Saturn, 2004–'05

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A report of the Saturn, Uranus & Neptune Section. Director: M. Foulkes

During 2004–'05 the angle of opening of the rings fell slightly from the 2003 maximum to –22°.9 at opposition. The planet's atmosphere was relatively quiet: white spot activity in the South Tropical Zone considerably declined, but the South Equatorial Belt Zone remained active, with two white ovals slowly converging in longitude. One SEBZ white oval endured for more than seven months, much longer than any such feature from 2003–'04. A small amount of activity was again recorded outside these latitudes, at the N. edge of the SEB and in the EZ(S), and the slow Equatorial Current of 1994–'95 onwards was still in operation. The reappearing N. hemisphere was bluish in contrast to the warm-tinted south. The disk of Titan was resolved by visual and imaging observations, and one image indicated a colour/intensity difference between the north and south hemispheres.

An Appendix presents a summary of all the rotation periods derived by members of the Saturn Section since 1891 and an analysis of wind speed by latitude, with a comparison with recent data from the *Cassini* mission.

Introduction

The 2004–'05 apparition was very well observed (see Table 1), though the planet showed less atmospheric activity than in the previous apparition. Many images were obtained at visible, infrared, ultraviolet and methane band wavelengths. The decline in visual observation continued, but enough data were submitted for good average visual intensity estimates (Table 2). The planet was at opposition in Gemini on 2005 Jan 13 (the previous opposition having occurred on 2003 Dec 31, so there was none in 2004), at declination +21°. Solar conjunctions occurred on 2004 Jul 8 and 2005 Jul 23. Our observers monitored the planet from 2004 Aug 15 (Gray) till 2005 Jun 9 (Yunoki). The rings had closed slightly, and at opposition the sub-Earth latitude (D_e) equalled –22°.9, having reached a minimum of –21°.7 in 2004 November. The value of D_e would rise to a temporary maximum of –23°.9 in 2005 March.

A short note about the Section's work appeared in the report of Council,[1] and Dr R. A. H. Paterson published a drawing of the planet made with the 32cm reflector previously owned by W. T. Hay.[2] Online archives were maintained by the International Outer Planet Watch,[3] the UAI,[4] and the ALPO Japan (JALPON).[5] High resolution imaging was achieved by numerous observers, and high resolution visual work came from Biver, Bowen, Gray, Hernandez and McKim. In 2005 Apr–May, Peach was able to secure some superb images during the first of his trips to Barbados.[6] The spectacular success of the *Cassini* mission continued, the craft having arrived on 2004 July 1, and we saw the *Huygens* probe safely reach the exotic surface of Titan on 2005 Jan 14.[7–11] An apparition report was published by the ALPO.[12]

This Section report, the eleventh and final one in a series by the writer (1994–'95 to 2004–'05) continues the record from 2003–'04.[13] A forthcoming 2005–'06 report by the Director, M. W. Foulkes,[14] will fill the remaining gap in publication.

The 2004–'05 apparition saw the completion of the second Saturnian year to be observed and reported upon without a break by members of the Association since its detailed post-WW2 programme was created by Dr A. F. O'D. Alexander in 1946. To mark this event, we present an Appendix containing all the reliable rotation periods measured by BAA members since the creation of the Section in 1891.

Table 1. Observers

Observer	*Location(s)*	*Instrument(s)*
T. Akutsu	Tochigi, Japan	320mm refl.
N. D. Biver	Versailles, Paris, France	256mm & 407mm refls.
R. D. Bowen	Wakefield, W. Yorks.	300mm refl.
M. Brown	York	254mm refl.
P. Casquinha	Palmela, Portugal	203mm refl.
R. Chavez	Powder Springs, GA, USA	235mm SCT
E. Colombo	Milan, Italy	152mm refl.
B. A. Colville	Cambray, Ontario, Canada	200mm MKT & 300mm SCT
J. Cooper	Wootton, Northants.	355mm SCT
D. Dierick	Ghent, Belgium	235mm SCT
G. Elston	Chesham, Bucks.	203mm SCT
C. Fattinnanzi	Macerata, Italy	250mm refl.
M. Foulkes	Hatfield, Herts.	203mm SCT & 254mm refl.
M. Giuntoli	Montecatini Terne, Italy	203mm SCT
E. A. Grafton	Houston, TX, USA	356mm SCT
D. L. Graham	Ripon, N. Yorks.	152mm MKT
D. Gray	Kirk Merrington, Co. Durham	415mm DK
A. W. Heath	Long Eaton, Notts.,	203mm SCT & 254mm refl.
C. Hernandez	Miami, FL, USA	229mm MKT
D. Hunter	York	250mm refl.
T. Ikemura	Nagoya, Japan	310mm refl.
K. Johnson	Selsey, W. Sussex	140mm MKT
T. Kumamori	Sakai City, Osaka, Japan	600mm Cass.
P. R. Lazarotti	Massa, Italy	252mm refl.
T. Lepine	St. Etienne, France	356mm SCT
R. J. McKim	Upper Benefield, Northants.	410mm DK
C. Meredith	Manchester	215mm refl.
M. P. Mobberley	Bury St Edmunds, Suffolk	250mm refl.
D. Mottershead	Manchester	254mm SCT
D. Niechoy	Göttingen, Germany	203mm SCT
T. Olivetti	Bangkok, Thailand	180mm MKT
P. W. Parish	Rainham, Kent	152mm OG
D. C. Parker	Miami, FL, USA	254mm DK
D. A. Peach	Loudwater, Bucks., &	
	St Phillip, Barbados, W. Indies	235mm SCT
	Flackwell Heath, Bucks.	279mm SCT
C. E. Pellier	Bruz, France	178mm MKT & 210mm DK
J. H. Phillips	Charleston, SC, USA	203mm & 229mm OGs
Z. Pujic	Brisbane, Australia	310mm refl.
J. R. Sánchez	Córdoba, Spain	279mm SCT
D. B. V. Tyler	Flackwell Heath, Bucks.	152mm MKT & 279mm SCT
K. Yunoki	Sakai City, Japan	200mm refl.

Abbreviations: SCT= Schmidt–Cassegrain; DK= Dall–Kirkham Cassegrain; MKT= Maksutov–Cassegrain.

The globe

Nomenclature

In this series of reports, we have used nomenclature in accord with previous long-term studies.[15,16] In his reports starting with 2006–'07,[17] Foulkes has used a few slightly different descriptions:

McKim, 1994–'95 to 2004–'05	*Foulkes, 2006–'07*
STB	STB S. component
STropB	STB N. component
EZ(S)B	narrow belt in EZ(S)

For a diagram of belt latitudes, see our previous report.[13]

Latitudes

Both the SEB(S) and SEB(N) were double, and as on a previous occasion only their extreme edges were measured. The centres of belts, where stated, were calculated from measures of their edges. See Table 3. Compared with 2003–'04 there were few significant changes, but all features from the pole down to the SEB(S)s had moved systematically – albeit mostly very slightly – closer to the equator. In particular, the SSPB was significantly thinner, positioned a few degrees further north. The EZ(N)B was appreciably closer to the equator. The EB was a little narrower, and its latitude was variable with both longitude and time. In general the 2006–'07 data,[17] also quoted in Table 3, confirm the shift of several belts towards the equator since 2003–'04, and in the case of the SPB and SEB, further movement in that direction.

When viewed graphically, the latitude data for the southern belts since 1992–'93 show a slight general trend towards the pole as the value of D_e increases, followed by a return to lower latitude as it decreases. This is in the same sense as our results for the N. hemisphere as described in the 1999–2000 report,[18] but the effect for the S. globe is less marked. A full analysis will be appropriate in a later Section report, when the S. hemisphere becomes completely covered by the rings as seen from Earth.

