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Raman Scattering in the non-isothermal giant planet atmospheres

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Abstract. The influence of non-isothermal atmosphere on the intensity of details of Raman Scattering is computed for spectra of Uranus and Neptune. It follows that the intensity of this scattering depends on the depth of the level formation in an optically homogeneous non-isothermal atmosphere; neglecting of real temperature profiles during the analysis of observation data leads to large errors in the parameters of the atmosphere upper level.

Keywords. Raman Scattering, Planetary nonisothermal atmosphere.

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1. Introduction

Raman scattering is the light interaction with matter which is incoherent meaning that the scattered radiation frequency has another value than the frequency of the incident radiation. We can observe the Raman spectra even in molecules which are not observed in infrared spectrum and the best example of Sun molecule is hydrogen. So we can observe the details of Raman scattering in the giant planet Ultra Violet spectrum although the atmosphere of these objects consist of nearly 85% of hydrogen molecules.

In the row of papers (see, for instance, [Dementiev (1992)-Morozhenko(2001)])there were proposed to use the details of Raman Scattering in spectrum of the giant planets where were used isothermal atmosphere for determination of the optical features and vertical structure of the upper layers of the atmospheres, including relations τ_a/τ_R and τ_κ/τ_R (τ_a ,τ_R - scattering part of optical depth of the aerosol and gas, accordingly, τ_κ - absorbing forming optical depth).

2. Calculation Method

Taking into account the effect of Raman scattering was done on the basis of the analysis proposed by J.B. Pollack [J.B. Pollack *et al.* (1986)]. Expressions for single-scattering albedo ω was taking in the form

$$\omega = \frac{\tau_R + \tau_a + \sum \tau_R^i (f_{\lambda_i}/f_{\lambda_0})}{\tau_R + \tau_a + \tau_\kappa + \sum \tau_R^i} = \frac{\sigma_R + \sigma_a + \sum \sigma_R^i (f_{\lambda_i}/f_{\lambda_0})}{\sigma_R + \sigma_a + \sigma_\kappa + \sum \sigma_R^i} \tag{2.1}$$

where $\sigma_R^i(\tau_R^i)$ - averaged of the line of sight the volume coefficient (optical depths) of the Raman scattering by molecules, f_{λ_i} - the intensities of Sun radiation on the wavelengths, from which corresponding to transition in process of the Raman scattering light photon is carried on wavelength λ_i and f_{λ_0} on wavelength λ_0 .

Taking into account that necessary accuracy of the account of the Raman scattering is reached for Stocks rotation S(0), O(2), S(1) and Q1(1) vibration transition [Belton *et al.* (1973), Cochran, Trafton (1978)], and that real atmosphere of giant planets are hydrogen-helium (with relative concentration of these gases about 0.85 and 0.15) then the corresponding sums of (2.1) are:

$$A = 0.85 * (N_0\tau_{S(0)} + N_2\tau_{O(2)} + N_1\tau_{S(1)} + \tau_{Q_1(1)})/\tau_R \tag{2.2}$$

$$D = 1 + 0.85 * [((N_0\tau_{S(0)} + N_2\tau_{O(2)})f_{\lambda_1} + N_1\tau_{S(1)}f_{\lambda_2} + \tau_{Q_1(1)}f_{\lambda_3})/f_{\lambda_0}\tau_R] \tag{2.3}$$

where $f_{\lambda_1}, f_{\lambda_2}, f_{\lambda_3}$ - spectral value of the energy in spectrum Sun on the wavelength, from which rotation $(S(0), O(2), S(1))$ and vibration $(Q_1(1))$ Stocks transition of Raman scattering carries the sun photon on wavelength λ_0 accordingly; $\tau_{S(0)}, \tau_{O(2)}, \tau_{S(1)}$ and $\tau_{Q_1(1)}$ - are optical thicknesses of the Raman scattering of corresponding transition.

