DUST INFLUENCE ON ^{12}CO MOLECULAR SPECTRUM IN MOLECULAR–DUST CLOUDS

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The study of space molecular clouds is of particular interest due to star-birth occurrence. The analysis of their molecular radiative spectra is one of the principal methods to get information about their spatial structure, temperature and density. The existence of dust in clouds can lead to an appreciable variation of radiation line parameters. Therefore, for correct understanding the observational data it is necessary to build up the model describing the radiation transport processes in a gas-like dust substance. In the present paper we determine the rate of dust influence on molecular CO radiative spectra, using a spherical cloud model.

An effective method of solving the radiative transfer problem is the Monte-Carlo method. This method was developed by Bernes [1] for a cloud model containing only the gas component. Including the dust component in this method does not lead to noticeable complications and comes to the following. The model photons should present now not only the radiation of molecules, but also the dust radiation. The model photon weight on $j-i$ transition will be written in the form:

$$W_{ij} = \left\{ n_{j,m} A_{ji} + \frac{16\pi}{h\nu_{ij}} B_{\nu_{ij}}(T_d) k_d(\nu_{ij}) \right\} \frac{V_m}{N},$$

where $n_{j,m}$ is the population of j level in the m cell, ν_{ij} is the frequency of the $j-i$ transition, A_{ji} is the Einstein coefficient for spontaneous radiation, $B_{\nu_{ij}}(T_d)$ is the Plank function at the frequency ν_{ij} for the dust temperature T_d, $k_d(\nu_{ij})$ is the coefficient of dust absorption, V_m is the cell volume, h is the Plank constant, N is the total number of the model photons.

The expression in brackets is the number of the true photons born in 1 cm^3 in 1 sec at the frequency ν_{ij} in a cell by number m due to molecules as well as to dust grains. The second addendum (which gives the contribution from the dust) is written on the assumption that the dust grains are absolute black bodies.

During the propagation, the radiation is attenuated due to absorption by molecules and dust grains (the scattering by dust in the (sub) millimeter-wavelength range can be neglected), but when calculating the mean intensity on every transition the account is made only for that part of radiation which was absorbed by molecules, therefore, the number of absorption events per 1 molecule in every cell through which the model photon is passing can be written as following:

$$D_{ij,m+k} = \frac{h\nu_{ij}}{c} \varphi_{ij}(\nu) B_{ij} \frac{l_k W_{ij,m}}{\tau^{(g)}_{ij,m} V_{m+k}} e^{-\sum\limits_{s=1}^{k-1} \tau_{ij,s}} \left(1 - e^{-\tau^{(g)}_{ij,m+k}}\right),$$

$$\tau_{ij,k} = \tau^{(g)}_{ij,k} + \tau^{(d)}_{ij,k} = \frac{h\nu_{ij}}{c} \varphi_{ij}(\nu)(n_{i,m+k} B_{ij} - n_{j,m+k} B_{ji}) l_k + k_d(\nu_{ij}) l_k.$$

Here $\tau^{(g)}_{ij,k}$ and $\tau^{(d)}_{ij,k}$ are the optical thicknesses of the gas and the dust substance taken apart, l_k is the path passed by the photon at the k step, B_{ij} and B_{ji} are the Einstein coefficients. It is assumed that the line profile is determined by the Doppler broadening which takes place for majority of molecular dust clouds.

The values $D_{ij,m+k}$ obtained after taking account of all the model photons are no other than the mean intensities in every cell at every transition, and they can be used when calculating new populations in the next iteration.

