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Wideband Photometry of Saturn in 2004-2005

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WIDEBAND PHOTOMETRY OF SATURN IN 2004-2005

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ABSTRACT

The writer made 60 photometric measurements of Saturn + rings between Nov. 5, 2004 and Jan. 21, 2005. The normalized magnitudes of Saturn for a ring tilt angle of 22° are: B(1,0) = -8.55 ± 0.01, V(1,0) = -9.60 ± 0.01, B(1,0) = -10.27 ± 0.01 and I(1,0) = -10.47 ± 0.01; the corresponding solar phase angle coefficients are: c_B = 0.027 ± 0.006, c_V = 0.021 ± 0.005, c_B = 0.020 ± 0.005 and c_B = 0.022 ± 0.005. The 2005 opposition surge values (in magnitudes at α = 0°) are: B = 0.24 ± 0.05, V = 0.18 ± 0.05, R = 0.16 ± 0.05 and I = 0.27 ± 0.05.

Key Words: Saturn, photoelectric photometry, opposition surge

INTRODUCTION

During the past year, several important Saturn studies have been carried out. Munoz and co-workers (1), for example, report that Hubble Space Telescope (HST) images at different wavelengths are consistent with two haze layers in Saturn's atmosphere. They suggest that the altitudes of the haze layers change with Saturn's seasons. McGhee and co-workers (2) analyzed almost three dozen HST images made between 1996 and 2004 and found that the contrast of ring spokes was highest at low ring tilt angles. They go on to show that their data are consistent with the spokes being caused by meteoritic impacts. In a third study, de Pater and co-workers (3) confirm that Saturn's E-ring has a blue color whereas Saturn's G-ring has a red color; these colors appear to be unrelated to Saturn's seasons. In another study, Verbiscer and co-workers (4) used HST data to compute opposition surge values of Saturn's moon Enceladus at several wavelengths. The opposition surge value is a non-linear increase in the brightness of an object when it is near opposition. Whole-disc brightness measurements made over several years may yield information on seasonal changes in Saturn's haze layers, ring spokes and ring color. Opposition surge measurements of Saturn may yield information on how to interpret similar measurements of Enceladus. This paper will focus on Saturn's opposition surge along with other photometric constants measured in late 2004 and early 2005.

MATERIALS AND METHODS

The writer used an SSP-3 solid state stellar photometer along with a 0.09 meter Maksutov telescope and filters that were transformed to the Johnson B, V, R and I system to make all brightness (photometric) measurements; more information about the equipment can be found elsewhere (5, 6). Each measurement consisted of the sequence CSCSCSKC where C is the comparison star measurement, S is the Saturn measurement and K is the check star measurement. All measurements were corrected for both extinction and color transformation. The comparison and check stars for all measurements were iota Geminorum and epsilon Tauri respectively. Comparison star magnitudes were taken from Iriarte et al (7). The measured magnitudes of epsilon Tauri were: B = 4.56, V = 3.52, R = 2.81 and I = 2.32; these magnitudes compare well with literature values (7) and attest to the quality of the photometric measurements.

RESULTS

All magnitude measurements are listed in Table I. The date is in Universal Time. The second column lists the filter used and the third column lists the ring tilt angle, which is the minimum angle that the ring plane makes to a line defined by the centers of the Earth and Saturn. The solar phase angles are listed in the fourth column which is the angle between the Earth and the Sun measured from Saturn. All ring tilt angles and the solar phase angles on or before Jan. 3, 2005 were taken from the Astronomical Almanac (8, 9) while those taken after that date were computed from the JPL Solar System Ephemerides, which is located on the ALPO website (10). The fifth column lists the measured magnitudes and the sixth column lists the normalized magnitudes $X(1,\alpha)$ where $X(1,\alpha)$ was calculated from:

$$X(1, \alpha) = X_{mag} - 5.0 \log [r \times d] - 2.5 \log [k] + \Delta m(22.0°) - \Delta m(B) \quad (1)$$

where α is the solar phase angle, X_{mag} is the measured magnitude for filter X, 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; k is computed as:

$$k = (\cos \alpha + 1)/2 \quad (2).$$

Finally, $\Delta m(22.0°)$ and $\Delta m(B)$ are the magnitude changes caused by the rings at ring tilt angles of 22.0° and B; the Δm values are computed from the equations in Schmude et al (11).

