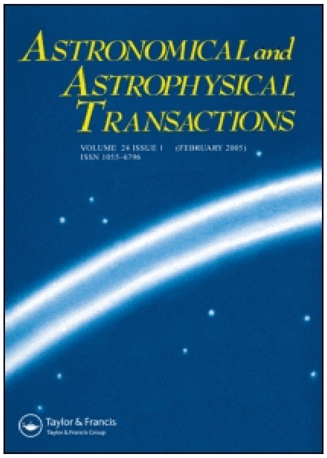

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Spatially resolved variations in the methane and ammonia absorption in the atmosphere of Jupiter

V. G. Tejfel [a]; V. D. Vdovichenko [a]; G. A. Kirienko [a]; G. A. Kharitonova [a]; N. V. Sinyaeva [a]; A. M. Karimov [a]
[a] Fesenkov Astrophysical Institute, Almaty, Kazakhstan

Online Publication Date: 01 August 2005
To cite this Article: Tejfel, V. G., Vdovichenko, V. D., Kirienko, G. A., Kharitonova, G. A., Sinyaeva, N. V. and Karimov, A. M. (2005) 'Spatially resolved variations in the methane and ammonia absorption in the atmosphere of Jupiter', Astronomical & Astrophysical Transactions, 24:4, 359 - 363
To link to this article: DOI: 10.1080/10556790500487239
URL: http://dx.doi.org/10.1080/10556790500487239

Astronomical and Astrophysical Transactions
Vol. 24, No. 4, August 2005, 359–367

Taylor & Francis
Taylor & Francis Group

Spatially resolved variations in the methane and ammonia absorption in the atmosphere of Jupiter

V. G. TEJFEL*, V. D. VDOVICHENKO, G. A. KIRIENKO, G. A. KHARITONOVA, N. V. SINYAEVA and A. M. KARIMOV

Fesenkov Astrophysical Institute, 050020 Almaty, Kazakhstan

(Received 19 October 2005)

A brief review of recent studies of the variations in the methane and ammonia absorption band over the disc of Jupiter carried out at the Fesenkov Astrophysical Institute observatory, with a spectrometer equipped with a charge-coupled device camera is given.

Keywords: Methane absorption; Ammonia absorption; Jupiter

1. Introduction

In 1917, in *Publications de l'Observatoire Astronomique de l'Université de Kharkow*, one of the first papers (it might even be the first) by V.G. Fesenkov [1] was published. It was especially devoted to investigations of the planet Jupiter. At the Astrophysical Institute that was founded by V.G. Fesenkov and is now named after him, investigations of Jupiter and other giant planets have already been carried out for more than 50 years. The behaviour of molecular absorption bands over the discs of Jupiter and Saturn is the main topic of these investigations. Methane and ammonia are the main gaseous components (after hydrogen and helium) in the Jovian atmosphere which may be easily detected from spectral observations (figure 1).

Their mixing ratios are small (0.07% of methane (CH_4) and 0.01% of ammonia (NH_3)). However, since methane and ammonia gases have moderate and strong absorption bands in the visible and near-infrared spectra of their atmospheres, then, by studying the variations in those band intensities over the disc of a planet, we can carry out remote sounding of the gaseous and aerosol layers of its atmosphere at the troposphere and lower stratosphere levels. It should be noted that, even using a 60 or 100 cm telescope equipped with a spectrometer, we have the opportunity to study systematically the variations in the absorption bands with latitude and time. These variations reflect the instability of the atmospheric structure at different latitudes of the planet, and their investigation allows us to specify some criteria so that the planetary

*Corresponding author. Email: tejf@hotmail.com

Astronomical and Astrophysical Transactions
ISSN 1055-6796 print/ISSN 1476-3540 online © 2005 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/10556790500487239

