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DETERMINATION OF THE CONTENT OF MOLECULAR HYDROGEN IN ATMOSPHERES URANUS AND NEPTUNE

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In the spectra of Uranus and Neptune, the intensities of the absorption bands of molecular gases are significantly enhanced in comparison with the observed intensities on Jupiter and Saturn. In addition, due to the small angular dimensions, it is still practically impossible to study the nature of variations in the intensity of molecular absorption bands along the disk of the planets Uranus and Neptune. For these planets, absorption line profiles in their spectra are formed over all reflected radiation.

Keywords: Uranus – Neptune – two-layer – molecular hydrogen

1. INTRODUCTION

Determining the amount of various gases in the atmospheres of giant planets allows us to understand the past and future paths of their evolution. For example, the fact that the relative amount of primary gas in the planets of Uranus and Neptune compared to the proto-sun is less than that of Jupiter and Saturn indicates that their masses reached a crisis value and were formed later than the first. It is possible to observe the intensity distribution of absorption bands (lines) in the atmospheres of Jupiter and Saturn, which have a large disk size, far from the center.

In 1976-1978, the 2.2-m telescope of the Mauna Kea Observatory with a Fabry-Pero interferometer recorded the profiles of the S(0) and S(1) lines of the $H_2(4-0)$ quadrupole band in the spectra of Uranus and Neptune. The obtained values of the equivalent linewidths turned out to be significantly smaller than those ob-

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tained earlier by other observers. The authors believe that this is due to some systematic instrumental errors in early studies, and the observed line profiles are interpreted within the framework of the simple reflection model and the model of scattering layers in the atmosphere. For these models, growth curves are calculated and an estimate of the H_2 content in the atmospheres of Uranus and Neptune is made: 240 ± 60 km.amagat for Uranus and > 200 km. amagat for Neptune - the most probable values. Since the determination of the amount of gases in the atmospheres of Uranus and Neptune was carried out within the framework of a simple reflection model, the results obtained are incorrect. Most importantly, the multiple scattering of light in the planet's atmosphere is not taken into account in such a model. On the other hand, in the atmospheric conditions of icy planets such as Uranus and Neptune, the dependence of physical quantities on height is more complex. It is also necessary to note that spacecraft detect methane in the upper layers of these planets, indicating the presence of a cloud. That is, the temperature value is higher than the freezing point of methane.

Taking into account the observational facts for the planets Uranus and Neptune, it is correct to carry out theoretical considerations of their atmospheres within the framework of the double atmosphere model, considering that the profile of absorption lines in the spectra of such planets belongs to the entire disk of the planet within the framework of a two-layer atmosphere model. The amount of molecular hydrogen should be determined, and calculations should be carried out. Based on the theory of the spectra of planetary atmospheres, it was necessary to construct a growth curve for the $S(0)$ and $S(1)$ lines of molecular hydrogen located in the visible region of the spectra of the planets Uranus and Neptune within the framework of the two-layer atmosphere model. Assuming that in all measurements, it is more correct to take the line $\mathrm{S}(1)\mathrm{H}_2(4-0)$, since this line of molecular hydrogen is subject to weak shock compression [1]. Although the quadrupole lines of molecular hydrogen, S(0) and S(1), located in the visible region of the spectrum, have high intensities in the spectra of the planets Uranus and Neptune, they are considered intact. On the other hand, the profile of the absorption line in the spectrum of the planet, the entire disk of which is observed, is due to radiation reflected from different points.

2. GENERAL FORMULAS

In the atmospheres of planets, radiation occurs due to scattering and absorption by both gas particles and aerosols. Denoting by the volume scattering coefficient and the true absorption coefficient in the continuous spectrum by σ and x, the scattering indicatrix by $\varkappa(\gamma)$ and ω_{c} in the continuous spectrum

$$\omega_c = \frac{\sigma}{\sigma + \varkappa}$$

for the single scattering albedo ω_v in the line $\omega_v = \frac{\sigma}{\sigma+\varkappa+\varkappa_v}$

$$1 - r_v(\eta, \xi, \varphi) = C(\eta, \xi, \varphi)\left(\sqrt{1-\omega_v} - \sqrt{1-\omega_c}\right) \tag{1}$$