Table I. Photometric measurements of Saturn made in late 2004 and early 2005.

Date (U.T.)	Filter	B (deg.)	Phase Angle (α) (degrees)	Measured Magnitude	X(1,α)
Nov. 5.280, 2004	V	21.7	6.0	0.00	-9.50
Nov. 5.303	B	21.7	6.0	1.13	-8.36
Nov. 5.337	R	21.7	6.0	-0.66	-10.16
Nov. 5.351	I	21.7	6.0	-0.85	-10.35
Nov. 15.268	R	21.8	5.7	-0.70	-10.16
Nov. 15.282	I	21.8	5.7	-0.90	-10.36
Nov. 15.292	V	21.8	5.7	0.00	-9.46
Nov. 15.306	B	21.8	5.7	1.03	-8.43
Dec. 3.256	V	22.0	4.4	-0.13	-9.52
Dec. 3.272	B	22.0	4.4	0.94	-8.45
Dec. 3.290	R	22.0	4.4	-0.78	-10.17
Dec. 3.307	I	22.0	4.4	-0.95	-10.34
Dec. 8.272	I	22.0	4.0	-1.00	-10.37
Dec. 8.291	R	22.0	4.0	-0.82	-10.19
Dec. 8.307	V	22.0	4.0	-0.14	-9.51
Dec. 8.326	B	22.0	4.0	0.94	-8.43
Dec. 15.240	V	22.2	3.4	-0.17	-9.52
Dec. 15.256	B	22.2	3.4	0.92	-8.43
Dec. 16.253	R	22.2	3.3	-0.83	-10.18
Dec. 16.267	I	22.2	3.3	-1.04	-10.39
Dec. 21.270	V	22.3	2.8	-0.20	-9.54
Dec. 21.283	B	22.3	2.8	0.860	-8.48
Dec. 21.298	R	22.3	2.8	-0.88	-10.21
Dec. 21.317	I	22.3	2.8	-1.05	-10.39
Dec. 29.201	V	22.5	1.9	-0.21	-9.53
Dec. 29.218	B	22.5	1.9	0.82	-8.50
Dec. 29.233	R	22.5	1.9	-0.94	-10.26
Dec. 29.246	I	22.5	1.9	-1.10	-10.42
Jan. 2.124, 2005	V	22.6	1.4	-0.25	-9.57
Jan. 2.141	B	22.6	1.4	0.79	-8.52
Jan. 2.159	R	22.6	1.4	-0.92	-10.24
Jan. 3.144	I	22.6	1.3	-1.15	-10.46
Jan. 3.164	V	22.6	1.3	-0.29	-9.60
Jan. 9.166	V	22.8	0.579	-0.33	-9.63
Jan. 9.187	B	22.8	0.577	0.68	-8.63
Jan. 9.202	R	22.8	0.575	-1.00	-10.30
Jan. 9.223	I	22.8	0.573	-1.17	-10.47
Jan. 10.147	R	22.8	0.462	-1.04	-10.34
Jan. 10.160	I	22.8	0.461	-1.18	-10.48

Table I. Continued.

Date (U.T.)	Filter	B (deg.)	Phase Angle (α) (degrees)	Measured Magnitude	X(1,α)
Jan. 12.138	V	22.8	0.225	-0.39	-9.69
Jan 12.154	B	22.8	0.223	0.58	-8.73
Jan. 12.168	R	22.8	0.221	-1.06	-10.36
Jan. 12.187	I	22.8	0.219	-1.29	-10.59
Jan. 15.064	V	22.9	0.125	-0.43	-9.73
Jan. 15.087	B	22.9	0.128	0.580	-8.72
Jan. 15.106	R	22.9	0.130	-1.08	-10.38
Jan. 15.130	I	22.9	0.133	-1.34	-10.63
Jan. 17.076	R	23.0	0.365	-0.99	-10.29
Jan. 17.095	I	23.0	0.368	-1.25	-10.54
Jan. 17.113	V	23.0	0.370	-0.36	-9.65
Jan. 17.133	B	23.0	0.372	0.66	-8.65
Jan. 18.144	V	23.0	0.493	-0.33	-9.63
Jan. 18.164	B	23.0	0.495	0.69	-8.62
Jan. 19.165	V	23.0	0.614	-0.32	-9.62
Jan. 19.183	B	23.0	0.616	0.71	-8.60
Jan. 19.202	R	23.0	0.619	-1.00	-10.30
Jan. 19.219	I	23.0	0.621	-1.21	-10.51
Jan. 22.226	V	23.0	0.740	-0.29	-9.59
Jan. 21.240	V	23.1	0.860	-0.31	-9.61
Jan. 21.263	B	23.1	0.863	0.72	-8.58