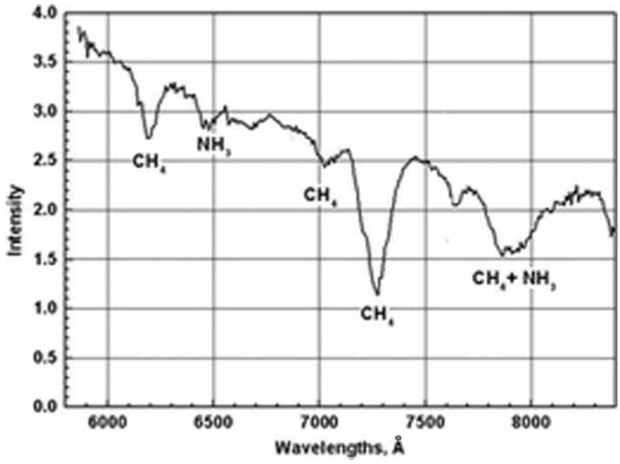

Figure 1. An example of the Jupiter-to-Saturn ring spectral ratio at 580–840 nm.

state can be estimated. We need those criteria for both ground-based and space planetary monitoring in the future.

2. The goals and observational technique

A main goal of the spectrophotometry of Jupiter, which has been carried out recently (with the use of the 0.6 m Cassegrain telescope and the SGS grating spectrograph equipped with an ST-7XE charge-coupled device (CCD) camera) is a systematic study of the variations in the molecular absorption band of the discs of Jupiter and Saturn. These variations may be connected with changes in the microphysical structure, height and volume density of the clouds in different parts of the planet. On each observation date, we recorded the spectra when the entrance slit of the spectrograph was oriented along Jupiter's central meridian (CM). As a rule, each smallest data set contained five or more spectrograms. So, a number of such data sets

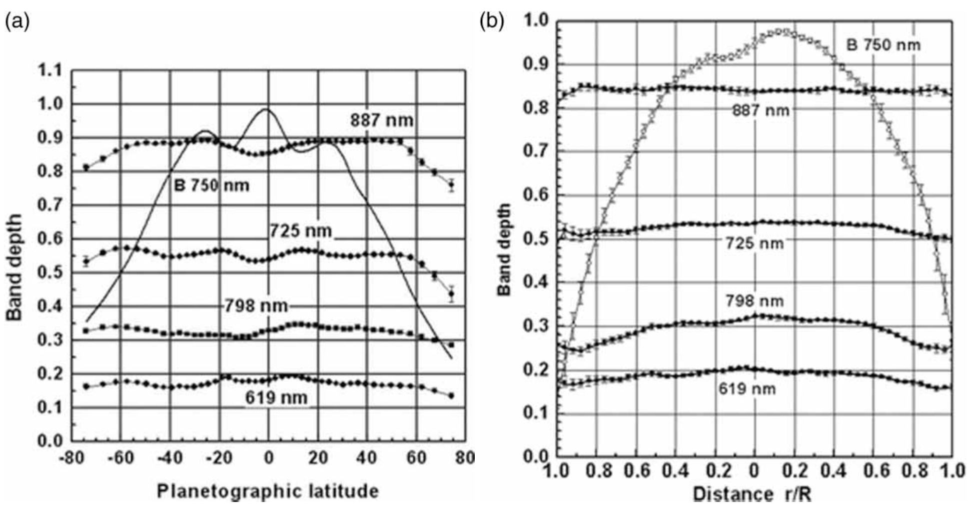

Figure 2. (a) Latitudinal and (b) equatorial variations in the methane absorption bands on Jupiter, observed on 26–27 February 2003.

were obtained nightly, as well as the spectra of Jupiter's equatorial belt. Subsequently, data reduction was performed including measurements of the profiles, central depths and equivalent widths of the methane and ammonia absorption bands in the wavelength range 580–800 nm. The average distributions of absorption along Jupiter's meridian and equator were derived from these data (figures 2(a) and (b)).