In the mentioned above papers where were analysed the data of intensities of the Raman scattering details isothermal atmosphere model were considered while the real atmosphere of the giant planets are characterized by rather complex warm-up profile [Lindal, (1992)]. It is very important that parameter D depends on not only wavelength, but also on temperature. Because when the temperature is changing the relative number of the molecules of the hydrogen in ortho- and para-conditions are changing too. We shall remind the hydrogen molecule has two atoms with alike value of spin (1/2), so the total spin can be equal 1 (symmetrical level or orto-hydrogen) or 0 (asymmetric level or para-hydrogen), for which density populations of the molecules are defined accordingly by expressions

$$N = 3(2j+1)\exp -B * j(j+1)\frac{hc}{kT}; j = 1, 3, 5\ldots \tag{2.4}$$

$$N = (2j+1)\exp -B * j(j+1)\frac{hc}{kT}; j = 0, 2, 4\ldots \tag{2.5}$$

where B - rotation constant, which for hydrogen molecule is equal $60sm^{-1}$, h - Planck constant, c - speed of light, k - Boltzman constant, T- temperature(in Kelvin).

The purposes of our work are using example of the temperature profile in atmospheres of Uranus and Neptune [Lindal, (1992)] to study:

1. The effect of changing Raman scattering depending on efficient depth of the forming of intensities of diffuse reflected radiations.(Figure1)

2. What are the errors when we neglect of real temperature profiles during the analysis of observation data? (table 1)

3. Do we have the differences between manifestations of Raman scattering details in Uranus and Neptune non-isothermic atmospheres? (Figure 3)

4. Can we apply this method to extrasolar planets? (Figure 4)

3. Discussion and Conclusions

We have computed the single scattering albedo for three levels in Uranus atmosphere (with the value of pressures 0.0025, 0.1, 2.309 bar) and in Neptune atmosphere (with the value of pressures 0.0025, 0.141, 6.268 bar)(figure 1).

Figure 1 shows, that the values of single scattering albedo (as parameters A and D) change with depth in the atmosphere. That is why the using of isothermal atmosphere model leads to faults in such determined values $\tau_a/\tau_R, \tau_\kappa/\tau_R$ and τ_κ/τ_S when we analyse the intensity of Raman scattering details. To estimate the probability of errors as observation of data we have calculated using lay expressions ((2.3) and (2.1)) the values of D and ω for level of pressure 0.141 bar and for wavelength where is the Fraunhofer line (F) (λ 397.0 nm) and its "ghost"(D). Then, when we use the isothermal atmosphere model with value of temperature $T = 51.7K$, from the system of equation

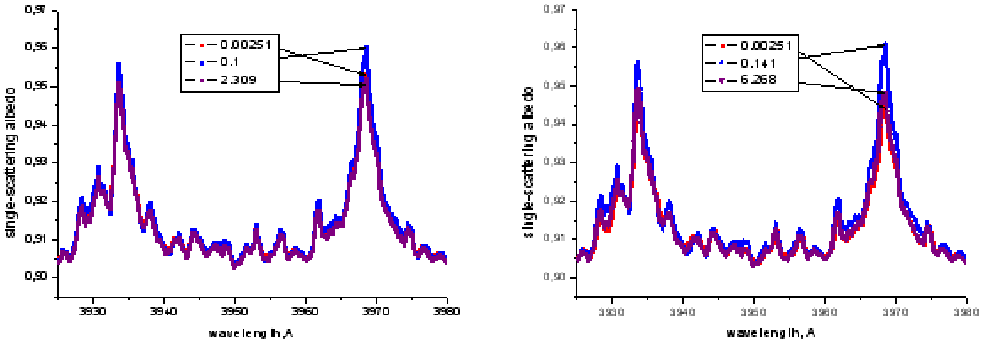

Figure 1. Single scattering albedo versus wavelength for pressure values of 0.0025, 0.1, 2.309 bar in wavelength range from 3925 to 3980 A for Uranus (left) and for pressure values of 0.0025, 0.141, 6.268 bar for Neptune (right).

Table 1. The Comparison of values which were finding from the system of equations with real value.

