

Latitudinal Variations of the Molecular Absorption on Saturn and Seasonal Changes of the Atmospheric State at S- and N- Hemispheres

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ABSTRACT

New spectrophotometric CCD-observations of Saturn were performed in 2003 - 2004 within the framework of an international effort in support to the Cassini space mission through 2008. A series of Saturn's spectra have been obtained and analyzed. Our purpose is to study current latitudinal variations in molecular absorption bands during the rings-opening maximum and best visibility conditions for observation of the southern hemisphere of Saturn. A comparison with data of previous years shows the presence of seasonal variation connected with changes in the insolation regime on Saturn.

(Key words: Saturn, Spectra, Atmosphere, Methane, Absorption, Latitudinal variations, Seasonal variations)

1. INTRODUCTION

The successful flight of the spacecraft "Cassini" with the atmospheric probe "Huygens" to Saturn stimulated an international program of ground based support to this mission, which started in 2003 and will continue to 2008. The institution coordinating this program is the Jet Propulsion Laboratory. To the Laboratory of Lunar and Planetary Research at Fessenkov Astrophysical Institute, we received an offer from JPL to participate in this program. Our observatory can fill a great proportion of the longitude-time breakup between observatories in Europe and the USA and thereby affords us the opportunity to observe possible short-time phenomena and events inaccessible from other locations.

Observations of Saturn that have been undertaken by our laboratory for many years

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(Tomasko et al. 1984, Tejfel 2001), have focused on the acquisition of systematic information about the state of the atmosphere and cloud cover of this planet from the spectral measurements of molecular absorption bands. The intensity of these methane absorption bands depends, to a considerable extent, on the character of radiative transfer within the absorbing-scattering cloud layers, i.e., it is connected with the structure and density of gas and aerosol components of the atmosphere.

Time-dependent variations in the methane absorption bands on Saturn were noted by Trafton (1985) and Ortiz et al. (1995). For Saturn's atmosphere, the seasonal changes in insolation may play an important role. Indeed, the 27 degrees inclination of Saturn's equator to the orbital plane and screening by the rings significantly reduces incoming solar radiation to the northern or southern hemisphere of the planet, especially when the rings are wide open. Special model calculations of seasonal variations in the temperature regime have confirmed this phenomenon (Barnet et al. 1992). Regular observational data about visible changes in both hemispheres of Saturn is required over an extended time period to improve our understanding of such phenomena. At present, the southern hemisphere of Saturn is directed towards the Sun,

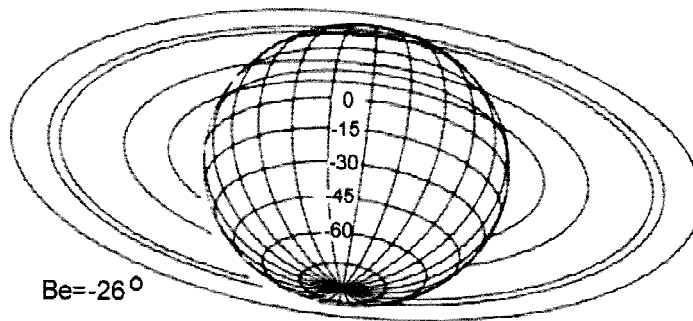


Fig. 1. Disk of Saturn and coordinate grid for the observations in 2003 - 2004.

and the northern one is shielded by the rings (Fig. 1).

2. DATA COLLECTION AND PROCESSING

During the period from November 2003 to March 2004, the observations of Saturn were carried out by a 0.6-meter telescope RZ-600 with CCD-camera ST-7XE manufactured by SBIG (USA), with a diffraction spectrograph SGS produced in the same company. This CCD-camera has better spectral sensitivity and needs shorter exposure times than the ST-6V camera that we used previously. The pixel size of the ST-7XE camera is $9 \times 9 \mu\text{m}^2$. The dispersion of spectrograph in the low-resolution mode is $4.3 \text{ \AA pixel}^{-1}$. The wavelength coverage is 3000 \AA . An additional CCD camera is used for guiding the observed objects on the spectrograph slit, although it is impossible to view the object and the spectrum simultaneously. The spectra were recorded in the wavelength region $\lambda\lambda 580 - 880 \text{ nm}$ with the spectrograph slit oriented along the central meridian or along the major axis of Saturn's rings. Then the CCD image containing

