Problem Set #2 [Due: Friday March 10, 2017]

Abundance Measurements, Clumpy Media, Reflection Nebulae, T_e and N_e

1. We saw that there was a trend that O/H in H II regions decreased as one moved from the center to the edge of the galaxy. Along with that, the temperature of the H II regions rose from about 9000 K to 11000 K owing to the reduced cooling rate of oxygen. Suppose there are two H II regions, the Democrat Nebula closer to the center and cooler with more heavy metals (log O = 8.5), and the Republican Nebula, located closer to the edge of the galaxy that is more pure H (log O = 8.4) and hotter. Other than that the two nebulae are identical (same stars, density). Which one has a higher flux ratio [O III]λ5007 / Hβ, and by what factor?

2. What effect does a clumpy medium have on determinations of N_e? Suppose a cm^3 within a volume V has a probability P(n) of having a density n (for a uniform density medium P(n) is a delta function). How does the density measured from a line ratio like [S II]λ6716/[S II]λ6731 compare with the mean, $< n_e > = \int n_e P(n_e) dn_e$, for both the LDL and HDL for an arbitrary P(n)? Try to express differences between the estimated n_e and the mean $< n_e >$ for LDL and HDL in terms of the variance of the distribution of n_e, defined as $\sigma^2 =< n_e^2 > - < n_e >^2$.

3. A spherical reflection nebula with a radius d is located a distance D from a star that has a surface brightness I_* and radius R_* (d << D). Particles in the nebula scatter light isotropically without absorbing, and the optical depth is such that no light

leaks out the back of the nebula, but the nebula appears to have a uniform intensity as seen by the observer. Our line of sight to the nebula is perpendicular to a line adjoining the star and nebula.

(a) Suppose we observe m_n, the surface brightness of the nebula in magnitudes per square arcsecond, and θ, the angular separation between the star and nebula in arcseconds. If m_* is the magnitude of the star, show that

$$m_* - m_n + 5 \log \theta = \text{constant} \tag{1}$$

and determine the value of the constant.

(b) How does your answer change if (i) our viewing angle is different, (ii) some light leaks through the nebula, (iii) the particles in the nebula are not completely reflective?

(c) A 10th magnitude star is located a distance 30 arcseconds away from a nebula that has a surface brightness of 18 magnitudes per square arcsecond. Can the star be responsible for exciting the nebula? What experiments might you perform to check to see if you identified the correct star?

4. The Ferreire paper summarized the phases of the ISM. Carefully read through the 'putting it altogether' section in the paper, and type up your own ~ 2 page summary of how all the pieces of the ISM relate to each other, and indicate the obser-

vations that provide us with the information we need to put together that story.

5. Problem 5 from the last homework set:

Write a program that calculates the populations in a 5-level atom, given all the A_{ul} for u>l and l=1-4, and all the Ω_{ij} collision strengths. You will also need to put in all the energy levels. Now look up (record and reference) all the values for the lowest 5 levels of S II. Your code should predict the emission line ratios you obtain for any input temperature T and electron density n_e. You observe the following line ratios:

[S II] λ6716 / [S II] λ6731 = 0.644;
[S II] $\lambda\lambda$(4068+4076) / [S II] $\lambda\lambda$(6716+6731) = 0.143.

Estimate the temperature and electron density. Unfortunately, the λ4068 line is blended with the λ4076 line. If you could deblend them, perhaps with better observations, what would you predict for their ratio?