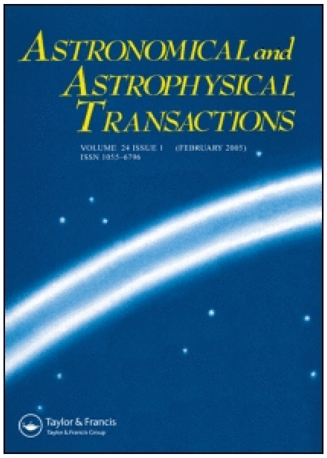

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COMPARATIVE MORPHOLOGY OF MOLECULAR ABSORPTION ON THE DISCS OF JUPITER AND SATURN

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Results on spectral observations of Jupiter and Saturn in the range of the methane and ammonia absorption bands are briefly described. Some peculiarities in the latitudinal and longitudinal variations in those absorptions are noted and the latitudinal asymmetry of the absorption distribution on Saturn's disc clearly expressed. The latter is evidently connected with seasonal changes and differences in the insolation regime caused by the very large tilt of Saturn's rotation axis and its rings. The behaviour of the absorption bands may be used as an important characteristics of the atmospheric state and structure in the future planetary monitoring programme.

Keywords: Jupiter; Saturn; Giant planets; Methane absorption

1 INTRODUCTION

Jupiter and Saturn are the largest planets in the Solar System with well-developed cloudy structures and brightly expressed dynamic processes in their atmospheres. The enormous sizes of the planets and their quick rotation, internal sources of heat and also variable seasonal insolation on Saturn, which result in a very large tilt of its axis, lead to significant differentiation between the horizontal and vertical movements of the gas masses, to formation of and change in the quasistable cloudy structures such as light zones and dark belt girding the whole planet, and to formation and disintegration of unstable chemical species which are responsible for the changing colouration of the aerosols of the clouds.

Observations of Jupiter and Saturn are one of the main topics of planetary research at the Astrophysical Institute from the 1960s. These were made during the years with the 70 cm AZT-8 reflector telescope and automated spectrophotometric planetary complex (ASPC) (Vdovichenko *et al*., 1991) and with the prism spectrometer and filter photometer equipped with an ST-6V charge-coupled device (CCD) camera using the 1 m telescope at the Assy observatory or the 0.6 m reflector at the Fessenkov Astrophysical institute (Tejfel, 2001a). The strategy of observations with the ASPC consisted in recording separate ranges of the planetary disc spectra or quasimonochromatic profiles of the discs. Recording of the spectra

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of a sequential set of areas of the discs of Jupiter and Saturn, as well as spectra of the central meridian and equator, was realized using CCD spectrophotometry, from which the central depths of the methane absorption bands at $\lambda = 619$, 725, 798 and 887 nm were measured. The CCD images of both planets were used for photometric measurements.

We shall give here a short description of some results on the distribution of the intensities of the molecular absorption bands over the discs of both planets. Note that the photometric and spectrophotometric features of Jupiter's and Saturn's atmospheres and the cloud reflectances in the continuum as well as the limb darkening coefficients in many areas on both planets were also researched.

2 JUPITER

There are weak, moderate and strong methane absorption bands and ammonia absorption bands that are superimposed (and combined) in the spectral range from 500 to 1100 nm. All these bands have different sensitivities to the change in the upper atmosphere parameters of Jupiter because of their different effective levels of formation.

So, for instance, within our spectral and spatial resolution the moderately weak methane absorption band at $\lambda = 619$ nm turns out to be only slightly sensitive to the possible change in the cloud structure and cloud top level of the disc of the planet. Spatial variations in the central depth of the band on the disc of Jupiter, studied from a series of CCD spectra, covering the whole disc, are rather chaotic and do not show a clear correlation with the zonal structure of the visible cloudy cover of Jupiter. It is expected that this is connected with the greater turbulence in the deep layers of the atmosphere in contrast with the zonal circulation.

Absorption in the centre of the band of methane at 725 nm, whose depth R_v exceeds 0.5, begins to show observable sensitivity to variations in the structure of the upper layers of Jupiter's atmosphere. The intensity of the band is minimal in the equatorial area, increases with increasing latitude, reaching a maximum at latitudes 40–50 degrees, and decreases towards the poles.