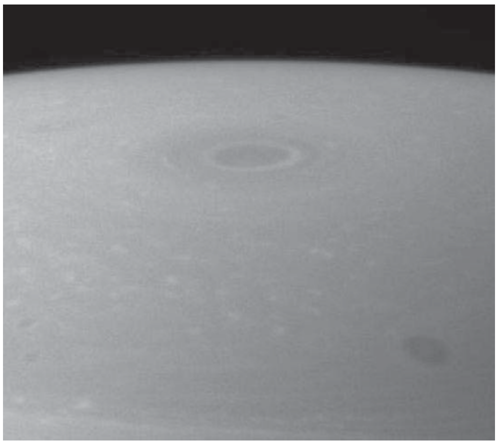

Figure 1. This near infrared (λ= 938nm) *Cassini* image from 6.8 million km on 2004 Jul 24 shows the S. polar region in great detail. Note the tiny dark S.S. Polar Cap (the 'polar vortex') within the general dusky SPC, and some small, round dark spots near the edge of the latter. (Note: South is uppermost in all figures unless stated otherwise.)

Figure 2. *Cassini* close-up of a STropZ white oval imaged on 2004 Jul 13 (λ= 889nm).

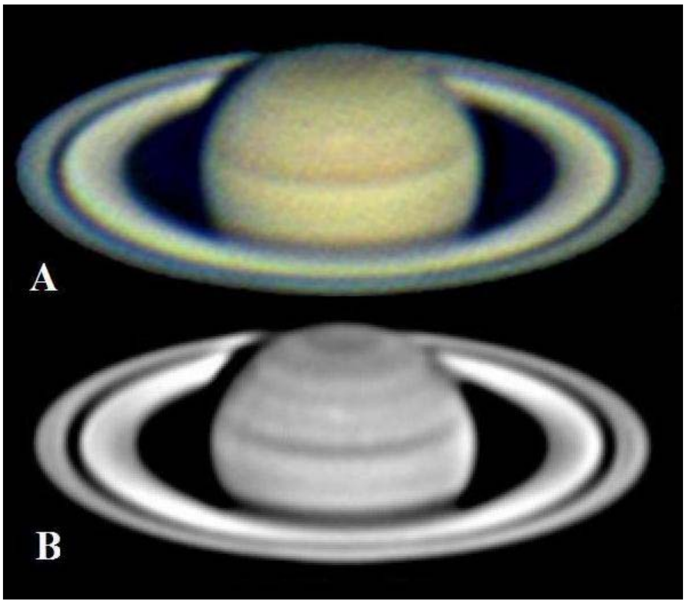

Figure 3. A short-lived STropZ white oval: (A) 2004 Sep 15, 20:16UT, ω_1= 135°, ω_3= 300°, 320mm refl. with ToUcam camera at f/23, RGB image, *T. Akutsu*; (B) 2004 Sep 17, 04:11UT, ω_1= 178°, ω_3= 298°, 178mm MKT with ATK-1HS camera, red image, *C. E. Pellier*. Both images show a white STropZ oval near the CM; (B) also shows SEBZ activity following the CM.

Global colours

Global colours showed very similar behaviour to 2003–'04, including filter reaction. The N. hemisphere began to return to visibility after some years in darkness. The strip of the North Temperate regions (up to latitude *circa* +67° at the limb) appeared blue or bluish-grey in colour in the images, in contrast to the warm-tinted south. The orbital geometry of *Cassini* allowed the spacecraft a better view.

On 2005 Jan 16 Ikemura found the SPR more reddish than formerly. Peach on Feb 6 considered the reddish SPR/SPB had darkened in recent weeks. Whether there was a change with time or not, the best images show very clearly that the SPR, SPB, SSSTB, SSTB, STB and SEB were all brownish or reddish-brown, and the EZ(S) yellowish. The SPC however looked colder, bluish or bluish-green, and as a result it appeared noticeably darker in red filter images. Tyler considered that the EZ(S) had changed from yellowish to a more pinkish tint in 2005 late February, but to the writer these latter images simply suggest a less strongly yellow tint.

On Jan 4 and 8 McKim thought the STropZ and STeZ had a slightly greenish cast in addition to the normal yellowish tone. On Jan 13 however the region merely looked yellowish. He also thought the SPR/SPB had a warm tone very much like the SEB on Jan 13 and Feb 7 and 15, while on Mar 17 and 25 and Apr 10, 18, 21 he explicitly called the SPR/SPB brownish. The EZ was always strongly yellow, perhaps more so than last opposition, while the thin strip of what he called 'NTeZ' simply looked grey. Foulkes also judged colours, and agreed that the SPR and SEB were brownish, the EZ(S) yellowish white and the EZ(N) greyish white.

South Polar Region

This region appeared much as in 2003–'04, but the decreasing value of D_e made it more difficult to see the dark spot (SSPC, or so-called 'polar vortex') in the centre of the dusky S. Polar Cap (SPC); however, Bowen and Hernandez were able to resolve it visually on a few occasions. We show here (Figure 1) a superb *Cassini* close-up of the south pole; some images (Figures 5, 7, 9 and 11) also show it with certainty. The N. edge of the SPC was again marked by a dark SSPB. Spot activity in the far south was very low: images by Dierick on Dec 9 (03:10UT) and Peach of Dec 11 (02:26UT) each suggest a minute dark spot on the SSPB N. edge. One of Yunoki's Jan 28 images may show the SSPB as irregular, and on Feb 4 Biver sketched a similar effect.

During 2004–'05, the S. Polar region north of the SSPB was quite shaded, and considerably darker than the STeZ or STropZ. The SPR had the usual dark SPB at its N. edge.

Between the SPB and the SEB there were only two obvious belts: the STB and SSSTB. The SSSTB was thin and dark and close to the SPB. On Dec 13 Lazzarotti saw a faint dark SSSTB spot at $\lambda_3 \sim 110°$.

South South Temperate Belt and Zone

The SSTB was very thin and weak between the SSSTB and the STB, and the vast majority of images fail to show it at all. It is shown in Figures 9 and 11. Its intensity and width have varied greatly since 1995. The SSTeZ was featureless.

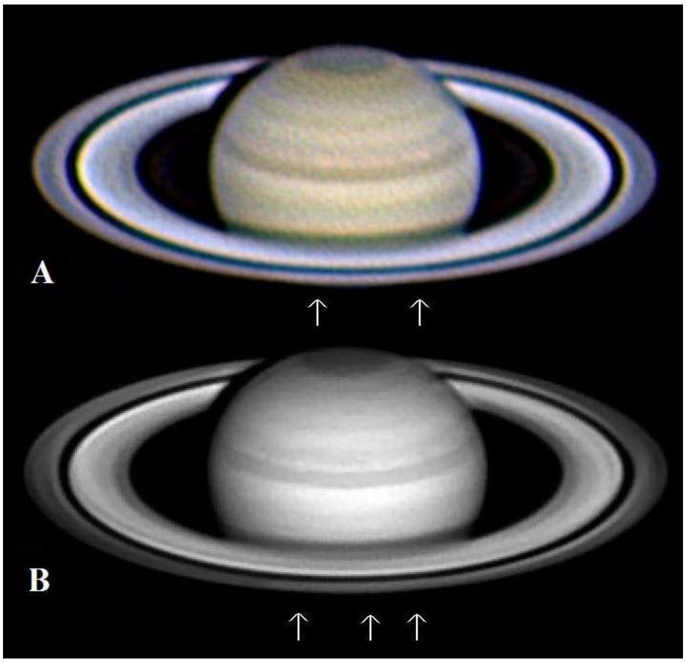

Figure 4. Features in the South Equatorial Belt Zone: (A) 2004 Nov 6, 18:31UT, ω_1= 059°, ω_3= 284°, 320mm refl. with ATK-1HS camera at f/26, RGB composite image, *T. Akutsu*. One SEBZ white oval is seen on each side of the CM (both arrowed); (B) 2004 Nov 26, 05:03UT, ω_1= 273°, ω_3= 206°, 279mm SCT with ToUcam camera at f/30 and red (W23A) filter, *J. R. Sanchez*. One SEBZ white oval is seen on each side of the CM, followed by a column across the zone (all arrowed). Note also the darkening of the SPC in red light.

