6243 (1995 Oct). HST Saturn images can be found at: **http://hubblesite.org/newscenter/archive/releases/solar-system/saturn/results**
12 Predictions in the BAA *Circulars* were courtesy of Dr D. Harper of Queen Mary & Westfield College, London. The predictions published in the BAA *Handbooks* for 1995 and 1996 were computed by E. R. Delo and J. Meeus.
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21 P. Tanga, *Astronomia*, 1994, No. 4, pp 25–28, and 1994, No. 5, p 32
22 See the account in *J. Brit. Astron. Assoc.*, **106**, 104 (1996).
23 The PHEMU campaigns with Jupiter were described in A. Dollfus, *La grande lunette de Meudon: Les yeux de la découverte*, CNRS Editions, 2006, p. 168. (English translation by R. J. McKim published under the title of *The Great Refractor of Meudon Observatory*, Springer, 2013, p. 128.)
24 *WINJUPOS* animations show that Titan's shadow fell upon the EZ(S) on 1995 Oct 9 and 25 and upon the EZ(N) on Nov 26 and in December. However, it apparently glanced across the rings into the EZ(N) on Nov 10: an extremely rare phenomenon, and one which the writer has never seen described in the literature. Was it witnessed by anyone on 1995 Nov 10? Whatever the case, the HST observed the very same phenomenon with Dione's shadow a week later in a remarkable image taken on 1995 Nov 17 (Figure 23B).

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