Exercises for Radiative Transfer in Astrophysics (SS2013)

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Exercise sheet 9

Spherical circumstellar dusty envelope model (part IV: CO lines)

1. **Molecular data files from the Leiden LAMDA database**

   (a) Find and download the molecular data file of CO from the LAMDA database[7]. Also download the files form the isotopologues ^{13}CO, C^{17}O and C^{18}O. Compute the wavelengths of the $J = 1 - 0$ line for all these, and determine the relative shifts. Do you have any idea why they are (slightly) different? Do you expect to observe them, for typical molecular clouds and protoplanetary disks, as separate lines or will they typically be blended together?

   (b) Assuming a gas temperature of $T = 50$ K, and assuming only thermal line broadening and zero gas velocity. Assume that the gas has an abundance of CO of 10^{-4} in number density with respect to the number of H_2 molecules in the gas (you can ignore the Helium presence, if you like). Compute the gas opacity $\alpha_\nu/\rho_{\rm gas}$ at line-center for the $J = 1 - 0$ transition of CO.

   (c) Do the same for ^{13}CO, which has a 50× lower abundance than CO.

   (d) Do the same for C^{18}O, which has a 500× lower abundance than CO.

2. **Adding CO to the 1-D envelope model**

   (a) With the above abundance, add CO to the 1-D spherical envelope model that you made a few weeks ago (take $\rho_{\rm dust,0} = 10^{-20}$ gram/cm^3). Please use the opacity without scattering! You must make the following additions to your model:

   - Rename the `co.dat` file to `molecule_co.inp`, and likewise for the other isotopologue files.
   - Add the line `tgas_eq_tdust = 1` to the `radmc3d.inp` file, so that the gas temperature is going to be taken to be equal to the dust temperature.
   - Create a `numberdens_co.inp` file (see manual) with the appropriate abundance of CO. NOTE: The gas-to-dust ratio should be taken to be 100 (masswise).
   - Create a `gas_velocity.inp` file (see manual), but assume that the velocity is everywhere 0 for now.
   - Create a `lines.inp` file (see manual) where you specify the to-be-used molecular data file.

   (b) Make a CO $J = 1 - 0$ line spectrum (see manual). Find the appropriate width of the velocity channel. Use 20 frequency points.

   (c) Do the same for ^{13}CO and C^{18}O, with the appropriate abundances (see above) and the appropriate molecular files.

[7] `http://home.strw.leidenuniv.nl/~moldata/`