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Wideband Photometry of Saturn in 2006-2007

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WIDEBAND PHOTOMETRY OF SATURN IN 2006-2007

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ABSTRACT

The writer carried out brightness measurements of Saturn and its rings with four different color filters. The selected normalized magnitudes of Saturn + rings for a ring tilt angle of 14° are B(1,0) = -8.25±0.03, V(1,0) = -9.36±0.03, R(1,0) = -10.01±0.04 and I(1,0) = -10.16±0.04. The opposition surge values for Saturn + rings on Feb. 11, 2007 (solar phase angle = 0.15°) were 0.19 and 0.06 magnitudes for the B and V filters respectively. The writer concludes that the B-V and V-R color indexes of Saturn + rings do not change much when the solar phase angle drops from 6° to 1°. The rings become a little bluer though as the solar phase angle drops from 1° to 0° due to the larger opposition surge in blue light.

Key Words: Saturn, photoelectric photometry, opposition surge

INTRODUCTION

Several recent studies show that Saturn undergoes seasonal and other changes, which may affect its brightness and color. Two groups of astronomers Pérez-Hoyos et al. (1) and Karkoschka and Tomasko (2) report that Saturn's haze layers undergo seasonal changes. Karkoschka and Tomasko report that Saturn's aerosol particles grew larger between 1995 and 2003. Pérez-Hoyos and co-workers report that HST images show that the tropospheric haze at 10° S, 40° S and 73° S grew darker in blue (439 nm) light between 1996 and 2003. This change is probably due to seasonal changes. McGhee and co-workers (3) report that Saturn's B ring has spokes that are probably made up of ~1 micron particles that lie either above or within the ring. They point out that the spokes are most obvious at low ring tilt angles.

Brightness measurements of Saturn and its rings covering at least one cycle of Saturn seasons (29.5 years) will reveal information on seasonal brightness and color changes. These measurements will also yield information on how the rings change in brightness and color with changing ring tilt and solar phase angles. In this report, I will summarize my brightness measurements made of Saturn between Oct. 30, 2006 and April 13, 2007. The purpose of this work is fourfold:

1) Gain brightness and color information on Saturn + rings with changing ring tilt angles

2) Measure the solar phase angle coefficient of Saturn + rings as the solar phase angle drops from 6° to 1°.
3) Establish a baseline of Saturn measurements so that when a large change on the disc occurs, we will be able to obtain more meaningful color and brightness information.
4) Measure the opposition surge of Saturn + rings.

METHOD AND MATERIALS

The writer used an SSP-3 photometer along with a 0.09 meter Maksutov telescope and filters transformed to the Johnson B, V, R and I system for all brightness measurements. The filters had approximate peak wavelengths and full-width-at-half-transmission values of: B (420 nm, 90 nm); V (540 nm, 90 nm); R (700 nm, 200 nm) and I (860 nm, 220 nm). All filters were transformed to the Johnson B, V, R and I system in the same way as is described in Hall and Genet (4). More information about the equipment can be found elsewhere (5, 6).

Magnitude measurements were carried out in the same way as in Schmude (7) except that Mu-Leonis was the comparison star. The magnitudes for this star were taken from Iriarte et al. (8). The check star was Epsilon-Leonis and its measured V filter magnitude was 2.99 ± 0.01, which is close to the literature value of 2.98 ± 0.01 (8). All magnitudes were corrected for extinction and color transformation.