The wavelengths range from 820 to 1100 nm contains very deep absorption bands of methane, superimposed by the absorption ammonia bands, which are insufficiently studied in this region of the spectrum. The presence of ammonia absorption is revealed by comparing the observed absorption band profiles in the spectrum of Jupiter with the spectrum of Saturn or with profiles computed on the basis of data on the methane absorption coefficients (Giver, 1978). As the main model for calculations we used a two-layer model with a semi-infinite scattering–absorbing cloudy layer and a purely gaseous atmosphere situated over it.

In the 820–950 nm range, two distinctive details are revealed: a long-wave wing of the observed band at 886 nm turns out to have moved by about 4–5 nm to a short-wave region with respect to the model profile; in the 910–940 nm range a depression is observed, which is possibly connected with the band of ammonia present in the atmosphere of Jupiter. At $\lambda = 950$–1070 nm in the spectrum of the disc centre (in the equatorial zone), divergences between the observed and modelled spectra are also constantly observed; in the observed spectra, at $\lambda = 970$–985 and 990–1010 nm, so-called 'inversion' regions with lowered absorption with respect to the model are constantly revealed, but the reason for this is still not clear; at $\lambda = 1020$–1060 nm the intensity inside the long-wave wing of the observed absorption band is significantly lowered with respect to the model spectrum as a result of the superimposed ammonia absorption bands that are present in this region.

Latitudinal variations in the intensities of the moderate and strong absorption bands, which occur from year to year, are characteristic of Jupiter. As a rule, a noticeably smaller absorption which is observed at the equatorial belt is in contrast with the midlatitude absorptions.

This feature had already been noted in the 1960s (Tejfel, 1966) and had probably occurred for a long time, as can be judged from the following observations (Vdovichenko, 1978, 1979; Moreno *et al.*, 1991, Tejfel *et al.*, 2001). On moving away from the equator, both the absorption in the methane bands and the additional absorption at 1020–1060 nm, stimulated by the presence of the ammonia absorption bands, increase.

In 1999, special observations of the latitudinal–longitudinal distribution of absorption in the methane bands on Jupiter were carried out. CCD spectra of the central meridian of Jupiter were recorded for each 3 mins that corresponded to a rotation of Jupiter by 1.8°. All the longitudes of the planet were covered twice. A comparison of the latitudinal dependences of absorption in the different absorption bands revealed some differences in the character of the latitudinal variations of absorption. So, the equatorial decrease in absorption is very obvious in the bands at 725 and 887 nm but is absent in the band at 619 nm. For the band at 798 nm, which is a combination of a methane band and an ammonia band, the decrease, if it is present at all, turns out to have moved northwards from the equator, in contrast with what was observed in the band at 887 nm (Figure 1). There is also an evident difference between the latitudinal variations of absorption in the bands at 887 and 725 nm; the absorption in the strong band at 887 nm is constant at all the midlatitudes, while in the band at 725 nm the absorption falls somewhat at latitudes of 30–40° in both hemispheres, demonstrating the comparatively smaller depressions in the latitudinal dependence of the central depths R_v in contrast with that present in the equatorial belt.

In the moderate and strong bands (at 725, 887 and 990 nm) a sharp fall in absorption is observed near the poles (the so-called light 'polar hoods'), which is a consequence of the presence of aerosol haze situated high in the upper atmospheric layers of the polar regions (Figure 2). Its optical thickness in this region of spectrum is so small that it is revealed only from an absorption band depth value more than 0.5 ($R_v > 0.5$). At the same time an ammonia absorption in the long-wave wing of the band at 990 nm (in the spectral region 1020–1060 nm) increases near the poles (Figure 3).