Table 2. Visual intensity estimates, 2004–'05

Feature	*RB*	*MF*	*DGy*	*AH*	*RM*	*CM*	*Ave.*	*No.*
SSPC	6.0	–	–	–	–	–	6.0	2
SPC	5.5	5.0	5.0	–	5.5	–	5.2	51
SSPB	–	–	5.8	–	–	–	5.8	14
SPR	5.0	4.4	4.2	–	4.8	5.0	4.7	67
SPB	5.4	–	5.1	–	5.2	–	5.2	34
SSTeZ	–	–	3.3	–	4.0	–	3.6	12
SSTB	–	–	4.0	–	4.2	–	4.1	11
STeZ	3.8	3.0	2.6	3.0	3.6	3.0	3.2	74
STB	4.2	–	4.3	–	4.3	–	4.3	27
STropZ	3.5	2.7	2.5	2.3	3.6	3.0	2.9	74
SEB(S)	5.0	3.9	3.8	–	4.9	–	4.4	67
SEBZ	3.5	–	3.0	–	3.9	–	3.5	58
SEB(N)	5.4	5.0	5.6	4.8	5.5	4.0	5.0	75
EZ(S)	1.5	1.5	1.9	2.0	2.1	0.5	1.6	75
EB	2.9	3.1	3.3	2.7	3.4	–	3.2	69
EZ(N)	2.0	2.3	1.4	–	2.1	0.5	1.7	69
NTeZ/ N. hemisphere	4.6	–	–	–	3.5	–	4.0	26
Ring A1	3.8	4.3	3.8	3.0	3.5	2.5	3.5	75
Encke's divn.	5.4	–	6.5	–	5.8	–	5.9	30
Encke complex	–	–	4.8	4.0	3.0	3.0	3.7	22
Ring A2	3.2	3.8	3.0	2.3	2.7	2.5	2.9	71
Cassini's divn.	10.0	10.0	9.3	10.0	10.0	9.0	9.7	75
Ring B1	1.0	1.0	1.1	1.0	1.2	1.0	1.0	74
Ring B2	2.3	3.0	2.5	1.5	2.3	1.2	2.1	72
Ring B3	–	–	3.9	–	3.4	–	3.6	25
Ring C	8.5	8.5	7.1	8.4	7.8	8.0	8.0	82
Ring C_m	6.4	7.8	4.6	8.5	5.3	9.0	6.9	71
ShRG	10.0	–	8.0	–	–	–	9.0	20
ShGR	10.0	10.0	–	10.0	10.0	9.0	9.8	53
Total used	640	74	379	76	291	15		1,475

Key to observers: RB, Bowen; MF, Foulkes; DGy, Gray; AH, Heath; RM, McKim; CM, Meredith.

South Temperate Zone

This was also a featureless light zone.

South Temperate Belt

The STB was thin, quite dark, and featureless apart from a dark condensation caught by Peach on the night of Dec 10/11. On the very same night (around 01:00UT) Parish remarkably confirmed the presence of this elusive detail by finding the STB 'mottled' using a 15cm OG under excellent conditions of seeing.

South Tropical Zone

The STropZ was lighter than the STeZ, and contained a thin, faint S. Tropical Band (STropB), as in recent years.

We have not reviewed all the *Cassini* images, but for example that of 2004 Jul 13 shows a small bright STropZ white spot (Figure 2). Despite intensive coverage, little STropZ white spot activity was seen in the ground-based data: observations by Akutsu [Sep 15, bright, λ_3= 299° (and confirmed by Koishikawa[5]) and Pellier (Sep 17, bright, λ_3= 298°)] demonstrate the existence of a transient feature, nearly stationary in System III: see Figure 3. It had not been visible close to the CM to Pellier on Sep 1 nor to Mobberley on Sep 5 or 9. *Cassini* imaged it on Sep 18, but it was no longer visible to Akutsu on Sep 19 (in poor conditions) nor to

Fattinnanzi on Sep 21. Thus it was visible during Sep 15–18, and a tentative period was derived:

Spot	*Limiting dates*	*No. obs.*	*Limiting longitudes*	*$\Delta\lambda_3$ (°/day)*
WS1c	2004 Sep 15–17	2	299–298	−0.902
STropZ period:	10h 38m 44s			

White spot activity in the STropZ would continue during 2005–'06.

South Equatorial Belt

The SEB was again the most prominent belt. The SEB(S) was nearly featureless, sometimes very much fainter than the SEB(N), and it was seen to be double with two narrow components. (In the following apparition the SEB(S) would darken considerably.) The SEB(N) was also closely double with the N. component much the wider and darker of the two: duplicity was noted only in the finest images, for example in Figure 9.

White spot activity in the SEBZ continued, at latitude −24°. Akutsu (Figure 4), Casquinha, Fattinnanzi, Grafton, Ikemura, Lazzarotti, Parker, Peach (Figure 9), Pellier (Figure 3), Phillips, Sanchez (Figure 4), Tyler and Yunoki all provided images for longitude measurement, and Biver sketched both spots on Mar 19 (Figure 8). There were only two long-lived features, and they were less conspicuous than last apparition. However, one lasted for over seven months from 2004 Sep 17 to 2005 Apr 27, a much longer period than any such feature in 2003–'04. The two spots – denoted WS1 and WS2 – very slowly converged, as the drift-chart (not reproduced here) shows. Figure 9 shows them close together in 2005 April. During the final observation their centres were only 13° apart. In addition to these two long-lived white ovals, a dusky column (DS1) across the zone was recorded on images from Nov 26–Feb 6 (being seen visually by McKim on Feb 7), and it exhibited a very similar drift-rate. It is shown in Figure 4. The zonal current was nearly a minute slower than in 2003–'04,[13] being closer to the value of −7°.1/day found by Foulkes for a single oval during 2006–'07[17] (and also for 2007–'08).

Spot	*Limiting dates*	*No. obs.*	*Limiting longitudes*	*$\Delta\lambda_3$ (°/day)*
WS1c	2004-09-17–2005-04-27	25	314–193	−7.00
WS2c	2004-11-06–2005-04-27	18	277–180	−6.83
DS1c	2004-11-26–2005-02-06	7	246–104	−6.90
Average:				−6.91
SEBZ average period: 10h 33m 58s				

Other short-lived white ovals were seen in March to April: some shared the same drift but data were less abundant, and some were seen only once or twice. One drifted at Äλ_3≈ 7°.5/day from Mar 19–20, in accord with the above zonal average.

The wide, dark SEB(N) again showed some small, darker spots to Biver (Mar 19), Bowen (on seven occasions between Jan 10 and Feb 19), McKim (always a mottled effect at the limit of vision, on Nov 29, Jan 13, Feb 7 and Mar 17) and Parish (Dec 11, a darker spotty or streaky section). Colombo on Mar 20 and Apr 27 reported a wavy SEB N. edge. In all, there were fewer instances than last apparition, and no CM transits. Peach's images for Jan 13 and Mar 19 also confirm these features, as does one by Phillips on Jan 25. All features were short-lived, but agreement in dates between observers tends to confirm activity during Jan 10–Feb 19 and Mar 17–20. No rotation periods could be deduced, but the chart suggests periods close to System I.

