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COMPARATIVE ANALYSIS OF THE BEHAVIOR OF WEAK ABSORPTION BANDS OF AMMONIA AT 552 AND 645 NM IN THE SPECTRUM OF JUPITER

Abstract. This article contains the first obtained results of measuring the latitudinal variations of the very weak ammonia (NH_3) absorption band at 552 nm along the central Jupiter meridian based on spectral observations in 2019. This study is preliminary in nature as the first attempt to clarify the possibility and advisability of further detailed study of this weak ammonia band behavior on the Jupiter disk. We obtained the latitude variations of the equivalent widths and equivalent absorption paths for the 552 nm NH3 band and, for comparison, the same characteristics for the more intense, but also weak NH3 645 nm band. The absorption maximum in both bands is observed in the equatorial zone, where in the center of the disk their equivalent widths are: W (552 nm) = 2.58 ± 0.29 A and W (645 nm) = 6.77 ± 0.25 A.

A feature that distinguishes the behavior of the 552 nm NH_3 band from the 645 nm NH3 band is a steeper decrease in absorption towards high latitudes, as well as small differences in the positions of absorption extrema in latitudes. The effect of latitudinal differences in the position of the extrema of the methane absorption bands was discovered by us as early as 1999 observations and was later noted also in the ammonia absorption bands. These features reflect structural differences in the Jupiter cloud layer and its troposphere and can serve as one of the means for its (troposphere) optical sounding.

Key words: Jupiter, atmosphere, troposphere, spectrophotometry, ammonia, methane, ammonium hydrosulfide, molecular absorption bands.

Introduction. In modern study of the Jupiter atmosphere and the processes occurring in it, a wide range of different methods of observing and measuring the planet's characteristics in a wide spectral region (including radio wavelengths) is used. Despite the repeated use of space crafts for studying Jupiter from close distance (Pioneer, Voyager, Galileo, Cassini, Juno), ground-based researches with the help of large telescopes and radio telescopes in the microwave and thermal infrared ranges play a significant role. A number of recent publications related to such researches can be noted [1-7]. They deal with measurements of the thermal Jupiter radiation emerging from various depths of its troposphere. For comparison, the observations of highly qualified amateur astronomers carried out in recent decades with obtaining high quality digital images of the planet, published on the ALPO Japan website [8], are useful. At the Laboratory of Lunar and Planetary Physics, we carry out long-term systematic observations related to studying the behavior of the methane molecular absorption bands at 619, 702 and 725 nm and ammonia ones at 645 and 787 nm in the Jupiter spectrum. In addition to them, we undertook the first experiments to study one more, the weakest, absorption band of ammonia NH_3 at 552 nm. This article sets out the preliminary results of studying this band based on observations made specifically for this purpose in 2019.

Formulation of the problem. The formation of molecular absorption bands in an atmosphere containing not only gases but also cloud layers is complex. The observed spatial-temporal variations in the intensity of these bands are due to heterogeneities and differences in the vertical structure of the planet's troposphere and the cloud layers present in it.

The formation of bands of different intensities occurs at different effective depths, that, in principle, provides the possibility of optical sounding the atmosphere. The weakest bands are formed at the greatest optical and geometric depths, that makes it possible, in comparison them with the stronger bands, to carry out such sounding based on the study of latitudinal-longitudinal variations in molecular absorption. In this respect, it is the very weak NH3 552 nm band that is of particular interest, although its study requires a special approach.