RESULTS

My magnitude measurements are listed in Table I. The first column lists the date of each measurement in Universal Time; hours and minutes were converted to a decimal date. The second, third and fourth columns list the filter used, ring tilt angle and the solar phase angle of Saturn. The solar phase angle is the angle between the observer and the Sun measured from the target, which in this case is Saturn. Most values for the solar phase angle and all values of the ring tilt angle are from The Astronomical Almanac (9, 10). When Saturn was near opposition (Feb. 6-11, 2007), I used reference (11) to determine the solar phase angle to two decimal places. The fifth column lists Saturn's measured magnitude; typical uncertainties are 0.02 magnitudes for the V and R values and 0.03 magnitudes for the B and I values. The next column lists the normalized magnitude at a ring tilt angle of 14°. Normalized magnitudes are computed from:

$$X(1,\alpha) = X_{mag} - 5.0 \log[r \times d] - 2.5 \log[k] + \Delta m(14°) - \Delta m(B) \qquad (1)$$

Table I. Measurements of Saturn's brightness and opposition surge made in late 2006 and early 2007.

Date	Filter	B (degrees)	α (degrees)	Measured Magnitude	X(1,α)	Oppsition Surge (magnitudes)
Oct. 30.410, 2006	V	12.7	6.0	0.48	-9.25	---
Oct. 30.424	B	12.7	6.0	1.50	-8.22	---
Oct. 30.435	R	12.7	6.0	-0.24	-9.97	---
Oct. 30.445	I	12.7	6.0	-0.36	-10.09	---
Nov. 26.457	V	12.3	6.1	0.44	-9.19	---
Dec. 19.240	R	12.4	5.2	-0.37	-9.92	---
Dec. 19.250	I	12.4	5.2	-0.50	-10.05	---
Dec. 19.260	V	12.4	5.2	0.34	-9.21	---
Dec. 19.272	B	12.4	5.2	1.40	-8.14	---
Jan. 2.213	V	12.7	4.2	0.18	-9.30	---
Jan. 2.226	B	12.7	4.2	1.26	-8.22	---
Jan. 2.238	R	12.7	4.2	-0.51	-10.00	---
Jan. 2.249	I	12.7	4.2	-0.62	-10.12	---
Jan. 26.206	V	13.4	1.8	0.08	-9.33	---
Jan. 26.224	B	13.4	1.8	1.17	-8.25	---
Jan. 26.241	R	13.4	1.8	-0.59	-10.00	---
Jan. 26.258	I	13.4	1.8	-0.73	-10.15	---
Jan. 31.210	V	13.5	1.3	0.08	-9.33	---
Feb. 6.192	V	13.8	0.56	0.03	-9.36	0.02±0.04
Feb. 6.212	B	13.8	0.56	1.03	-8.36	0.12±0.04
Feb. 7.183	V	13.8	0.45	0.04	-9.35	0.00±0.04
Feb. 7.206	B	13.8	0.45	1.06	-8.33	0.09±0.04

Feb. 8.176	V	13.8	0.34	0.00	-9.40	0.04±0.04
Feb. 8.203	B	13.8	0.34	1.03	-8.36	0.12±0.04
Feb. 11.165	V	13.9	0.15	-0.03	-9.41	0.06±0.04
Feb. 11.200	B	13.9	0.15	0.95	-8.44	0.19±0.04
Feb. 11.213	R	13.9	0.15	-0.72	-10.11	0.10±0.05
Feb. 11.227	I	13.9	0.15	-0.88	-10.27	0.12±0.05
Mar. 5.172	V	14.7	2.5	0.16	-9.23	---
Mar. 5.190	B	14.7	2.5	1.21	-8.18	---
Mar. 5.206	R	14.7	2.5	-0.54	-9.92	---
Mar. 5.222	I	14.7	2.5	-0.68	-10.06	---
Apr. 13.053	V	15.4	5.7	0.36	-9.13	---
Apr. 13.068	B	15.4	5.7	1.37	-8.12	---
Apr. 13.081	R	15.4	5.7	-0.36	-9.84	---
Apr. 13.101	I	15.4	5.7	-0.49	-9.96	---

In this equation, X_{mag} is the measured magnitude for filter X, α is the solar phase angle, $X(1,\alpha)$ is the normalized magnitude at a solar phase angle α, 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 Earth and k is computed from:

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

The $\Delta m(14°)$ and $\Delta m(B)$ terms are the brightness changes caused by the rings at a ring tilt angle of 14° and B. The $\Delta m(14°)$ and $\Delta m(B)$ values are computed from equations 3 – 6 in Schmude (12).

