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JUPITER: ZONAL SPECTROPHOTOMETRY OF WEAK AMMONIA ABSORPTION BANDS IN 2018

Abstract. Based on measurements of zonal spectrograms obtained by scanning the Jupiter disk in March – June 2018, the profiles of the 645 and 787 nm weak absorption bands of NH3, and the character of the zonal absorption variations at different latitudes are derived. A standard has been prepared for processing and analyzing data in relation to further studies of possible seasonal and sporadic variations based on Jupiter's spectral observations for the full period of its rotation around the Sun. The zonal and latitudinal variations of ammonia absorption are shown. As in previous years, the NH3 absorption depression is particularly prominent at the latitude of about + 150 in the NEB region. As in previous years, some differences in the latitudinal absorption of the 645 and 787 nm NH3 bands remain.

Keywords: Jupiter, Atmosphere, Clouds, Ammonia, Methane, Molecular Absorption Bands, Spectrophotometry.

Introduction

Ammonia in the atmosphere of Jupiter, despite a low relative abundance, plays a decisive role as the main cloud-forming factor in the upper troposphere. In the program of atmospheric research of Jupiter, which we carry out, special attention is now being paid to studying the behavior of the absorption bands of ammonia in the visible and near infrared region of the spectrum. These are two fairly weak bands in the region of the wavelengths of 645 nm and 787 nm. The bands are weak in intensity and very little have been studied so far, since no special observations of these bands have actually been made. The exception is a lot of data, possibly unique, from Jupiter's spectrophotometric observations, which we have carried out since 2004. We obtained the uniform observational data with a single technique during the full 12-year period of Jupiter's revolution around the Sun, which makes it possible to trace certain seasonal changes in the atmosphere and in the cloud layer of the planet. Some results, but far from all ones, have been published recently [1- 4].

The program of research of ammonia absorption on Jupiter as well as the characteristics of the planet's atmosphere depending on it, should cover a long period. Therefore, in order to preserve the homogeneity of the observation and processing, a standard procedure has been developed for the general problem of studying molecular absorption and atmospheric structure from spectral observations. This technique is described here using the example of processing one of the Jupiter scans received in 2018.

There are no descriptions of the observations of these two absorption bands of ammonia on Jupiter in the literature for the last decades. But it does not mean the absence of considerable attention to the problem of studying ammonia absorption on this planet. A whole series of works was carried out, one way or another, related to the content of ammonia and its variations in the atmosphere of Jupiter. The fact is that the absorption of radiation by NH_3 molecules can significantly affect the passage of infrared or microwave radiation in the Jupiter troposphere in those areas of the electromagnetic spectrum where there are fairly intense NH_3 absorption bands. An example of this is the observation of long waves of microwave radio emission in the region of 8–12 GHz [5-6]. In addition, both molecular absorption by gaseous ammonia and the cloud layer in the upper troposphere, consisting mainly of crystals of frozen NH_3, affect the transmission and output of infrared radiation in the 4÷8-micron range [7-13].

Studies of the behavior of the weak absorption bands of ammonia (NH_3 535, 645 and 787 nm) give some possibilities for optical sounding of the Jovian troposphere. Their formation occurs both inside the ammonia cloud layer and in deeper layers of the atmosphere. But there is some peculiarity in the conditions of their formation. Unfortunately, so far there have been a little laboratory studies of these bands [14-15]. Recently, in 2018, two publications were published [16-17]. But still, no completely reliable values of absorption coefficients have been obtained for these bands. This is due, in particular, to their complex rotational-vibrational structure.

Observations

The observations of Jupiter described here, were made on the night of 9 to 10 of May 2018, using an SGS diffraction spectrograph with a ST7-XE CCD camera installed in a 7.5-meter Kassegren focus of the 0.6-meter telescope RZ-600. The CCD matrix consists of 765x550 elements-pixels of 9x9 microns in size. The spectrograph dispersion is 4.3 Angstroms per pixel. An entrance slit width of 25 micrometers provides a resolution of about 8 Angstrom along wavelengths, and a formal resolution on the image of the planet is about 0.65 angular seconds. The actual resolution in the image, of course, is worse due to the influence of atmospheric turbulence. In the image of the spectrum, the scale is 4.08 pixels for 1 arc second.

