Physics 224: Homework 3
Spring 2016

In this homework you are going to investigate the properties of a simulated turbulent molecular cloud. The details of this particular simulated cloud can be found in Kritsuk et al. 2007[1]. This is the first time that I've ever tried this, so there are likely to be some issues I haven't thought of along the way. Please ask if you run into anything that doesn't make sense!

The dataset will be made available on a flash drive. There are two files ($\sim$ 4 Gb each) in `hdf5` format.[2] Each file holds a $1024\times1024\times1024$ cube. I have also created a smaller version, binned by a factor of two (so, 512^3) in case you find it too unwieldy to deal with the full resolution. One of the arrays holds density values at each grid cell. The other holds velocity in the z-direction (since we are going to "observe" the cloud and use line-of-sight velocities, one direction is enough). The data are in dimensionless form, such that the box size $L = 1$, the sound speed $c_s = 1$ and the mean density $\rho_0 = 1$. Velocities are scaled by the sound speed.

1. Make a plot of the density probability distribution function for the simulated cloud. How well is it approximated by a log-normal PDF?

2. Assume $L = 5$ pc, $n_0 = 10^3$ cm^{-3} and $T = 10$ K. Scale the densities and velocities to get physical units for each. Make three maps of the H_2 column density $N(H_2)$ by projecting the data along each of the three dimensions of the cube. Plot the PDFs of $N(H_2)$ from each of the three maps. Make a measurement of how they differ. Assess how well the column density PDFs behave like log-normals.

3. Using the properties above, calculate how many Jeans masses there are in the simulated volume.

4. *Optional but fun!* Produce a ppv (position-position-velocity) cube for the simulation. This is what we can observe, so we are going to "observe" the simulated cloud. This part is fairly challenging, think about how to do it first with a team and then work on implementing it in whatever language you are using. I'll give extra credit for this!

    - Use each grid cell's density with the $T = 10$ K assumption to predict its ^{13}CO emission (you might need to review what the emissivity j_ν is, also the population of levels by collisions, chapters 7, 17 and 19.3 have useful information). Assume there is no radiation field u_ν to populate levels. It is easiest to write a function that takes as input density and temperature and calculates the level populations, then outputs n_{upper}. It is worth thinking about whether it is ok to treat this as a two-level system or whether you need to also keep track of more highly excited levels. (You are welcome to treat it as a two-level

[1] `http://iopscience.iop.org/article/10.1086/519443/pdf`

[2] Here is a link for reading in `hdf5` files in `python`: `https://www.getdatajoy.com/learn/Read_and_Write_HDF5_from_Python`. Similar documentation is available for many languagues - google search is your friend.

system to keep things simple). The molecular data can be found in the tables of this paper: `http://arxiv.org/abs/1501.01629`. Use the $n_{crit}^{thin,nobg}$ value at our assumed 10 K.

- Next you are going to sum up the emission from each grid cell along one dimension of the cube to produce a spectrum for each of the 1024×1024 (or 512×512) positions on the sky. You can do this however you'd like but I would recommend something like: come up with a velocity range that encompasses all the velocities in the cube (with a velocity spacing set around 0.1 km/s or so - you can choose something bigger or smaller if you want, this will be the spectral resolution of your "observation"), using the frequency of ^{13}CO J=(1-0) convert this velocity range to a frequency range. This will be the frequency dimension of your spectral cube (note you are also welcome to do this in velocity instead of frequency if you prefer - frequency is what we observe, but we will convert it back to velocity at some point). Next do a loop over the x and y pixels and sum up the Gaussian lines (with doppler width set by the same T= 10 K in each grid cell) produced by each cell along the z direction. Save the spectrum at each position in a new cube that has dimensions 1024 by 1024 by however many velocities you chose to cover the range. This is your "observation"! Exciting!
- While you are at it, why not try doing this again for another line! Maybe C^{18}O or HCN. Try something with a pretty different critical density than ^{13}CO for fun. Make another cube.
- Now take your cubes and make integrated intensity maps, i.e. integrate under the line profile for each x-y position. This is going to be related to column density (although not exactly because populating the levels depends on density). Evaluate how closely your measured column density maps trace the actual H_2 column density. Describe the differences you see.
- If you have gotten this far and want to try more stuff, think about defining "clouds" in your ppv cube. Read up on some of the literature on how people have done this (check out CPROPs or Clumpfind). Find some clouds and measure their properties. I don't expect anyone to actually do this in the next two weeks - this is a tough problem. But if you are interested in this, I have a few research projects you might want to consider!