Researching the physical conditions in Jupiter atmosphere using remote sensing methods

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Abstract

New results of studying the north-south asymmetry in polarization of light reflected by Jupiter are presented. On the basis of 24-year (1981-2004) observational period, anticorrelation between asymmetry of Jupiter polarization and insolation has been found. The mechanism of influence of seasonal variations (with temperature changes) on north-south asymmetry of polarization has been proposed. Our estimates show that components of Jovian stratospheric haze which consists of polycyclic aromatic hydrocarbons (PAH) (crystal naphthalene, phenanthrene) particles may be formed by homogeneous nucleation. Temperature variations in Jupiter stratosphere have strong effect on PAH condensation; benzene does not condensate at T > 120 K. We have found that fluxes of solar cosmic rays may influence upon concentration of aerosol haze particles only through series of chemical reactions that produce source material for aerosol formation.

1 Seasonal variations of the north-south asymmetry of polarization

Remote sensing methods are effective for researching the atmosphere of the planets. The main mechanism of polarization origin in planetary atmospheres is the light scattering on electrons, atoms, molecules and aerosols. Light reflected by Jovian atmosphere is polarized in various atmosphere layers. Studying the distribution of polarization parameters over the planet disk and analysis of their temporal changes may promote to obtain new information about physical conditions in Jupiter atmosphere. As known, ground-based and cosmic polarimetric observations of Jupiter in visual spectrum range show the dependence of linear polarization degree *P* on phase angle and polarization increasing with latitude (even at zero orbital phase angle): polarization degree increases from zero (equatorial regions) to 7-8% (polar regions). Also it is known, that there is a north-south asymmetry of linear polarization at Jupiter [1-4].

To explain these observational facts, we have started regular polarimetric observations of Jupiter in 1981. In our previous works [e.g. 2], on the basis of Jupiter photopolarimetric observations in opposition at blue light during 1981-1999, seasonal variations of north-south asymmetry (P_N-P_S) of linear polarization *P* in polar regions and anticorrelation between P_N-P_S and insolation have been found. Parameter of asymmetry P_N-P_S is defined as a difference between values of linear polarization degree on north and south at the latitudes ±60° at the central meridian. P_N-P_S data are well organized if plotted in accordance with Jupiter's orbital location and there is some relation between P_N-P_S and insolation [2]. We are continuing our studying: 1) our new observations were used; 2) our old data (1981-1998) have been reprocessed using new improved technique; 3) Hall and Riley data [3] (1968-1974) (ultraviolet, visual spectrum range) are involved for analysis. New variant of P-asymmetry dependences on Jupiter's orbital location are presented in the Fig.1. To investigate the nature of the dependence the approximations have been made using different functions. Earlier, in paper [2], we used sinusoidal function with period 180°, but this approximation was difficult for physical interpretation. For new data the approximation by this function is unsuccessful. At the same time, one-periodic functions make a good approximation: sinusoid (Fig.1, Fig.2, curve *1*) gives significant decrease of dispersion in comparison with approximation by constant according to F-criterion with confidence probability 0.76 and “saw-shape” function ($P_N–P_S$ = 1.83–0.005L_S, for 160°<L_S<520°, period is 360°) with 0.96.

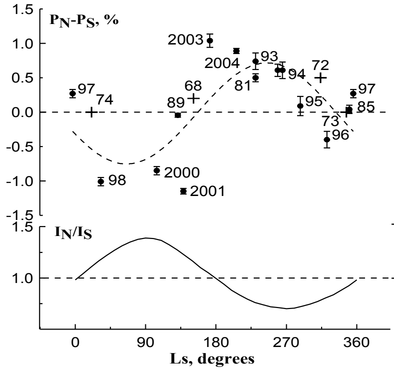

Figure 1.

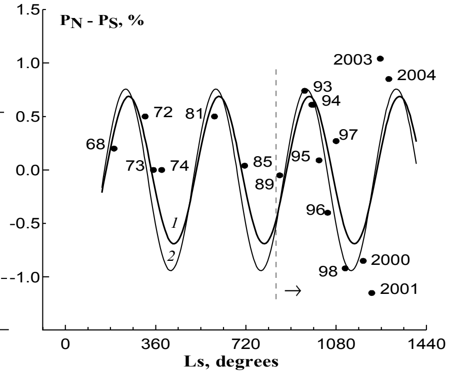

Figure 2.

Figure 1: Dependence of North-South asymmetry of polarization P_N-P_S on planetocentric orbital longitude of the Sun Ls (upper plot). Points correspond to the data obtained by averaging from our observations, crosses are the Hall and Riley data 1968-74 [2]. Bars are errors of mean. Dashed line is approximating curve: P_N-P_S= -0.67sin(L_S+0.32°) + 0.05. Solid line is theoretically calculated asymmetry of insolation of polar regions (intensity ratio I_N/I_S at latitudes ±60°).

Figure 2: Approximation of P_N-P_S dependence on Ls (for continuous Ls axis) by different functions: (1) sinusoid calculated over all observational data, (2) sinusoid calculated only using CCD observations.