The normalized magnitudes for each of the four filters are plotted in Figure 1. Magnitudes at solar phase angles of less than 1.3° were not included in Figure 1, because they are affected by the opposition surge. The X(1,0) values are the y intercepts in Figure 1 and are summarized in Table II along with the solar phase angle coefficients (c_x), which are the slopes. Uncertainties for the normalized magnitudes and the solar phase angle coefficients were computed in the same way as in Schmude (12).

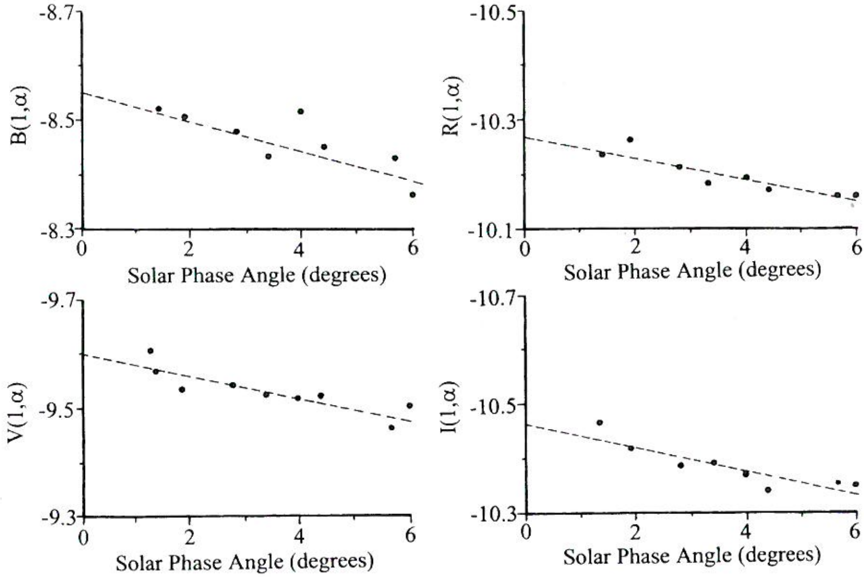

Figure 1. Plots of the normalized magnitudes X(1,0) where X = B, V, R or I filters versus the solar phase angle for Saturn + rings for the B, V, R and I filters.

Figure 2 shows plots of the opposition surge values for the B, V, R and I filters. The opposition surge values, OS, were computed from:

$$OS = X(1,0) + (c_x \times \alpha) - X(1,\alpha) \qquad (3)$$

where X(1,0) and c_x are listed in Table II, α is the solar phase angle in degrees and X(1,α) is a normalized magnitude value measured at $\alpha < 1.3°$ for filter X. As an example, the value of OS for the V filter on Jan. 12.138, 2005 is:

OS = -9.60 mag. + (0.021 mag./deg. × 0.225 deg.) - -9.69 mag. = 0.09473 mag.

