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WIDEBAND PHOTOMETRY OF SATURN IN 2007-2008

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ABSTRACT

The writer made 45 brightness measurements of Saturn + rings between Nov. 28, 2007 and April 24, 2008. The selected B(1,0), V(1,0), R(1,0) and I(1,0) values for Saturn + rings for b = 7° are: -8.10 ± 0.01, -9.14 ± 0.01, -9.77 ± 0.01 and -9.87 ± 0.02 respectively. The selected solar phase angle coefficients (in magnitudes/degree) are: 0.041 ± 0.006, 0.034 ± 0.005, 0.022 ± 0.007 and 0.027 ± 0.007 respectively. It is concluded that the angle between the ring plane and the Sun (B') has as much affect on the results as the angle between the ring plane and the Earth (B). As a result of this, a new parameter, b, is defined as $b = (B' \times B)^{1/2}$. Saturn's opposition surge on Feb. 24 was 0.02 magnitudes in the V-filter.

INTRODUCTION

McKim and Blaxall summarized Saturn observations made between 1943 and 1981 (1). One important finding they report is that the hemisphere eclipsed by the rings has a different color than the one exposed to the Sun. They also show that the hemisphere exposed to the Sun had a more yellowish or brownish hue than the other one. This trend was evident in numerous images made during the 2007-2008 apparition. This trend will also have important implications for the overall color and brightness of Saturn.

This report is a continuation of a long term study of the brightness and color of Saturn and its rings. The purpose of this study is to yield additional information on:

1) The brightness and color of Saturn + rings as it passes through different seasons,
2) Saturn's solar phase angle coefficients in different colors and in different seasons,
3) The opposition surge in different colors, and
4) The influence of the Sun's position with respect to the ring plane.

These data can yield information about seasonal changes on Saturn including the color change that occurs when parts of Saturn are eclipsed by the rings.

METHOD AND MATERIALS

The writer used an SSP-3 solid-state photometer along with filters transformed to the Johnson B, V, R and I system. A 0.09 meter Maksutov telescope was also used. The photometer-telescope combination had a fieldof-view of 13.6 arc-minutes. More information about the equipment can be found elsewhere (2-4).

Mu-Leonis was the comparison star and Epsilon-Leonis was the check star for all magnitude measurements. The measured visual magnitude of Epsilon-Leonis in 2007-2008 was 2.98 ± 0.01, which agrees with that reported by Iriarte et al (5). The magnitudes used for the comparison star are from Iriarte et al (5).

In all cases, magnitude measurements were corrected for both extinction and transformation.

RESULTS

The relevant brightness measurements are listed in Table I. The first column lists the decimal date in Universal Time, the second column lists the filter, the third, fourth and fifth columns lists the angle between the ring plane and the Earth (B), the angle between the ring plane and the Sun (B') and b which equals $(B \times B')^{1/2}$. The sixth column lists the solar phase angle of Saturn. (The solar phase angle of Saturn is the angle between the Sun and observer measured from the center of Saturn.) Values of B and B' are from (6, 7) while the solar phase angle for all dates except Feb. 24 are from (6, 7). The solar phase angle on Feb. 24 was taken from (8). The seventh column lists the measured magnitude of Saturn corrected for both atmospheric extinction and color transformation. The eighth column lists the normalized magnitude which is how bright Saturn would be if it were 1.0 astronomical unit (au) from both the Earth and Sun and with B = 7° and at a solar phase angle of α. The normalized magnitude is computed from:

$$X(1,\alpha)' = X_{mag} - 5.0 \log [r \times d] - 2.5 \log k + \Delta m(7°) - \Delta m(B) \quad (1).$$

In this equation, X_{mag} is the measured magnitude for filter X, $X(1, \alpha)'$ is the normalized magnitude at a solar phase angle α and B = 7°, r and d are the Saturn-Earth and Saturn-Sun distances in astronomical units, k is the fraction of Saturn + rings that is illuminated by the Sun as seen from the Earth and k is computed from $k = (1 + \cos \alpha)/2$. The $\Delta m(7°)$ and $\Delta m(B)$ terms are the brightness changes caused by the rings at B = 7° and whatever B is at the time of measurement. The $\Delta m(7°)$ and $\Delta m(B)$ values are computed from equations 3 to 6 in Schmude (9). The ninth column in Table I lists the normalized magnitude computed from:

$$X(1,\alpha)'' = X_{mag} - 5.0 \log [r \times d] - 2.5 \log k + \Delta m(7°) - \Delta m(b) \quad (2).$$

In this equation, $b = (B \times B')^{1/2}$, and all other terms are the same as those in equation 1.

Table I: Brightness measurements made of Saturn + rings.