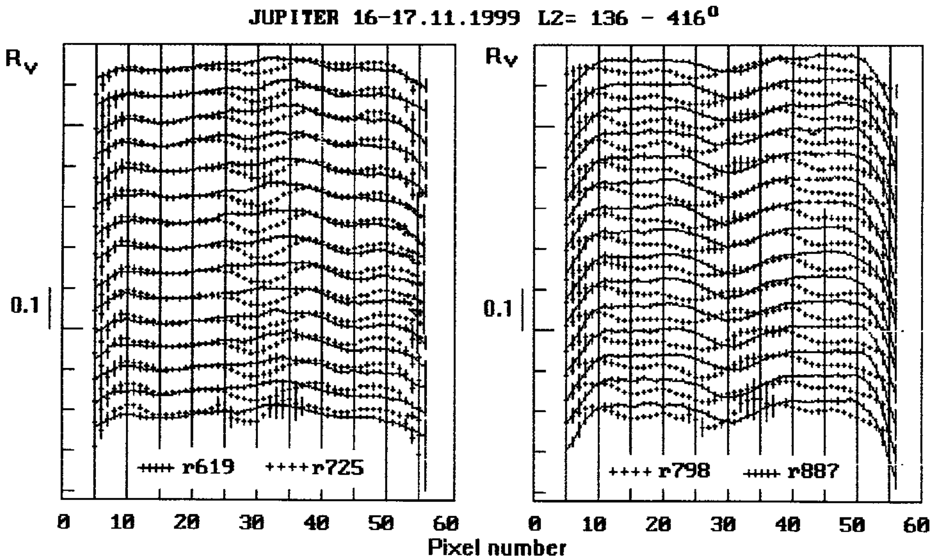

FIGURE 1 Comparative distribution of four absorption band depths R_v along the central meridian of Jupiter at different longitudes in 1999. For clarity the curves were moved vertically by a step of 0.1.

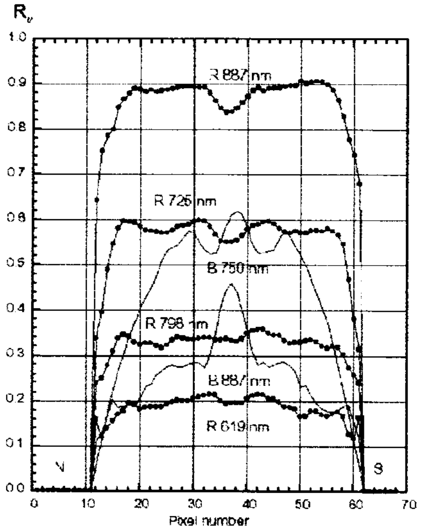

FIGURE 2 Latitudinal variations in the absorption R_v on the Jupiter central meridian for four bands in 2002. The meridional brightness distributions at 750 nm and 887 nm are shown also.

Lowered absorption in the strong bands of methane is also observed in the Great Red Spot, while the zonal variations in R_v are weakly revealed. The so-called effect of the 'centre-limb' (changing intensities of absorption bands from the centre of the disc to the limb) is an important characteristic allowing us to evaluate the properties of the aerosol component of the atmospheres of giant planets (Figure 4).

In the event of very thick cloud cover (with the volume scattering coefficient $\sigma = 10^{-5}\,\text{cm}^{-1}$), when general molecular absorption is created by the atmosphere above the clouds, strengthing absorption bands towards the edge of a disc are observed. However, if the cloud cover has a smaller volume density and a large optical thickness, then multiple scattering in the cloud layer begins to play a main role in the formation of absorption bands. In that case the integral intensities of the absorption bands are strengthed near the centre of the disc but weakened towards the limb as follows from the theoretical calculations of radiative transfer. The effect of the decrease in or almost constancy of absorption towards the limb occurs for most of Jupiter's zones as was shown, in particular, with the data of zonal

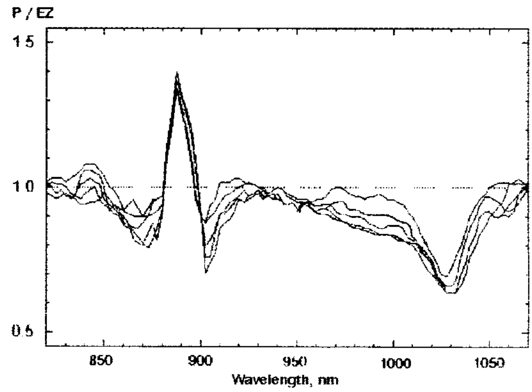

FIGURE 3 The ratio of the spectra of the polar regions of Jupiter to the spectrum of the equatorial region.

