Astronomy 208: The Physics of the Interstellar Medium

Take-Home Final

Distributed: January 17, 1997; *Due:* January 24, 1997 by 5 P.M.

Please sign and date the declaration below, for the record, and attach this page to your completed exam.

I ________________________________ did not collaborate with any other person on the material attached.

Signed: ________________________________ Date:__________________________

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There are three parts to this exam, which total 100 points worth of potential credit:

Part I A series of questions are designed to test your general knowledge of the Physics of the ISM, and to satisfy the Astronomy Department's desire to institute comprehensive final exams in lieu of "General Exams." (40 points)

Part II A (much) more thought-provoking question on the influence of forming and dying stars on the evolution of a GMC. (40 points)

Part III A medium-length question about what one expects when a QSO is viewed through extragalactic, intergalactic, and Galactic ISM. (20 points)

Please be careful to explain all of your comments and calculations carefully. In grading this exam, we are as interested in your reasoning as your results. If you find that information necessary for a solution is "missing" from any problem, please realize that this information was probably omitted on purpose--we expect you to make reasonable assumptions about missing information, not unlike what goes on in the *Astrophysical Journal*. And last, but not least, keep in mind that presentation counts, to the extent that it is hard to award many points to unreadable work.

Part I: General ISM Questions. (Total of 40 points.)

Remember to show <u>all</u> of your assumptions and calculations--quoting answers to these questions directly from "the literature" will not get you any credit. The point values should guide you as to how much time (and writing space) to spend on each question.

a) Estimate the mass of all of the interstellar gas in the Galaxy. Break down your estimate of the total into a sum of components made up of the relevant combinations of: hot/cold; neutral/ionized; atomic/molecular. (4 points)

b) What is the peak wavelength of emission from dust in a region of "average" density in a "typical" Giant Molecular Cloud? (2 points)

c) Calculate the frequency of the J=3-2 line of the CO molecule. To what observatory might you go to observe this line? Under what physical conditions would you expect emission from this line to be the strongest in the CO rotational ladder? (3 points)

d) Assuming you are observing at a 10-m diameter radio telescope with 100% efficiency, calculate and graph the expected line profile of H I 21-cm emission, for a line of sight where there is just one spherical cloud with a radius of 1 pc, a volume density $n = 10\ \mathrm{cm}^{-3}$, a kinetic temperature of 100 K, and a velocity distribution with dispersion $\sigma = 8\ \mathrm{km\ s}^{-1}$ (based on a Gaussian fit), at a distance of 100 pc. Assume that the LSR velocity of the cloud is $\mathrm{v}_{\mathrm{LSR}} = 10\ \mathrm{km\ s}^{-1}$, and that it is in Local Thermodynamic Equilibrium. (8 points)

e) For a binary star system comprised of one O5 star and one B0 star separated by 50 A.U., what would be the approximate size of the ionized region created by the system, and what might it look like (describe its approximate three-dimensional shape)? Assume that the star system is embedded in a molecular cloud where the average neutral particle density is $n = 10^3\ \mathrm{cm}^{-3}$. (3 points)

f) What are the dominant sources of heating and cooling in H II regions? Why? (3 points)

g) What are the dominant sources of heating and cooling in a dense core (with $n = 3 \times 10^4\ \mathrm{cm}^{-3}$; $T_K = 10$ K)? Why? (3 points)

h) What observations of pulsars would you use to determine the magnetic field strength in the ionized ISM? Give an algebraic example of this method. (3 points)

i) In the vicinity of an H II region, you might expect to find both photoionized and shocked gas. What kind of observations can you make to discriminate among these two kinds of gas, and why will they work? (3 points)

j) Describe the processes by which: *(i)* an 800 Å photon; *(ii)* a 6000 Å photon; and *(iii)* a 100 keV photon, interact with the various constituents of the ISM. What cross-sections describe these interactions, and *why* are they relevant? (8 points)

Part II: (Total of 40 points.)

This question asks you to calculate the **time-evolution of a star-forming Giant Molecular Cloud**. We expect you to use a combination of literature references, analytical estimates, and possibly numerical calculations in your answer. Please be sure to provide clear documentation.

Assume the following conditions at $t = 0$:

- total mass, $M_{TOT} = 5\times10^5$ $M_\odot$
- filling factor, $f = 10\%$
- average density of "filled" regions, $n_\circ = 40$ cm^{-3}
- average kinetic temperature in "filled" regions, $T_{K,o} = 50$ K
- initial magnetic field permeating cloud, $B_\circ = 6$ μG
- stellar population interior to the cloud: none
- stellar population exterior to the cloud: well-represented by a Miller-Scalo IMF

And, make the following assumptions in general:

- The length of time it takes to form a star of a mass M_* is equal to $t_f = \left(M_\odot / M_*\right)\times10^7$ yr.
- Every star goes through an outflow phase, which lasts for the last 90% of t_f.
- The IMF formed by the molecular cloud is a representative sample of the field IMF in the Galaxy.

