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STUDY OF THE POLIDISPERS STRUCTURE OF STRATOSPHERIC AEROSOL OF THE GIANT PLANETS

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The inverse problem of the polydisperse light scattering of the Jovian Planets stratospheric aerosol layer is gradually considered. An analytical and numerical solution of this problem is given. The microstructure parameters of the optically active aerosol particles for the vertical column of a single-section aerosol layer are restored.

1. INTRODUCTION

The Jovian Planets (sometimes called giant planets) are Jupiter, Saturn, Uranus, and Neptune. Jovian planets are gas giants and do not have a solid surface, so they have powerful atmospheres. The study of the atmosphere of the Jovian Planets is of great interest for comparative planetology, as an atmosphere in extreme conditions [1, 2].

The chemistry of the giant planet atmospheres is driven by both the convective processes that loft disequilibrium species from the deep atmosphere into the stratosphere and the interaction between stratospheric materials and ultraviolet sunlight [2–4]. As a result, powerful cloud formations are formed in the Jovian Planets stratosphere. The data of long-term photometric observations of Jovian Planets suggest that these cloud formations significantly affect the apparent brightness of these planets. It can be assumed that these clouds form an aerosol layer, which by nature are fine aerosol particles formed in situ (due to gas-phase photochemical reactions [2, 5], and not coarse dust particles introduced into the atmosphere of Jovian Planets from the outside (entry of dust from the Jovian Planets ring system, [6]).

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In this paper, we solve the inverse problem of atmospheric optics of an aerosol in order to restore the polydisperse composition of the Jovian Planets stratospheric aerosol layer. For a comparative analysis of the fractional composition of aerosols, we use a power-law and log-normal particle size distribution. As the input data, real estimated values of the optical backscattering thickness of the aerosol layer were used, which is the most informative parameter of the spatial structure of the field of concentration of aerosol particles and most fully characterizes the diffuse reflection of light radiation in the region of the aerosol cloud. Estimates of the optical thickness of the aerosol layer were carried out according to long-term measurements of the geometric albedo of the Jovian Planets stratosphere in the visible spectral region during the confrontation of the planet

2. CALCULATION METHOD

Analytical Aerosol Model. The main characteristic of an aerosol is their polydisperse structure [7, 8]. In order to characterize the backscattering of sunlight, we will consider the polydisperse structure of aerosol particles in the vertical column of the aerosol layer. To describe the polydisperse composition of optically active aerosol particles, we will use the asymmetric log-normal distribution function of the number of aerosol particles N(r) over the radius of r in the atmospheric column of a single section:

$$f(r) = \frac{1}{\sqrt{2\pi\nu}} exp\left[-\frac{1}{2\nu^2} ln^2 \frac{r}{r_m}\right] \tag{1}$$

where rm is the modal particle radius, ν is the half width (standard deviation) of the particle size distribution.

Restoration of the aerosol microstructure. To restore the parameters of the microstructure of aerosols (spectrum of sizes, modal sizes, particle concentrations) we will be based on the inversion of the polydisperse integral

$$\tau_\lambda = \pi \int_{r_1}^{r_2} r^2 Q(r, \lambda) n(r) dr \tag{2}$$

Here τ is the aerosol optical thickness, Q(r,λ) is the factor of the efficiency of scattering of light by particles, which characterizes the optical section of particles, different from their geometric section due to the wave nature of light [8, 9], n(r) = Nf(r) is the density of the numerical particle size distribution, where N is the concentration of particles in the vertical volume of the aerosol layer of a unit cross section of dimension L^{-2}.

In (2), to calculate the Q(r,λ) - scattering efficiency factor, we use the Van de Hulst approximation:

$$Q(r,\lambda) = 2 - \frac{4}{\Psi} sin\Psi + \frac{4}{\Psi^2}(1 - cos\Psi) \quad (3)$$

where $\Psi 2\rho(n-1)$; $\rho 2\pi r/\lambda$is the Mie parameter, n is the actual refractive index.

To reverse the integral (2) we write this integral in the form:

$$\tau_{\lambda_i} = S\bar{Q}(\lambda_i) = S\int_{r_1}^{r_2} Q(r,\lambda_i) f_s(r)dr \quad (4)$$

where τ_{λ_i} is the optical density of the aerosol layer of the working wavelength λ_i, is the polydisperse scattering efficiency factor, S= N is the total (full) geometric cross section of particles in the atmospheric column of a single section; $f_S(\bar{r})$ is the distribution of cross sections of particle size r, which can be associated with the distribution of the number of particles f(r) by the ratio in the form:

$$f_S(r) = r^2 f(r) / \int_{r_1}^{r_2} r^2 f(r)dr \quad (5)$$

The inversion (4) is carried out by the method of optimal parameterization from the following minimization condition at various wavelengths λ_i [7]:

where λ_{max}max corresponds to the largest value of optical thickness, τ_{λ_i} is the measured and is the model values of optical thickness. It is obvious that the magnitude of the residual (6) does not depend on S, but is only a function of r_m. The value of S is then estimated by the formula amount of discrepancy

$$S = \sum_{i=1}^{n} \tau_{\lambda_i} Q(r_m^{\bullet}, \lambda_i) / \sum_{i=1}^{n} Q^2(r_m^{\bullet}, \lambda_i) \quad (6)$$