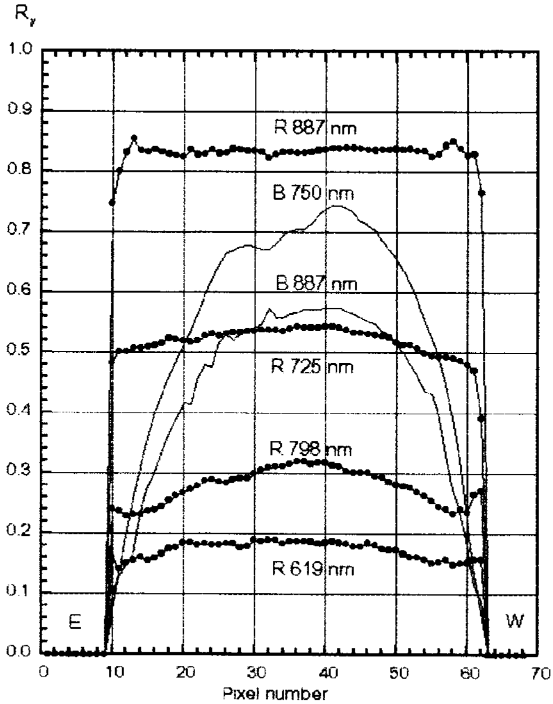

FIGURE 4 Variations in the absorption R_v along Jupiter's equator in 2002.

spectrophotometry obtained in 1997 and 1998. From these data a computer atlas of the zonal variations of absorption was complied, and an atlas of latitudinal–longitudinal variations in the central depths of the absorption methane bands was compiled from the observations in 1999 (Figures 5 and 6).

It should be noted that the decrease in absorption towards the limb of the disc of Jupiter does not occur at the limb. A certain increase in the depths R_v of the bands is observed at the limb, but whether this phenomenon is real requires additional verification, as inaccuracy in measurements of the profiles of the bands are enhanced at the limb if by chance the intensities are small there, in spite of the linearity of light transmission that is peculiar to CCD matrices. In 2002 we conducted a special CCD recording of the spectra of the regions adjacent to the limb in the equatorial belt and near the poles of Jupiter with an increased exposure time. For this, the counts obtained at the continuum were the same as for the regions near the centre, whose spectra were recorded with a shorter exposure time. A certain increase in absorption at the east and west limbs nevertheless was obtained, while significant weakening of the absorption towards the polar limb was observed in all the bands.

It failed to reveal some systematic east–west asymmetry in absorption, probably because of the inhomogeneous structure of the cloud cover of Jupiter along the longitudes. Longitudinal variations in absorption at different latitudes, obtained from the spectrograms of the central meridian in 1999, do not exceed 5% (general trend), and the dispersion of the values of R_v at the adjacent longitudes is within 1–2%. There is also no sharply expressed asymmetry in absorption between the north and south hemispheres (Figures 2 and 7), with the exception of small differences in the values of R_v in the band at 887 nm at the mid-latitudes; in the period from 1997 to 2002, absorption in the southern hemisphere was somewhat higher than in the northern hemisphere.