the spectrum was digitized as a numerical array of 600×110 pixels (at $\lambda\lambda$ 586 - 842 nm). The exposure time for each spectrum of Saturn was 120 seconds. The maximum count number in the spectrum reached 24000, and the minimum (in the decline of the CCD spectral sensitivity at $\lambda\lambda > 800$ nm) was about 2000 - 3000 counts.

The additional computer processing was carried out by means of the Microsoft EXCEL package. After calculating the average spectrum of Saturn's rings, which was used as a calibration standard, all the spectra of the central meridian of Saturn were related to the ring spectrum (Fig. 2). These ratio spectra enabled us to eliminate the influence of the CCD spectral response and telluric absorptions on the planetary absorption bands profiles. Then the obtained array of spectral brightnesses was used to derive the residual intensity, central depths and equivalent widths of the absorption bands. Further processing was performed in two ways: a) an averaging of the results of individual spectra with standard deviation estimation, and b) a preliminary averaging of several images of the spectra, followed by a digitization of that averaged image. As Fig. 3 shows the dispersion of the data for individual spectra is quite low. Thus the procedure of averaging 5 - 10 individual images of spectra may be generally acceptable.

3. RESULTS AND DISCUSSION

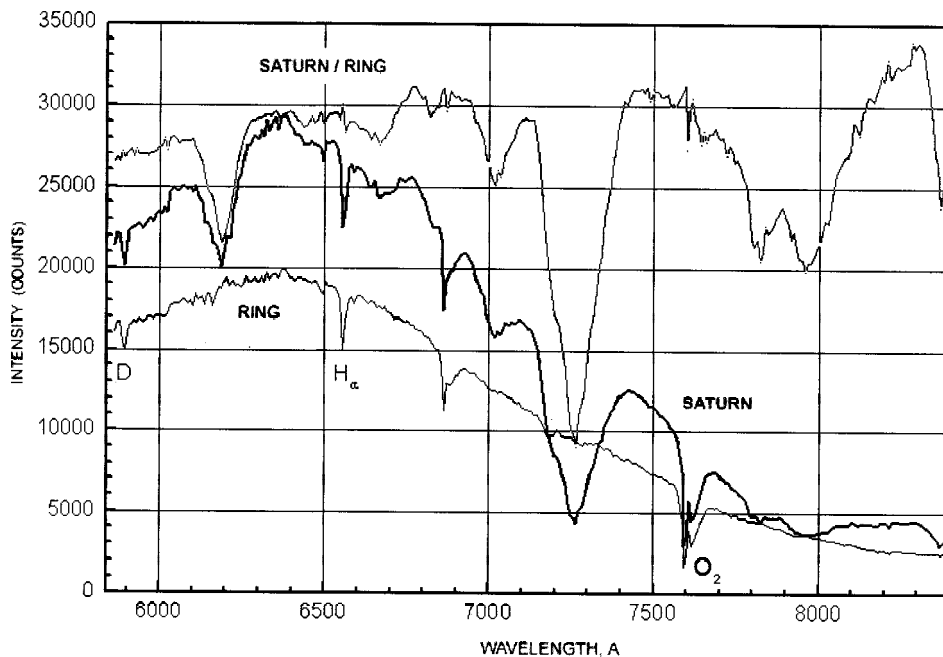


Fig. 2. Profiles of recorded spectra of Saturn and the ring and ratio of Saturn's spectrum to the ring spectrum in arbitrary units.