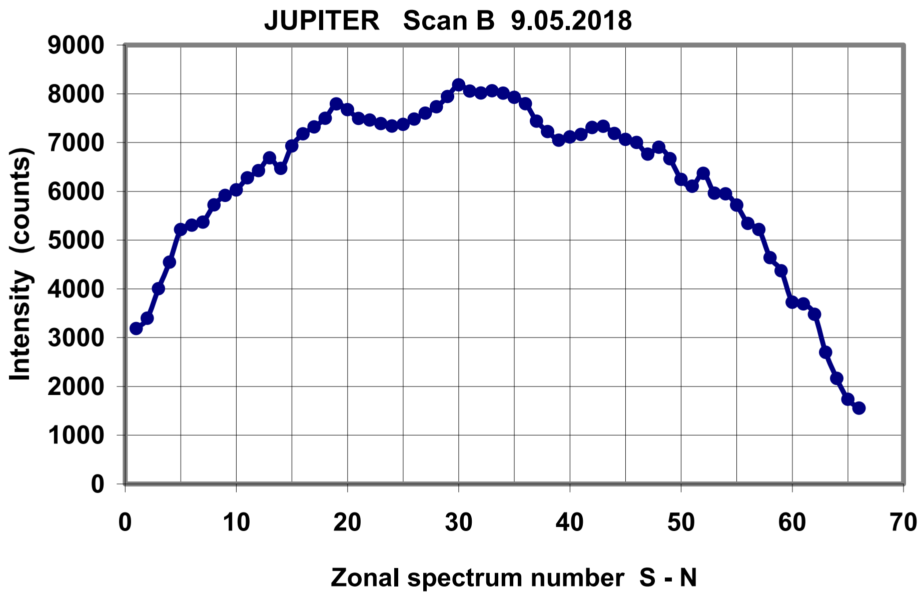

Figure 1 - Photometric profile of Jupiter’s disc scan. Each point corresponds to a separate zonal spectrogram

The entrance slit of the spectrograph was oriented parallel to the planet's equator, and when scanning the Jupiter disk, 66 zonal spectra were obtained from the South to the North Pole. Figure 1 shows the brightness profile along the central meridian of Jupiter, constructed from the intensity readings in each of the spectra.

The duration of exposure of each spectrum was 20 seconds, and the entire scanning process lasted 24 minutes. During this time, Jupiter rotates by 15 degrees, so the observations belong to the visible hemisphere of Jupiter with the longitude of the central meridian of 220 ± 7 degrees in the 2 rotation system. Figure 2 shows a longitudinal sweep map in Jupiter’s second rotation system [18], where the longitude interval of the central meridian during the scan period and the entire longitude interval covered by the zonal spectra, are marked.

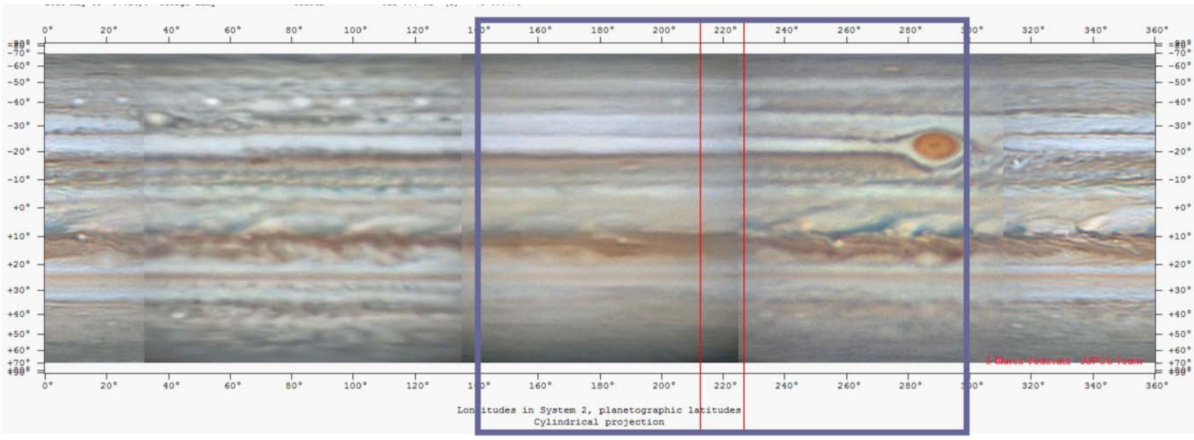

Figure 2 - The scanned region of Jupiter on the map for May 2018 (ALPO Japan)