3. The latitudinal variations in methane absorption

From the results of a great number of observational data obtained in 2004, a graphic atlas containing latitudinal variations in the absorption on Jupiter (about 100 pages) has been compiled. Some of these data are presented in figures 3 and 4.

The data in these graphs were also presented in the form of computer animations to show time–longitudinal differences between the absorption distributions along Jupiter's CM and

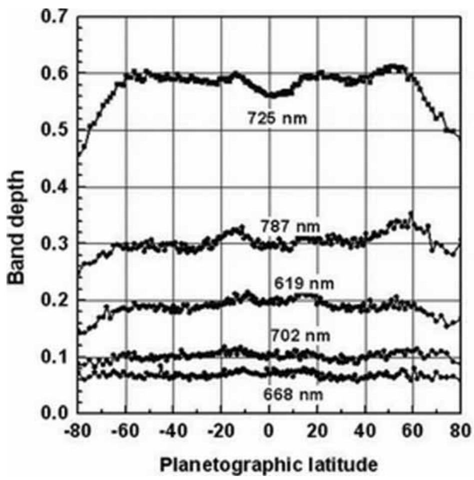

Figure 3. Part of the atlas of the latitudinal variations in methane absorption on Jupiter, observed on 22–23 March 2004.

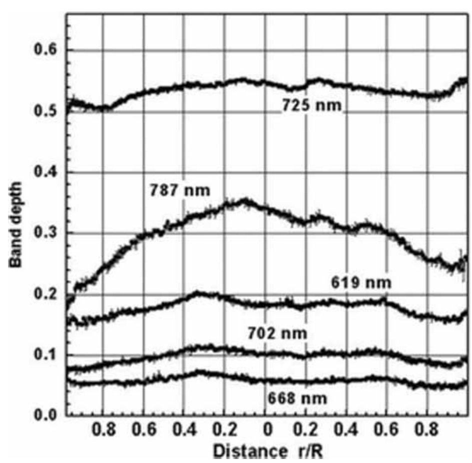

Figure 4. Part of the atlas of the equatorial variations in methane absorption on Jupiter, observed on 27–28 March 2004.

equator. From these data, as well as from a preliminary analysis of the 2003–2005 observations, we can see that the zonal character of the absorption variations remained from year to year for the most intensive methane absorption bands. A reduction in the absorption in the equatorial belt is usually seen, and an increase in absorption at temperate and high (subpolar) latitudes but a sharp decrease in absorption near the poles are seen.

For the weak and moderate absorption bands formed at large effective optical depths in the atmosphere, we can observe sharper but less regular variations connected with local inhomogeneities in the Jovian clouds. At the equatorial belt, the variations in methane absorption in the weak and moderate bands reveal, in general, a decrease from the disc's centre to the limb. This indicates the important role of multiple scattering in the clouds. Pure absorption inside the clouds of large optical thickness causes the visible intensity of the band to decrease at the limb's edges, contrary to the situation when all the molecular absorption is formed above the clouds, in a pure gaseous atmosphere.

4. Zonal and longitudinal variations in the methane absorption

Spectrography of the Jovian CM is not a unique way to study the latitudinal motions of absorption and reflectivity although it is simple and fast. In 1997, we suggested and tested another method that could be applied to Jupiter and Saturn. It is called zonal spectrophotometry, when the entrance slit of a spectrograph (parallel to the equator) was moved on the disc from one pole to another. Thus, we obtained about 100 spectrograms of separate planetary zones which allowed us not only to investigate absorption variations along the CM but also to watch the absorption distribution from one edge of the disc to the other. Of course, that method requires a longer observational time but, on the other hand, it gives quite more information about space variations in absorption and other reflection characteristic space variations over the planetary disc. The 0.6 m telescope has no electronic control, and a small error in setting the polar axis of the telescope caused a slow movement of the image of the planet on the slit of the spectrograph along declinations. It was used for scanning the planetary disc. If necessary, a small adjustment of the clockwork quartz generator of the telescope could allow us to achieve slow scanning along hour angles. In that case the slit was oriented parallel to the rotation axis of the planet, and scanning was carried out from the east limb to the west limb (or vice versa). One advantage of zonal spectra is that there is the possibility of measuring

