ON A MECHANISM OF POLARIZATION ORIGIN AT THE POLAR REGIONS OF JUPITER

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We propose the following mechanism of linear polarization origin at Jupiter's polar regions: the principal contribution in polarization is made by the light reflected by cloud layer and then scattered by stratospheric aerosol particles. The linear polarization distributions along the central meridian for two spectral bands (0.46 μm and 0.70 μm) are calculated. They are in good qualitative agreement with observational data. The mean scattering particle radius is estimated as $r_{mean} = 0.5$ μm.

INTRODUCTION

At present, the following observational facts are well-known.

1. Ground-based polarimetrical observations of Jupiter in the visual portion of spectrum show linear polarization degree P dependence on phase angle α. For the central region of Jupiter disc, the polarization changes from zero value at the phase angle $\alpha = 0°$ to several fractions of percent at $\alpha = 11°$ [9].
2. Observations show that P increases with latitude even at the zero phase angle for Jupiter [11–13]. At the polar regions (latitudes are more than 45°– 50°), P reaches 7–8% for the blue region of spectrum (Fig. 1) [11–13].
3. There is a strong P dependence on wavelength at the polar regions (with change of P sign and crossing the zero value at $\lambda = 0.75$ μm) [12].
4. At the Kharkiv Astronomical Observatory, in 1981, Starodubtseva and Akimov started regular polarimetric observations of Jupiter near opposition. Based on more than 20-year observations, the North–South asymmetry of P and its seasonal and longitudinal variations were found [11]. Let us name *asymmetry* a difference between values of P in the North and the South at the latitudes ±60° on the central meridian.

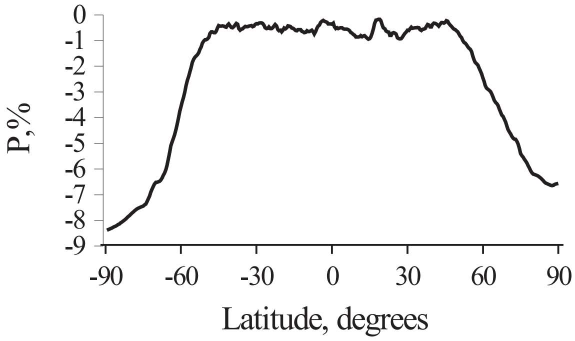

Figure 1. Typical distribution of P along the central meridian of Jupiter near opposition ($\lambda_{\text{eff}} = 0.46$ μm)

For explanation of the observational facts, various models were developed, for example, Morozhenko's and Yanovitskij's models of Jupiter's atmosphere [9], Dlugach's and Mishchenko's model [2]. For interpretation of space data, Smith and Tomasko [10] proposed and Braak *et al.* [1] used the four-layer model of Jupiter's atmosphere.

It should be noted that all presented models were developed and used for interpretation of observations of the central regions of Jupiter. They do not provide an explanation of P behaviour at the polar regions and, especially, do not give any mechanism of polarization origin at the zero phase angle of Jupiter.

Therefore, we start developing such a model to apply it for interpretation of our observations.

OUR PHYSICAL MECHANISM OF POLARIZATION ORIGIN AT THE POLAR REGIONS

It is known that polarization at the polar regions of Jupiter is caused by scattering in upper layers of the atmosphere. We suppose that the principal part of polarized light at zero phase angle is the radiation reflected from the planet surface, *i.e.*, underlaying surface (clouds) and then scattered by stratospheric aerosols.

Data of observations and simulations at other wavelengths (especially, at UV and blue spectral regions) show that there is a stratospheric haze at altitudes with a pressure about a few tenths of mbar with much more abundance at the polar regions [6, 10, 14]. It is very likely that aerosol in haze is unstable and sensitive to changes of physical conditions which can influence aerosol formation or destruction and thus radiation scattering processes. It is a qualitative explanation of seasonal (caused by changing the atmosphere insolation) and longitudinal (caused by influence of the Jovian magnetic field on charged particles falling on stratosphere) variations of North–South asymmetry of P.

The light I which is detected by an observer consists of three parts: $I = I_c + I_{ch} + I_h$, where I_c is the light reflected by planet surface (clouds); I_{ch} is the light reflected by the surface and then scattered by aerosols (beam is shown in Fig. 2); I_h denotes the light scattered only by aerosol haze.