Spectrogram processing

We perform the initial digitization of spectrograms using the standard program for CCD Camera. An area of 765x220 pixels is selected. The resulting digital array is transferred to an Excel spreadsheet, where a wavelength calibration is performed so that H-alpha line of the Fraunhofer spectrum always falls on the same line number. Then the array is transferred to the processing Excel-program. All further operations are carried out in this program automatically up to the output of the corresponding resulting graphs. The processing includes following stages: background accounting, calculation of the relation to the reference spectrum, interpolation of the continuous spectrum in the region of the molecular absorption bands of methane and ammonia for further calculation of the profiles of these bands in units of residual intensity. Then, for each band, the absorption band equivalent widths are calculated for each point of the zonal profile of the Jupiter disk. All this is done within the same file pertaining to the same spectrogram. In this way, the plots of the absorption band equivalent widths course along one or another zone are obtained. We show some examples of such graphs in Figure 3.

Separation of the NH_3 645 and 787 nm absorption bands is a complicated enough procedure, since both of these bands overlap with the absorption bands of methane. The 645 nm band falls on the weak wing of the methane absorption band, so that its separation is carried out simply by interpolating the methane band profile, which is almost linear in that spectral region, which the ammonia band profile belongs to. For similar spectral regions, the spectrum of the Saturn ring is used as a reference, because it does not contain any absorption bands. For the 787 nm band, which falls in the middle of the more intense methane band, we used the spectrum of the center of the Saturn disk as a reference. This spectrum also contains methane absorption bands, but ammonia absorption is practically absent there, so the ammonia band profile stands out in the relation of the Jupiter spectrum to the Saturn's one, as described in [2]. At the time, it was paid attention to the presence of the ammonia band in the relation of the Jupiter spectrum to the Saturn's one [19], but no special measurements of this band were made. The results obtained for each spectrum are then transferred to another summary table for the derivation and comparative analysis of absorption variations at different Jupiter latitudes.

The absorption bands profiles

From each zonal spectrogram, profiles of ammonia absorption bands in units of residual intensity were obtained. From them we calculated equivalent widths of the bands. To study the latitudinal absorption of ammonia on each zonal spectrum, we selected and averaged equivalent widths over ten pixels corresponding to the position near the central meridian of Jupiter. These results are presented as a set of 66 profiles for each of the two NH_3 bands. We show the absorption band profiles for zones with numbers 25, 30, 35, 40 in Figures 3 and 4 as the samples.