Estimation of the optical thickness of the aerosol layer. We will consider the reverse scattering of the aerosol layer during the confrontation of the planet. We assume that the brightness coefficient of the aerosol layer is averaged during the observation, then this value for the reflected light radiation equals the geometric albedo of the planet. The calculations below are carried out for the angle of incidence of the sun's rays 75° near the polar region of the planet. In this case, it is believed that a single reflection of light is effective. Accordingly, for a single reflection [10], the brightness coefficient can be represented as

$$\rho_\lambda = \frac{\gamma(\pi)}{8\mu_0}[1 - exp(-2\tau_\lambda/\mu_0)] \quad (7)$$

Here, ρ_λ is the brightness coefficient generated as a result of pure backscattering of light radiation, τ_λ is the optical thickness of pure scattering, $\gamma(\pi)$ is the normalized backscattering indicatrix, arccos μ_0 is the angle of incidence of sunlight.

3. CALCULATION RESULTS

The initial measured data of the geometric albedo of the giant planets is given in Table 1 These data are given for the visible region of reflected sunlight. In this area, aerosol scattering plays a significant role in the formation of the visible brightness of the planet. In accordance with the results of the work [5, 12, 13],

Table 1. Geometric albedo of the planets of the Jovian Planets.

λ mkm	ρ_λ Jupiter [11]	λ mkm	ρ_λ Uranus [13]	ρ_λ Uranus [4]	λ mkm	ρ_λ Saturn [11]	ρ_λ Neptune [11]
0.4200	0.4040	0.5430	0.240	0.255	0.400	0.2255	0.5691
0.4600	0.4490	0.5760	0.335	0.325	0.4500	0.3466	0.5902
0.5000	0.4830	0.5970	0.350	0.330	0.500	0.4278	0.5828
0.6300	0.5470	0.6190	0.110	0.115	0.550	0.4871	0.5522
0.7300	0.4150	0.6670	0.160	0.190	0.600	0.5434	0.3507
0.8600	0.3050	0.7020	0.105	0.145	0.6500	0.5649	0.2718

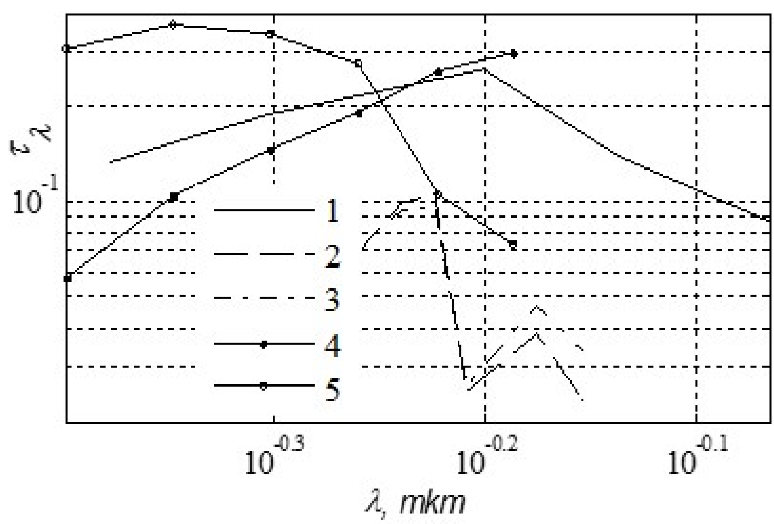

Fig. 1. The spectral dependence of the optical thickness of Jovian Planets according to:1- [11], 2- [13], 3- [4], 4- [11], 5- [11].

we assume that in (3) the index n = 1.5 and the standard deviation in the distribution (1) ν= 0.30. When calculating τ_{λ_i}, the value of the scattering indicatrix

$\gamma\pi$for sbm - particles is assumed to be 1.3 [7, 8]. For the visible spectral region, where aerosol scattering is significant, the data of $\tau_\lambda$values calculated by formula (8) are shown in figure 1.

As can be seen from this figure, the maximum value of $\tau_\lambda$from the aerosol cloud falls in the middle of the visible region of sunlight. This confirms the significance of the aerosol cloud in the formation of the brilliance of the planet.

