APPEARANCE OF LINEAR POLARIZATION AT POLAR REGIONS OF JUPITER.

O. S. Shalygina\textsuperscript{1,2}, E. V. Shalygin\textsuperscript{1,2}, V. V. Korokin\textsuperscript{2} and Yu. I. Velikodsky\textsuperscript{2}; \textsuperscript{1}Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany, \texttt{(o.shalygina@mps.mpg.de)}; \textsuperscript{2}Institute of Astronomy of V. N. Karazin Kharkiv National University, Kharkiv, Ukraine, \texttt{(dslpp@astron.kharkov.ua)}.

Introduction: As known, the basis of Jupiters visible atmosphere consists of layers of clouds, and over the dense clouds the thin aerosol haze with greater concentration in polar regions is placed. At present time the following observational facts are well known from polarimetric observations. Polarization plane has radial orientation. Ground-based and cosmic observations of Jupiter in visual spectrum range show the dependence of linear polarization degree \( P = (I_r - I_t)/(I_r + I_t) \) (where \( I_r \) - tangential component of intensity, \( I_t \) - radial component of intensity) on phase angle and polarization increasing with latitude. Even at close to zero orbital phase angle \( \alpha \) (angle between the Sun, Jupiter and Observer) the absolute value of polarization degree increases from zero (equatorial regions) to 7-8\% (polar regions) (Figure 1). Polarization sign in polar regions changes with wavelength rising (zero value at 0.75 \( \mu \)m) \textsuperscript{[2]}. Also it is known, that there is a north-south asymmetry of linear polarization of light reflected by Jupiter (e.g., Figure 1). \textsuperscript{[1],[3]}). To explain these observational facts, the regular polarimetric observations of Jupiter near oppositions were started in 1981 at Kharkiv observatory. On the basis of these observations in blue light during 1981–2007, the seasonal variations of north-south asymmetry \( (P_N - P_S) \) of linear polarization \( P \) in polar regions and inverse relationship between \( P_N - P_S \) and insolation, which has jump-like nature, have been found (polarization is higher in colder hemisphere) \textsuperscript{[1]}. Parameter of asymmetry \( P_N - P_S \) is defined as a difference between modules of values of linear polarization degree on north and south at the latitudes \( \approx 60^\circ \) at the central meridian. More detailed information abot the study of seasonal variations of polarization one can find in \textsuperscript{[1]} and \textsuperscript{[4]}.

For explanation of above listed observational facts the different models were developed. For example, Morenozenko and Yanovitsky’s Jovian atmosphere models \textsuperscript{[5]}, Dlugach and Mishenko’s model \textsuperscript{[6]} For interpretation of cosmic data, Smith and Tomasko \textsuperscript{[3]} proposed and Braak et al. \textsuperscript{[7]} used four-layer model of Jupiter atmosphere. It should be noted that all these models have been developed and used for interpretation of observations of the central regions of Jupiter. They do not provide an explanation of \( P \) behavior at the Polar Regions and especially they do not give a mechanism of polarization origin at the zero orbital phase angle. Therefore, we started development of such a model to apply it for interpretation of our observations.

Origin of linear polarization in polar regions of Jupiter at zero orbital phase angle: For significant polarization appearance at zero orbital phase, nonzero or non 180\( ^\circ \) angles of scattering are needed. They might be realized, e.g., by multiple scattering in clouds. However there is increase of polarization toward the poles, but not towards East and West limbs of Jupiter. Thus, it is not possible to explain observed distribution of polarization by Jovian disk only by multiple scattering in the clouds. Using the fact that the stratospheric aerosol is more concentrated in the polar regions, we can suggest that the last scattering, which produces the polarization, is the scattering on the aerosol particles. Light sources for such a scattering are the Sun and the Jovian tropospheric clouds which have a large albedo. The first source has zero scattering angle and does not produce polarization. So, we propose following geometry of polarization appearance at zero orbital phase angle: light from the Sun is reflected by opaque clouds then is scattered in upper layers of atmosphere and then comes to observer. This configuration makes possible to obtain the necessary scattering angles (including the angles close to 90\( ^\circ \) on poles) and may give significant polarization at scattering, e.g. on atmospheric aerosols.