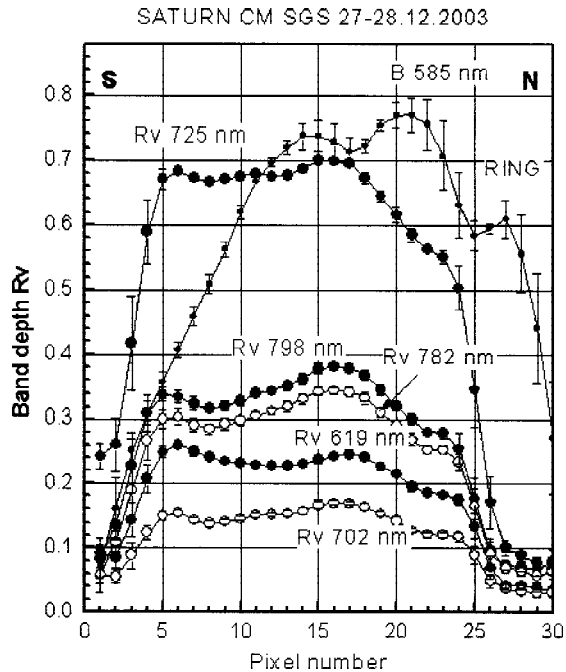


Fig. 3. The central meridian (CM) profiles of the absorption band central depths (R_v) and relative brightness (B) profile averaged from 5 spectra for 27-28 December 2003.

Figures 3 and 4 illustrate the results of determinations of the CH_4 absorption bands depths and their latitudinal variations on Saturn's disk on the night of 27 - 28 December 2003 and 30 - 31 January 2004. For other dates during this period, when the Saturn's Southern hemisphere shows the maximum inclination to the Sun, the results are very similar as can be seen in Figs. 5 and 7.

Figures 4, 5, and 6 show photometric profiles of the central meridian of Saturn in the continuum (λ 585 nm) and in the methane absorption band center (λ 725 nm). From these figures, it can be readily seen that the absorption on different latitudes varied significantly. The values of the band depths R_v versus planetographic latitudes (Fig. 8) show that the absorption is largest at latitudes between 20S and 40S, having a maximum at 30S.

Increasing CH_4 absorption is also observed near the south pole. In the latitudinal belt from 40S to 80S the absorption is noticeably weaker, but the minimum absorption is observed in the equatorial lighter belt of the planet. The equivalent widths (EW) of the absorption bands behave similarly (Fig. 6), but with a particularity: the latitudinal variations of the 798 nm band equivalent widths (and central depth too) are different from the behavior of the 725 nm band. The EW of the 798 nm band is growing sharply towards the temperate latitudes than the EW of

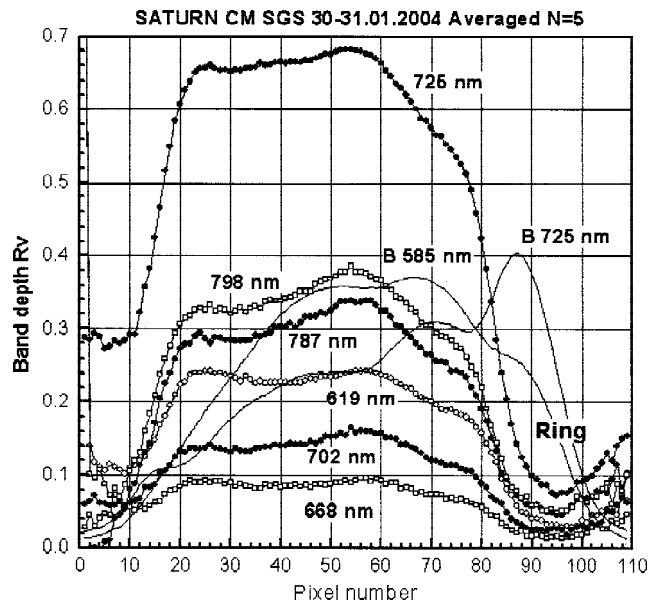


Fig.4. Profiles of R_v and B (in the continuum and in the center of 725 nm band) averaged from 5 spectra for 30 - 31 January 2004.

