ASTRONOMY 220C

Problem Set 4
Due March 7, 2019

Short answers

1) Describe what is meant by a "convectively bounded flame". For what range of stellar massses might such flames be important during oxygen burning?

2) An iron core in a massive star has a mass of 1.6 $M_\odot$. Suppose this core collapses and ejects all the matter external to it. In the process it emits 3×10^{53} ergs in neutrinos. What is the gravitational mass of the resulting neutron star?

3) About how many neutrinos per cm^2 s^{-1} are expected to arrive at the Earth from all the supernovae that have ever happened (look it up in the notes)? Compare this with the results of the following crude estimate: a) 1 SN / second in the observable universe; b) typical distance 5 billion light years; c) average neutrino energy 15 MeV; d) BE of neutron star 3×10^{53} erg; e) only electron antineutrinos are detectable.

4) In the presupernova model for a Type IIp supernova there are regions where the quantity $\rho(r)r^3$ increases with increasing r and places where it decreases. As a shock wave moves through these regions where will it speed up, slow down, and move at constant speed?

5) What evidence is there for the operation of *two distinct* neutron capture processes, the r- and the s-process, operating in the synthesis of the heaviest (pot-iron-group) elements? Not just one continuous smear of exposures but two disjointly, distinctively different processes.

6) What is the observational difference, spectroscopically, between Type Ia, Ib, and Ic supernovae?

7) Does the ratio of Na/Mg and Al/Mg vary with the initial metallicity of the star? Why or why not? (See Z = 0 nucleosynthesis).

8) What is the most common class of supernova (Roman numeral plus a letter)?

Longer Problems:

1) The moment of inertia, $I \approx 2/5MR^2$, of a standard neutron star (10 km, 1.4 $M_\odot$ is near 1×10^{45} gm cm^2. Neutron stars with rotational periods less than 1 ms will deform and emit copious gravitational radiation, hence losing their angular momentum rapidly. Rotational energy is $0.5I\omega^2$ where ω is the angular rotational speed in radians s^{-1}. What is the maximum rotational energy of a "non-deformed" neutron star?

2) What are the physical conditions that determine the temperature for *explosive* oxygen burning vs. hydrostatic oxygen burning? Suppose a layer of pure ^{16}O existed at a at a radius 2500 km from the center of a 1×10^{51} erg core-collapse supernova. What would be the temperature experienced in the explosion and what would be the most abundant nucleus ejected?

3) Why does the path of the r-process of nucleosynthesis in the periodic chart of the isotopes depend on the neutron density *and* on the temperature? Will the time scale for the r-process to go to uranium say be shorter at higher temperature (say 5×10^9 K) or lower temperature (say 2×10^9 K) for the same high neutron density (qualitative answer only, don't compute the r-process at $\mathrm{T}_9 = 2$ and 5)? What are a typical time scale, temperature, and neutron density (in neutrons cm^{-3}) for the r-process? How do these compare with conditions for the s-process (give numbers)?

4) (Greek) alphabet soup - define and give the major nucleosynthesis and probable site(s) for each of the following: a) ν-process, b) γ-process or "p-process", c) neutron-rich NSE, d) α-rich freeze out, and e) r-process.

5) Consider an expanding sphere of initial radius 2×10^8 cm and mass 1.4 $M_\odot$ initially heated to 10^{10}K (SN Ia model). Assuming constant density, total ionization, $Y_e = 0.5$, homologous expansion ($v \propto r$), and opacity due to electron scattering, calculate the radius the expanding sphere would have when it first became optically thin. (aside: the gas does not really remain totally ionized but the Doppler broadened forest of iron lines in a SN I provides an opacity comparable to electron scattering; use $\kappa_e = 0.2$ cm^2 g^{-1} throughout). If the expansion were adiabatic ($\rho \propto T^3$) as well as homologous what would be the temperature inside the star at this point. Obviously this is too cold because you have left out the effect of radioactive decay.