Table 3. Saturnicentric latitudes, 2004–'05

Feature	*2004–'05 average*	*Standard devn (±)*	*No. of measures*	*2003–'04 average*	*2006–'07 average*
SSPCn	−86.6	0.4	2	−88.4	–
SSPBs	−71.2	0.2	2	−77.1	–
SSPBn	−67.8	1.0	4	−73.0	−67.8
SPCn	−67.8	1.0	4	−73.0	−67.8
SPRn	−61.8	1.1	4	−62.6	−61.0
SPBs	−61.8	1.1	4	−62.6	−60.1
SPBc	−60.2	–	–	−61.1	−58.2
SPBn	−58.5	0.3	4	−59.6	−56.2
SSSTBs	−54.3	0.3	4	−55.2	–
SSSTBn	−52.4	0.5	4	−53.1	–
SSTBs	−48.4	0.4	2	−49.6	–
SSTBc	−47.3	–	–	−48.2	−48.6
SSTBn	−46.2	0.2	2	−46.7	–
STBs	−42.2	0.2	4	−42.6	−42.5
STBc	−40.6	–	–	−41.0	−40.4
STBn	−39.0	0.4	4	−39.4	−38.4
STropBs	−35.5	0.2	2	−36.6	−35.5
STropBn	−34.3	0.0	2	−35.0	−33.3
SEB(S)s	−31.0	0.5	4	−31.8	−29.5
SEB(S)n	−25.5	1.0	4	−25.0	−24.6
SEB(N)s	−22.4	0.5	4	−21.8	−20.6
SEB(N)n	−15.9	0.4	4	−15.7	−15.3
EZ(S)Bs	−12.6	0.8	4	−12.2	–
EZ(S)Bc	−11.8	–	–	−11.2	−12.4
EZ(S)Bn	−11.0	1.1	4	−10.3	–
EBs	−6.6	1.0	4	−7.2	−7.5
EBc	−4.3	–	0	−4.2	−3.2
EBn	−2.0	1.3	3	−1.3	+1.0
EZ(N)Bs	+0.1	0.0	2	+2.7	–
EZ(N)Bn	+1.3	0.1	2	+4.6	–
Total			79		

Key to observers: Selected best images from Lazzarotti, Peach and Tyler were reduced by McKim.
Note: We give comparisons with 2003–'04[13] and 2006–'07:[17] the latter report quoted Saturnigraphic latitudes (L), which have been converted to Saturnicentric (C) in the above table using the formula:
$\tan C = \tan L / (1.12)^2$.[24]

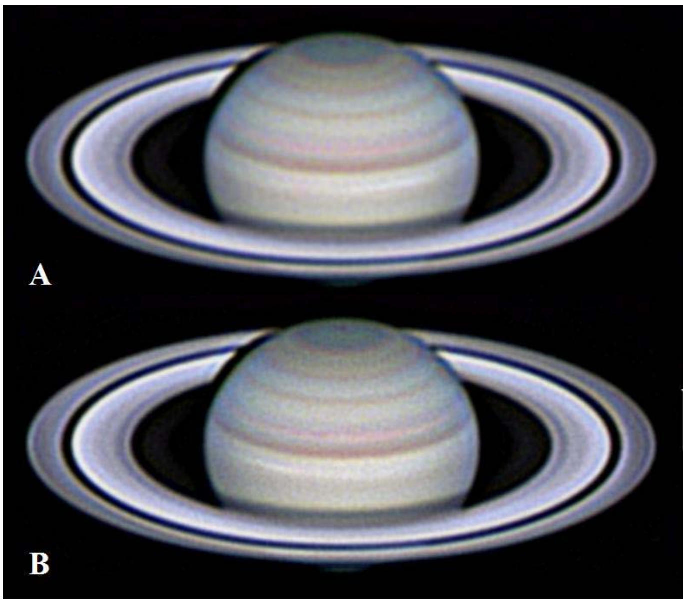

Figure 5. A bright white streak in the EZ(S) passes from the *p.* to the *f.* side of the CM in two 2004 Dec 11 images, 235mm SCT with ATK-1HS camera at f/39, *D. A. Peach*: (A) 00:37UT, ω_1= 183°, ω_3= 340°; (B) 02:19UT, ω_1= 242°, ω_3= 037°. Note also ring and belt detail in these high-contrast processed images, together with a strip of N. hemisphere north of the rings as well as ShRG N. of the rings.

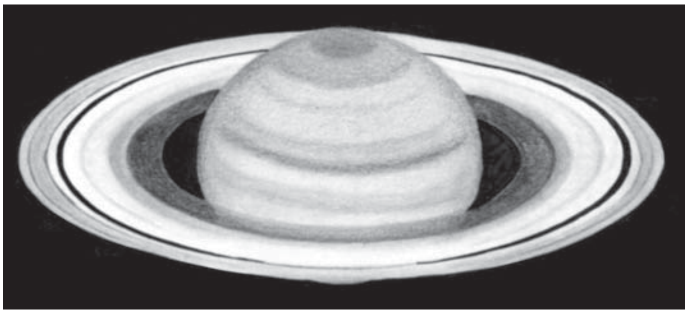

Figure 6. 2005 Jan 13, 21:20 UT (exact opposition, 23:07 UT), ω_1= 337°, ω_3= 079°, 410mm DK Cass., ×410, *R. J. McKim*. Compare this drawing with the images by Mobberley and Tyler (Figures 10, 11) for opposition night. Note the fine divisions in ring A, the steps of brightness in ring B and the small amount of N. hemisphere on view. The planet's belts exhibit no spot activity at all.

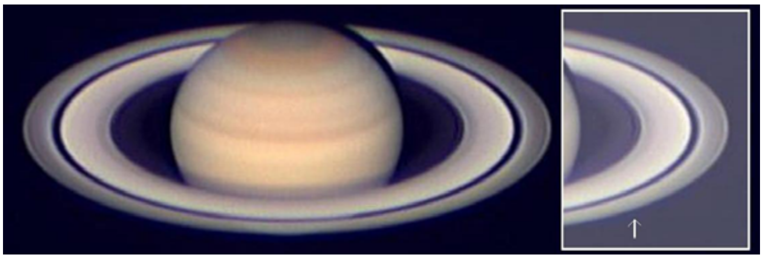

Figure 7. 2005 Feb 9, 21:45UT, ω_1= 109°, ω_3= 026°, 355mm SCT with ToUcam Pro camera, *T. Lepine*. The brightened inset shows the division (arrowed) near the outer edge of ring C. Enlargement of the original reveals a very tiny sliver of N. hemisphere north of the rings crossing the globe.

Equatorial Zone

The EZ showed very little activity, with a few white spots. The EZ(S)B was faint and thin, located in the southern part of the zone. The central Equatorial Band (EB) was broad and easy to see, though its edges were sometimes diffuse: the presence of a narrow and fairly dark EZ(N)B to the north sometimes made the EB look double.

An elongated bright white streak in the EZ(S) stretching from λ_1~ 183 to 222° (located between the EZ(S)B and EB) was seen by Peach (Figure 5) and Tyler (Figure 11) on Dec 11: the feature was ill-defined on the following side, and the EZ(S)B was considerably darker at its S. edge. Lazzarotti imaged it again *p.* the CM with its *f.* end at λ_1~ 253° on Dec 14, now fading, and Fattinnanzi on Dec 15 caught its *f.* end, still more faintly, at λ_1~ 269°. Peach captured a much smaller and diffuse light EZ(S) feature with *f.* end around λ_1~ 328° on Dec 20/21: all represent the same object with a drift rate of +10.7°/day. Therefore the slow Equatorial Current of recent past years was still in operation.

Peach found another small EZ(S) light area on Jan 6, McKim recorded a diffuse brightening in the EZ(S) on Mar 17 and Tyler's Apr 2, 3 and 10 images suggest some very small light areas close to the SEB(N) N. edge.

Spot	*Limiting dates*	*No. obs.*	*Limiting longitudes*	*$\Delta\lambda_3$ (°/day)*
WS1f	2004 Dec 11–20	4	222–328	+10.67
EZ(S) period:	10h 21m 52s			

Transient tiny dark patches upon the EB S. edge (or N. part of the EZ(S)) were recorded in Lazzarotti's images on Jan 12, and in Peach's for Apr 24 (Figure 9).

Only a thin strip of the EZ(N) was visible north of the EB, of similar brightness to the EZ(S).