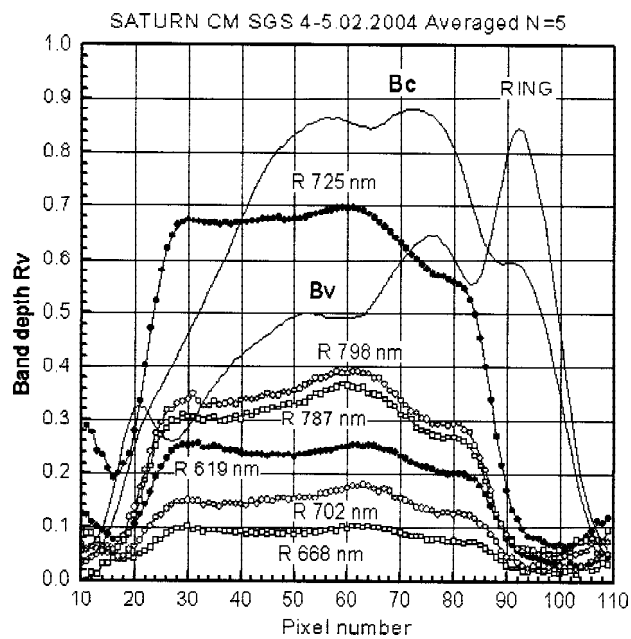


Fig. 5. Same as Fig. 4, but for 4 - 5 February 2004.

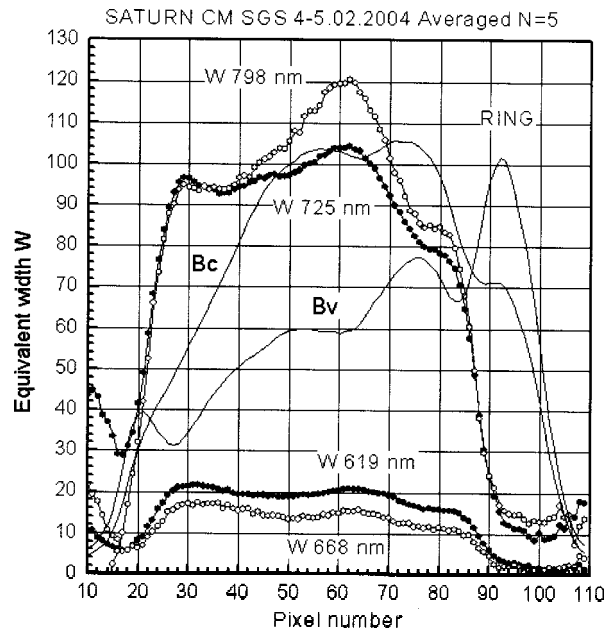


Fig. 6. Profiles of the equivalent widths (EW) and brightness (B) for 4 - 5 February 2004.

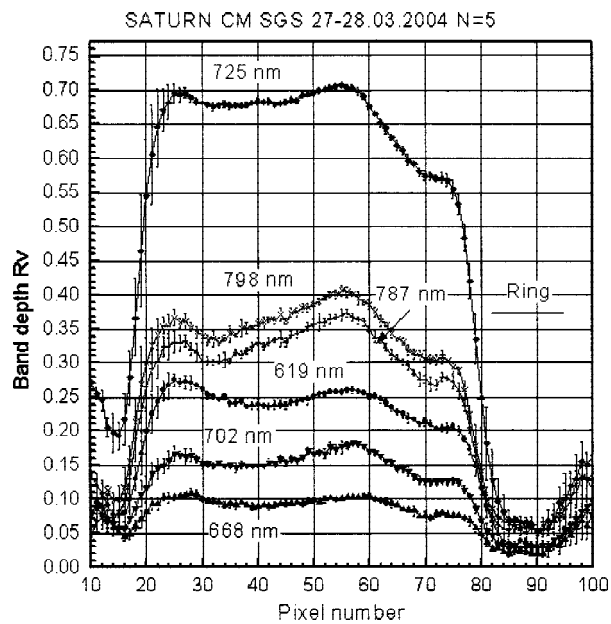


Fig. 7. Profiles of R_v for 27 - 28 March 2004.