Despite the rather long history of the discovery and observation of the NH_3 absorption band at 552 nm in the Jupiter spectrum, the total number of publications dedicated to this band is not very large. Due to the limited size of the article, we can only list individual publications without their detailed review. Apparently, the works published in 1969 [9] and in 1971 [10] were among the first descriptions of the presence of the 552 nm NH_3 band in the Jupiter spectrum. Spectrometric measurements of the profiles of the NH_3 bands at 552 and 645 nm in the Jupiter spectrum were performed in 1977 [11]. In the same work, growth curves were derived for both absorption bands. Measurements of the 552 nm NH_3 band intensity in different parts of the Jupiter disk obtained from observations in the mid-1970s, are described in [12, 13]. An analysis of the 552 nm NH_3 absorption band intensity measurements available by 1979, was carried out in [14]. It was made from the standpoint of the possible structure of the Jovian cloud cover. As for laboratory studies of this absorption band, in addition to the above-mentioned work [10], one can also point to works [15-19].

Our previous studying the behavior of molecular absorption bands on Jupiter concerned only the more intense ones and was limited to the wavelength range from 580 nm to 940 nm, corresponding to the dimensions of the CCD matrix of the ST-7XE camera included in the SGS diffraction spectrograph. Using another camera with an array of large linear dimensions, we carried out a test shooting of the Jupiter spectra in a wider wavelength range from 400 to 900 nm. So it became possible to observe the 552 nm NH_3 absorption band simultaneously with other, longer-wavelength, absorption bands. Accordingly, it became possible to trace and compare how the intensities of the two ammonia absorption bands at 552 and 645 nm change with latitude on the Jupiter disk. First of all, it was necessary to investigate the possibility of correct selection of the very weak 552 nm band and measuring its equivalent width and profile.

Observations. In the 2019 season of Jupiter's visibility, the standard long-term program of spectral observations of Jupiter with the ST-7XE camera was carrying out. In this season a number of spectrograms of the Jupiter central meridian with the SBIG STT-3200ME camera were also obtained. The CCD of this camera has a 2184x1472 pixel format. The size of each photosensitive element is 6.8x6.8 microns, the spectral dispersion is 3.24 A / pixel, that is, slightly higher than the dispersion with the ST-7XE camera. The scale of the planet's image on the spectrogram was 5.41 pixels / arc second. The size of the Jupiter polar diameter is 220 pixels. From the obtained spectrograms recorded with different exposure times on July 2, 2019, three spectrograms of the Jupiter central meridian with an exposure of 100 seconds and with the highest S / N ratio were selected and processed. They were used to measure the latitudinal behavior of absorptions in the 552 and 645 nm NH_3 bands. It should be noted that the 2019 season was the least favorable for observing Jupiter due to its greatest negative declination and, accordingly, a low position above the horizon. Nevertheless, the results of the observations themselves turned out to be quite suitable for a preliminary study of the 552nm NH_3 band behavior as a basis for a program of further researches**.**

Results. In spectral observations of Jupiter, as a rule, we use Ganymede's spectrum as a reference. This choice of the reference spectrum is preferable, since it can always be obtained on the same night as the planet's spectrum and at the same zenith distance. This makes it possible to most correctly improve the purity of the isolated profiles of weak ammonia absorption bands, especially in the long-wavelength wing of the 645 nm band, where some water vapor weak bands are located. The control over the alignment of the main and reference spectra by wavelength was carried out with use of the Hα line within the accuracy of 1 pixel.

Figure 1 shows, as an example, the profiles of the 552 and 645 nm ammonia absorption bands measured in the equatorial zone at the center of Jupiter's disk.

In the spectrum of Jupiter central meridian, the 552 nm NH_3 absorption band equivalent width, according to our measurements, is on average only about 2.8 Å, and the depth of the line's profile at the absorption maximum does not exceed 0.05. The equivalent width of the 645 nm NH_3 band reaches 6.77 Å and the central depth does not exceed 0.10. This does not contradict the earlier separate measurements of these bands at individual points of Jupiter, for example, [10-13]. The main difficulty in studying these bands is that they overlap with methane absorption bands of similar intensity and, in addition, weak telluric bands are superimposed on them. The effect of the latter on the purity of the 645 nm ammonia absorption band profile and its intensity is well illustrated in [20].