The value of the left side in equation (1) consists of two factors, one of which, $C(\eta, \xi, \varphi)$ [2] depends only on the location on the disk and the other only on the frequency. Therefore, this value of the left side of (1), as a function of τ_v in relative units, is the same on the entire disk $\sqrt{1-\omega_v} - \sqrt{1-\omega_c}$. Substituting (1) into the equivalent width expression and taking into account the

$$C(\eta, \xi, \varphi) = \frac{4}{\sqrt{3-x_1}} \frac{u_0(\eta) u_0(\xi)}{\rho_0(\eta, \xi, \varphi)} \tag{2}$$

we get

$$W(\eta, \xi, \varphi) = QC(\eta, \xi, \varphi) \tag{3}$$

where x_1 - parameter is the first coefficient of the expansion of the scattering indicatrix in Legendary polynomials, i.e.

$$x_1 = \frac{3}{2} \int_0^{\pi} x(\gamma) \cos\gamma \sin\gamma d\gamma \tag{4}$$

where ρ_0- is the reflection coefficient in the spectral line. In [3] for the expression Q after some mathematical transformations, it turns out

$$Q = 2\Delta v \sqrt{(1+b)(1-\omega)} f(p) \tag{5}$$

where b $= \frac{\varkappa_0}{\sigma+\varkappa}$, $p = \frac{\omega b}{(1+b)(1-\omega)}$, $\varkappa_0, \varkappa_v$ are coefficients of adsorptions. The function of $f(p)$ can be expressed in the following form

$$f(p) = \sqrt{1+p}\left[K\left(\sqrt{\frac{p}{1+p}}\right) - E\left(\sqrt{\frac{p}{1+p}}\right)\right] \tag{6}$$

where, K and E are complete elliptic integrals. As a result, for the equivalent width of the line (or stripe), we get:

$$\mathrm{W}/\alpha_{\mathrm{D}} = 2\mathrm{C_s} f(p) \sqrt{(1-\omega_c)\,\omega_c}/\omega_{v_0} \tag{7}$$

Let us apply the two-layer model to the atmospheres of Uranus and Neptune, hence taking into account that it was impossible to obtain data on the distribution of brightness over the disk for these planets from our observations. The two-layer model is characterized by the following parameters: scattering indicatrix, single scattering albedo (ω), optical thickness of the outer atmosphere (τ_v), and aerosol scattering coefficient (δa). Assuming that $\beta_v = \varkappa_v/\alpha_a =$ const and $\varkappa_v$ changing according to one law within the two-layer model, we obtained expressions for calculating the geometric albedo. After some transformations in the expression geometric albedo, the parameter gas layer size is included in the parameter β_v :

$$1 - \frac{A_{gv}}{A_{gc}} = \frac{\rho_{ov}}{\rho_{oc}} (2k_c + 1) \int_0^1 \mu^{2kv} e^{-\frac{b^\bullet \beta_v}{\mu}} d\mu \tag{8}$$

After integrating equality of (8), finally we get :

$$\frac{W}{\alpha_D} = \frac{\rho_{ov}}{\rho_{oc}} (2k_c + 1) \int_0^1 \mu^{2kv} e^{-\frac{b^\bullet \beta_v}{\mu}} d\mu \tag{9}$$

Taking the logarithm from the equality of (9), we obtain the following integral equality

$$\lg \frac{W}{\alpha_D} = \lg \frac{\rho_{ov}}{\rho_{oc}} + \lg (2k_c + 1) + \lg \left[\int_0^1 \mu^{2kv} e^{-\frac{b^\bullet \beta_v}{\mu}} d\mu \right] \tag{10}$$

After that, we construct the dependence of the geometric albedo value on $\lg \beta_v$ land the observed value of the geometric albedo, we calculate β_v and after that, we calculate the content of molecular hydrogen.

3. CONCLUSION

Thus, calculations have shown that the amount of molecular hydrogen in the atmosphere of the planet Uranus is 5 ± 0.2 km.amaga and in that of Neptune it is 5.2 ± 0.2 km.amaga.

In general, the amount of molecular hydrogen in the atmospheres of the planets Uranus and Neptune is less than that of Jupiter and Saturn. For physical reasons and based on mathematical reasoning, the result we obtained can be considered quite realistic [4].

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