The writer computed the opposition surge values listed in the last column of Table I in the same way as is described in Schmude (7). The uncertainties are estimated values.

I computed a linear equation for the $X(1,\alpha)$ versus α values for each filter in the same way as was done elsewhere (7). The resulting $X(1,0)$ and c_X values are listed in Table II for each filter; these values correspond to a ring tilt angle of 14°. I computed the uncertainties in the same way as in Schmude (13).

Table II. Selected normalized magnitude and solar phase angle coefficients for Saturn in late 2006 and early 2007.

Filter	X(1,0)	c_x (magnitude/degree)
B	-8.25±0.03	0.014±0.015
V	-9.36±0.03	0.027±0.013
R	-10.01±0.04	0.016±0.020
I	-10.16±0.04	0.020±0.017

DISCUSSION

According to equations 3 – 6 in Schmude (12), the B(1,0), V(1,0), R(1,0) and I(1,0) values at a ring tilt angle of 14° are predicted to be -8.31, -9.38, -10.04 and -10.21. The normalized magnitudes in Table II are 0.02 to 0.06 magnitudes fainter than the predicted values. This discrepancy may be due to the high uncertainties in Table II values.

Figure 1 shows values of the V filter opposition surge of Saturn + rings during the last five apparitions (7, 14-16) at a solar phase angle of 0.15°. The opposition surge reached a peak value in 2005 when the ring tilt angle was 22°. Almost the entire opposition surge is probably caused by Saturn's rings. Figures 2 and 3 show images of Saturn made by Christopher Go. Saturn had respective solar phase angles of 5.5° and 0.1° on Dec. 12, 2006 (19:01 UT) and Feb. 10, 2007 (15:49 UT). The portion of the rings in front of Saturn's disc is much brighter than Saturn in the Feb. 10 image whereas this is not the case in the Dec. 12 image. The rings are brighter in the Feb. 10 image because they have a large opposition surge compared to Saturn's disc.

Figure 1: A plot of the V filter opposition surge of Saturn + rings at a solar phase angle of 0.15° versus the ring tilt angle. The length of the bar is the uncertainty.

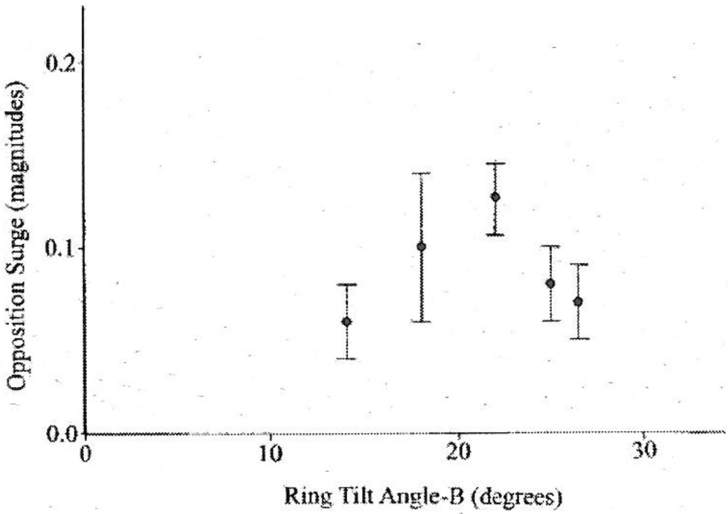


Figure 2: An image of Saturn made on Dec. 12, 2006 at 19:01 UT by Christopher Go. He used a 0.28 meter Schmidt Cassegrain telescope to make this image. Reproduced with permission from Christopher Go; © Christopher Go.