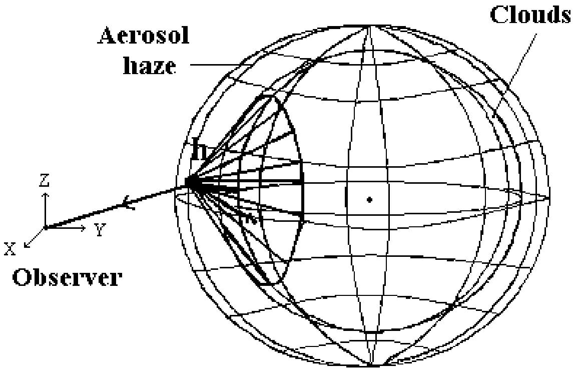

Figure 2. General model scheme

According to estimated data from [4], particle concentration in aerosol haze is relatively small (1–10 cm^{-3}), therefore the most part of radiation I_c probably will freely pass to observer and will make the principal contribution to the summary intensity. If we consider that the surface radiates unpolarized light, then the I_c-component contribution to the polarization must be taken into account as depolarization. Factual data on small particle concentration allow us to suppose that just single scattering makes the main contribution to polarization.

I_h-component makes an insignificant contribution to polarization at the zero phase angle of the planet and as a first approximation it may be ignored.

Thus, the mechanism of polarization origin at the polar regions of Jupiter lies in scattering of light, which was reflected by underlaying surface, by aerosol haze. It is clear that radiation comes to the haze area from the surface part, limited by horizon line (cone in Fig. 2). Therefore, the characteristic scattering angles differ greatly from zero value.

Proposed scenario was realized in the analytic-computer model as a component in IRIS program complex environment [7].

MODEL DESCRIPTION

Computer model was developed with the following assumptions:

1. Phase angle of Jupiter equals zero.
2. Jupiter is a sphere. There is a homogeneous thin layer of aerosol haze at the altitude h above surface (Fig. 2).
3. The aerosol haze consists of spherical unabsorbing particles. To describe light scattering, the Mie theory is used.
4. The size distribution is the normal one with two parameters: the mean size of particles r_{mean} and standard deviation σ_r^2.
5. Only single scattering (by haze particles) is taken into account.
6. The underlaying surface (clouds) reflects light by Lambert's law.

We separate symbolically input parameters into two groups: *physical* and *geometrical*. *Physical* parameters are: refractive index of haze particles m; the size distribution parameters; effective wavelength of light λ. *Geometrical* parameters are: haze altitude h (see in Fig. 2); planetocentric coordinates of the Sun and observer.

The results of calculations are P distributions over Jupiter's disc for specified regions.

RESULTS OF COMPUTER SIMULATION

Figure 3 gives the results of the simulation (bold lines). The following input parameters were used for the calculations: $Re(m) = 1.5$; $Im(m) = 0.0$; $h = 300$ km; $r_{mean} = 0.5$ μm; $\sigma_r = 0.01$ μm. Values of the input parameters are difficult to choose, therefore, we made an additional research, results of which are presented in the next item of the paper.

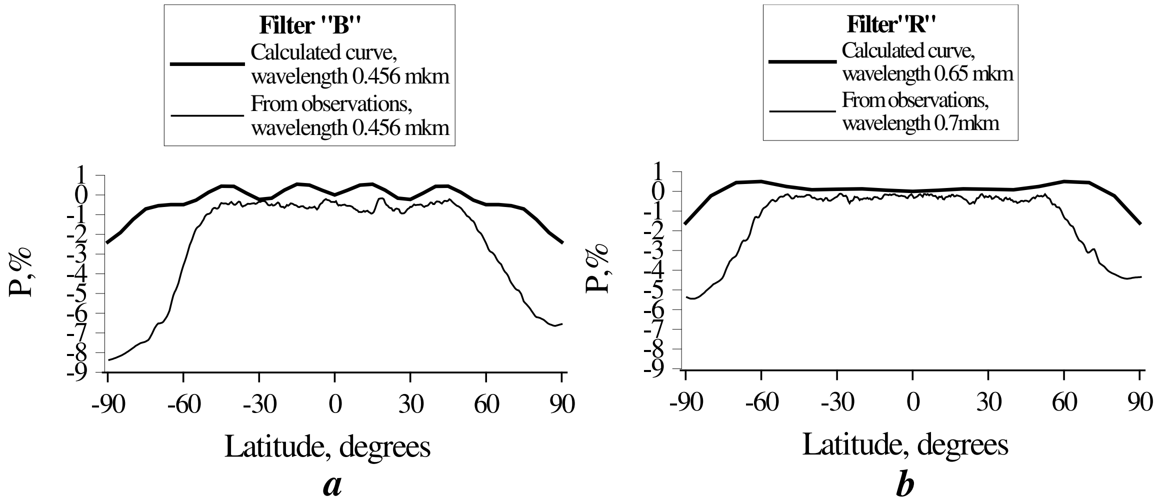

Figure 3. Dependence of linear polarization degree P on latitude along the central meridian for (a) blue light and (b) red light