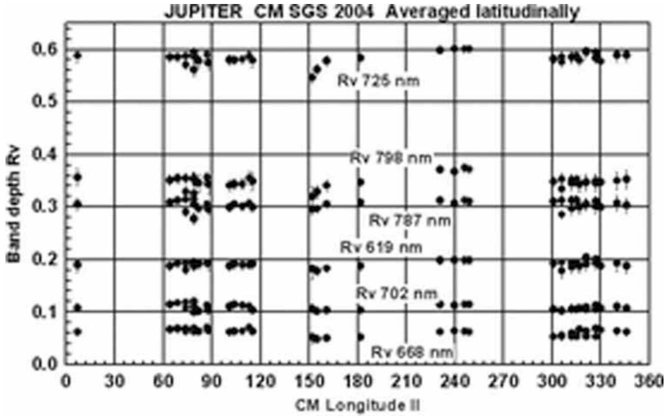

Figure 5. Longitudinal variations in the latitudinally averaged methane absorption in 2004.

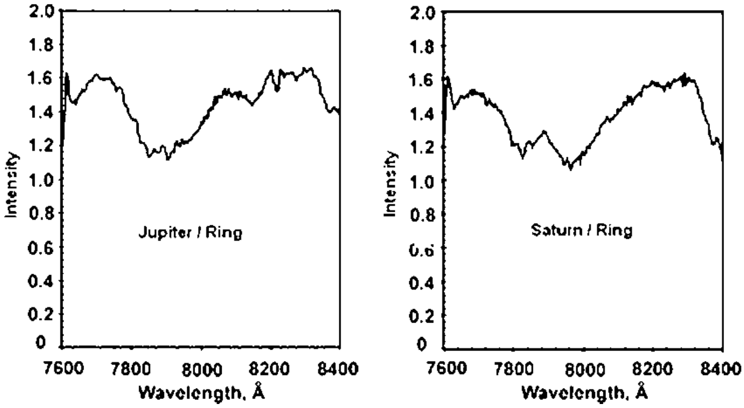

Figure 6. The methane–ammonia absorption band centred at 787 nm in the spectra of Jupiter and Saturn.

the absorption band parameters not only at a single point, as in the spectrum of the CM, but also, in any case, at five or more points which are adjacent to the CM where the limb effects no longer influence these parameters. Thus, we can obtain a more exact average estimate of absorption at a latitude, together with some estimate of the local dispersion of the values. In order to see how large the longitudinal variations in absorption over the whole disc of Jupiter are, the central depths of the methane absorption band at the CM, taken from the 2004 data, were averaged for each latitude, and these were plotted versus the CM longitudes in the II Jovian rotation system (figure 5).

It can be seen that there are no distinct changes in the longitudinal motion of absorption, although there are some deviations (oscillations), but they are within the usual dispersion of individual values of the absorption band depths. It should be noted that the past data had also shown a rather smooth longitudinal motion of absorption on Jupiter (figure 6 in [2]). In that figure the latitude–longitudinal variations in absorption at the 887 nm methane band were presented in a three-dimensional view. In principle, by carrying out special observations with almost continuous recording of the Jovian CM spectra, one could solve the problem of Jovian seismology about possible large-scale wave processes on the planet, which is currently being discussed. However, there are still no definite data which indicate such processes.