From system of equations 8				Real values		
P, bar	τ_a/τ_R	τ_κ/τ_R	τ_κ/τ_S	τ_a/τ_R	τ_κ/τ_R	τ_κ/τ_S
0.00251	1.79009	0.28269	0.101	1	0.2	0.1
0.141	1.0459	0.20422	0.0998			
6.268	1.52713	0.257076	0.1017			

$$(D/\omega)^F - 1 = (\tau_\kappa/\tau_R) - [(1/\omega)^F - 1](\tau_a/\tau_R), \tag{3.1}$$

$$(D/\omega)^D - 1 = (\tau_\kappa/\tau_R) - [(1/\omega)^D - 1](\tau_a/\tau_R) \tag{3.2}$$

we determined the values of $\tau_a/\tau_R, \tau_\kappa/\tau_R$ and also

$$\tau_\kappa/\tau_S = \frac{\tau_\kappa/\tau_R}{1 + \tau_a/\tau_R},$$

which are listed in Table 1.

As you can see when we ignore the real temperature profile, the values of single scattering albedo for isothermal atmosphere has the large errors in parameters of atmosphere.

The answer on the question: "Do we have the differences between manifestations of Raman scattering details in Uranus and Neptune non-isothermic atmospheres?" you can receive from figure 3. As you can see the values of single-scattering albedo for two planets are different. In previous papers there were considered single-scattering albedo for the effective temperature which was the same both for Uranus and Neptune. But these values are different for two planets and what is more, as we noted earlier, when we don′t take into account real temperature profile, the values of single scattering albedo for isothermal atmosphere have the substantial differences.

Can we use this method to extrasolar planets? This question is very important. If we could use this method to exoplanets, we could define the optical characteristics of there atmospheres. It would be a new method to define very important parameters of atmospheres. As you can see from figure 4 this effect is more visible for low temperature and when the temperature increase, the differences between single scattering albedo

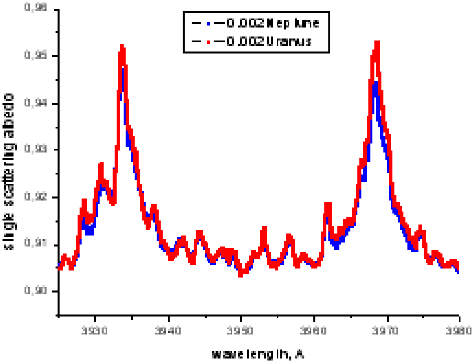

Figure 2. Single-scattering albedo versus wavelength in range of 3925-3980A for Uranus and Neptune atmospheres for the mean of pressure of 0.002bar.

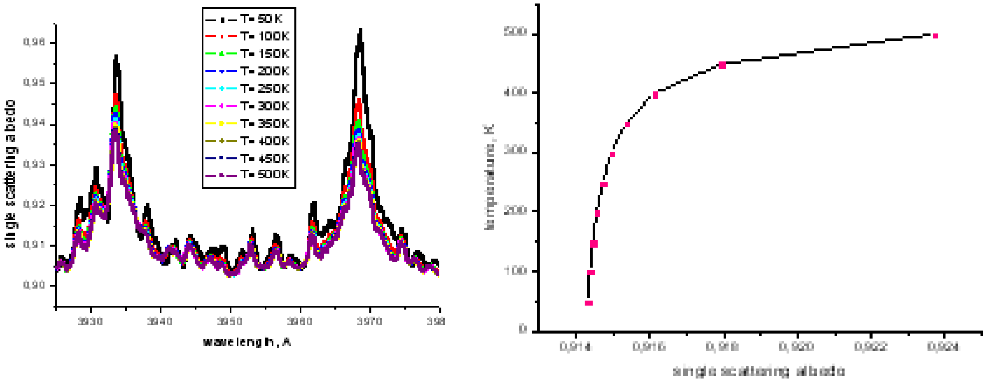

Figure 3. Temperature versus single scattering albedo for 3970A(left) and single scattering albedo versus wavelength for different values of temperature in wavelength range from 3925 to 3980 A for (right).

for this value of temperature decrease. So, we can use this method for not very close exoplanets, not for "hot Jupiter", but we can use it for exoplanets with large orbital period.

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