According to the data of a figure 1 in eable 2 ,using the the distribution (1,)the calculated values of the microstructure parameters of aerosol particles are given.

Table 2. Parameters of the aerosol microstructure over log-normal particle size distribution

№	λ_{max}, mkm	λ_i mkm	r_m, mkm	$\bar{r^2}$, mkm	N, sm^{-2}	S
[11].	0.630	0.42,0.46, 0.50 0.73, 0.86	0.314	0.3434	4.4892e+07	0.1663
[13]	0.6670	0.5430, 0.5760 0.5970, 0.6190, 0.6670, 0.7020	0.090	0.0985	2.1181e+08	0.0645
[4]			0.10	0.1094	1.7186e+08	0.0646
[11]	0.650	0.400, 0.4500, 0.500, 0.550 0.600, 0.6500	0.050	0.0547	1.5882e+09	0.1493
[11]	0.500		0.080	0.0875	1.1337e+09	0.2729

The numerical values of the main characteristics of the r_m and N distribution (1) in Table. 2, obtained as a result of inversion of the polydisperse integral (2) are consistent in order of magnitude with the results of other works (Atreya, Sushil K., et all, 2005; Shalygina O. S., 2009, Morozhenko A. V., Yanovitskii E. G., 1973). For the distribution dN(r)/lnr, as well as for the distribution dS(r)/lnr in fig. 2, constructed according to the data of this table, is characterized by the narrowness of particle size distributions. This is due to the small value of the half-width of the distributions ν=0.30, indicating the constancy of the shape of the distributions in Fig. 2 and, respectively, on the strong dependence of the shape of the distributions on the average climatic conditions of the stratospheric aerosol cloud of the planets. The values of the numerical values of the aerosol distributions in Fig. 2, which determine its optical activity, depend on a narrow range of sbm - particles in a narrow neighborhood of their modal sizes and nominal concentrations of N, S, whose estimates are given in table. 2.

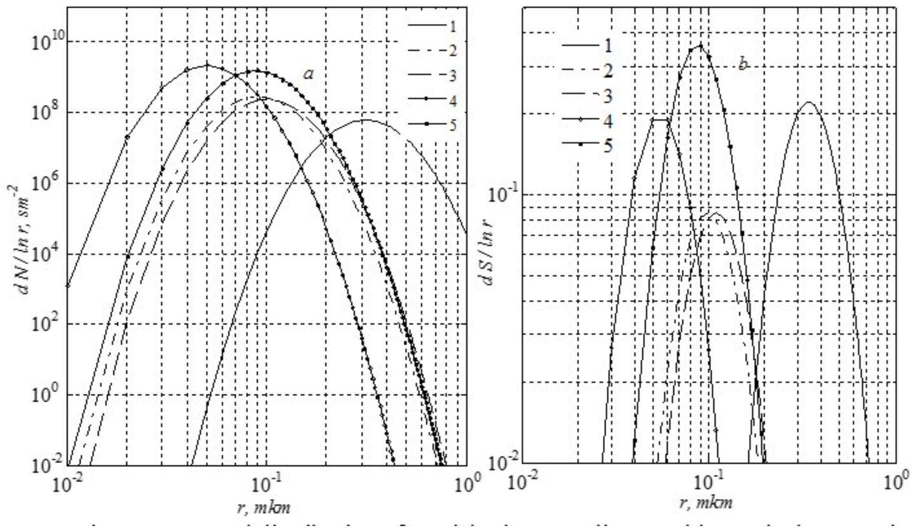

Fig. 2. Lognormal distribution of particle size according to table 2: a is the numerical concentration, b is the geometric section of particles in the atmospheric column of a single section according to: 1- [11], 2- [13], 3- [4], 4- [11], 5- [11].

As can be seen from figure 2, the modal size of aerosol dispersive particles falls within the range of sbm particles. This phenomenon is typical for all atmospheres of Jovian Planets. In the figure, relatively large particles correspond to the stratospheric cloud of Jupiter and Saturn, while the smallest particles correspond to Neptune.

4. CONCLUSION

1 The method of solving the inverse problem of light scattering on aerosol particles is given for the conditions of the aerosol cloud in the Jovian Planets stratosphere. The solution of the problem is carried out in the representation of a lognormal distribution of particle sizes.

2 The optical backscattering thickness of the aerosol layer was estimated from photometric measurements of the planet's geometric albedo in recent years.

3 The modal sizes, numerical concentrations and total geometric section of particles in the column of a stratospheric aerosol layer of a single section, Jovian Planets, were estimated. It is shown that the optically active aerosol particles form a narrow-band asymmetric sbm-mode.

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