5. The latitudinal variations in ammonia absorption

The methane absorption bands in the Jovian spectrum are more intensive than the ammonia absorption bands; moreover, the ammonia bands often overlap methane bands; so their separation is somewhat difficult, and this complicates the investigation of variations in ammonia absorption over the planetary disc. Therefore, there have been too few studies in which spatiotemporal variations in ammonia absorption have been investigated. Evident latitudinal distinctions in the motion of ammonia absorption over Jupiter's disc were revealed as a result of Voyager 1 data [3] and Hubble Space Telescope observations [4].

In order to solve that problem in some way, we used the fact that ammonia absorption in the visible and near-infrared spectra of Saturn is almost absent or is very small. So, if one takes the ratio of the absorption in the Jovian spectrum to that in the Saturnian spectrum, then the following will be obtained. Since the methane absorption bands for Saturn are more intensive than the methane absorption bands of Jupiter, then, in that ratio, the methane absorption spectral region will be brighter than the continuum spectrum.

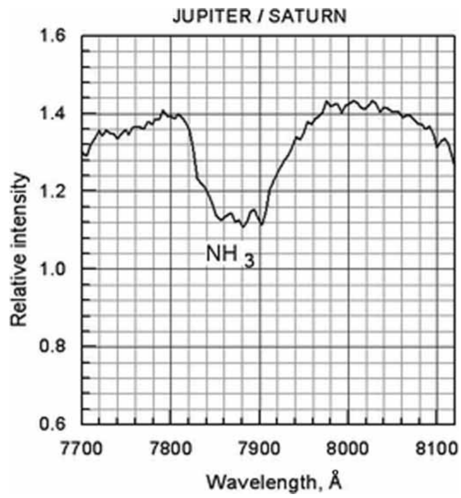

Figure 7. The 787 nm ammonia absorption band, detected by the Jupiter-to-Saturn spectrum ratio.

However, ammonia absorption, compared with that brightening of the spectrum, will be seen as an absorption band whose profile and equivalent width can be measured. In the spectral region of Jupiter, which is studied using the SGS spectrograph, there are two ammonia absorption bands: at 643 and 787 nm [5]. The 787 nm band falls almost in the middle of the methane absorption band. This can be seen from figure 6, where the methane band profiles in the spectra of Jupiter and Saturn are shown. On Saturn that band is seen as double or forked, while on Jupiter its central part is occupied by the ammonia band. The Jupiter-to-Saturn spectrum ratio shows us the ammonia absorption profile near $\lambda = 787$ nm (figure 7).

In order to calculate the ratios, depths and equivalent widths of the ammonia bands, we have made a special program template in Excel. It allows us to accomplish entire reduction of the digital data array of the whole CM or the equator spectrum of Jupiter. More than 200 CCD spectrograms of the CM and equator of Jupiter, obtained in 2004, were processed. Then the equivalent widths of the 643 and 787 nm ammonia absorption bands, which were distinguished by the method described above, were calculated. As a result, a rather strange feature in the distribution of ammonia absorption along the CM of Jupiter was revealed. It looks as if there is a considerable decrease in the absorption at lower and temperate latitudes of the northern hemisphere of Jupiter. The equatorial spectra did not show such a feature. They only showed a more or less uniform absorption decreasing from the centre to the limb. In figure 8 the patterns of absorption distributions (we call them absorption profiles), represented as the average values of five spectrograms, are shown.

Of course, there is the question of whether some instrumental reasons could explain those features, *e.g.* the inhomogeneity of the CCD field (or the CCD-matrix sensitivity) in the direction across the spectral dispersion. For all the spectrograms, the y-coordinate values of the upper boundary of each spectrum were noted. Then computer animations were made where all the absorption profiles derived were used, with the y value labelled on each graph. Those animations convincingly showed that the position of the decrease in absorption was not dependent on the spectrum position in the matrix field, and it was always in the same region of the northern part of the CM. The separate cases of the variations in absorption at the CM of Jupiter are connected with the inhomogeneous structure of the Jovian clouds at that time. In fact, within a time of about 5 min, when a data set of five spectra was recorded, the profiles were found to be similar to each other, but other series could show other features