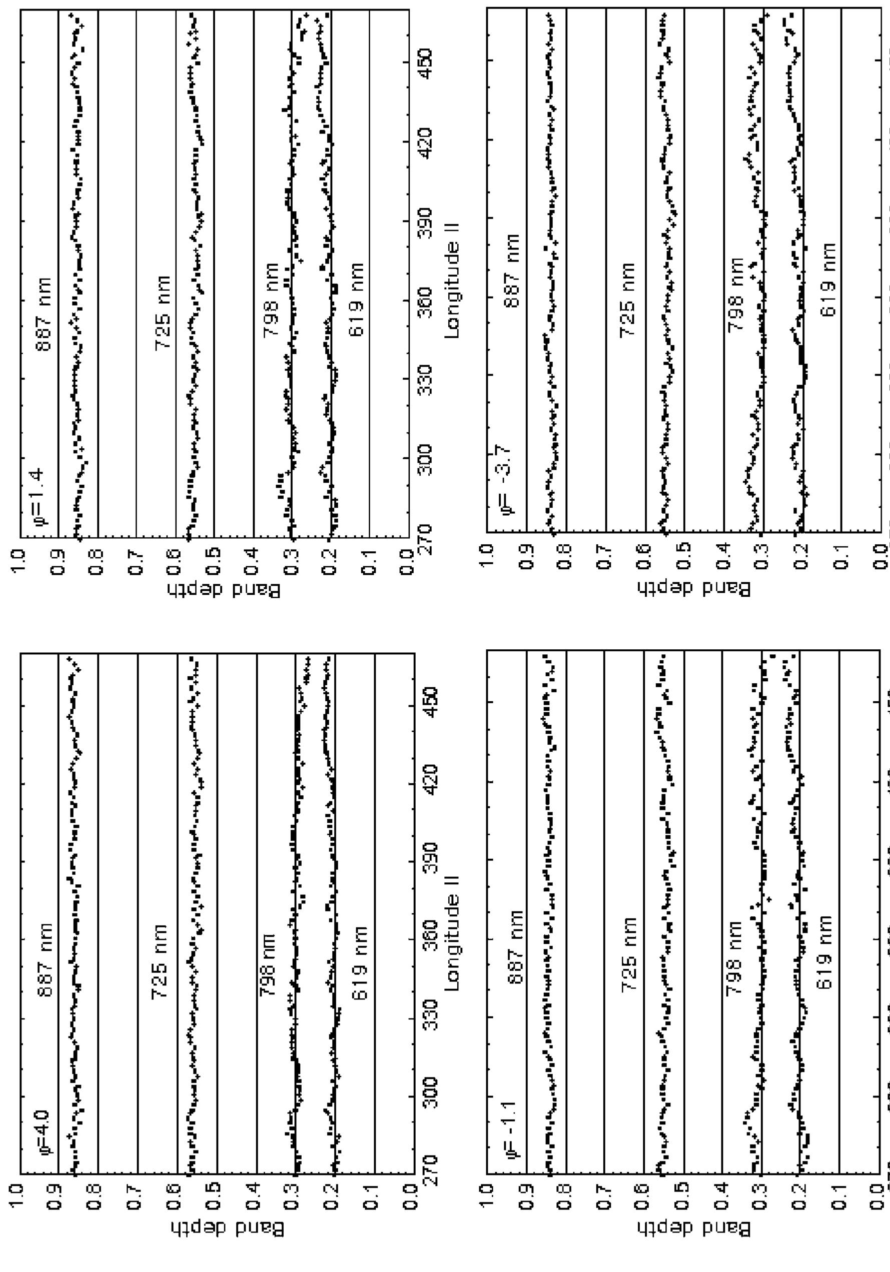

FIGURE 5 Fragment of the atlas of latitudinal–longitudinal variations in the absorption band depths R_v on Jupiter in 1999.

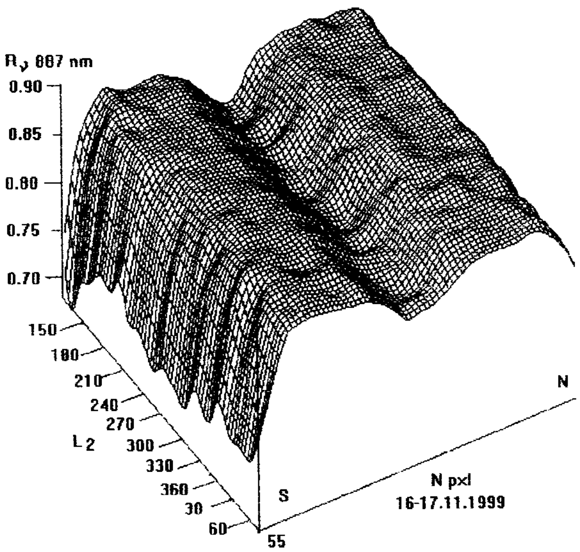

FIGURE 6 Three-dimensional graph of the latitudinal–longitudinal variations of the 887 nm absorption band depth R_ν on Jupiter.