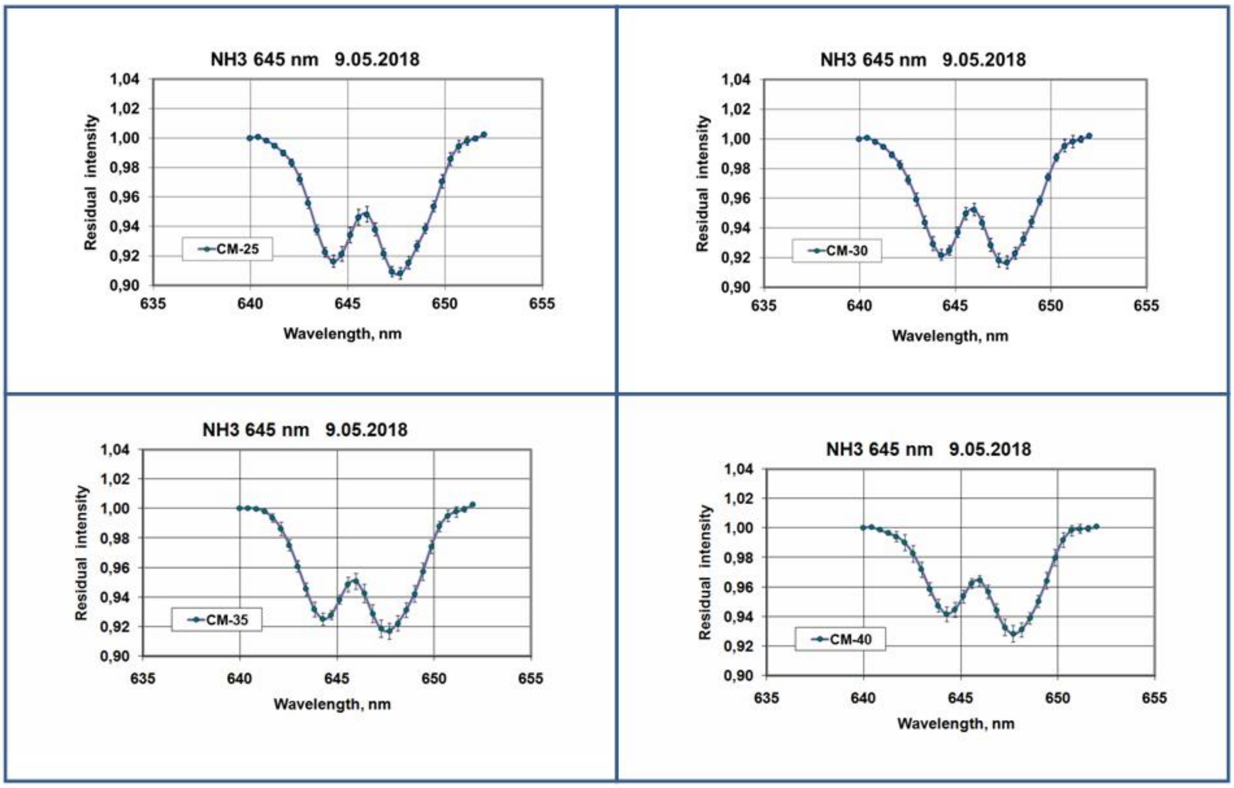

Figure 3 - Fragment of a set of profiles of the 645 nm absorption band

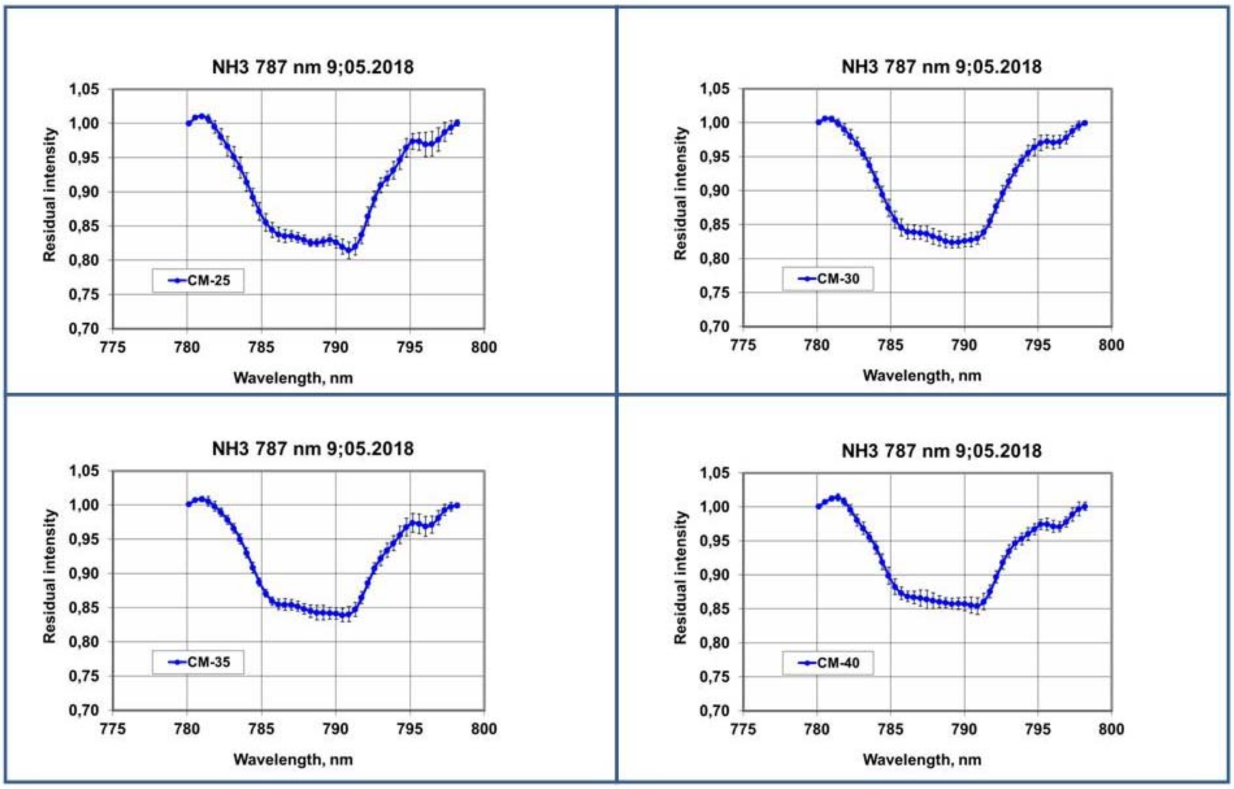

Figure 4 - Fragment of a set of profiles of the 787 nm absorption band

To compare the profiles of the studied lines, we selected seven of them, corresponding to the seven following belts and zones of Jupiter: southern temperate belt (STB), southern tropical zone (STrZ), southern equatorial belt (SEB), equatorial zone (EZ), northern equatorial belt (NEB), northern tropical zone (NTrZ), and Northern temperate zone (NTB). The comparison results we present in Fig. 5 and 6. These figures show a pairwise comparison of the absorption bands corresponding to the symmetric zones or belts. One can see that the both absorption bands corresponding to the Northern Equatorial Belt (NEB), have the lowest intensities.

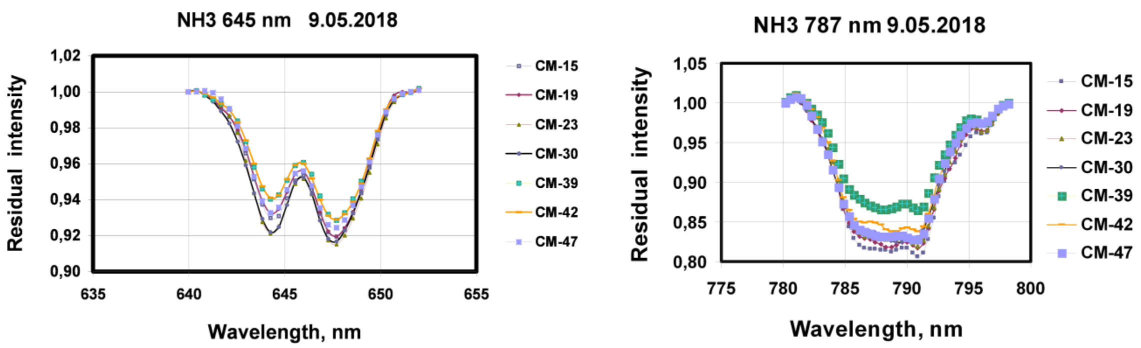