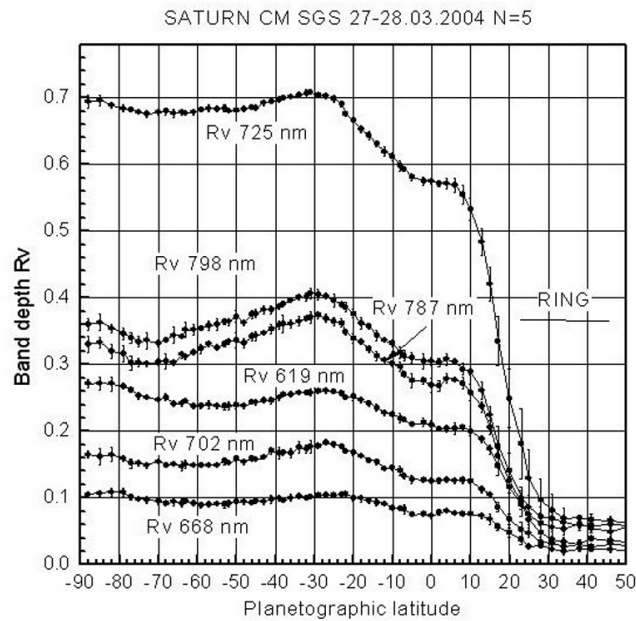


Fig. 8. Latitudinal variations of R_v for 27-28 March 2004.

the 725 nm band, in contrast with high and low latitudes, where both bands show a similar behavior.

This particularity is present at all graphs related to the equivalent widths. It was tempting to attribute it to the ammonia absorption because the NH_3 band falls into the same spectral range. Indeed the conditions of the NH_3 absorption formation in the atmosphere of Saturn are different to methane absorption. Contrary to methane, ammonia condenses at the temperatures of Saturn's atmosphere. However, this result needs a more careful study because the 798 nm band is located where the CCD spectral response is already declining.

In 1995, the equator of Saturn and rings were oriented "edge-on" with respect to the Earth and the Sun, so that the insolation was the same for both hemispheres. However, from our observations (Tejfel 1996, 1997; Tejfel et al. 2003) we have found a significant asymmetry in the latitudinal variations of the methane absorption bands (Fig. 9). In the Northern hemisphere the absorption was larger than in the same latitudes in the Southern hemisphere, although in both hemispheres an increase from the equator to the poles (to latitudes of 60 degrees) took place. A highly significant asymmetry was also detected from measurements of the zonal limb darkening coefficients (Tejfel 1997).

At this point, it is important to note that before 1995 the northern hemisphere was exposed to the Sun, i.e., it received a greater amount of solar radiant energy than the southern hemisphere, which was shaded by the rings, during at least the 10 previous years. Probably, the main reason for the asymmetry in the absorption is connected with this long-term insolation of one hemisphere and reflects real differences in the volume density and height of the cloud cover of