3 SATURN

Unlike Jupiter, Saturn is significantly more strongly subject to seasonal variations, as the tilt of the equator of the planet to the orbital plane is nearly 27°. The presence of the rings, which shield part of the solar radiation, creates an additional reduction in the influx of solar energy in a 'winter' hemisphere. Equality of conditions of insolation for both hemispheres occurs once in 15 years, when the rings of the planet are oriented in an 'edge-on' manner to the Sun. It is exactly these moments that present most interest for study of the possible differences between atmospheric conditions in the northern and southern hemispheres. The most favourable possibilities for such observations were in 1995, when it was possible to carry out zonal spectrophotometry of Saturn with a 1 m telescope using a CCD camera

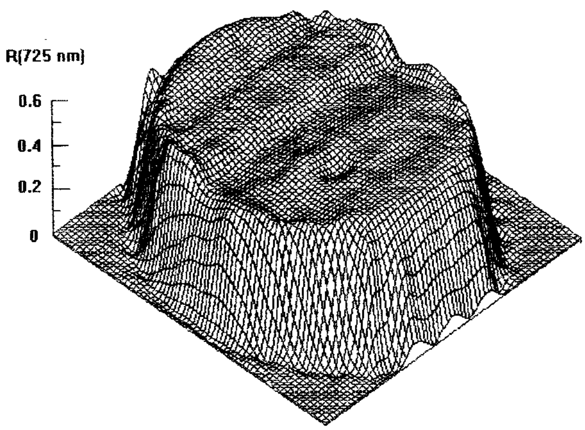

FIGURE 7 Three-dimensional graph of the absorption distribution on Jupiter's disc at the 725 nm band.

and spectrograph (Tejfel, 1997a,b). The zonal profiles of the absorption band depths R_v obtained show that for most zones (measurements were made for eight to 16 zones) a distinctive small strengthening in absorption from the central meridian to the edges of the disc was observed. It is less than the absorption variations on changing the latitudes, which were defined from both the zonal spectra and Saturn's central meridian spectra.

Latitudinal differences in the methane absorption on Saturn's disc show high asymmetry in the values of absorption between the northern and southern hemispheres. The equatorial belts of both Jupiter and Saturn are characterized by the least absorption; moreover this minimum absorption occurs for all the methane bands (Figures 8 and 9). Strengthing absorption towards the midlatitudes in the northern and southern hemispheres occurs differently; both in 1995 and in 1966 ('edge-on' situation), absorption in the northern hemisphere was much greater than it was in the southern hemisphere. An inverse picture was observed in 1979 (West *et al.*, 1982), when the slope of the equator was not zero, but small enough to make a comparison of the hemispheres. From the observations in 1980 (Vidmachenko, 1984), absorption in the southern hemisphere of Saturn was also higher. This is a very important result, the confirmation of which in 2010 (during the next orientation of the rings is an 'edge-on' manner to the Sun and the Earth) will be of great significance.

Latitudinal variations in R_v in 1995 turned out to be very different between the northern and southern hemispheres; a steeply-increasing absorption in the northern hemisphere occurs in the latitude interval from 2 to 28°, and then from the latitude $+30°$ the increase in absorption becomes gently sloping. In the southern hemisphere a sharply increasing absorption is observed in the latitude interval from 0 to $-20°$, and then from latitude $-40°$, while in the latitude range from -20 to $-40°$ a more gently sloping absorption takes place (Figures 8 and

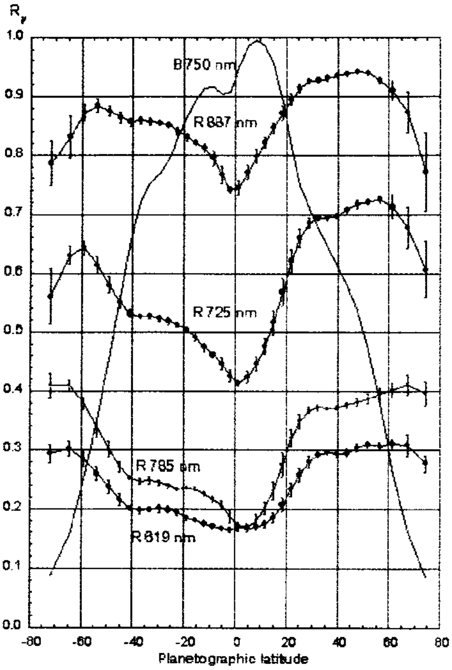

FIGURE 8 The latitudinal variations in the absorption on Saturn's central meridian in 1995 (during the 'on-edge' orientation of the rings).