Therefore, specific techniques are required in order to correctly draw the level of the continuous spectrum and to isolate precisely the ammonia bands' profiles. This problem is discussed in detail in [22-24] and in our articles, for example, in [25].

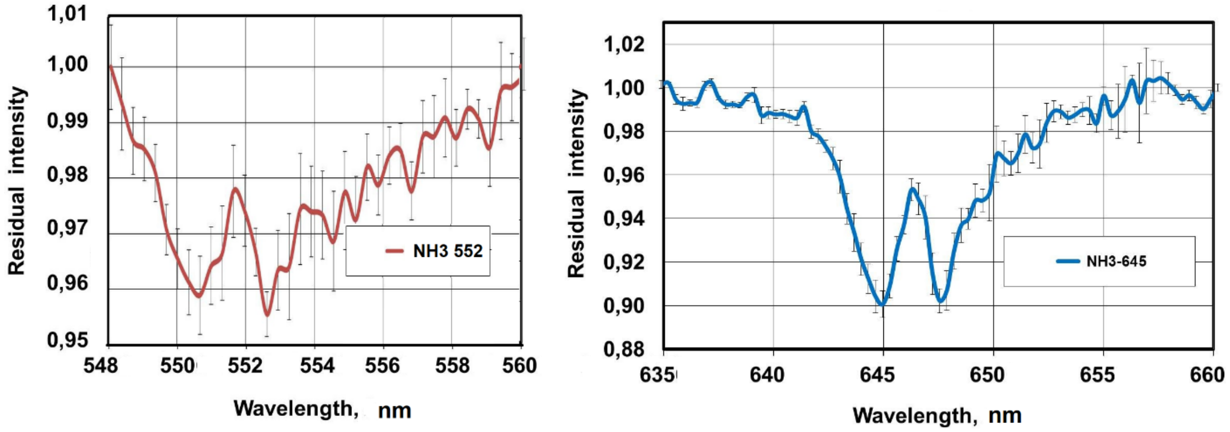

Figure 1. Profiles of the 552 nm and 645 nm ammonia (NH3) bands in the center of Jovian disk.

Figure 2 shows the latitudinal passage of equivalent width of the 552 and 645 nm NH_3 absorption bands in absolute values and in relative ones, normalized to the values in the equatorial zone. Values of equivalent widths at the equator in the center of the disk are estimated as W (552 nm) = 2.58 ± 0.29 A and w (645 nm) = 6.77 ± 0.25 A.

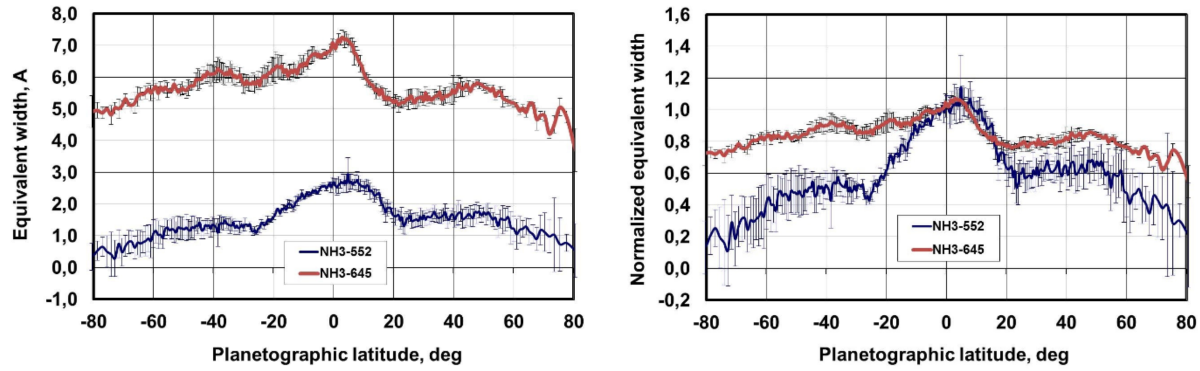

Figure 2. On the left - latitudinal variations of equivalent widths of the 552 and 645 nm NH_3 absorption bands at the Jupiter central meridian. On the right - a comparison of the relative values of the 552 and 645 nm NH_3 bands' intensities on the Jupiter central meridian normalized to the equator.