Date (2007-2008)	Filter	B	B'	b	α	Measured Magnitude	X(1, α)' from B	X(1,α)" from b
Nov. 28.419	V	6.7	9.6	8.0	6.1	0.64	-9.03	-8.98
Nov. 28.440	B	6.7	9.6	8.0	6.1	1.77	-7.91	-7.86
Dec. 5.452	R	6.7	9.4	7.9	6.1	-0.04	-9.72	-9.65
Dec. 5.466	I	6.7	9.4	7.9	6.1	-0.13	-9.80	-9.72
Dec. 12.416	V	6.6	9.3	7.8	5.9	0.63	-8.99	-8.95
Dec. 12.438	B	6.6	9.3	7.8	5.9	1.69	-7.94	-7.89
Dec. 12.458	R	6.6	9.3	7.8	5.9	-0.05	-9.67	-9.62
Dec. 12.482	I	6.6	9.3	7.8	5.9	-0.14	-9.77	-9.71
Jan. 2.422	V	6.8	9.0	7.8	5.1	0.53	-9.01	-8.97
Jan. 2.442	B	6.8	9.0	7.8	5.1	1.60	-7.94	-7.91
Jan. 4.410	R	6.8	9.0	7.8	5.0	-0.20	-9.74	-9.69
Jan. 4.426	I	6.8	9.0	7.8	5.0	-0.24	-9.79	-9.73
Jan. 13.337	V	7.0	8.9	7.9	4.3	0.48	-9.01	-8.98
Jan. 13.355	B	7.0	8.9	7.9	4.3	1.54	-7.96	-7.92
Jan. 13.374	R	7.0	8.9	7.9	4.3	-0.21	-9.71	-9.67
Jan. 13.394	I	7.0	8.9	7.9	4.3	-0.29	-9.79	-9.75
Jan. 21.268	V	7.2	8.7	7.9	3.7	0.40	-9.07	-9.04
Jan. 21.292	B	7.2	8.7	7.9	3.7	1.49	-7.98	-7.95
Jan. 27.249	R	7.4	8.6	8.0	3.1	-0.28	-9.75	-9.70
Jan. 27.267	I	7.4	8.6	8.0	3.1	-0.36	-9.80	-9.78
Jan. 27.288	V	7.4	8.6	8.0	3.1	0.37	-9.08	-9.05
Jan. 27.308	B	7.4	8.6	8.0	3.1	1.46	-7.98	-7.96
Feb. 2.226	V	7.6	8.6	8.1	2.5	0.33	-9.10	-9.08
Feb. 6.240	R	7.7	8.5	8.1	2.1	-0.31	-9.73	-9.72
Feb. 7.236	V	7.7	8.5	8.1	2.0	0.33	-9.09	-9.07
Feb. 7.258	B	7.7	8.5	8.1	2.0	1.34	-8.07	-8.06
Feb. 7.288	R	7.7	8.5	8.1	2.0	-0.34	-9.75	-9.74
Feb. 7.306	I	7.7	8.5	8.1	2.0	-0.42	-9.83	-9.81
Feb. 10.194	V	7.8	8.4	8.1	1.6	0.32	-9.09	-9.08
Feb. 10.216	B	7.8	8.4	8.1	1.6	1.38	-8.03	-8.02
Feb. 10.233	R	7.9	8.4	8.1	1.6	-0.35	-9.76	-9.75
Feb. 10.251	I	7.9	8.4	8.1	1.6	-0.46	-9.85	-9.84
Feb. 24.223	V	8.4	8.2	8.3	0.20	0.23	-9.15	-9.16
Feb. 24.251	B	8.4	8.2	8.3	0.20	1.28	-8.09	-8.10
Feb. 24.278	R	8.4	8.2	8.3	0.20	-0.44	-9.82	-9.82
Feb. 24.296	I	8.4	8.2	8.3	0.20	-0.58	-9.94	-9.95
Mar. 17.158	R	9.2	7.9	8.5	2.4	-0.33	-9.70	-9.72
Mar. 17.178	I	9.2	7.9	8.5	2.4	-0.42	-9.77	-9.80
Apr. 17.103	V	9.9	7.4	8.6	5.0	0.54	-8.89	-8.94
Apr. 20.082	V	9.9	7.4	8.6	5.3	0.54	-8.91	-8.95
Apr. 20.099	B	9.9	7.4	8.6	5.3	1.66	-7.78	-7.83
Apr. 20.126	R	9.9	7.4	8.6	5.3	-0.18	-9.61	-9.66
Apr. 20.153	I	9.9	7.4	8.6	5.3	-0.25	-9.66	-9.72
Apr. 24.074	V	9.9	7.3	8.5	5.5	0.57	-8.89	-8.94
Apr. 24.094	B	9.9	7.3	8.5	5.5	1.62	-7.83	-7.88

A linear equation for the X(1,α)' versus α values was computed for each of the four filters (B, V, R and I) and the results are shown in Figure 1. The Y-intercepts are the normalized magnitudes at α = 0° and the slopes are the solar phase angle coefficients. Both values for all four filters are summarized in Table II. Uncertainties for all values in Table II were computed in the same way that is described in Schmude (10).