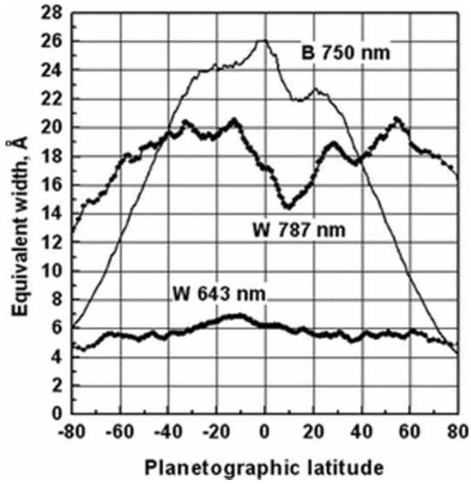

Figure 8. Variation in the equivalent width of the 787 nm ammonia absorption band along the CM of Jupiter, observed on 22–23 March 2004.

on the profiles corresponding to other longitudes (because of the fast rotation of Jupiter), although the main decrease in absorption remained at the same latitudes. It was interesting to examine what had happened on Jupiter in other years. The 1997 and 1998 spectrograms obtained with the 1 m telescope equipped with another spectrograph (ASP-9) and another CCD camera (ST-6V) were processed. The results turned out to be the same. Then we carried out another independent investigation, using another technique. We used two series of CCD spectrograms. Each series consisted of 100 spectra recorded in 2005, when the disc of Jupiter was being scanned from north to south, with the slit oriented parallel to the planetary equator. The points near the CM were chosen in every spectrogram; the measured equivalent widths were averaged. As a result, variations in the absorption along the CM were obtained (figure 9).

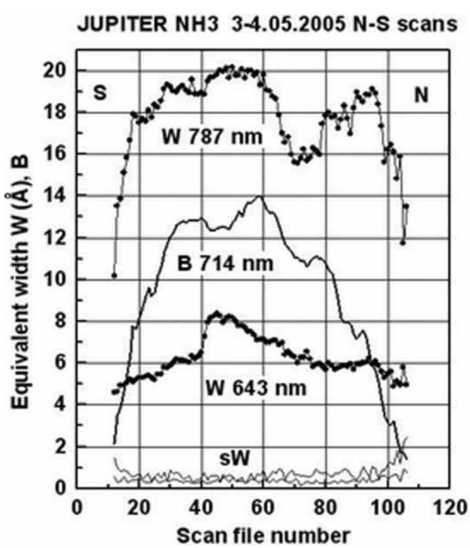

Figure 9. Variations in the 643 and 787 nm ammonia absorption bands along the CM from the spectral scanning of Jupiter's disc on 3–4 May 2005. The brightness profile and standard deviations for the equivalent widths are also plotted.

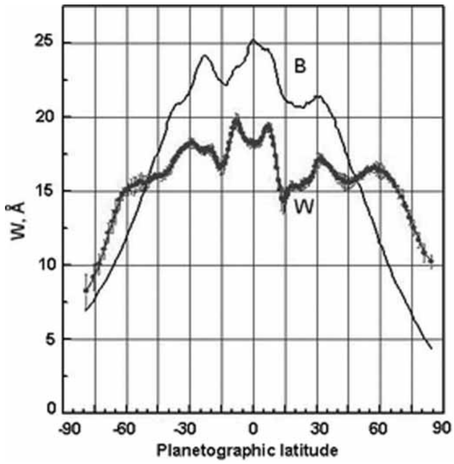

Figure 10. Latitudinal variations in the 787 nm ammonia absorption band and the brightness profile, obtained under good atmospheric conditions on 16–17 April 2005.