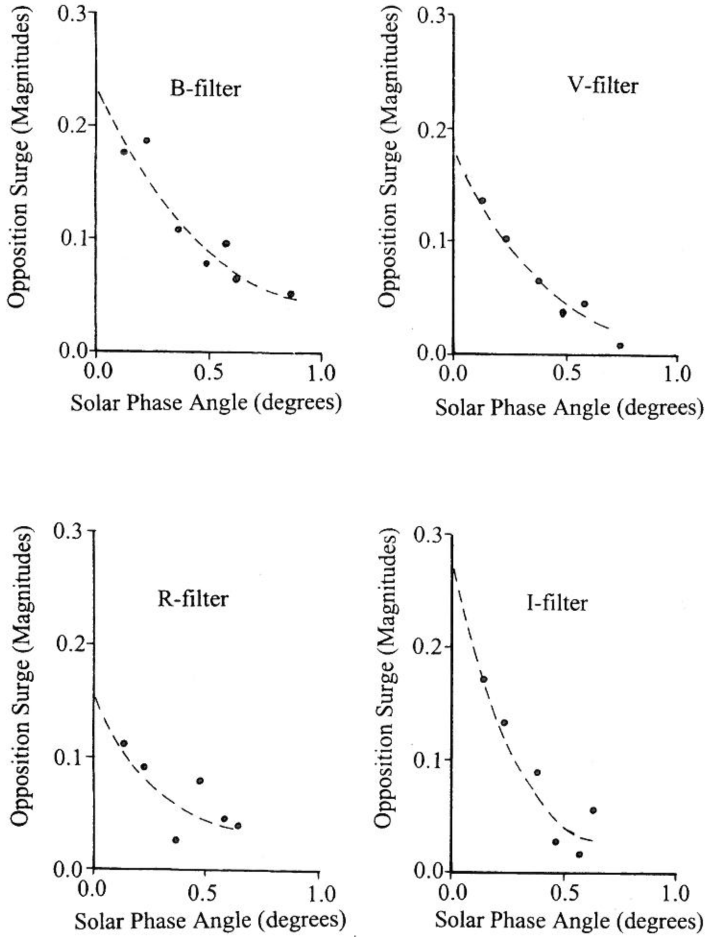

Figure 2. Plots of the opposition surge values versus the solar phase angle (α) for Saturn + rings for the B, V, R and I filters. The opposition surge is the non-linear brightness that occurs when a planet gets close to opposition (or low phase angles).

The 2005 OS values were fit to a quadratic equation and the resulting best fits are equations (4) – (7). The opposition surge values at $\alpha = 0°$ are the last number in equations (4) – (7) and are listed in Table II. The average deviation for each of the equations was computed by subtracting each opposition surge value from the opposition surge value computed in the equation. The absolute value for each distance was used in computing the average deviation. The average deviations are 0.013, 0.007, 0.015 and 0.015 magnitudes for equations 4, 5, 6 and 7 respectively.

$$OS = 0.220\alpha^2 - 0.408\alpha + 0.238 \quad \textit{Blue filter} \quad (4)$$
$$OS = 0.268\alpha^2 - 0.410\alpha + 0.181 \quad \textit{Visual filter} \quad (5)$$
$$OS = 0.369\alpha^2 - 0.408\alpha + 0.156 \quad \textit{Red filter} \quad (6)$$
$$OS = 0.712\alpha^2 - 0.825\alpha + 0.274 \quad \textit{Infrared filter} \quad (7)$$

Table II. Photometric constants of Saturn measured in 2004-05 from Figure 1.

Filter	Normalized Magnitude X(1,0)	Solar Phase Angle Coefficient (magnitude/degree)	Opposition Surge (magnitudes) for α=0° in 2005
B	-8.55 ± 0.01	0.027 ± 0.006	0.24
V	-9.60 ± 0.01	0.021 ± 0.005	0.18
R	-10.27 ± 0.01	0.020 ± 0.005	0.16
I	-10.47 ± 0.01	0.022 ± 0.005	0.27

DISCUSSION

The predicted (13) normalized magnitudes at a solar phase angle of 0° for a ring tilt angle of 22.0° are: B(1,0) = -8.50, V(1,0) = -9.61, R(1,0) = -10.27 and I(1,0) = -10.48, which are within 0.01 magnitudes of the V(1,0), R(1,0) and I(1,0) values in Table II. There is a larger discrepancy for the B(1,0) value, which may be due to the larger extinction correction for this filter.

The solar phase angle coefficients are consistent with those measured in 1999 at a similar ring tilt angle. The solar phase angle coefficient is below the value of 0.044 mag./degree reported by Muller cited in Harris (14).

The opposition surge values in Table II are higher than those reported in Schmude et al., (11) Schmude, (13) and Schmude (15). Part of the discrepancy may be due to the fact that the rings were beginning to close up in early 2005 compared to 1-3 years earlier. Uncertainties for the opposition surges are larger than for measured magnitudes because OS values depend on a best fit equation; a small uncertainty in a measured magnitude is magnified in an OS value at α = 0.0°.

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