To check stability of solution, we have carried out the experiment: approximative function was found only on part of data obtained using the CCD (1989-2004) (Fig.2, curve *2*). Obtained dependence, prolonged to small values of Ls, shows a good agreement with our earlier data and Hall and Riley data. So, one might assert that *periodic* variations of polarization are exist.

Correlation coefficient between P_N-P_S and I_N/I_S is -0.7, i.e. there is significant *anticorrelation*. Our earlier assumption [2] is confirmed by new data and we can speak about *seasonal variations* of polarization.

2 Causes of seasonal variations of Jupiter polarization

We assume that variations of insolation are the principal cause of the seasonal variations of polarization. Jupiter has a small axial tilt (about 3 degrees). However, the orbital eccentricity of 0.05 results in 20% variation in the dilution factor $1/r^2$ values due to the change of the distance r from the Sun. Besides, the perihelion and maximum of Jovian latitude of the Sun are almost coinciding in time. These factors produce significant seasonal fluctuations of the incident solar radiation and result in north-south asymmetry in insolation and temperature. Thus, seasonal variations of stratospheric temperature appear: temperature difference at the polar regions in Jupiter’s atmosphere may vary in the range ±25 K [5, 6].

As known, observational data and theoretical modeling indicate the presence of stratospheric aerosol haze on p ~ 20 mbar pressure level with greatest abundance at polar regions [7,8]. This haze conceivably consists of benzene and polycyclic aromatic hydrocarbons (PAH) like naphthalene, phenanthrene, pyrene [8]. Model calculations [9] estimate the mean radius of haze particles r=1-1.5 μm. We have shown in [10] that main contribution in registered polarization in Jovian polar regions is produced by the light reflected from underlying surface (clouds) and then scattered on aerosol haze particles. Aerosols of this haze may be in unstable state, and temperature changing may influence on forming/dissociation of particles.

Anticorrelation of polarization asymmetry and insolation may be caused by following mechanism. Because of essential heating of thin stratospheric aerosol layer (during Jovian summer) the substance of haze may leave state of supersaturated vapor. Condensation becomes slower, concentration of particles decreases and polarization also decreases (as known, the rate of condensation decreases when temperature increases). Thus, possible scenario of polarization asymmetry appearance is: seasonal variations of insolation are led to –> seasonal variations of temperature –> changes of activity of aerosol formation –> aerosol concentration changes –> polarization changes –> changes of north-south asymmetry of linear polarization.

2.1 Temperature effect on aerosol haze formation

Average temperature in polar regions of Jovian stratosphere is about 150 K [8]. This temperature is lower than triple points of naphthalene and benzene (359 K and 278 K, respectively), so they may produce crystal nucleus from gaseous phase. Let's consider homogeneous particle nucleation (i.e. proceeding without additional condensation centers). Equilibrium condition for nuclei of a crystal with radius *r* and surrounding gas is defined as following [11]:

$$r=r_c=\frac{2\alpha\,\Omega}{\Delta\mu(T,\xi)} \quad , \qquad (1)$$

where r_c – critical radius (nuclei with smaller radius evaporate, and bigger ones grow); Ω is specific volume of molecule in crystal; $\mu = kT\xi$ is chemical potential; $\xi = \ln[p(T)/p_0(T)]$ is supersaturation, $p(T)$ is vapor pressure in atmosphere; $p_0(T)$ is saturated vapor pressure; α is surface tension coefficient; for particles in solid phase α is close to the value in liquid phase near melting temperature.

Eq. (1) is unstable. For formation of a nucleus with radius *r*, the system should overcome potential barrier G:

$$\Delta G(\xi,r)=-\frac{4}{3}\pi r^3\frac{\Delta\mu(T,\xi)}{\Omega}+4\alpha\pi r^2 \quad , \qquad (2)$$

where G is Gibbs potential. Homogeneous nucleation takes place when radius of critical nucleus is close to molecular sizes; at the same time, supersaturation ξ is about or larger than 1. For example, for naphthalene (α=30 erg/cm^2) at T=150 K and ξ = 10 critical radius r_c = 6 Å, i.e., in Jovian stratosphere homogeneous nucleation can occur.

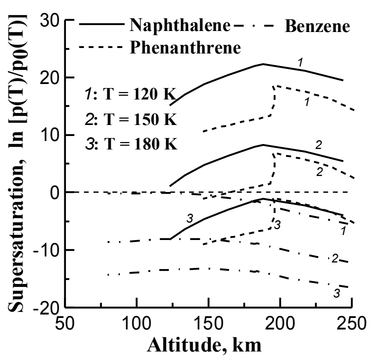

Figure 3: Altitude distributions of PAH supersaturation for different Jovian temperatures.

To study the effect of temperature changes on PAH formation, we used altitude concentration profiles from [8]. Temperature values for calculations (Fig.3) were selected because of average temperature at the pressure level 20 mbar (probable aerosol haze location) is 150 K [12], and its season changes in north and south Jupiter polar regions reach up to ±30 K [6]. Our estimates show (Fig.3) that temperature changes have strong effect on processes of homogeneous nucleation in Jupiter stratosphere: benzene does not condensate at T>120 K (negative supersaturation means vapour undersaturation), whereas probability of naphthalene and phenanthrene nucleation at T=120 K and T=150 K is considerable.

