GAS AND DUST TEMPERATURE IN THE INTERSTELLAR FILAMENTARY INFRARED DARK CLOUDS

Olga Ryabukhina[1,2], Igor Zinchenko[2], Maria Kirsanova[1]

[1]Institute of Astronomy of the Russian Academy of Sciences, Moscow, Russia
[2]Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod, Russia
ryabukhina@ipfran.ru

The study of the processes of star formation in interstellar clouds is one of the most relevant topics in astrophysics. Recent studies have shown that these clouds have a filamentary structure [1]. To build a deeper model of the processes of star formation, we must restore the physical parameters in dark infrared clouds. One of these parameters is the temperature, for the determination of which various methods based on radio or infrared observations are used.

The conditions of local thermodynamic equilibrium (LTE) are often realized in dense interstellar clouds, under which the excitation temperature (T_{ex}) of the second most abundant ^{12}CO molecule approaches the kinetic temperature (T_{kin}) of the gas. T_{ex} of ^{12}CO is calculated by:

$$T_{ex} = 10.6/ln\left(1+\frac{10.6}{T_B+0.2132}\right), \tag{1}$$

where T_B^{12} is the brightness temperature of the optically thick line J = 2–1 ^{12}CO at 230.538 GHz [2]. However, due to the high optical thickness in the line, it shows the conditions on the cloud surface.

Analysis of the thermal emission in the far infrared range can be used to obtain the dust temperature (T_d). To do this, we simulated the spectral energy distribution of dust emission according to Herschel (160-500 m). Blackbody expression with free parameters T_d and column density of hydrogen $N(H_2)$ was built:

$$S_\nu(\nu) = \Omega(1-e^{-\tau(\nu)})(B_\nu(\nu,T_d) - I_{bg}(\nu)) \tag{2}$$

$$\tau(\nu) = N_H m_H k_d(\nu) M_d/M_H, \tag{3}$$

where $S_\nu(\nu)$ is the observed flux density at frequency ν, Ω is the solid angle, $\tau(\nu)$ is the optical depth, $B_\nu(\nu,T_d)$ is the Planck function, $I_{bg}(\nu)$ is the background flux level, $N_H = 2\times N(H_2)+N(H)$ is the total hydrogen column density, m_H is the hydrogen mass, M_d/M_H is the dust-to-hydrogen mass ratio, and $k_d(\nu)$ is the dust mass absorption coefficient. Thus, the temperature of the gas in the filament G192.76+00.10 which is located in the star forming complex S254–S258 was calculated using CO (2–1) emission, the temperature of the dust using Herschel data.

The kinetic temperature of the gas can be calculated from the emission of inversion transitions of ammonia. Due to the tunneling of the nitrogen through the plane created by the hydrogen nuclei, the transitions have hyperfine splitting. The populations of the metastable levels (1,1) and (2,2) are determined by collisions.

$$T_{kin} = \frac{T_{rot}}{1-\frac{T_{rot}}{42K}ln(1+1.1exp(\frac{-16K}{T_{rot}}))}(K), \tag{4}$$

where T_{rot} is rotational temperature which can be derived from the intensity of the lines NH_3 (1,1) and (2,2) and the optical depth of NH_3 (1,1) [2]. The temperature of the gas in the filament WB 673 was calculated from the emission of ammonia.

The kinetic temperature of the gas was estimated from observations of the CH_3CCH line using the "population diagrams" method. The methylacetylene molecule is a type of symmetric top and is a reliable indicator of kinetic temperature, since it may separate the effect of temperature and density on the excitation of rotational transitions [3]. The dependence on E_u was built:

$$\ln\left(\int T_A dv/[g_I g_K(J^2-K^2)]\right), \tag{5}$$

where E_u is the energy of the upper level, T_A is the brightness temperature in a line, v is the radial velocity, $\int T_A dv$ is the integrated intensity of the line, g_K is the statistical weight of the level K, g_I is the statistical weight due to nuclear spin, J is a quantum number that determines the moment of the momentum of motion; K is a quantum number that determines the projection of the moment on the axis of symmetry of the molecule. The kinetic temperature is found as the reciprocal of the slope of a straight line approximated by this dependence. Thus the temperature in the filament G351.78-0.53 was calculated.

This research was supported by the Russian Foundation for Basic Research (grant No. 18-02-00660)

[1] André, P. and Di Francesco, J. et al., From Filamentary Networks to Dense Cores in Molecular Clouds: Toward a New Paradigm for Star Formation, Protostars and Planets VI, 27 (2014).

[2] Rohlfs, Kristen and Wilson, Thomas L., Tools of radio astronomy (2004).

[3] Bergin, E. A. and Goldsmith, P. F. et al., CH3C2H as a temperature probe in dense giant molecular cloud cores, The Astrophysical Journal, **431**, 674-688 (1994).

[4] Wienen, M. and Wyrowski et al., Ammonia from cold high-mass clumps discovered in the inner Galactic disk by the ATLASGAL survey, Astronomy & Astrophysics, **544**, A146, (2012).