Northern hemisphere

The variation of D_e during the apparition made for two periods of visibility of a fraction of the N. hemisphere: both early and late in the apparition the N. Temperate Zone (NTeZ) and regions immediately north of it partly projecting north of rings AB_m. According to *WinJUPOS* simulations, this could not have been seen before 2004 Aug 1, and (given adequate resolution) would have remained visible till 2005 mid-February, becoming invisible again till late April. (The situation is complicated by the presence of the shadow of the rings on the N. globe before 2005 mid-January.)

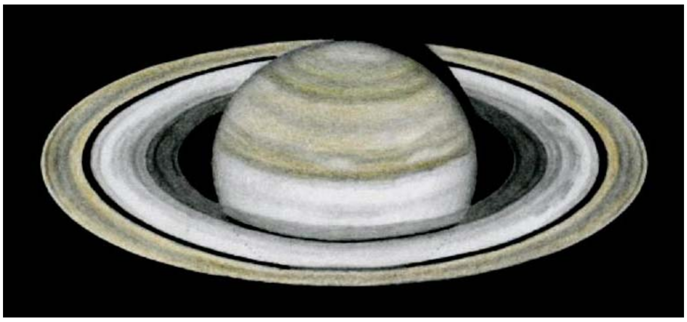

Figure 8. 2005 Mar 19, 20:45UT, ω_1= 116°, ω_3= 202°, 407mm refl., ×700, *N. D. Biver*. Two SEBZ white ovals are visible in this drawing, together with many ring details including an intensity minimum between the Encke Gap and the dusky inner edge of the Encke Complex, and the division near the outer edge of ring C.

The projecting N. hemisphere can be seen in some of the highest resolution images by Peach and others, for example in Figure 5, where it appears bluish-grey or cold grey. The earliest reliable sighting is a 2004 Sep 16 image by Pellier. The greatest vertical extent of it occurred in November. Lepine's image of Feb 9 (Figure 7) was the last to show it with certainty. None of the post-April images reveal it, though Peach's images of late April (Figure 9) show it clearly brightening ring A crossing the globe, and about to reappear.

Visually, Biver, Bowen and McKim all saw the 'NTeZ' well. McKim observed from 2004 Nov 29 onwards, and saw it on every occasion up to and including 2005 Feb 7 and 8 (at high power only on the last two dates, when only 0.1" of the N. hemisphere was theoretically visible). See Figure 6. On Mar 17 (after a long break due to bad weather) it was no longer to be seen; however, ring A was not yet visible to the south of the S. limb, the theoretical projection being only 0.05". The N. hemisphere continued to be invisible during Mar 18–Apr 21, but in a later observation on May 11 McKim glimpsed it once more: again, only a 0.1" (N–S) sliver was observable.

The rings

Fine views of the closing ring system were still to be enjoyed; indeed, the image quality now attainable as a result of the 'webcam revolution' ensured that better images than ever before were secured in 2004–'05, despite the slightly smaller value of D_e. Several observers watched the planet at the precise moment of opposition, when there was a striking increase in the brightness of the rings,[1] ring B1 being remarkably bright to Bowen, McKim (Figure 6), Mobberley (Figure 10) and several others. The EZ and the southern hemisphere looked pale by comparison at this time as the pair of images by Tyler (Figure 11) illustrates.

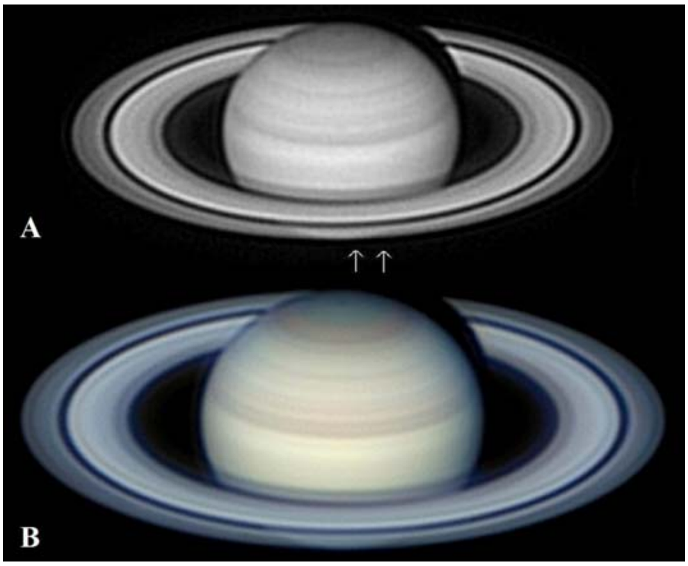

Figure 9. (A) 2005 Apr 24, 22:38UT, ω_1= 334°, ω_3= 290°; (B) 2005 Apr 28, 22:30UT, ω_1= 070°, ω_3= 255°, both with 235mm SCT with Lumenera LU075M CCD camera at f/42, *D. A. Peach* (Barbados). In (A), note the two small SEBZ white ovals (arrowed), then approaching the CM, had become very close together; there is a darker area in the north part of the EZ(S) approaching the CM, confirmed by an animation sequence. In both images, many fine details remain visible far from opposition, and the STB and STropB form a pair mirroring the double SEB(S) and SEB(N) so that there is the impression of three broad double belts south of the EZ.

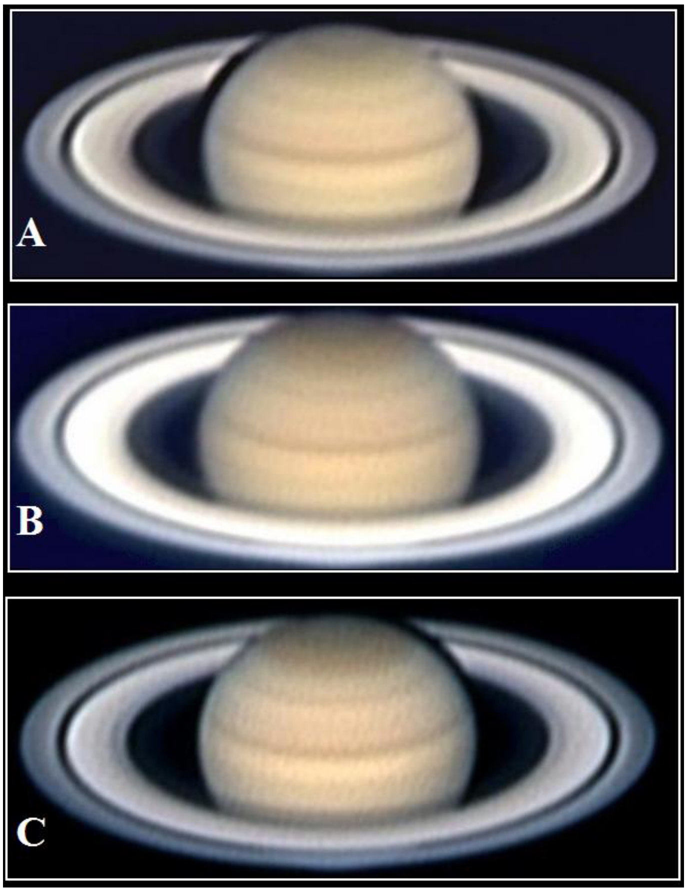

Figure 10. Illustrating the 'opposition effect', where the rings brighten sharply at opposition. The effect is especially clearly shown for ring B in these RGB images which have been approximately normalised for the brightness of global details. 254mm refl. with ToUcam Pro camera at f/37–38, *M. P. Mobberley*. (A) 2004 Oct 1, 04:47UT; (B) 2005 Jan 13, 22:48UT (exact opposition, 23:07UT); (C) 2005 Feb 6, 22:00 UT.