Figure 5 - Comparison of the profiles of the NH_3 absorption bands for 7 Jupiter belts and zones (STB, STrZ, SEB, EZ, NEB, NTrZ, NTB) at the central meridian

Zonal variations of the ammonia absorption

The main objective of this study is primarily considering the behavior of ammonia absorption during the transition from the central meridian to the edges of the Jupiter disk within each of the zones (or belts). In our previous publications [1-2], we have already noted that the intensity of the weak NH_3 absorption bands decreases to the limb rather steeply, so that the zonal absorption variations differ from the latitudinal variations observed along the central meridian, where the decline occurs mainly at high latitudes.

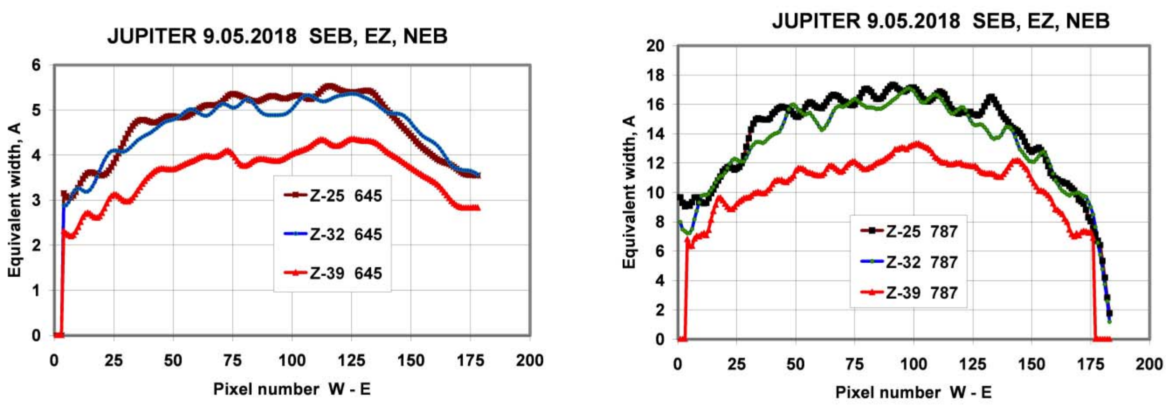

Figure 6 - Comparison of profiles of the ammonia absorption zonal variations in the three Jupiter belts (SEB, EZ and NEB)