To compare the latitudinal behavior of the absorption in two ammonia bands, in addition to equivalent widths, we made an estimate of the corresponding equivalent absorption paths. To do this, we used the laboratory growth curves published in [11]. Since both bands relate to weak ones, they fall on the linear portion of the growth curve representing the relationship between the effective thickness of the absorbing gas and the equivalent width. When recalculating the dimension of equivalent widths from inverse centimeters in angstroms, these linear ratios are obtained: C_{NH3} (552) = $W_{(552)} \cdot 41.7$ m-amagat, C_{NH3} (645) = $W_{(645)} \cdot 4$ m-amagat. If the growth curves are accepted according to [11], for example, for the center of the Jupiter disk, then estimates of the equivalent absorption paths for two ammonia bands, are: $C_{(552)} = 107.5 \pm 12.1$ m-amagat and $C_{(645)} = 27, 1 \pm 1.0$ m-amagat.

It should be borne in mind that these values cannot be considered as direct estimates of the gaseous ammonia abundance due to the complex formation mechanism of the absorption bands in the gas-aerosol environment of the Jupiter atmosphere.

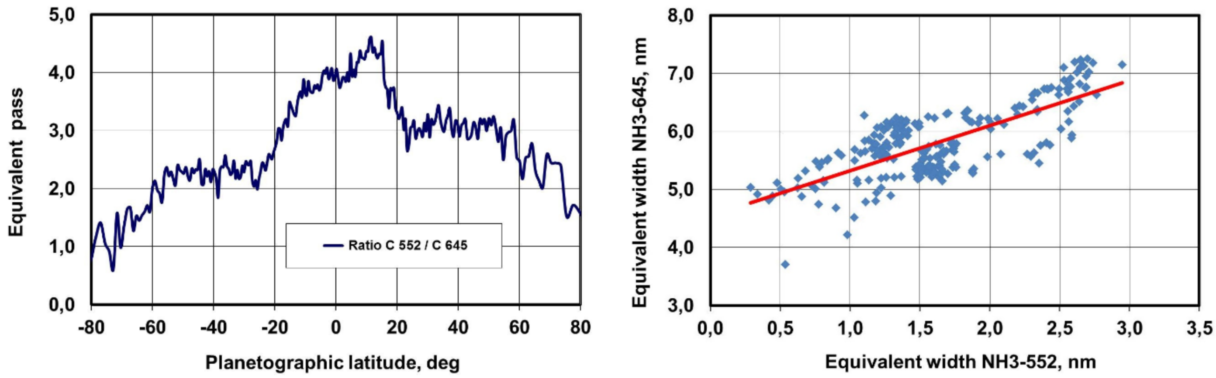

Figure 3. On the left - latitudinal variations of the ratio of equivalent absorption paths of the ammonia bands C_{552} / C_{645}. On the right - the correlation between the 645 and 552 nm ammonia bands' equivalent widths.

The left part of Figure 3 shows how the ratio of absorption equivalent paths calculated for the two ammonia bands, changes.

The right part of the figure shows the correlation diagram between the equivalent widths of the two ammonia absorption bands.

Consider the data described above in details.

In the meridional movement of the observed variations of both ammonia (552 and 645 nm) absorption bands' equivalent widths, there are similar elements and differences.

Both bands show the maximum absorption in the equatorial zone and a well-pronounced minimum in the transition zone between the equator and the northern equatorial belt at the latitude of 20-25 degrees. And in the 552 nm band, this minimum is narrower and slightly shifted to the north by about 5 degrees. Both bands have a clearly expressed maximum absorption at the latitudes of (+40) ± (+60) degrees and a weakly pronounced maximum at (-40) ± (-60) degrees. Both bands show a decline in absorption on the poles (60-85 degrees).