Figure 3 shows the results of comparison of the calculation data (bold lines) with observational data (thin lines). These observations were carried out by Korokhin and Starodubtseva on September 10, 1998 at the Chuguev Observational Station with the telescope AZT-8.

As seen from the plots, the model and observed curves are in good qualitative agreement.

It should be noted that the increase of polarization with latitude at the blue light begins earlier than at the red light, which corresponds to the observational data as well.

MODEL ANALYSIS

Figure 4a shows some results of haze altitude h varying. Selecting the value $h = 300$ km, we followed results from [8]. However, in [4] the value $h = 150$–200 km is proposed.

Figure 4a illustrates that value of P increases with haze altitude. Although the curve for $h = 1200$ km has better argument with observations, we selected value $h = 300$ km (bold line), since there are not any rational arguments for choice of greater values.

We chose benzene as an aerosol material. In [4, 8, 16], probable microphysical and chemical schemes of polyaromatic hydrocarbons and benzene production at Jupiter's atmosphere are proposed. For the first time benzene at Jupiter's atmosphere was detected in 1985 using the Voyager's IRIS (Infrared Interferometer Spectrometer) at the North region near a latitude of 60° [5]. Later, the Complex IR Spectrometer aboard the Cassini spacecraft observed benzene at North and South high Jupiter's latitudes [3].

Known refractive index of benzene in standard conditions is $m = 1.5 - 0.0i$. So, this value was selected for further calculations.

However, it should be keeping in mind that the Mie theory is sensitive to refractive index m changing. As Figure 4b shows, even small changing the real part of m results in very dramatic changes of P value. Therefore, the question of refractive index choosing for Jupiter aerosol haze is still an open one.

In the Mie theory, scattering depends heavily on relative radius of particles, so-called "size parameter" (ratio of particle size to wavelength).

Figure 5a demonstrates a strong P dependence on wavelength (with sign changing), which corresponds qualitatively to observations.

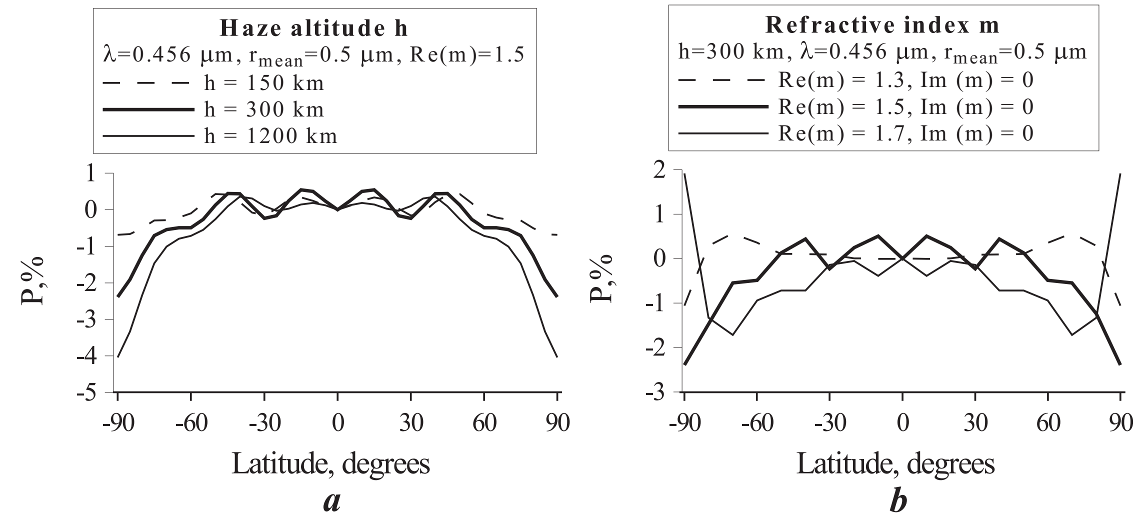

Figure 4. Dependence of linear polarization degree P on latitude along the central meridian for (a) different aerosol haze altitudes and (b) different refractive indexes