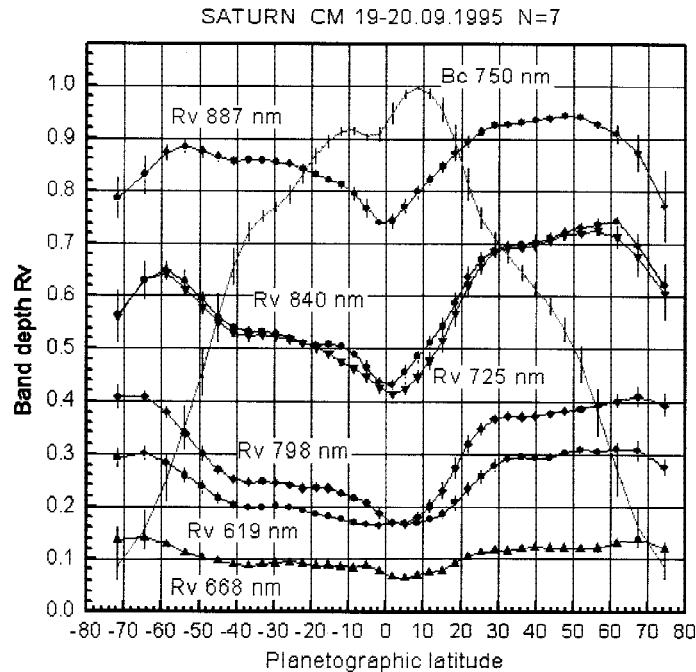


Fig. 9. Latitudinal variations of R_v for 19 - 20 September 1995 (averaged from 7 spectra). North-South asymmetry is strongly expressed.

Saturn.

In the following years (after 1995) the southern hemisphere of Saturn was gradually exposed to more and more solar radiation. As a result, a redistribution of the latitudinal variations of the cloud structure parameters and the visible latitudinal dependence of the absorption bands depths and equivalent widths should have happened. This is distinctly seen from the measurements in 1996 - 2004. Unfortunately, during the preceding "edge-on" orientations of Saturn rings and equator in 1980 and 1966 there were no detailed spectral observations of this planet to make a comparison.

The only available observations near the 1980 ring plane crossing were the observations of West et al. (1982), who obtained images of Saturn in 1979 through filters centered on different methane absorption bands. Processing and analysis of these data lead to the conclusion that in that period the largest amount of absorption occurred in the southern hemisphere, which was pointed to the Sun before 1979 - 1980. In 1991, Ortiz et al. (1993) studied CCD images of Saturn which were recorded through filters centered on the methane absorption bands at 619, 725 and 892 nm (Fig. 10). As seen from comparison of this figure and the previous ones, their estimates of R_v in the northern hemisphere are close to those observed in 2003 - 2004 in the southern hemisphere. The inclination of Saturn's equator in 1991 was about 20 degrees. In 1986 - 1989 Karkoschka and Tomasko (1992) measured the EW and R_v for six

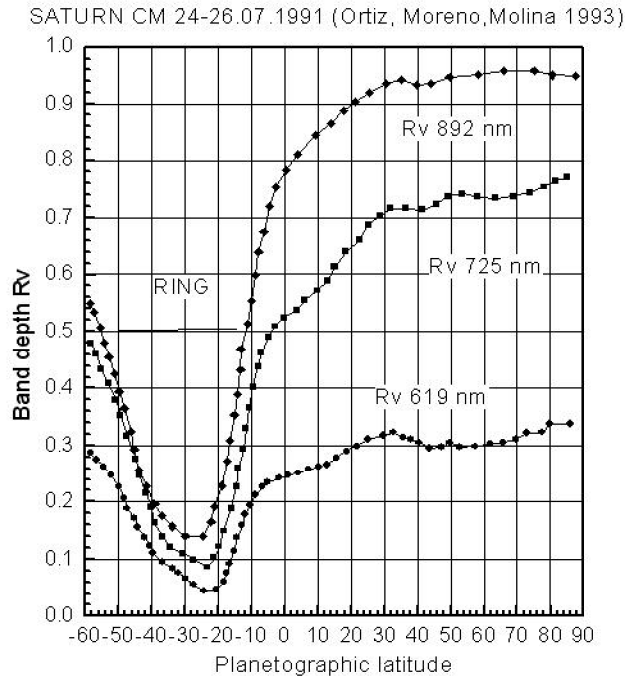


Fig. 10. Latitudinal variations of R_v in July 1991 (Ortiz et al. 1993).

belts in the equator and northern hemisphere at maximum inclination of the rings (about 25 - 27 degrees) with similar results.

4. CONCLUSION

The above long term observations of molecular absorption bands on Saturn reveal a seasonal nature to changes occurring in its atmosphere, and further analysis is expected to be done within the framework of the project "Planetary Monitoring" (Tejfel 2002).

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