2.2 Mechanism of the effect of irregular factors (solar cosmic rays) on aerosol haze

We have investigated influence of solar wind, solar cosmic rays and X-rays on Jupiter polarization. One can see (Fig.4), there is some relation between P_N-P_S and solar cosmic rays flux (protons, E>10 MeV). Marked points (1998, 2000, 2001) greatly deviate from general group. In what way extremely large flux of high-energy protons registered in this years had influence on increasing of polarization values? First, high-energy protons may increase concentration of ions that participate in chemical reactions, which can enhance synthesis of source material (PAH molecules) for aerosol formation. Second, the ions may serve as additional condensation centers of aerosols. At last, chemical reactions stimulated by additional ionization of the atmosphere occur with heat release or absorption, which may result in temperature change at high altitudes (similar effect is well known for the Earth stratosphere [13]). This can change aerosol concentrations and, consequently, polarization values at both poles. Because of nonlinear dependence of vaporization-condensation processes on temperature, the stratosphere aerosol concentration is different in both polar regions, which may produce polarization asymmetry. Only second mechanism (nucleation in gas containing ions) can be described quantitatively. Gibbs potential in this case is:

$$\Delta G(\xi,q,r)=-\frac{4}{3}\pi r^3\frac{\Delta\mu(T,\xi)}{\Omega}+4\alpha\pi r^2-\frac{q^2}{2}\frac{\varepsilon-1}{\varepsilon}\left(\frac{1}{r^*}-\frac{1}{r}\right) \quad , \qquad (3)$$

where r is the radius of charged sphere, r^* is the ion radius; q is ion charge, and ε is dielectric permeability of nucleus. The new term on the right in Eq.(3) describes screening of a charge q by growing particle.

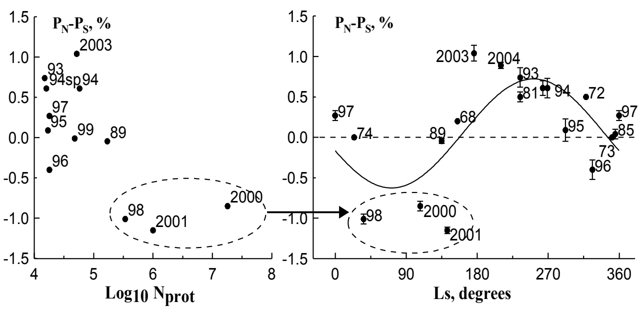

Figure 4.

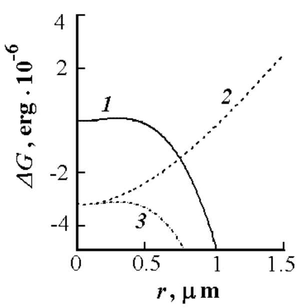

Figure 5. a

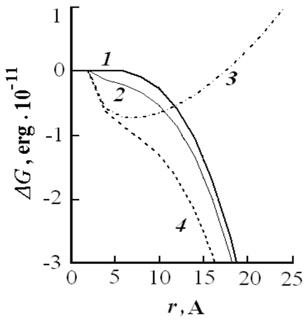

Figure 5. b

Figure 4: Comparison of solar cosmic rays flux (amount of high energy protons, GOES-10 data) with polarization asymmetry (left) and Fig.1 (right).

Figure 5: Thermodynamic potential ΔG (ξ, q, r) changing of system which content nucleus with radius r was formed on ion with charge q (q in charges of electron): a: small supersaturation, big charges, r~μm, ΔG (0.01,0,r) (1), ΔG (0.001,103,r) (2), ΔG (0.01,103,r) (3), b: high supersaturation, real charges, r near molecular sizes, ΔG (8,0,r) (1), ΔG (8,1,r) (2), ΔG (0.01,2,r) (3), ΔG (8,2,r) (4).

Assuming $\varepsilon = 2.3$, $r^* = 2$ Å the plots in Fig. 5 have been obtained. As shown in Fig. 5a, additional domain of stability (local minimum of function G (ξ,q,r)) does not appear in the range of our interests (particles sizes ~1 μm) even for unreally great charges (Fig. 5a, lines *2*, *3*). At real values of charges (1-2 charge of electron), stability appears only very close to molecular sizes (Fig. 5b, line *3*), i.e. only charged molecular clusters (not particles) can be stable (not evaporating and not growing). Thus, mechanism of aerosol particles formation on charges is not effective.

3 Conclusion

(1) There is an anticorrelation between polarization asymmetry and insolation Jupiter's atmosphere. (2) Seasonal variations of insolations (through variations of temperature) is the principal cause of variations of north-south asymmetry of polarization. (3) Jovian stratospheric haze which consists of PAH (naphthalene, phenanthrene) particles may be formed by homogeneous nucleation. (4) Temperature variations in Jovian stratosphere have strong influence on PAH condensation; benzene does not condensate at T>120K. (5) Flux of solar cosmic rays may influence on concentration of aerosol haze particles only through series of chemical reactions that produce source material for aerosol formation.

References

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