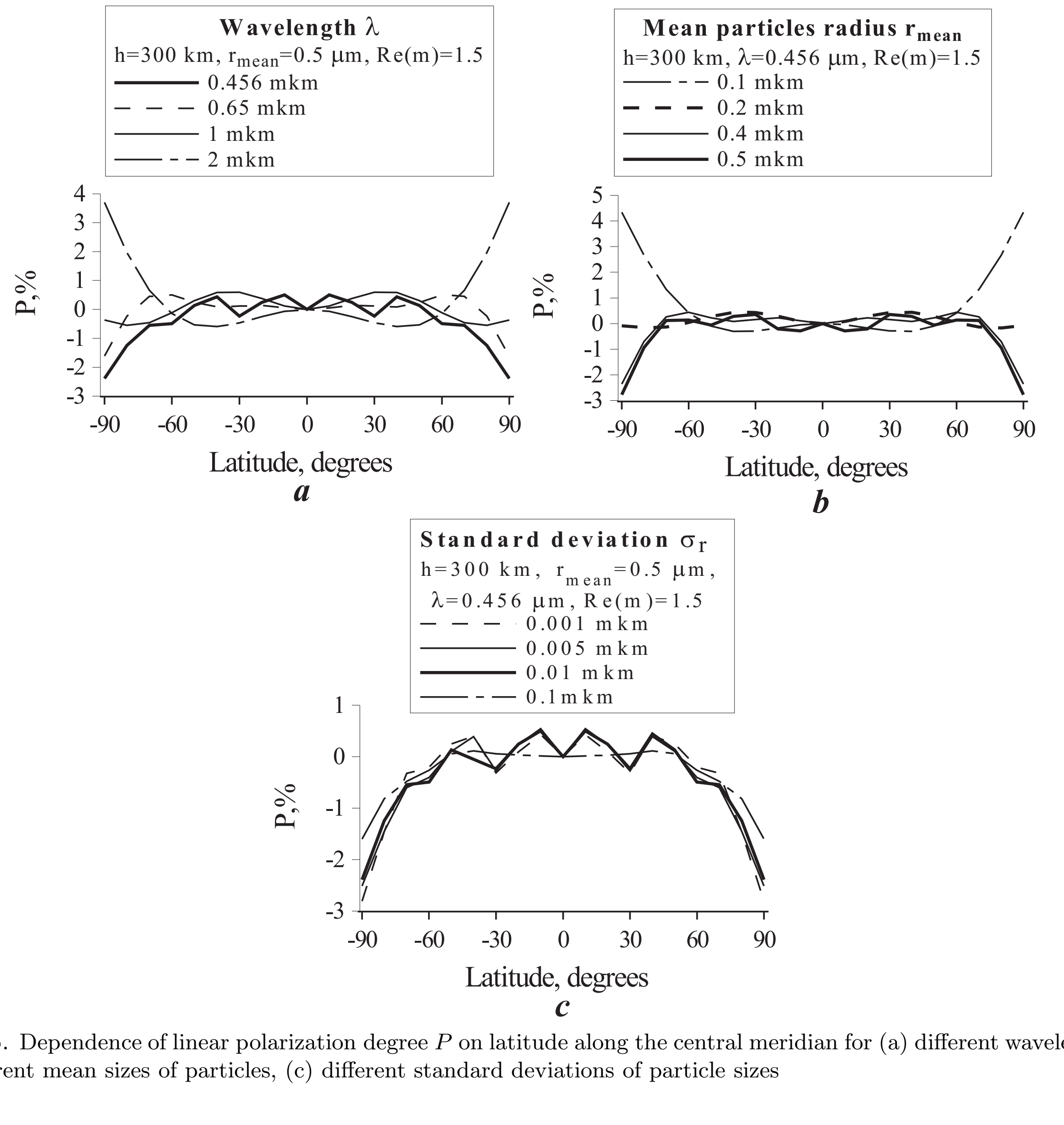

Figure 5. Dependence of linear polarization degree P on latitude along the central meridian for (a) different wavelengths, (b) different mean sizes of particles, (c) different standard deviations of particle sizes

The mean radius of particles $r_{mean} = 0.5$ μm is selected as the main value (Fig. 5b) because for this value there is a change of polarization sign analogously to observations. This value is rather different from proposed in [12] $r_{mean} = 1.0 \div 1.5$ μm but it should be noted that in [12] other refractive index values, $m = 1.33$ and $m = 1.44$, are used.