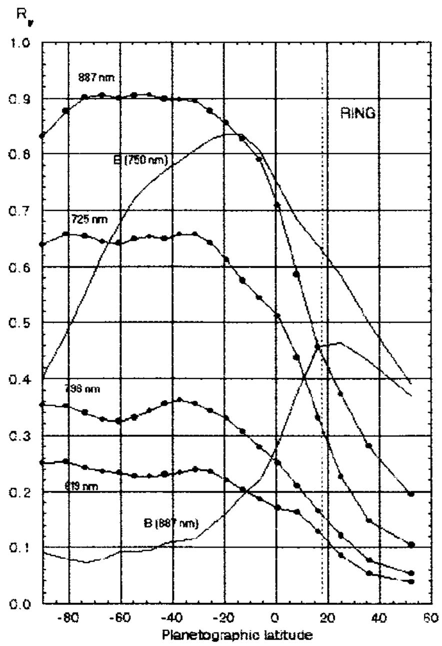

FIGURE 9 The latitudinal variations in the absorption on Saturn's central meridian in 2001.

10). A sharp increase in R_v towards the south pole does not occur only in the absorption band at 887 nm.

4 CONCLUSIONS

In this paper, we have only described the observed particularities of the molecular absorption latitudinal variations over Saturnian and Jovian discs and compared them. All the obtained data show that the Saturnian latitudinal changes in the residual intensities (or the depths R_v) of the absorption bands are expressed much more strongly than Jovian changes, as well as asymmetrical latitudinal variations in R_v in the northern and southern hemispheres. In general, the methane absorption bands in the spectrum of Saturn have greater intensities

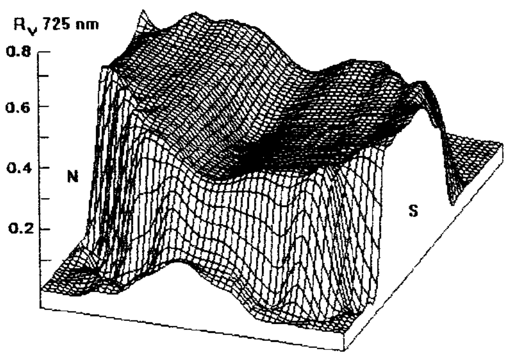

FIGURE 10 Three-dimensional graph of the absorption distribution on Saturn's disc at the 725 nm band in 1995.

than in the spectrum of Jupiter. At least, one can partly explain this phenomenon as the result of the somewhat greater thickness of the gaseous atmosphere (above the clouds), as judged by the strengthing of the bands observed towards the edges of the disc of Saturn. On Jupiter, however, weakening absorption to the limb is observed, which is due to the multiple scattering effect in an optically thick cloud cover. The seasonal variations in absorption on Saturn excite particular interest, for they probably influence the observed asymmetry of the optical characteristics between the northern and southern hemispheres of the planet. Because of significant (nearly 27°) tilt of the rotation axis, one of the hemispheres is in a less favourable regime of insolation for most of the time; as a result of this, together with a lower luminosity from the Sun because of the greater angles of descent (when counting from a local vertical), an essential part of the solar radiant energy flux is shielded by the rings of Saturn. This regime of irradiation influences the atmospheric states in the appropriate hemisphere and, because relaxation is slowed, that state does not have time even to become in the same atmospheric state as the opposite hemisphere at the moment when both hemispheres are subject to the same irradiation. Most probably, that is the reason for the observed asymmetry between the optical characteristics of the hemispheres during periods when the orientation of the rings is 'edge on' to the Sun. With respect to this, the year 2010 will be particularly important as we shall then have the possibility to make sure that the change in the nature of asymmetry between the hemispheres, depending on which had been 'winter' and which had been 'summer,' really occurs. All these data confirm the need to continue careful studies of the behaviour of the molecular absorption bands on discs of the giant planets. Later it can serve as a good indicator of the state and instability of a planetary atmosphere in realizing a planetary monitoring programme, with the aim of studying climatic changes on the planets of the Solar System (Tejfel, 1997b; Korablev *et al*., 2001).

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