ASTRONOMY 12

Problem Set 3 – due February 24, 2011

1) Identify each and discuss with a few sentences:

a) Local bubble

b) Coronal gas

c) Molecular Cloud

d) H II Region

e) T-Tauri star

2) What mass (in solar masses) would a cloud composed of pure hydrogen at a temperature 40 K and density $n_H = 1000$ cm^{-3} need in order to be gravitationally bound? Assume a physicist's cloud (spherical, constant density and temperature). Would a more massive cloud having the same density and temperature be more tightly bound by gravity or unbound by thermal energy? How many grams per cubic centimeter is 1000 hydrogen atoms per cubic centimeter? For comparison, air is about 0.001 g cm^{-3}.

3) Consider a sphere of constant density, ρ gm cm^{-3}, mass M, and radius R. Assuming hydrostatic equilibrium, a) what is the central pressure for this sphere in terms of M, ρ and R ? [you can look up the answer in the class notes (Lecture 12), no need to derive it]. Suppose the radius of the spherical star now decreases by a factor of two and the mass does not change. The new density will now be higher. Assume that new density is also constant, i.e., does not vary with location inside M, b) by what factor did the density increase? c) By what factor did the central pressure increase due to the change in both R and ρ (but not M)? If the sphere is an ideal gas, d) by what factor did the temperature increase? You should find that the density increases by a much greater factor than the temperature and in fact, the density scales like T^3, i.e., $\rho/\rho_o = (T/T_o)^3$.

4) Consider a degenerate gas of ionized carbon ($Y_e = 0.50$) with density, ρ, near 10^5 g cm^{-3}. Assume that the temperature is close to zero so that ideal gas pressure and radiation pressure are negligible. If the density of the gas is doubled, a) by what factor does the pressure increase? b) by what factor does the speed of the electrons increase?

5) The size of the deuteron (^{2}H) is set by the length scale of the strong force, about 10^{-13} cm. Considering the electrical repulsion between two protons, and assuming that each proton has only the kinetic energy available because the gas is hot, i.e., $(3/2)kT$, estimate the temperature required for two protons to come within 10^{-13} cm of each other before being repelled apart (mke your estimate ignoring quantum mechanical barrier penetration). Compare this temperature with what the Virial Theorem and other approaches give - about 10^7 K. How do you reconcile this difference? [hint: total energy is conserved. At large separation the total energy is just kinetic. At closest approach when the velocity goes to zero and the total energy is just electrical potential energy, e^2/r. The force is repulsive in this case, so the potential energy is positive.]

6) Since the sun generates its energy by the fusion of hydrogen into helium, two neutrinos are produced every time a helium nucleus is formed (two protons have somehow to turn into two neutrons along the way). Given how much energy is released each time a helium nucleus is produced (26.2 MeV = 4.20 $\times 10^{-5}$ erg) and the luminosity of the sun, 3.83×10^{33} erg s^{-1}, estimate a) the number of helium nuclei being produced per second in the sun; b) the number of neutrinos being produced per second in the sun; and c) the flux of neutrinos crossing one square cm of the Earth's crust (and your body) every second. Assume that the cm^2 is held perpendicular to the line connecting the Earth and the sun. Does it matter whether it is day or night? Hints: The answer to part b) is just 2 x the answer to part a) (Why?). Once you have the number of neutrinos made per second, use the definition of flux in terms of luminosity to see how many arrive per cm^2 at earth.

Shorter Questions

1) Write down the series of nuclear reactions responsible for powering the sun. Similarly write down the sequence of reactions that would power a 10 $M_\odot$ star on the main sequence. Give the reactions, not just the name of the series.

2) Give three ways that energy can be transported (moved from a smaller radius to a larger one) in main sequence stars. Which dominates in the center of the current sun? And which one dominates near its surface?

3) Why is there a minimum mass a star can have on the main sequence and what is the value of that mass? What happens to a contracting protostar below that mass?

4) The fusion of hydrogen in the sun's interior releases 6.4×10^{18} erg g^{-1} (see notes lecture 12). The combustion of a gram of gasoline with air releases 4.4×10^{11} erg g^{-1}. Assuming the same fraction of the sun's mass participates in the burning, that the luminosity of the sun does not change, and that the lifetime of the sun fusing

hydrogen to helium is 10 billion years, what would be the sun's lifetime if it were gasoline powered?

5) The sun rotates *differentially*, i.e., it rotates faster at its equator than at other latitudes. A point on its equator goes around once every 26.8 days, but a point at 75 degrees latitude (either north or south) takes 31.8 days to go round. In 10 years, how many more times has the sun rotated at its equator than at 75 degrees latitude?

6) List the three kinds of gas pressure discussed in class. Indicate which ones depend on the temperature and/or the density. Which kind of pressure dominates in the sun's center?