A third intensity minimum in ring A between the Encke Gap and the inner edge of the Encke Complex was widely imaged in the best work (Figures 5, 7, 9, 11), and was also seen visually by Biver (Figure 8) and Yunoki. Biver also recorded a lot of detail in ring B (Figure 8), including a division within the darkest inner part, B3. Gray systematically compared the ansae of ring C. On 15 dates (Aug 15–Mar 24, most being pre-opposition) the *p.* ansa was slightly (*ca.* half an intensity point) brighter than the *f.* one; on only one occasion were they judged as equal. Lepine drew attention to the obvious visibility of the division near the outer edge of ring C upon his 2005 Feb images (Figure 7): this division was also imaged by others, and was seen visually by Biver (Figure 8).

The shadow of the globe on the rings (ShGR) was seen to within three days either side of opposition (Jan 13). Observers witnessed the illusion of there being a shadow on both sides, due to the influence of the Cassini Division and contrast with the bright ring B. For example, Bowen on Jan 10 saw the ShGR clearly on the *p.* side but there appeared to be a fragment of shadow *f.* the globe at the Cassini Division, while on Jan 21 these effects were reversed. This common illusion can also be seen upon many images, though it is reduced in excellent seeing conditions. The shadow of the rings on the globe (ShRG) was recorded at the N. limit of C_m on several occasions. Bowen specifically looked for it, and saw it on nearly every occasion between mid-January and May 11 (his last good observation). *WinJUPOS* showed that it could have been seen from Jan 17 to Jul 21. Before mid-January, some of the observations had revealed the ShRG upon the globe N. of the rings: see Figure 5B especially.

With Saturn at high altitude on Dec 2 Heath found the *p.* side of ring C a grey-blue tone, while on Feb 8 Peach noted that the rings generally were brighter on the *f.* side, especially in red light. Otherwise, there were no positive observations of the so-called bicoloured effect. Spokes were not recorded on images, but Biver's best drawing of Mar 19 (Figure 8) portrays spoke-like dusky patches on the *f.* ansa.

The illusory Terby White Spot was reported by Heath following opposition (Feb 1, May 11) on the *f.* side of the rings.

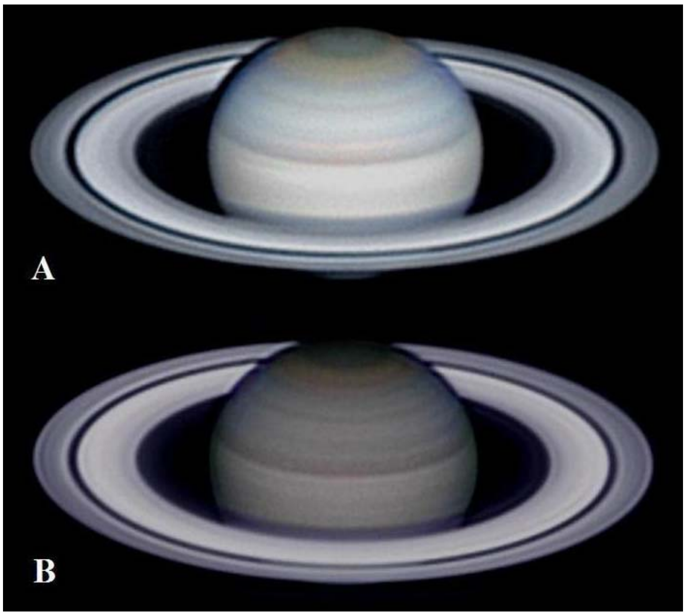

Figure 11. Also illustrating the 'opposition effect'. These LRGB images have been roughly normalised for the brightness of the rings. 279mm SCT with ATK-1HS camera at f/37, *D. B. V. Tyler*. (A) 2004 Dec 11, 02:18UT; (B) 2005 Jan 13, 22:52UT (exact opposition, 23:07UT). Note also the EZ(S) white streak *p.* the CM in (A) which is also shown in Figure 5.

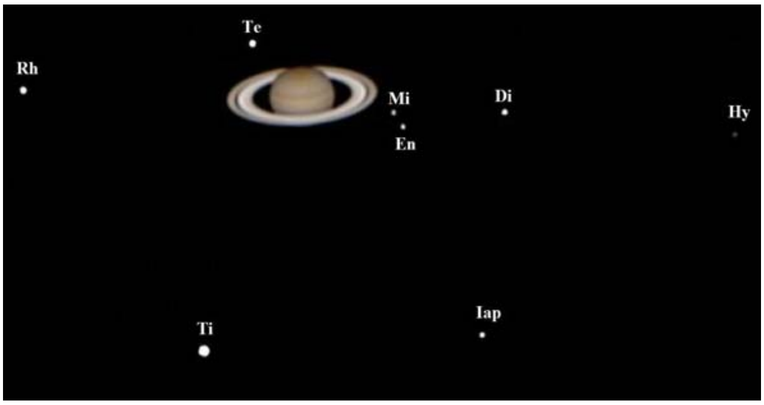

Figure 12. Starfield surrounding Saturn with eight satellites identified, 2005 Jan 15, 21:23UT, 279mm SCT with ToUcam Pro camera, *J. Sussenbach*.

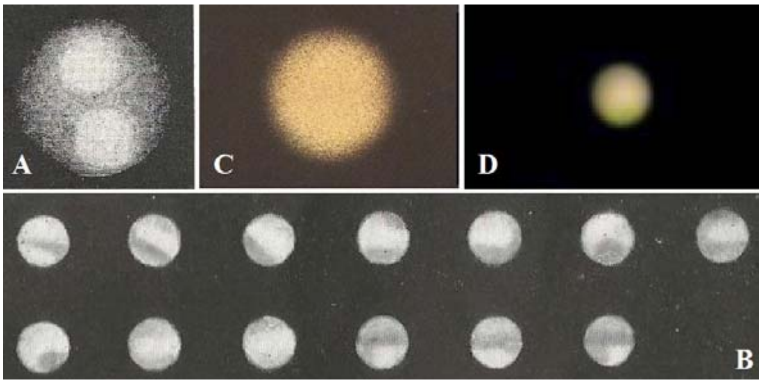

Figure 13. Ground-based views of Titan, 1907–2004. (A) Titan drawn by J. Comas Solá from Barcelona with a 38cm (15-inch) OG on 1907 Aug 13, 24:00UT. Note the albedo markings and strong limb darkening. *From ref. 19.* (B) Titan drawn by the Pic du Midi observers (including B. Lyot & A. Dollfus) with the 60cm OG in the 1940s. Drawings arranged in order of increasing planetocentric longitude (measured from superior conjunction). The markings are atmospheric. *From ref. 22.* (C) Titan drawn by P. B. Doherty with a 419mm refl., ×372, 1977 Apr 14, 22:00UT. Again note the strong limb darkening as well as the obvious warm tint. (D) Titan imaged by R. Chavez, 235mm SCT with ToUcam camera at f/25 on 2004 Nov 26, 08:18UT. There is a difference in albedo and colour intensity between north and south in this considerably enlarged image.

The satellites

Foulkes, Sanchez, Sussenbach (Figure 12) and Tyler succeeded in capturing Mimas and/or Enceladus by imaging.

An exceptional image by Chavez on Nov 26 (Figure 13) sharply resolved the orange disk of Titan, showing an apparent difference in albedo and colour intensity between north and south. Biver resolved the disk on Mar 19. McKim saw Titan's disk clearly on Apr 10, when it appeared obviously yellowish. An earlier drawing by Paul Doherty is also shown in Figure 13.

Although limb darkening and albedo variation across this satellite were first noted by José Comas Solá (Figure 13) from Barcelona in 1907,[19,20] and variable atmospheric markings by the French observers (also Figure 13) during the 1940s,[21,23] this is the first indication the writer has seen of possibly objective detail captured with amateur equipment.

The *Cassini* spacecraft approached Titan at just 1,174km on 2004 Oct 26, with a full programme of infrared imaging, and again on Dec 23. The *Huygens* probe separated from the spacecraft on Dec 25, with a gentle parachute landing on the moon's surface on 2005 Jan 14. To conclude we present a *Cassini* image showing the thick layers of photochemical haze, and one of Titan's icy surface by the *Huygens* lander (Figure 14).

