ASTR 592
M/W/F 3:00 - 3:50 PM
Due February 4

Problem Set #1

1. Properties of the Interstellar Medium

(a) Fill out this table of the properties of common components of the interstellar medium in the Milky Way, and cite at least one source for your answers.

Table 1: The Milky Way Interstellar Medium

	Molecular Clouds	**Cold Neutral Medium**	**Warm Neutral Medium**	**Warm Ionized Medium**	**Coronal Gas**
Temperatures (K)					
Densities (cm^{-3})					
Type of Hydrogen					
Scale Height (kpc)					
Volume Filling Fraction					
Observed Wavelengths					
Primary Coolants					

(b) Assume that the Milky Way consists of a disk with a radius $R = 20$ kpc and a roughly spherical halo with a radius of 50 kpc. Pick two of these components and estimate the total gas mass in solar masses (think carefully about whether each ISM component is primarily found in the disk or the halo).

(c) If an astronomer outside of our Galaxy were to observe the Milky Way, make an estimate for what they would measure for the total luminosity of CO emission from the molecular clouds. Assume the cooling rate (per unit volume) for CO is $\Lambda_{CO} = 10^{-45}\, n(H_2)^2$ where n is the average number density of the gas in m^{-3}, and the units of Λ_{CO} are J m^{-3} s^{-1}. Make the simplification that the molecular ISM is made up of just H_2 and CO, and the CO abundance (by number of molecules, not mass) is 10^{-4}. Assume that the total mass of molecular gas in the Milky Way is $8\times10^{\,8}$ $M_\odot$.

2. Carbon Monoxide

(a) The CO molecule is one of the most commonly-observed tracers of cold molecular gas, as it is the second most abundant molecule in the ISM (after H_2, which cannot be directly observed in cold gas). The spectrum of frequencies for the rotational transitions of a linear molecule like CO can be described as:

$$\nu = \frac{h\,J}{4\,\pi^2\,I} \qquad \text{for} \qquad J = 1, 2, \ldots, n \tag{1}$$

Recall that $I = mr_e^2$ describes the moment of inertia of the molecule, where r_e is the equilibrium separation of the nuclei and m is the reduced mass of the molecule. For CO we will assume the intranuclear separation is $r_e = 1.1306$Å. More generally, for a diatomic molecule :

$$m = \frac{m_A\, m_B}{m_A + m_B} \tag{2}$$

Determine ν for the $(J, J-1)$ = (1-0), (7-6), and (13-12) lines of CO.

(b) For this same set of transitions, calculate the energy of the lower-J rotational level using

$$E = \frac{J(J+1)\hbar^2}{2I} \qquad \text{for} \qquad J = 0, 1, 2, \ldots, n \tag{3}$$

Then represent these energies as temperatures (in K) using $E = kT$

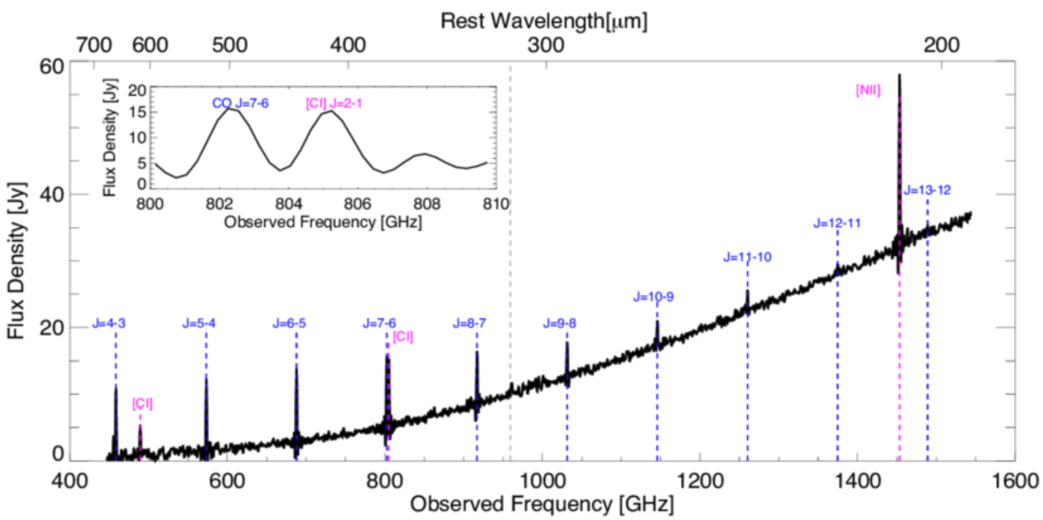

Figure 1: CO lines (on top of dust continuum) observed with Herschel toward the spiral galaxy NGC 7552. Inset shows an enlargement of the spectrum of the CO 7-6 line and a nearby [CI] line. Figure from Rosenberg et al. (2015).

(c) The observed central frequency of the CO 7-6 line in NGC 7552 is 802.3432228 GHz. How fast is gas in this galaxy moving with respect to the solar system?

(d) The full width at half-maximum (FWHM) of a Gaussian fit to the deconvolved CO 7-6 spectrum is 0.48 GHz. What temperature would be required to explain this line broadening? Is this reasonable for the molecular ISM? What (turbulent) velocity would be required to explain this line broadening?