As known, data of polarimetric observations are sensitive to presence of stratospheric aerosol haze at top levels of Jovian atmosphere, observed at high latitudes (on pressure level \( p \sim 20 \) mbar, e.g., \textsuperscript{[8]}). According to \textsuperscript{[9]}, the observed aerosol haze consists of benzene and polycyclic aromatic hydrocarbons (PAH) like naphthalene, phenanthrene, pyrene. To check the proposed mechanism of polarization formation the computer experiment has been performed. A simple model was considered: at a some height (100–300 km) above the layer of Jupiter’s clouds the thin aerosol layer consisting of spherical non-absorbing benzene particles (refractive index \( m = 1.5 + 0(i) \) is located. Only a single scattering of light (on aerosol) was taking to account. It was assumed that underlying surface (opaque clouds) reflects light by Lambert law. The calculations were performed using the Mi theory. Size distribution of particles was log-normal. Main results of experiment are shown at Figures 2, 3 and

Figure 1: Typical distribution of \( P \) (absolute value) of light reflected by Jovian atmosphere along the central meridian of Jupiter near opposition (0.465 \( \mu \)m) \textsuperscript{[1]}.
they are in agreement in whole with observations: radial orientation of polarization plane; increase of polarization with latitude; polarization sign changing with wavelength increase. Though obvious simplicity proposed model demonstrates qualitative agreement with observations and permits to estimate mean radius of aerosol particles 0.5 $\mu$m which does not contradict estimations of other researchers. However, the calculated absolute value of polarization is less than the observations yield and it can be explained by failure to take into account all possible factors because of simplicity of used model. The main purpose of this study was to test the proposed mechanism of polarization appearance in the atmosphere of Jupiter at phase angles that are close to zero and it was shown the plausibility of proposed geometry. Further studying the properties of upper atmosphere of Jupiter and obtaining the quantitative agreement of calculations with observations needs carrying out the precise optical modeling of light scattering in Jovian atmosphere.

**Modeling the light scattering in Jupiter’s atmosphere using Monte-Carlo radiative transfer code:** To produce a significant polarization in polar regions the aerosols in the stratosphere of Jupiter should yield strong polarization in forward hemisphere. Spherical particles can not satisfy these conditions. Moreover, aerosol haze probably consists of solid particles [1] i.e. particles with irregular shape. So the next step towards more accurate calculation is using the non-spherical shaped particles. The radiative transfer code based on Monte-Carlo method has been developed and used for modeling of light scattering in the atmosphere in the above proposed configuration: the aerosol haze with given optical thickness is placed at an altitude of 200 km from the underlying surface (clouds) that reflects light by Lambert law. Refractive index of particles $m = 1.5 + 0i$; particle size distribution is log-normal (average particle size is equal to the equivalent volume sphere radius of 0.5 $\mu$m; parameter $ln(\sigma)^2$ amounted to 0.05, wavelength $\lambda = 0.456 \mu$m. As example, the results of calculations for elongated ellipsoids ($e = 0.8$) are shown on Figure 4 and they demonstrate that in case of scattering on the haze consisting of this kind of particles it is possible to obtain larger values of polarization.

![Figure 2: Comparison of calculated dependences of linear polarization degree $P$ on latitude along the central meridian with observations: $a = 0.456 \mu$m and $b - 0.7 \mu$m.](image)

![Figure 3: Calculated wavelength dependence of linear polarization distribution on latitude along the central meridian of Jupiter.](image)

**Conclusions:** (1) The mechanism of polarization appearance at zero orbital phase angle in polar regions of Jupiter was proposed: the principal contribution in polarization is produced by the light reflected by underlying clouds and then scattered on aerosol haze; (2) Modeling using Monte-Carlo based radiative transfer code and preliminary studying of influence the shape of aerosol particles were done. Preliminary results show that ellipsoids may give observed value of linear polarization degree; (3) Further progress of this work should involves the development of more detailed optical model that includes multiple scattering in clouds, non-flat atmosphere and the particles with different shapes.