Table II. Normalized magnitudes and solar phase angle coefficients of Saturn + rings measured during the 2007-2008 apparition based on B only.

Filter	X(1,0)	Solar Phase Angle Coefficient, c_x (magnitude/degree)	Opposition Surge* (magnitudes)
B	-8.12 ± 0.03	0.041 ± 0.014	-0.02
V	-9.17 ± 0.03	0.037 ± 0.013	-0.01
R	-9.77 ± 0.02	0.015 ± 0.010	0.05
I	-9.85 ± 0.03	0.016 ± 0.013	0.09

* Opposition surge at a solar phase angle of 0.20°.

DISCUSSION

The large uncertainties in Table 2 are due mostly to the late measurements made between March 17 and April 24. In all cases, these measurements were about 0.1 magnitudes dimmer than expected and are shown as filled circles in Figure 1. Early measurements made in November through February are shown as open circles. One possible explanation for the discrepancy between early and late measurements is the changing angle between the ring plane and the Sun (B') – this value was higher between Nov. 28 and Feb. 10, 2008 (~11° to 12°) than between Mar. 17 and April 24, 2008 (~9° to 10°). See Table I. This change will cause Saturn + rings to become dimmer. The sub-solar latitude is especially important near ring plane crossings. The writer feels that both the sub-earth and sub-solar latitudes should be considered when describing Saturn's brightness. The normalized magnitudes of Saturn + rings were recomputed using equation 2. The Δm(7°) values were computed from equations 3 to 6 in Schmude (9) except that b replaced B. The resulting graphs of X(1,α)" versus the solar phase angle are shown in Figure 2. Once again, open circles are measurements made before Feb. 25 and filled circles are those made after that date. The agreement is much better in Figure 2 than in Figure 1. The resulting normalized magnitudes and solar phase angle coefficients from Figure 2 and equation 2 are listed in Table III. The uncertainties in this table were computed in the same way as discussed elsewhere (10).

Figure 1: Plots of X(1,α)' versus α for the B, V, R and I filters. The X(1,α)' values were computed from equation 1. Open circles denote measurements before February 25, 2008. Solid circles denote measurements after February 25, 2008.

