ASTR705 ISM
HW #4
Due Friday, 2/17, at the beginning of class

1) Analyze H I, now! Give me as much narrative on your process as possible. Download the H I data from the website. This is from the "VLA Galactic Plane Survey" (VGPS), a combined VLA and GBT survey of the first Galactic quadrant in H I. These data are in the form of a "cube" with axes of $(\ell, b, v_{\rm lsr})$. The cube I gave you is "continuum subtracted" - essentially the background term in the radiation transfer equation has been removed.

   Hint: you have in your notes equations to compute the Galactocentric and heliocentric distance of a source given its velocity.

   a) (3 pt) Play with the data! You can flip through spectral channels (velocities). Extract the H I spectrum for a single location "voxel" (3D pixel). You can do this in DS9 (http://ds9.si.edu/site/Home.html), IDL, Python, or many others. If using DS9, go to "Edit," then "Region." Click to place a circle, double click the circle, in the dialog that pops up go to "Analysis" and "Plot3D." If using IDL or Python, you'll have to access the array ([glong, glat, velocity] in IDL; [velocity, glat, glong] in Python). I can help.

   Plot the intensity as a function of velocity. If you need them, the conversion factors from channel# to LSR velocity can be found in the header:
   $V_{LSR} = (channel\# - CRPIX3) \times CDELT3 + CRVAL3.$

   b) (4 pt) Identify one emission peak in the spectrum. Note the location of that peak on the plot from a) and tell me the maximum kinetic temperature, its Galactocentric radius, its two possible heliocentric distances, and the column density. H I has blended spectra, so do your best to find a peak that is isolated.

   c) (5 pt) Do the same with an absorption spectrum. Plot one spectrum with absorption, pick one absorption signal, determine the Galactocentric and heliocentric distances, the spin temperature and the column density.

   d) (3 pt) Assume the on source direction contains a continuum source (part c) and the off source direction does not (parts a+b). Work through the radiative transfer equation to derive an expression for ΔT_B only in terms of the continuum temperature of the on source direction and the optical depth. Assume that the spin temperatures for the two lines of sight (on and off) are the same and remember that the absorption spectrum already has the background subtracted off (extra $-T_{\rm BG}$ term on right hand side).

2) (3pt) Before, we derived an expression for the density ratio between upper and lower states in terms of the Einstein A, the collisional rate coefficient, the kinetic temperature, and the radiation temperature. What does this expression reduce to in the Rayleigh-Jeans limit? Your final expression should have only $T_{\rm ex}$ on the left hand side, and should use

the substitution $T^* = h\nu_{u\ell}/k$.

3) (3 pt) You can use observations of the (often) optically thin tracer ^{13}CO to derive molecular cloud masses by balancing gravity with thermal pressure. Such a "Virial" mass of a molecular cloud with Gaussian density distribution in units of Solar mass is

$$\frac{M_{\rm vir}}{M_\odot} = 378 \frac{R}{\rm pc} \left(\frac{\Delta v}{\rm km\,s^{-1}} \right)^2 , \tag{1}$$

where R is the cloud radius in pc and Δv is the ^{13}CO FWHM line width in $\rm km\,s^{-1}$, and all conversion factors have been accounted for. This is valid in the absence of external pressure or magnetic fields.

Let's assume that you measure the ^{13}CO antenna temperature across a spherical molecular cloud of radius $R = 20'$ in regular $30''$ spacings. Each position has exactly the same antenna temperature of 20 K and FWHM linewidth of 3 $\rm km\,s^{-1}$. What is the ratio of the LTE mass (see notes and Simon et al. 2001 paper on tthe website) to the Virial mass, and is the cloud gravitationally bound? Assume the cloud is at a distance of 5 kpc.