Astronomy 208: The Physics of the Interstellar Medium

Final Exam

Distributed: January 21, 1999 at 5 P.M. on the web
Due: January 27, 1999 at noon at AG's mailbox (3rd floor of 160 Concord Avenue)

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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[*] Use of class notes and any printed reference material is allowed. Only collaboration with others is not allowed.

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There are two parts to this exam, which total 100 points of potential credit.

Part I A series of questions designed to test your general knowledge of the Physics of the ISM, and to satisfy the Astronomy Department's mandate to use final exams in core courses in lieu of "General Exams." (45 points total)

Part II A substantially more thought-provoking question on whether H I supershells created by Gamma Ray Bursts would be observationally distinguishable from those created by correlated SNe. This question is intended to test whether you have learned enough about the ISM in this class to address "real" (as-yet-unanswered) research questions about the ISM. (55 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 45 points)

Remember to show all 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 Milky Way. Break down your estimate into a sum of components made up of the relevant combinations of: hot/cold; neutral/ionized; atomic/molecular gas. (4 points)

b) Estimate the total mass of dust in the Milky Way. Explain what observations can be used to arrive at this estimate. (3 points)

c) What would be the approximate peak wavelength (averaged over the face of the Galaxy) from dust in the Milky Way as viewed from another galaxy in the Local Group? Why? (2 points)

d) Calculate the frequency of the J=7-6 line of CO. What would the approximate redshift of a galaxy need to be in order to observe this line with a mm-wavelength telescope? (3 points)

e) Assuming you are observing at the Arecibo Observatory 1000-foot telescope, which has an efficiency of roughly 60%, calculate and graph the expected 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 cm^{-3}, a kinetic temperature of 100 K, and a velocity distribution with dispersion σ=8 km s^{-1} (based on a Gaussian fit), at a distance of 2 kpc. Assume the LSR velocity of the cloud is –10 km s^{-1}, and that it is in Local Thermodynamic Equilibrium. (8 points)

f) For a binary star system comprised of one O4 star and one B0 star separated by 80 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} cm^{-3}. (3 points)

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

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

i) Near the center of an active galaxy, one can find both photoionized and shock-ionized gas. If you could observe such a galaxy with very high spatial resolution, what kind of observations would you make to distinguish shock- from photo- ionized gas? (4 points)

j) Describe the processes by which: *(i)* a 6000 Å photon; *(ii)* an 800 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? (7 points)

k) What is the hydrogen Gunn-Petersen effect, and has it been detected? What makes this very difficult to detect? Is it be easier or harder to detect the He Gunn-Petersen effect? Explain why. Has this been observed? (5 points)

Part II: The Creation of H I Supershells (55 points)

This problem asks you to consider two competing theories for the origin of H I Supershells. The first theory proposes that spatially and temporally correlated supernova explosions provide the energy necessary to create H I supershells. The second theory, proposed by Avi Loeb and Rosalba , proposes that Gamma Ray Burst events may create the supershells (e.g. Loeb & Perna 1998).[1]

We define a "supershell" as a structure that requires $E>3 \times 10^{52}$ erg of energy input to create it (after Heiles 1979).

Using what is known about the phases of supernova remnant evolution, discuss how one might observe differences between the properties of a GRB-created supershell vs. a shell created by correlated supernova explosions. (55 points)

This question is stated in such general terms intentionally. The idea is to give you an opportunity to be creative and use what you have learned in class, and what you can find in the literature, to think *quantitatively* about this question. Feel free to write about ideas you have that you ultimately decide would not work, as well as those that might. (In other words, since most properties of GRB shells and SN supershells will be indistinguishable, you should mention similarities as well as differences.)

You should address many of the following questions, and any others that occur to you, in your (stated) assumptions and "solution" for this problem:

- How large a region will an explosion of energy E effect in time t?
- How much breakout of hot gas might each kind of explosion cause?
- How close together in time and/or space would SNe need to be in order to mimic a GRB shell?
- How does the density distribution effect your conclusions? For example, what about:
  - a constant density environment
  - a radial density profile with $n \sim R^{-b}$, where b is a reasonable exponent (explain origin of b)
  - lumpy distribution with lumps of density n and voids of density zero, with filling factor f
- Will the time evolution of the supershell give any hints as to its origin?
- Will the heating and cooling of the shell depend on its progenitor(s)? (*Hint: think about the pre-explosion environment of various types of exploding objects.)*

Please note that a very interesting solution to this problem would ultimately be worthy of a publication, and Avi Loeb and I might be interested in collaborating with any of you who find this as interesting a question as we do. Also note though, that this is just an exam question for now, and I am not asking for *ApJ*-ready material at this time—just a clear, detailed, exposition of your thoughts on this question.

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[1] Note that the GRB theory is actually similar to one of the oldest theories of supershells, proposed by Shklovskii (1970), which hypothesizes super-supernovae as the origin of supershells.