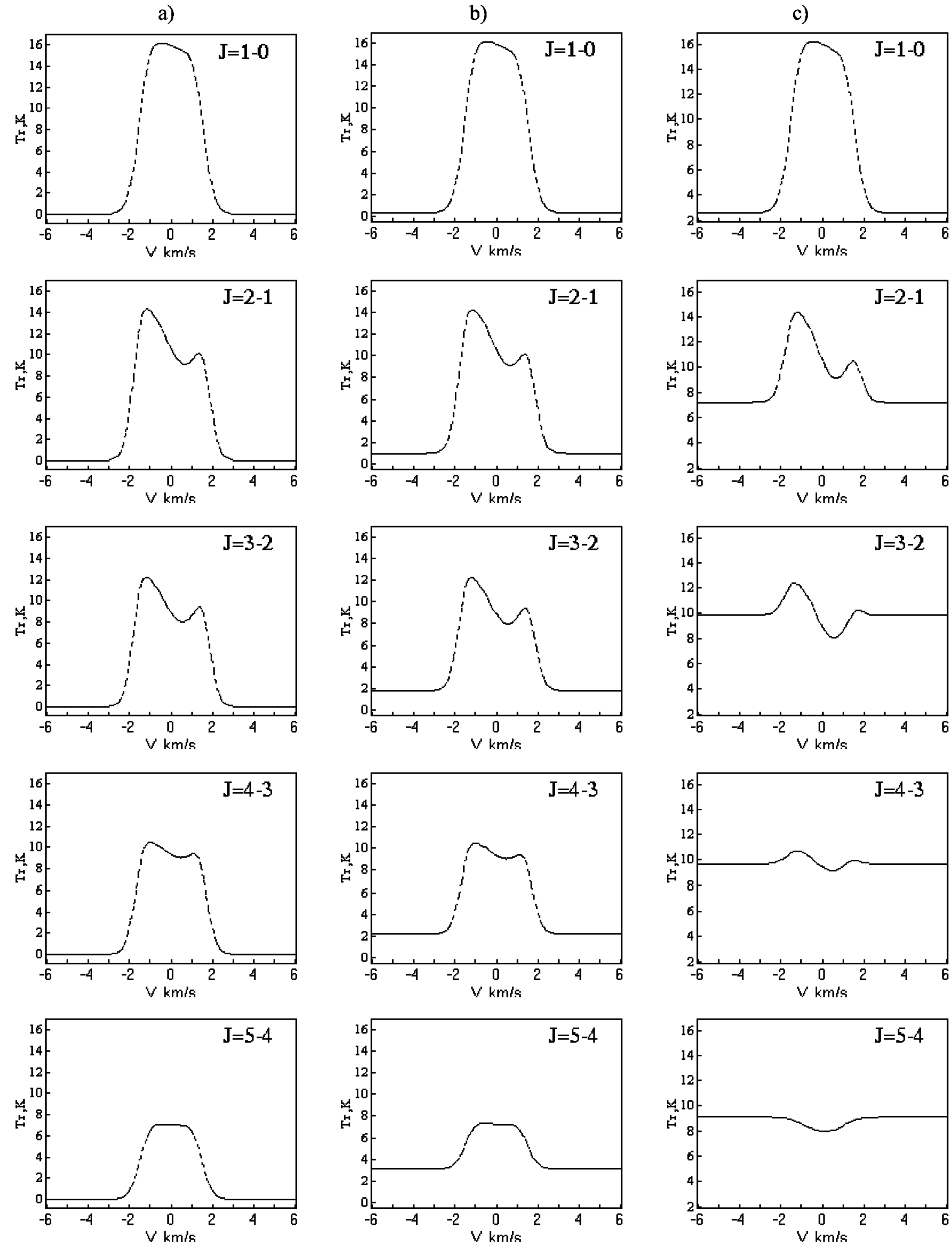

Figure 1: CO lines at the different transitions in the collapsing cloud with various dust-to-molecule density ratio. The cloud radius is $R_{cloud} = 1$ pc, the kinetic temperature of gas is equal to the dust temperature $T_{kin} = T_{dust} = 20$ K, concentrations of compounds of gaseous component in the cloud center are $n(CO) = 0.1$ cm^{-3}, $n(H_2) = 10^4$ cm^{-3}, $n(He) = 2{\times}10^3$ cm^{-3}: a) $\rho_d/\rho_{\rm g} = 0$; b) $\rho_d/\rho_{\rm g} = 10$; c) $\rho_d/\rho_{\rm g} = 100$

After calculation of populations with the required precision, one can calculate the intensities of emerging radiation:

$$I_{ij}(\nu) = I_0 e^{-\tau(X)} + \int\limits_0^X \left(k_d(\nu_{ij}) B_{\nu_{ij}}(T_d) + \frac{h\nu_{ij}}{4\pi} \varphi_{ij}(\nu) n_{j,m(x)} A_{ij} \right) e^{-\tau_{ij}(X-x)} dx,$$

where I_0 is the intensity of external radiation incident on the cloud, $m(x)$ is the cell number, and $\tau_{ij}(x)$ is the optical thickness of the gas-dust medium.

We consider the model of a cloud with spherical geometry only. This model can be used for analysis of the observation data because it is assumed that the molecular dust clouds have a spherical form at early stages of star formation.

The gas component in a cloud is represented by H_2 and ^{12}CO molecules, and also by He atoms, and the dust one is represented by spherical particles covered by dirty ice. By the calculation six lower rotational levels of the ground vibratory state of ^{12}CO molecules are considered. It is assumed that ^{12}CO molecules are excited by collisions with Helium and molecular Hydrogen (the excitation by collisions with the dust grains as well as adsorption of molecules by dust grains is not accounted).

The absorbing and scattering properties of dust particles are defined using the Mie theory taking account of the effective value of the dielectric permeability calculated for the dust grain of the "core-mantle" type. The dielectric permeabilites for silicate and dirty ice are taken from [3, 4]. It is assumed that the dust particles are distributed with radius as $n(a) \sim a^{-3.5}$ ($a_{min} = 40$ nm, $a_{max} = 1$ μm) [2].

The calculation was carried out for a collapsing cloud in which the systematical velocity increases proportionally with the distance r from the cloud center taking value 1 km/sec at its boundary, and the gas and dust densities vary as r^3. The characteristic velocity of micro-turbulent motion was taken 1 km/sec and the microwave background radiation temperature $T_{bg} = 2.7$ K.

The results are presented in Fig. 1. In the collapsing cloud the noticeable dust influence on spectra is observed at significant dust quantities. When the density ratio of the dust component to the gaseous one is equal to $\rho_d/\rho_g = 10$, the spectrum of molecules is observed on the background of continual radiation of a dust. When the dust density exceeds 100 times the gaseous one, a "conversion" of the emission molecular spectrum to the absorption spectrum occurs. For CO this effect is observed only at transitions between the upper excited levels. The radiation at lower transition $J=1-0$ which is observed the most frequently is weakly sensitive to the dust presence. The effects may allow to proceed the examination of the dust component by spectra of CO molecule radiation.

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