Einführung in die Astronomie und Astrophysik 2

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Physical Processes in the ISM — Hand in on May 19, 2011

5.1 Molecular excitation

Giant molecular clouds (GMCs) are composed almost entirely of molecular hydrogen (H_2), but also contain small quantities of tracer molecules. The most important of these tracers is carbon monoxide (CO). Assume that the molecular hydrogen in a GMC has a Maxwell-Boltzmann velocity distribution. Compute the temperature at which an H_2 molecule with a kinetic energy equal to the mean kinetic energy of the distribution can excite a CO molecule from its ground state to the:

1. $J = 1$ excited rotational level ($\Delta E = 4.76 \times 10^{-4}$ eV)
2. $v = 1$ excited vibrational level ($\Delta E = 0.266$ eV)
3. B $^1\Sigma^+$ excited electronic level ($\Delta E = 10.5$ eV)

[Note: $1\,\mathrm{eV} \simeq 1.6 \times 10^{-12}\,\mathrm{erg}$]. Ignore the effects of any internal excitation of the H_2 molecules, and the contribution of the CO to the mean molecular weight of the gas.
In a typical GMC, the temperature of the gas is in the range $10 - 20\,\mathrm{K}$. Which of these levels will be excited? (4 points)

5.2 Strömgren radius

The Strömgren sphere is the region of fully ionized gas surrounding a massive star.

1. Derive the expression for the radius R_S of the Strömgren sphere in hydrogen gas. Assume that the surrounding gas is homogeneous and calculate the number of recombinations per unit volume per second as $\alpha\, n_e\, n_p$, where $\alpha = 3.1 \times 10^{-13}\,\mathrm{cm}^3\,\mathrm{sec}^{-1}$ and n_e and n_p are the electron and proton number density, respectively. Inside R_S the number of recombinations is equal to the number of ionizing photons from the star.
2. Calculate the Strömgren radius for an O5 star ($T_\mathrm{eff} = 54.000\,K$, $L = 2 \times 10^5\,L_\odot$) embedded in a cloud of atomic hydrogen with number density $n_\mathrm{H} = 10^4\,\mathrm{cm}^{-3}$. To calculate the number of ionizing photons from the star use Wien's law and assume for simplicity that all photons are emitted at the peak frequency of the spectrum. (3 points)

5.3 Cloud in emission or absorption

Consider a simple model of an extended uniform HI cloud with a physical temperature of $T_\mathrm{K} = 2.73\,\mathrm{K}$.

1. Assume the only background source to be the $2.73\,\mathrm{K}$ cosmic microwave background radiation. Would you expect to observe the HI line from the cloud in emission, absorption or not at all? Explain your answer.

2. Now assume that there is a background source with main beam brightness temperature, $T_{\mathrm{B}} = 3\,\mathrm{K}$. What would be the temperature of the absorption feature from the source ΔT_{L} in Kelvin if the optical depth of the cloud is $\tau = 1$?

3. What do you observe if the kinetic (physical) temperature of the cloud is $T_{\mathrm{K}} = 3.5\,\mathrm{K}$?

   Consider the equations of radiative transfer in the Rayleigh Jeans limit where the intensity I is proportional to the temperature T of thermal radiation. Recall that the Planck function is

$$B_\nu(T) = \frac{2h\nu^3/c^2}{\exp\left(h\nu\,/\,kT\right) - 1}\,,$$

   and that the brightness temperature T_{B} is defined by $I_\nu = B_\nu(T_{\mathrm{B}})$. (4 points)