Differences consist in the fact that the equivalent widths of the 645 nm NH_3 band vary across the disk within 15-20%, while for the 552 nm NH_3 ammonia band these variations reach 40-45%. Total (integral) absorption in the 645 nm band in the northern hemisphere is less than in southern one by about 10%, and in the 552 nm band - is on the contrary.

Differences in the latitudinal passage of ammonia absorption (accurate to a certain multiplier) can be calculated by taking the ratio of the meridional movement of equivalent paths C_{552} / C_{645}. Equivalent paths were determined by the method described above.

From Figure 3 (left) it follows that the equivalent path in the 552 nm NH_3 band in the center of the disk is 4 times higher than that for the 645 nm NH_3 band and it decreases to the poles remaining about two times more.

Discussion. Molecular methane and ammonia absorption bands, which are present in the infrared and microwave thermal radiation of Jupiter, have a significant impact on the transport and release of this radiation from the planet's deep layers. Studying the spatial distribution of the brightness temperatures of the outgoing thermal radiation reveals a number of interesting and not always easily explainable features associated with the internal atmospheric gas-aerosol structure and its latitudinal and longitudinal variations.

In the microwave radio and infrared ranges at wavelengths greater than 8 μm, the outgoing thermal radiation fluxes are almost or completely unaffected by the cloud layers on Jupiter, in which the particle sizes are significantly smaller than the observed wavelength. In a shorter wavelength range of near infrared and visible radiation, Jupiter's cloud cover begins to play a very noticeable, if not decisive, role in the passage of its own thermal radiation and in the formation of sunlight reflected from the tropospheric cloud layer. This is clearly manifested in the observed differences in brightness temperature at a wavelength of about 5 μm, where the transparency window of methane absorption is located. The same applies to the visible wavelength range, where the relatively weak absorption bands of methane and ammonia are located. Variations in their intensity are largely associated with the features of the structure and density of Jupiter's clouds. It is studying these absorption band space-time variations that constitutes the program of long-term observations and researches of Jupiter carried out by the authors of this article. Over the past 17 years, systematic annual uniform observations of Jupiter have been carried out by spectrophotometry of the planet in the range of 0.5-0.9 μm. They have been carried out with the expectation of covering (by 2028) two full revolutions of Jupiter around the Sun. This is necessary in order to identify possible changes in the atmospheric and cloud cover characteristics of the planet, associated with the ellipticity of Jupiter's orbit and a change in its heliocentric distance. The most important energy source on Jupiter, influencing the dynamics of its atmosphere, is the release of internal heat and the rapid rotation of the planet around its axis. However, a change in the influx of solar radiation, reaching 20%, may affect the state of the upper atmosphere and cloud cover. But to reveal such regularities, long-term and uniform spectral and other observations are required.

The main feature of interest to us in the absorption band's behavior and their latitudinal variations is the discrepancy in the latitude of the equivalent width extrema for different bands, both methane and ammonia. We noticed this feature in the methane bands even when observing Jupiter in 1999 [26], and then the same feature was noticed in the ammonia absorption bands [27-28].

The NH_3 552 nm band was no exception, showing the difference in the latitudinal direction from one for the 645 nm NH_3 band, both in local deviations and in the general tendency for a greater decrease of the intensity towards high latitudes. The preliminary results described in this article indicate the possibility, expediency and prospects of further research of the ammonia NH_3 552 nm band in combination with other weak and moderate absorption bands observed in the Jupiter spectrum.