Acknowledgments

This series of papers (covering 1994–'95 to 2004–'05 inclusive) has been a pleasant change for the writer from reporting upon the rocky worlds of the inner Solar System. I thank the Director Mike Foulkes for his wise advice throughout the process. The delay in publication enabled the full use of colour printing (impossible in the *Journal* in 1994), as well as the inclusion of some important late contributions.

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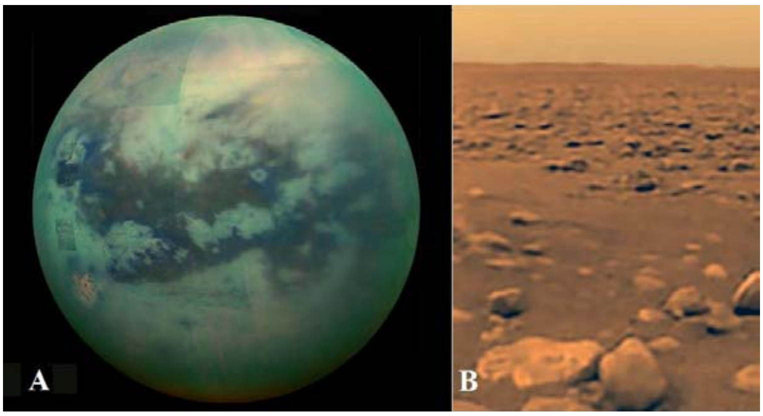

Figure 14. Titan imaged by spacecraft, 2005–2015. (A) False colour infrared view of Titan by *Cassini* on its T-114 bypass on 2015 Nov 13, a decade after the *Huygens* landing. North is uppermost. (B) *Huygens* image of the surface of Titan on 2005 Jan 14.

Table 4. BAA Saturnian rotation period data, 1891–2008

Apparition	*Analyst(s)*	*Region*	*Period(s)*
1891	A. S. Williams & W. F. Denning	EZ(S)	10h 14.4m
1892	A. S. Williams	EZ(N)	10h 13.6m
1893	A. S. Williams	EZ(N)	10h 13.0m
		NEB(S)	10h 14.8m
		NEB(N)*	(10h 14.8m)
1894	A. S. Williams	EZ(N)	10h 12.6m
		NEB(S)	10h 15.2m
1896	E. M. Antoniadi	NEB(S)	10h 14.2m
1897	E. M. Antoniadi	NEB(S)	10h 14.1m
1903	W.F.Denning	NTropZ [GWS; Saturnicentric latitude +36]	10h 37.9m
1910–'11	T. E. R. Phillips	STeZ [–41]	10h 36.8m
1932	M. S. Butterton	NEB(S) [+16]	10h 20m
1933	B. M. Peek	EZ(N) [GWS; +0]	10h 15.0m, decreasing to 10h 13.0m; average about 10h 14.4m
1942–'43	W. H. Haas	SEB(N) [–11]	10h 17.7m
1946–'47	A. F. O'D. Alexander	SEB(S)** [–26]	(10h 14.0m)
		SEB(N) [–8]	10h 15.9m
1947–'48	W. H. Haas	SEB(S)** [–28]	(10h 14m, decreasing to 10h 09m)
1949–'50	W. H. Haas & E. J. Reese	NTB *** [+45]	(10h 14m, decreasing to 09h 55m)
1952–'53	M. B. B. Heath & C. D. Reid	NEBZ [+17]	10h 20.7m
1960	M. B. B. Heath	NTeZ/NNTeZ [GWS; +51]	10h 39.9m
1968–'69	K. J. H. Phillips	EZ(S) [–8]	10h 14.1m
1971–'72	R. J. McKim	STropZ [–31]	*ca.* 10h 39.4m
	G. E. Satterthwaite	EZ(S) [–8]	*ca.* 10h 15m
1975–'76	A. W. Heath	STeZ [–43]	*ca.* 10h 36m
1977–'78	A. W. Heath	EZ(S) [–7]	10h 18m
1978–'79	A. W. Heath	EZ(S) [–6]	10h 14.8m
1979–'80	P. B. Doherty & R. J. McKim	NEB(S) [+9]	10h 13.9m
1980–'81	P. B. Doherty & R. J. McKim	NEB(S) [+11]	10h 14.0m
1981–'82	R. J. McKim	NEB(S) [+12]	10h 13.8m
1982–'83	R. J. McKim	NEB(S) [+13]	(10h 13.6m)
1984	R. J. McKim	NEB(S) [+14]	(10h 13.6m)
1990	R. J. McKim	EZ(S) [2]	10h 16.0m
		EZ(N) [+7]	10h 10.8m
		EZ(N) [GWS; +5 to +12]	10h 16.9m decreasing to 10h 13.4m; average 10h 13.8m
		NEBZ [+16]	10h 24.8m
1991	R. J. McKim	EZ(S) [4]	10h 15.0m
		EZ(N) [+9]	10h 14.0m
		NEB(S) [+13]	*ca.* 10h 14m
1992	R. J. McKim	EZ(N) [+10]	10h 14.0m
		NEB(S) [+13]	10h 14.0m
		NTropZ [+27]	10h 37.7m
1993	D.L.Graham	EZ(N) [+10]	10h 14.0m
		NTropZ [+29]	10h 38.5m
		NTeZ [+40]	10h 39.4m
1994–'95	R. J. McKim	EZ(N) [+10]	10h 21.8m
		NEBZ [+20]	10h 36.3m
		NEB(N) [+23]	10h 37.9m
		NTropB [+29]/ NTropZ [+31]	10h 38.5m
1995–'96	R. J. McKim	SEB(N) [–11]	10h 13.6m
		EZ(S) [-6]	10h 13.8m
		EZ(N) [+10]	10h 20.1m to 21.9m
		NEB(S) [+14]	10h 13.6m
		NEB(N) [+26]	10h 37.7m
		NTropZ [+31]	(10h 38.1m)
1996–'97	R. J. McKim	STropZ [–34]	10h 37.6m
		EZ(S) [-10]	10h 21.7m
		NEB(S) [+14]	10h 14.3m
1997–'98	R. J. McKim	STropZ [–33]	10h 37.5m
		SEB(S) [–27]	10h 37.7m
		EZ(S) [–11]	10h 21.5m
		EZ(N) [+10]	10h 12.8m
1998–'99	R. J. McKim	SSTB [–49]	10h 38.5m
		STropZ [–34]	10h 37.1m
		SEB(S) [–29]	10h 37.8m
		EZ(S) [–11]	10h 22.6m
		EB [–4]	10h 22.0m
		EZ(N) [+10]	10h 21.1m
1999–2000	R. J. McKim	STeZ [–44]	10h 38.7m
		EZ(S) [–11]	10h 22.2m
2000–'01	R. J. McKim	STropZ [–35]	10h 38.6m
2002–'03	R. J. McKim	STB [–41]	10h 39.5m
		STropZ [–35]	10h 39.8m
		SEBZ [–23]	10h 33.2m
		EZ(S) [–12]	10h 18.9m
2003–'04	R. J. McKim	STropZ [–37]	10h 39.6m
		SEBZ [–24]	10h 33.1m
		SEB(N) [–16]	10h 14.9m
		EZ(S) [–12]	10h 16.2m
2004-05	R. J. McKim	STropZ [–37]	10h 39.4m
		SEBZ [–24]	10h 34.0m
		EZ(S) [–9]	10h 21.8m
2006-07	M.Foulkes	SEBZ [–23]	10h 33.8m
2007-08	M.Foulkes	STropZ [–34]	10h 39.6m
		SEBZ [–23]	10h 33.8m

General notes: GWS = Great White Spot.
Curved brackets ( ) denote periods which seem to the writer to be not so well established. These, together with the pre-1903 results, have not been graphed in Figure 15.