It also showed a sharp decrease in ammonia absorption in the northern hemisphere of Jupiter, and with the same amplitude as that observed in 2004. Additional measurements of the CM spectrograms of Jupiter taken between April and May 2005 also distinctly show the absorption decrease at the 787 nm ammonia band in the north equatorial belt. It must be noted that, under the condition of minimal terrestrial atmospheric turbulence, the features of latitudinal variations in ammonia absorption become more prominent, while they are smoother in poorer spectral images of Jupiter. This can be seen from figure 10, where the results of reduction of the six spectrograms of the CM obtained for the best-quality images are presented.

It is necessary to make special investigations to study more definitely the character of the observed variations in ammonia absorption. Only after that can we interpret the formation of the absorption band using the scattering–absorbing atmospheric models. One fact is evident: the gaseous ammonia abundance in the Jovian atmosphere is subjected to large spatiotemporal fluctuations compared with the methane abundance, because the latter is not condensed while ammonia freezes at temperatures typical for the visible clouds of the planet. So, convective motions arising in the Jovian atmosphere lead to noticeable changes in gaseous ammonia concentration because of condensation or evaporation of crystals and liquid ammonia drops. From the images of Jupiter, one can see many photometric inhomogeneities in the cloud structure, and consequently in the microphysical structure, that can cause the observed longitudinal distinctions in the latitudinal distribution of ammonia absorption.

It is interesting that from the radioastronomy data, as shown in [6–8], the ammonia concentration exactly in the north equatorial belt is noticeably lower than in the equatorial belt (by about 30 at the cloud top, at the 300 mbar pressure level). At least, our results described above do not contradict these estimates, although a more detailed comparable analysis has yet to be carried out.

6. Conclusions

The analysis of the Jovian absorption bands measurements performed both in the last few years and previously shows that the variations in absorption are distinctly noticeable, although they do not have a large amplitude. Unfortunately, the ground-based observations are always influenced by turbulence in the Earth's atmosphere. The atmospheric quality of the images influences the spatial resolution of spectrograms, and some absorption fluctuations turn out to be rather smooth. So, while both such systematic research and study of albedo variations over the discs of the major planets are being carried out, the main emphasis must be on observations from space. Even a small telescope equipped with a spectrometer and placed on an orbital station can give much valuable information which is not subject to atmospheric hindrances [9]. The making of such a telescope will have to become the subject of and an urgent task for international cooperation.

Acknowledgements

The authors are very grateful to Dr Neil Bowles for kindly sending us his laboratory data about ammonia absorption which will be used in our future work and to Dr Glenn Orton for presentation of our paper at the 37th Meeting of the Division for Planetary Science, American Astronomical Society, in Birmingham in September 2005.

References

[1] V.G. Fesenkov, Publns Obs. Astron. Univ. Kharkow **9** 225 (1917).
[2] V.G. Tejfel, V.D. Vdovichenko, G.A. Kirienko and G.A. Kharitonova, Astron. Astrophys. Trans. **22** 135 (2003).
[3] P.J. Gierasch, B.J. Conrath and J.A. Magalhaes, Icarus **67** 456 (1986).
[4] S.G. Edgington, S.K. Atreya, L.M. Trafton, J.J. Caldwell, R.F. Beebe, A.A. Simon, R.A. West and C. Barnet, Icarus **133** 192 (1998).
[5] V.G. Tejfel, A.M. Karimov and V.D. Vdovichenko, Bull. Am. Astron. Soc. **37** 30 (2005).
[6] I. Pater, D. Dunn, K. Zahnle and P.N. Romani, Icarus **149** 66 (2001).
[7] R.J. Sault, E. Chermelle and I. de Pater, Icarus **168** 336 (2004).
[8] A.P. Showman and I. de Pater, Icarus **174** 192 (2005).
[9] V.I. Moroz, O. Korablev, G. Avanesov, V. Rodin, G. Bellucci, V. Tejfel and A. Vidmachenk, *Proceedings of the 34th COSPAR Scientific Assembly*, Houston, Texas, USA, 2004 (2004), pp. 2201.