A decrease in the absorption to the edges of the disk is observed for all zones of Jupiter and is inherent to the studied weak molecular absorption bands of 645 and 787 nm of ammonia and 702 and 619 nm of methane. The formation of weak absorption bands occurs mainly in the Jupiter troposphere inside the upper cloud layer. If the cloud cover optical thickness is large enough, the multiple light scattering on cloud particles plays an important role, because this increases the optical absorption path in the gaseous medium. Theoretical calculations show that, with the approach to the edges of the planet's disk, the number of scattering events decreases and, accordingly, the effective optical absorption path decreases.

In fact, those things are not so simple. While we cannot exclude the fact that the ammonia cloud layer has a finite optical thickness, and absorption in weak bands also occurs in a sub-cloud layer of pure gas. In addition, large-scale images from the JUNO space probe, which is next to Jupiter, indicate a very complex horizontal vortex and turbulent cloud structure of Jupiter [16]. Therefore, many of the effects observed in the cloud zones of Jupiter may manifest themselves differently depending on the scale and spatial resolution.

Latitude variations of ammonia absorption

The study of latitudinal differences in intensities of the ammonia absorption bands one can carry out in two ways: by zonal spectra and by the spectra of the central meridian, when the spectrograph slit is oriented in the south-north direction. In digital arrays derived from zonal spectrograms, we selected and averaged the values of equivalent widths of the ammonia bands near the central meridian (10 points on each side). Within these longitude intervals, the absorption is almost the same, so averaging just gives a smaller random scatter of estimates. Figure 7 presents absorption graphs for each ammonia band, indicating standard deviations. One can see that they are small, whereas the resulting latitudinal differences in some zones clearly superior to them. This figure also shows the meridional course of brightness in the continuous spectrum. We recall that each point on the curves corresponds to a separate zonal spectrogram.

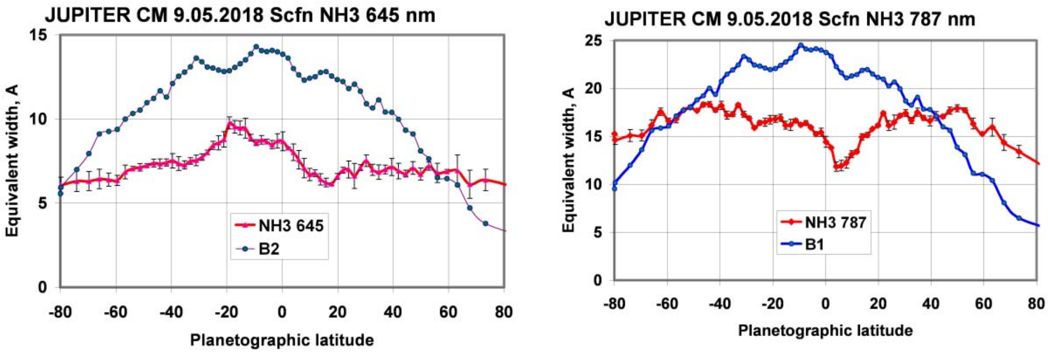

Figure 7 - Variations of equivalent widths of the ammonia absorption bands in latitudes at the central meridian of Jupiter from measurements of zonal spectrograms

Interestingly, the latitudinal courses of intensities of the two ammonia absorption bands always show very noticeable differences, as one can see, for example, from figure 8. In that figure there are the both bands' variations normalized to the equatorial zone and shown in the scale of planetographic latitudes. Here one can see the mismatch of absorption minima located north of the equator. In the NH_3 787 nm absorption band, the minimum occurs at a latitude of about 15 degrees, and in the NH_3 645 nm band it is shifted to the north, i. e. to a latitude of about 20 degrees. From radio observations of Jupiter in the microwave spectrum [6], the researchers also note that the minimum of ammonia absorption, which corresponds to the maximum output of thermal radio emission, falls not in the middle of the Northern Equatorial Belt (NEB), but on the border between Equatorial zone and NEB.

