AST 515 – ISM and Star Formation – Fall 2015
<u>MIDTERM Due: Tuesday Oct 06</u>

You must do the exam on your own. Use all resources available except directly googling/copying worked answers.

1. In the first homework, you worked through the basic transitions for neutral Carbon (CI) with a ground state of $1s^2\ 2s^2\ 2p^2$. In this problem, we consider ionized states of Carbon.
   (a) Look up the ionization potential of CI to form CII. How many eV is the ionization potential and how does it compare to the ionization potential for Hydrogen? What does this imply for the ability to ionize Carbon in regions where Hydrogen is neutral?
   (b) What are the terms for the the lowest energy ground state fine structure transition of CII, what is the wavelength (to the nearest micron), and which radiation multipole best describes this transition? [N.B. this line is one of the most important coolants in the ISM of galaxies.]
   (c) If one of the 2s electrons of CII becomes excited into the 2p orbital, the lowest energy term in this excited state is ^4P_J. What are the possible values of J for this term and what is the parity of this term?
   (d) If we further ionize Carbon to form CIII, a line at 191 nm can be observed in “hard” ionizing environments such Planetary Nebula and Quasars (AGN). The terms for this transition are $^3P^o_2$ – $^1S^e_0$. Which (lowest) radiation multipole is best described this transition?
   (e) If we further ionize Carbon to form CIV, what is the ground state configuration and term for CIV? Are there fine structure transitions in this ground state term?

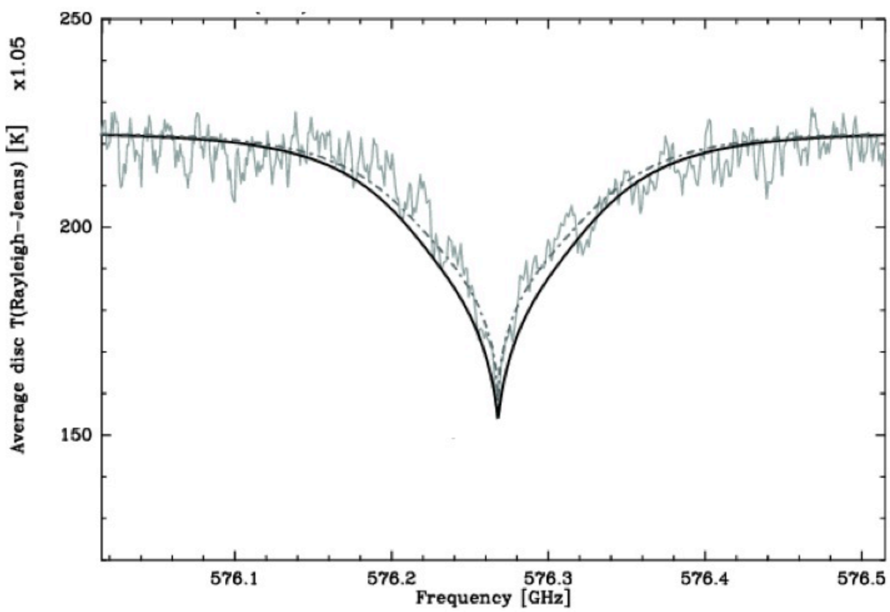
2. Molecular Spectroscopy Problems.
   (a) Which rotational energy levels are allowed for the linear molecules $^{12}C_2$ and $^{14}N_2$ by spin statistics in the ground electronic state? Explain. [Hint: the ground electronic states are both $X^1\Sigma^+_g$]

(b) Are pure rotational transitions of C_2 and N_2 easily observed in the ISM? Explain.

(c) The IRAM 30m radio telescope has a spectrometer that can observe 8 GHz of continuous bandwidth in the 3-4 mm region of the spectrum. How many isotopologues of CO (i.e. combinations of ^{12}C, ^{13}C, ^{16}O, ^{17}O, ^{18}O) can be observed in a single observation which includes the ground state line of the most abundant $^{12}C^{16}O$ J = 1-0 transition? [Note: Ignore hyperfine structure.]

(d) In the late 1930s, the CN radical was one of the first molecules to be detected in the ISM. It turns out that the ground state rotational transitions of CN are very sensitive to the Zeeman effect and are therefore one of the best tracers of magnetic field strengths in dense molecular gas. The ground electronic state is $^2\Sigma^-$. In the ground vibrational state, how many rotational transitions are there to the ground rotational state ($N_J = 0_{1/2}$) and what are their quantum numbers? [Hint: Both fine and hyperfine splitting are important. You may assume Hund's Case B.]

(e) The spectrum below was taken towards Mars and shows an absorption line in its atmosphere. What is the molecule, what are the quantum numbers of the transition, and why does it appear in absorption? [Note: you have to watch out for these lines when you use planets as flux calibrators for radio telescopes.]



3. All About Eddington Factors.

(a) Consider an expansion of the form $I(\mu) = I_0 + \sum_n I_n \mu^n$.
Show that f=1/3 if the sum includes only odd powers of n.

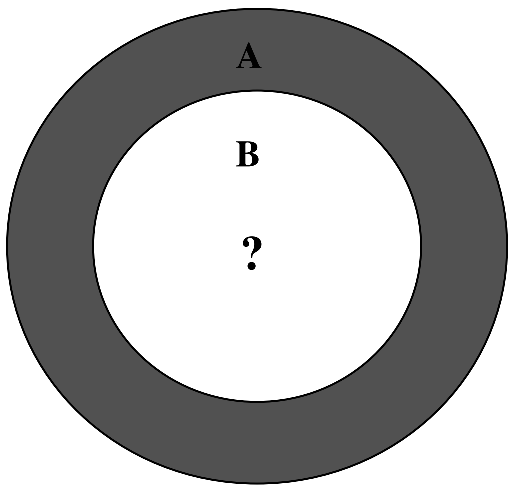
(b) Suppose that $I(\mu) = I_1$ for $(0 \leq \mu \leq 1)$ and $I(\mu) = I_2$ for $(-1 \leq \mu \leq 0)$. Show again that f=1/3. This representation of I is called the two-stream approximation and is useful for describing a stellar radiation field, where $\frac{I_2}{I_1} \rightarrow 0$ at the surface and $\frac{I_2}{I_1} \rightarrow 1$ at high optical depth.

(c) Consider a sphere of radius R that radiates outward an angle-independent specific intensity I. Find the expression for the first three moments of the radiation field and use them to calculate the Eddington factor at a distance $r \geq R$. Discuss the behavior of the Eddington factor at the two limits: $r = R$ and $r \gg R$.

4. Consider the "mystery" object described by the illustration and the table below. In addition, you may assume

- no magnetic field,
- no dust in either region
- LTE between gas and all photons
- the object is not resolved: all the emission is observed as one beam at any frequency

(a) Is the ionized fraction in Zone B what you expect it to be? Why or why not?
(b) Predict, by presenting a plot of intensity versus frequency, the full spectrum of radiation from this mystery object. Consider the various radiative processes. Assume that the size of Zone B is such that the emission is optically thick below 10^{12} Hz. I'm looking for the general idea and not detailed calculations.



Layer	Gas Temperature	Neutral Density	Electron Density	Composition
Zone A	**30 K**	**10^4 cm^{-3}**	**1 cm^{-3}**	**Atomic hydrogen**
Zone B	**10^4 K**	**1 cm^{-3}**	**10^5 cm^{-3}**	**Hydrogen**