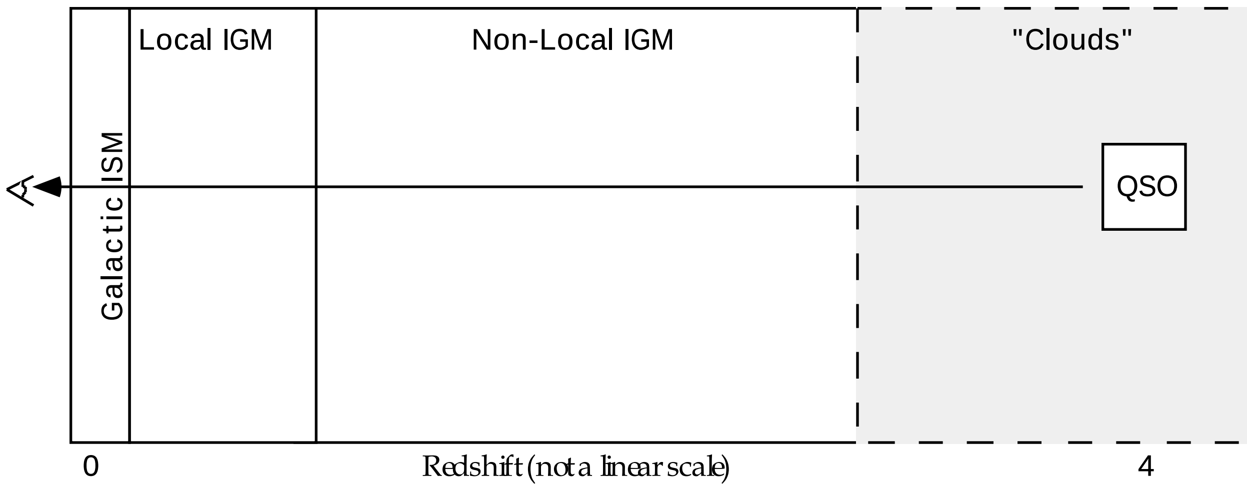
a) Describe, in words, and a few hard numbers, what you expect will happen to this cloud from $t = 0$ onward, and why.

b) Estimate how long this "Giant Molecular Cloud" will be able to form stars, assuming there is no "ambient" gas (i.e. gas not in the original cloud at t=0) within 1 kpc of the cloud.

Obviously, in order to answer this question in a reasonable length of time, you are going to need to make several more assumptions, and they are going to need to be very *drastic*. (For example, you will have to make simplifying assumptions about outflow velocity and structure as a function of time, as well as about the locations and frequency of any supernovae that might occur. You may even want to "smooth out" the material, and ignore the whole "filling factor" issue.) **The main point of this problem** is for you to use what IS known about GMCs and the stellar births and deaths that go on there to identify that which IS NOT known about these processes. These unknown parameters (many of which you will be making educated guesses about) are critical to real solution to this problem. In fact, some of them are so poorly known, and so important, that they would be great thesis topics. The trick here is to use what you do know to realize what you (and the rest of us) don't know.

The more correct relevant information you provide, the better, but keep in mind that we do not expect you to spend more than the amount of time you spent on Part I of the exam answering this question.

Part III: A View through the Clouds (Total of 20 points.)



In the (very!) schematic diagram above, the labels are meant to represent:

- *Galactic ISM* = all the gas and dust in the Milky Way, assuming you're looking along a line of sight almost perpendicular to the Galactic disk
- *Local IGM* = non-stellar material within the Local Group of galaxies
- *Non-local IGM* = any material at moderate redshifts
- *"Cloud"* = mysterious semi-primordial clouds, regime may overlap with much of Non-Local IGM
- *QSO* = position of quasar at high redshift, z~4

Given all of this...

a) Ignoring the effects of "Clouds," the Local ISM, and the Local IGM, draw a schematic illustration of a hypothetical spectrum of the QSO in the wavelength range from 900 Å to 7000 Å, assuming that the IGM is made of neutral Hydrogen. Mark the important features of the spectrum and explain their significance. Note how the shape of your spectrum will vary according to assumptions about the density of the Universe. (3 points)

b) How similar is the spectrum you drew in (a) to real QSO spectra in this wavelength range? (Find one and show it.) Do you expect that 21-cm emission from neutral H will ever be observed from the Non-Local IGM? Why or why not? (3 points)

c) Looking at the real QSO "absorption line" spectrum you found for (b), briefly explain what can be learned about the properties of the hypothetical "Clouds" shown above. (3 points)

d) Now consider all the components shown in the diagram. If you sought to determine the total mass of all of the "Clouds" seen at redshifts greater than z=2, how would you do it? Assume you have infinite financial resources, graduate students, and observing time. (5 points)

e) In the project you describe in (d), what are the most important effects of the "foreground" (e.g. Galactic ISM, Local IGM) material that you would need to correct for? Estimate their magnitude. (6 points)