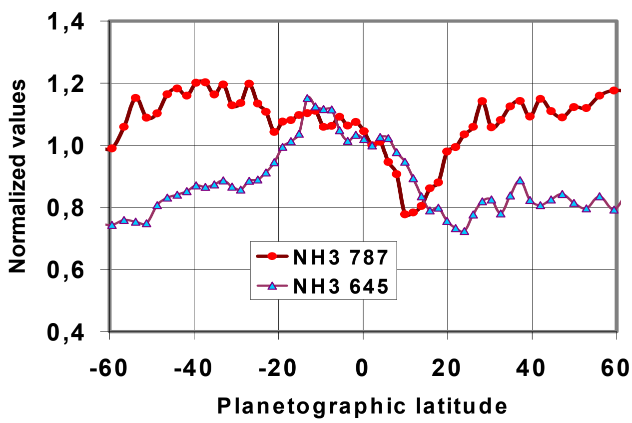

Figure 8 - Comparison of latitudinal variations of equivalent widths of the 645 and 787 nm absorption bands normalized to EZ

Another difference in the absorption latitudinal course is that the 645 nm band has a greater decrease in absorption when moving to temperate latitudes.

Conclusion

Because of a limited scope of this article we cannot present all the results and details of the conducted research. Really, even only the 2018 observational material comprises more than 4,500 spectrograms of individual zones.

There is still a number of problems and tasks, including the search of the most correct methods for the best separation of ammonia absorption from methane one, as well as the problems of interpretation of the obtained data using different models of absorption band formation.

The study of the behavior of the ammonia weak absorption bands is of interest, in particular, because their formation in the cloud layer is most susceptible to the influence of multiple scattering, especially if the optical thickness of the clouds is considered as semi-infinite. But an occasion of the relatively small optical thickness of the cloud layer is also possible. Then the observed features of the absorption bands should be largely determined by their variations in latitude and longitude. The local values of the density and thickness of the ammonia cloud layer must be interrelated with the temperature regime and the concentration of gaseous ammonia. So comprehensive studies in this direction are necessary in the future.

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ЮПИТЕР: ӘЛСІЗ ЖОЛАҚТЫ АММИАК ЖҰТЫЛУЫНЫҢ АЙМАҚТЫҚ СПЕКТРОФОТОМЕТРИЯСЫ

Аннотация. 2018 жылдың наурыз-шілде айларында Юпитер дискасын сканерлеуден кейінгі алынған аймақтық спектрограммалар негізінде әлсіз жұтылу жолақтары NH3 645 және 787 нм кескіндері өлшенді және әртүрлі ендіктегі жұтылудың аймақтық өзгерістерінің сипаттамалары анықталды. Юпитердің толық Күнді айналу периодының спектрлік бақылау мәліметтері бойынша кездейсоқ және мезгілдік мүмкін болатын болашақтағы зерттеулерге қолданылатын мәліметтерді өңдеуге және талдауға арналған әдіснама дайындалды. Ендік және аймақ бойынша аммиактың жұтылуының айнымалылығы көрсетілген. NEB ауданында шамамен +15 градус ендікте NH3 жұтылуының тоқырауы былтырғы жылдағыдай ерекше байқалады. Өткен жылдағыдай, NH3 645 және 787 нм жолақтарының ендік бойындағы жұтылу жолдарының кейбір айырмашылықтары сақталады.

Түйін сөздер: Юптер, атмосфера, бұлт, аммиак, метан, молекулалық жұтылу жолағы, спектрофотометрия.

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ЮПИТЕР: ЗОНАЛЬНАЯ СПЕКТРОФОТОМЕТРИЯ СЛАБЫХ ПОЛОС ПОГЛОЩЕНИЯ АММИАКА

Аннотация. На основе измерений зональных спектрограмм, полученных при сканировании диска Юпитера в марте-июне 2018 года, измерены профили слабых полос поглощения NH3 645 и 787 нм, и выведены характер зональных вариаций поглощения на разных широтах. Подготовлен стандарт методики обработки и анализа данных применительно к дальнейшим исследованиям возможных сезонных и спорадических вариаций по материалам спектральных наблюдений Юпитера за полный период его обращения вокруг Солнца. Показаны вариации аммиачного поглощения по зонам и по широте. Как и в прошлые годы особенно выделяется депрессия поглощения NH3 на широте около +15 градусов в районе

NEB. Как и в предыдущие годы сохраняются некоторые различия в широтном ходе поглощения у полос NH3 645 и 787 нм.

Ключевые слова: Юпитер, атмосфера, облака, аммиак, метан, молекулярные полосы поглощения, спектрофотометрия.

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