We analysed behaviour of P on varying standard deviation of particle sizes (Fig. 5c). One can see that, with dispersion increase, curves are "smoothing". Because of limitation of computational resources, the main value $\sigma_r = 0.01$ μm was selected for further investigation. Unfortunately, such a small value of σ_r causes periodical "oscillations" of calculated profiles at low latitudes.

CONCLUSIONS

1. A mechanism of polarization origin at Jupiter's polar regions is proposed.
2. The linear polarization distribution along the central meridian for two spectral bands (0.46 and 0.70 μm) is calculated.
3. The calculations are in good qualitative agreement with observations.
4. The dependence of polarization on model input parameters is analysed.
5. Calculated $P(\lambda)$ dependence passes zero at near IR, which is in good agreement with observations.
6. We estimated the mean scattering particle radius $r_{mean} = 0.5$ μm, which does not contradict other researchers' results.

In future, the following evolution of the model presented are planned: adding the possibility to use various reflective laws; taking into account the haze absorption; adding the mechanisms which will produce the North–South asymmetry of P and taking into account latitudinal and longitudinal irregularity of haze distribution.

[1] *Braak C. J., de Haan J. F., Hovenier J. W., Travis L. D.* Galileo Photopolarimetry of Jupiter at 678 nm // Icarus.–2002.–**157**, N 2.–P. 401–418.

[2] *Dlugach J. M., Mishchenko M. I.* The effect of particle shape on physical properties of the Jovian aerosols obtained according earth-based spectropolarimetric observations // Abstracts of NATO ASI, 2003.

[3] *Flasar F. M.* CIRS observations of Jupiter // COSPAR abstract.–2002.

[4] *Friedson A. J., Wong A.-S., Yung Y. L.* Models for Polar Haze Formation in Jupiter's Stratosphere // Icarus.–2002.–**158**, N 2.–P. 389–400.

[5] *Kim S. J., Caldwell J., Rivolo A. R., et al.* Infrared polar brightening on Jupiter // Icarus.–1985.–**64**.–P. 233–248.

[6] *Kim S. J., Drossart P., Caldwell J., Maillard J. P., et al.* The 2-μm polar haze of Jupiter // Icarus.–1991.–**91**.–P. 145–153.

[7] *Korokhin V. V., Beletski S. A., Velikodsky Yu. I., et al.* Experience in the use of CCD photodetectors at the Kharkiv Observatory // Kinematics and Physics of Celestial Bodies.–2000.–**16**, N 1.–P. 63–67.

[8] *Mallama A., Krobusek B. F., Collins D. A., et al.* The radius of Jupiter and its polar haze // Icarus.–2000.–**144**.–P. 99–103.

[9] *Morozhenko A. V., Yanovitskij E. G.* The optical properties of Venus and the Jovian planets. I. The atmosphere of Jupiter according to polarimetric observations // Icarus.–1973.–**18**.–P .583–592.

[10] *Smith P. H., Tomasko M. G.* Photometry and polarimetry of Jupiter at large phase angles. II. Polarimetry of the South Tropical Zone, South Equatorial Belt, and the Polar regions from the Pioneer 10 and 11 missions // Icarus.–1984.–**58**.–P. 35–73.

[11] *Starodubtseva O. M., Akimov L. A., Korokhin V. V.* Seasonal variation of the North–South asymmetry of polarized light of Jupiter // Icarus.–2002.–**157**, N 2.–P. 419–425.

[12] *Starodubtseva O. M., Teifel V. G.* Polarization at the polar regions of Jupiter // Astron. Bull.–1984.–**18**, N 3.–P. 179–190.

[13] *Teifel V. G.* The polar regions of Jupiter and Saturn // Astron. Bull.–1985.–**19**, N 1.–P. 48–63.

[14] *West R. A.* Voyager 2 imaging eclipse observations of the Jovian high altitude haze // Icarus.–1988.–**75**.–P. 381–398.

[15] *Wong A.-S., Anthony Y. T., Yung Y. L.* Jupiter: Aerosol chemistry in the polar atmosphere // Astrophys. J.–2000.–**534**.–P. L215–L217.

[16] *Wong A.-S., Yung Y. L., Friedson J. A.* Benzene and Haze Formation in the Polar Atmosphere of Jupiter // Geophys. Res. Lett.–2003.–**30**.–P. 30.