Saturnicentric latitudes (denoted by square brackets [ ]) have been given for the centres of zones, or the edges of the appropriate belts. The latitude for the centre of a zone was calculated from neighbouring belt edges: thus for the STeZ, the SSTBn and STBs would be used, and for the EZ(S) the SEB(N)n and the EBs, etc.

Specific notes: * A. Stanley Williams sometimes found that the NEB(S) dark spots were often accompanied by NEB(N) dark spots at the same longitude, and inferred that the NEB(S) period had extended over the whole NEB. Much later, Williams agreed with a very reasonable suggestion by B. M. Peek[27] that these had only been chance conjunctions, so there is no evidence that the NEB(S) period extended across the whole belt.
** The period quoted is surely in error.
*** It must have been a case of mistaken identity for these NTB features, as such fast periods have never subsequently been encountered upon the planet, though the NTBs jetstream on Jupiter is well known.

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Appendix I

Saturn's rotation periods at different latitudes: BAA work from 1891 to 2008

Rotation periods derived from the work of BAA observers since the formation of the Section in 1891 were published both by successive Directors and by individual observers. In Table 4 we give a summary of drift rates from 1891 till 2007–'08, from an exhaustive search of BAA publications. In many apparitions, and certainly for all those from 1975–'76, an average latitude was derived for each belt or zone by measuring the best drawings and images. It will be seen that the majority of data have been gathered in the wake of the digital era. The very early data lack accurate latitude measurements, and so only data from 1903 onwards have been used in the wind speed analysis that follows.

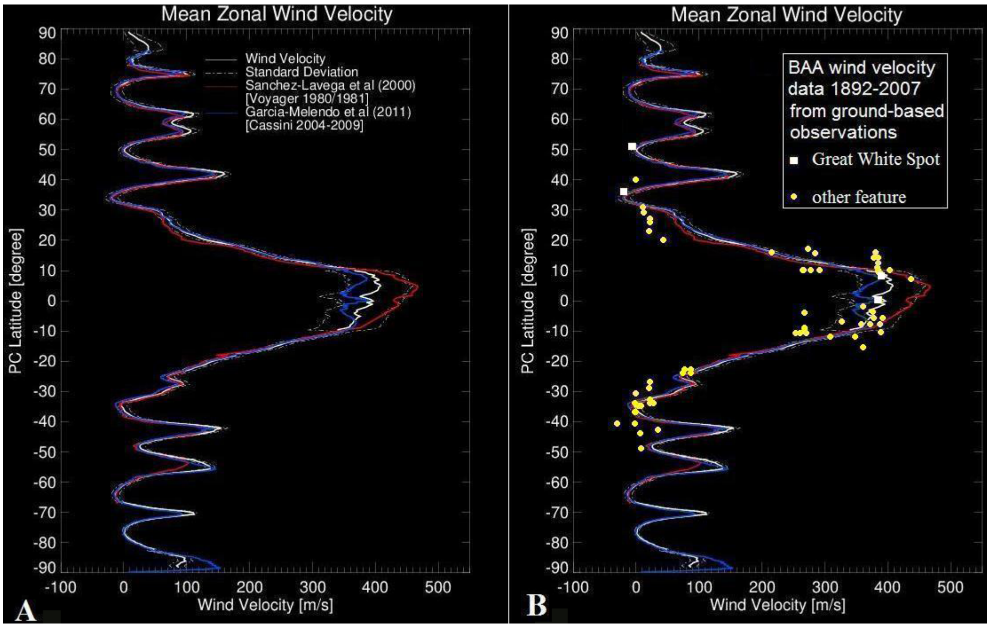

Figure 15. Saturn zonal wind profiles showing velocities in ms^{-1} (m/s) relative to System III: (A) *Cassini* data compiled by Sayanagi & Blalock[28] as published online; (B) BAA ground-based data for 1891–2008 represented as filled yellow circles overlain upon the *Cassini* data.

Saturnicentric latitudes before 1946 are those quoted by observers. For the NEB(S) in 1932 I have used a figure published by Peek for 1934. For the SEB(N)n in 1942–'43, the 1943–'46 average Saturnigraphic latitude by W. H. Haas[25] has been used, after conversion to Saturnicentric. For the 1960 GWS (Great White Spot), the average period quoted by A. Dollfus,[26] who used BAA data in his analysis, was used. Otherwise for the period 1947–'76, if no latitude was available for a feature in a particular apparition, the deduced period has been plotted against the average of the 1947–'76 latitudes as calculated by McKim & Blaxall[15] from the measurements by Hollis:[16] thus the white spots in the STeZ seen by Phillips in 1910 would be at about –41°, the 1952–'53 NEBZ activity at about +17°, the EZ(S) activity of 1968–'72 at about –8° and the 1971–'72 STropZ white spots at about –31° latitude.

Before 1891, the only reliable periods obtained were by Asaph Hall for the EZ(N) GWS of 1876 (10h 14.4m) and by William Herschel for the SEB in 1794 (*ca.*10h 16.0m, clearly applicable to the belt's N. component). Ground-based rotation period data published by the professional community have sometimes been stated in Section reports, but the present analysis is limited entirely to BAA work.

Wind speeds with respect to the System III 'core period' can be calculated for the appropriate Saturnicentric latitude only with knowledge of the circumference of Saturn at that latitude. The circumference C of the planet is given by:

$$C = 2\pi r$$

where r is the perpendicular distance from the axis of rotation to the cloud tops at a particular Saturnicentric latitude θ. At the equator, r is equal to the equatorial radius; at the pole, it is zero. For intermediate latitudes we can easily show that:

$$r = ab/\sqrt{b^2 + (a^2 \tan^2\theta)}$$

where a and b are, respectively, the semi-major and semi-minor axes of the planet. In the 2010 BAA *Handbook* equatorial and polar diameters measured at the 1 bar pressure level are 120,536 and 108,728km, so that a and b are 60,268 and 54,364km, respectively.

A more useful working formula is:

$$r = b/\sqrt{b^2/a^2 + \tan^2\theta}$$

Inserting the actual values of a and b we obtain:

$$r = 54{,}364\text{ km}/\sqrt{0.81367 + \tan^2\theta}$$

(Note: The degree of oblateness, ellipticity, or polar flattening f is given by the expression $f = (a–b)/a$ which is 0.09796 for Saturn, or about 1/10.)

We now proceed to convert the rotation period data to wind speeds with respect to the System III 'core' period of 10h 39.4m, being the benchmark period in the professional literature. For example, for the 1903 GWS, θ= +36°, so r= 46,936km and C= 294,910km. Hence the rotation period for an atmospheric feature at cloud top level at that latitude is 27,674km/h or 7,687m/s at the System III rate. The 1903 GWS accomplished one rotation of the planet in 10h 37.9m, but System III rotates only by 359°.2 in that time, so the spot was travelling 0.8° per day faster than System III, or, in proportion, a modest 17m/s faster. At the equator, C= 378,675km, and the rotation speed is 35,534km/h or 9870 m/s. Here, for a feature moving in System I at 10h 14m, the respective figures would be 345°.7, 14°.9 and 408 m/s, illustrating the difference in wind speed from the equator to the temperate regions and the existence of a marked equatorial jet.

We converted all the rotation periods to wind speeds. The results are graphed in Figure 15 as a function of latitude, and compared with spacecraft data acquired during the *Cassini* mission. (For variable periods we have graphed the averages.) The accord is excellent, and Figure 15 further demonstrates the high range of variability of wind speed within the equatorial jet. We have observed periods from 10h 10.8m to 10h 22.6m in our groundbased work for the EZ in the decade up to 2007, while the earlier work (the very rapid 10h 10.8m having been associated with the expansion of a stream of white cloud from the *p.* end of the 1990 GWS, even faster than the 10h 12.6m found by Williams in 1894) amply confirms the existence of a wide range of rotation periods within the EZ.

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