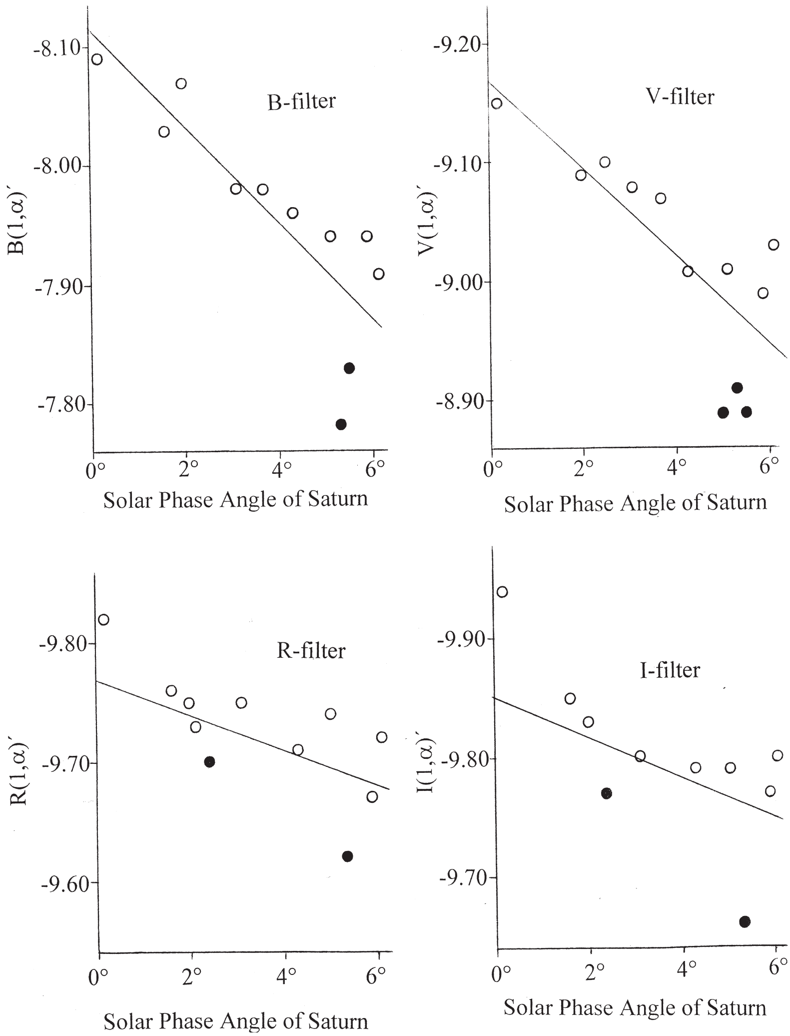

Figure 2: Plots of X(1,α)" versus α for the B, V, R and I filters. The X(1,α)" values were computed from equation 2. Open circles denote measurements before February 25, 2008. Solid circles denote measurements after February 25, 2008.

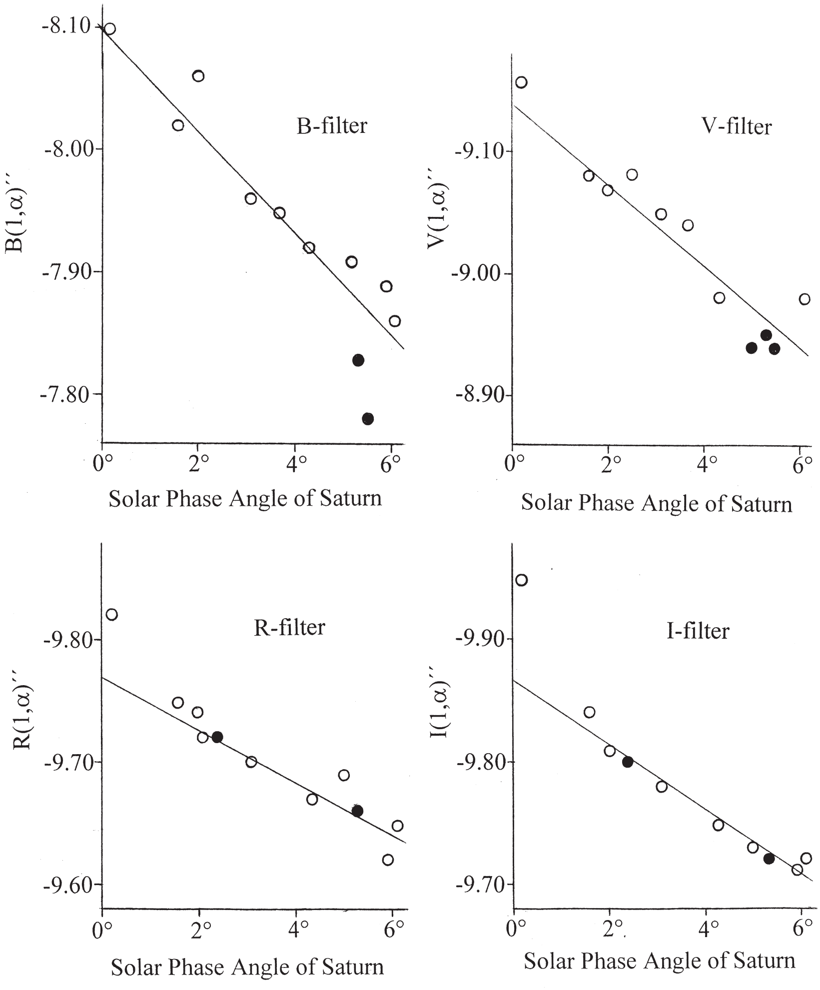

Table III: Normalized magnitudes and solar phase angle coefficients of Saturn + rings measured during the 2007-2008 apparition based on b.

Filter	X(1,0)	Solar Phase Angle Coefficient, c_x (magnitude/degree)	Opposition Surge* (magnitudes)
B	-8.10 ± 0.01	0.041 ± 0.006	0.00
V	-9.14 ± 0.01	0.034 ± 0.005	0.02
R	-9.77 ± 0.01	0.022 ± 0.007	0.05
I	-9.87 ± 0.02	0.027 ± 0.007	0.09

* Opposition surge at a solar phase angle of 0.20°.

The uncertainties in Table III are about half of those in Table II. This along with the better agreement between points in Figure 2 than in Figure 1 leads the writer to conclude that the angle of the ring plane with respect to the Sun (B') needs to be considered in future photometric studies of Saturn. The selected photometric constants of Saturn + rings at b = 7° are summarized in Table III.

Neither the writer (11, 12) nor Harris (13) considered the Sun's position in past studies of Saturn's brightness. Part of the reason for this is that almost all of the writer's measurements after 2002, were made before Saturn reached opposition when B' > B. The writer plans to carry out a re-evaluation of past measurements in a future report based on b instead of B.

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