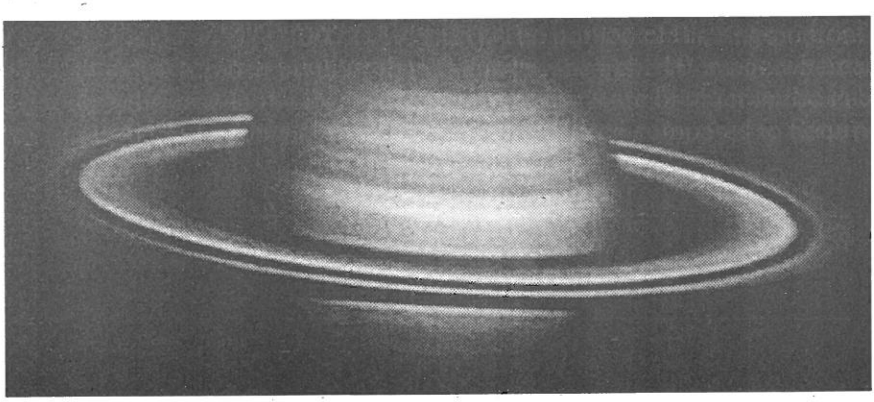
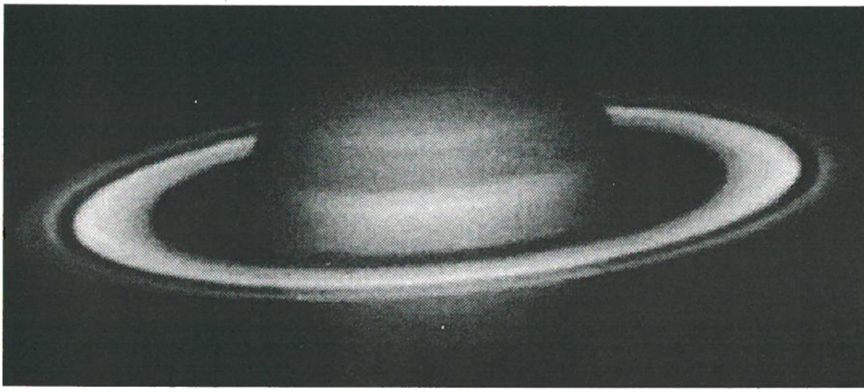


Figure 3: An image of Saturn made on Feb. 10, 2007 at 15:49 UT by Christopher Go. He used a 0.28 meter Schmidt-Cassegrain telescope to make this image. Reproduced with permission from Christopher Go; ©Christopher Go.



The lower opposition surge values in 2006 and 2007 are probably due to the lower percentage of light reflected by the rings in the Saturn + rings system in these years compared to 2005. The rings in 2005 reflected 1.8 times as much light in the V filter as they did in Feb. 2007.

Do the rings get redder as the solar phase angle drops form 6° to 1°? If one assumes that Saturn's color does not change then one can estimate color changes of the rings as the solar phase angle drops. The solar phase angle coefficients, c_B, c_V and c_R show how much Saturn + rings brighten in blue, green and red light as the solar phase angle drops form 6° to 1°. A large value of c_B compared to c_V and c_R would be evidence that the rings become bluer with decreasing solar phase angle. I have calculated average values of $c_B - c_V$ and $c_V - c_R$ for the 1996-2007 apparitions; the results are:

$$\text{Average } c_B - c_V = 0.000 \pm 0.003$$

$$\text{Average } c_V - c_R = 0.002 \pm 0.002$$

These results are consistent with almost no color change in the rings as the phase angle drops from 6° to 1°. The writer concludes that the B-V and V-R color indexes of the combined light from the rings does not change much as the solar phase angle drops form 6° to 1°.

At solar phase angles below ~1°, the opposition surge plays an important role in ring color. If the opposition surge is greater in one color than in the others then the rings will have more of that color at low solar phase angles. During the 2004-2007 apparitions, the B filter opposition surge was consistently ~0.1 magnitudes larger than the V and R filter opposition surges. As a result, the rings as a whole became several percent bluer as the solar phase angle drops from 1° to 0°.

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