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ЮПИТЕР СПЕКТРІНДЕГІ 552 ЖӘНЕ 645 НМ АММИАКТЫҢ ӘЛСІЗ СІҢІРУ ЖОЛАҚТАРЫНЫҢ ӘРЕКЕТІН САЛЫСТЫРМАЛЫ ТАЛДАУ

Аннотация. Бұл мақалада 2019 жылғы спектрлік бақылаулар бойынша Юпитердің орталық меридианының бойындағы NH_3 552 нм аммиактың өте әлсіз сіңіру жолағының ендік вариацияларын өлшеу нәтижелері алғаш рет алынған. Бұл зерттеу Юпитер дискісіндегі осы әлсіз аммиак жолағының әрекетін одан әрі егжей-тегжейлі зерттеудің мүмкіндігі мен мақсатқа сәйкестігін анықтаудың алғашқы әрекеті ретінде алдын-ала сипатына ие. Біз NH_3 552 нм жолағы үшін эквиваленттті ені мен эквиваленттті сіңіру жолдарының мәндерінің ендік бойымен жүрдік және салыстыру үшін NH_3 645 нм-нің қарқындырақ, бірақ әлсіз жолағы үшін бірдей сипаттамаларды алдық. Қос жолақта максималды сіңіру экваторлық аймақта байқалады, мұнда дискінің ортасында олардың эквивалентті ені сәйкесінше тең: W(552 нм) = 2.58 ± 0.29 A и W(645 нм) = 6.77 ± 0.25A.

NH_3 552 нм жолағының NH_3 645 нм жолағынан ерекшелігі-сіңірудің жоғары ендікке қарай күрт төмендеуі, сондай-ақ ендік бойынша сіңіру экстремумдарының орналасуындағы шамалы айырмашылықтарында. Метанның сіңіру жолақтарындағы экстремумдардың жағдайындағы ендік айырмашылықтардың әсерін біз 1999 жылғы бақылаулар бойынша анықтадық, кейінірек аммиактың сіңіру жолақтарында да байқалды. Бұл ерекшеліктер бұлт қабаты мен Юпитердің тропосферасындағы құрылымдық айырмашылықтарды көрсетеді және оны оптикалық зондтау құралдарының бірі бола алады.

Түйін сөздер: Юпитер, атмосфера, тропосфера, спектрофотометрия, аммиак, метан, аммоний гидросульфиді, молекулалық сіңіру жолақтары.

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ ПОВЕДЕНИЯ СЛАБЫХ ПОЛОС ПОГЛОЩЕНИЯ АММИАКА 552 И 645 НМ В СПЕКТРЕ ЮПИТЕРА

Аннотация. Данная статья содержит полученные впервые результаты измерения широтных вариаций очень слабой полосы поглощения аммиака NH_3 552 нм вдоль центрального меридиана Юпитера по спектральным наблюдениям в 2019 году. Это исследование носит предварительный характер как первая попытка выяснить возможность и целесообразность дальнейшего детального изучения поведения этой слабой аммиачной полосы на диске Юпитера. Мы получили ход по широте значений эквивалентных ширин и эквивалентных путей поглощения для полосы NH_3 552 нм и для сравнения такие же характеристики для более интенсивной, но тоже слабой полосы NH_3 645 нм. Максимум поглощения в обеих полосах наблюдается в экваториальной зоне, где в центре диска их эквивалентные ширины равны соответственно: W(552 нм) = 2.58 ± 0.29 A и W(645 нм) = 6.77 ± 0.25A.

Особенностью, отличающей поведение полосы NH_3 552 нм от полосы NH_3 645 нм, является более крутой спад поглощения к высоким широтам, а также небольшие различия в положении экстремумов поглощения по широте. Эффект широтных различий в положении экстремумов у полос поглощения метана был обнаружен нами ещё по наблюдениям 1999 года и позднее был отмечен также и у полос поглощения аммиака. Эти особенности отражают структурные различия в облачном слое и тропосфере Юпитера и могут служить одним из средств для её оптического зондирования.

Ключевые слова: Юпитер, атмосфера, тропосфера, спектрофотометрия, аммиак, метан, гидросульфид аммония, молекулярные полосы поглощения.

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