ASTRONOMY 12

Problem Set 4 – Due March 10, 2011

1) After helium burning in a low mass star like the sun, a degenerate core composed of carbon and oxygen is formed that has a temperature of roughly 10^8K, i.e., a white dwarf star. The ions (i.e., the nuclei) are not degenerate, even though the electrons are. The total *thermal* energy in the core (which is all that can be radiated away) is then $\sim N_{ion}$ k T where N is the number of nuclei in the core. a) Calculate the total number of carbon nuclei (which will be N_{ion}) in a (pure) carbon core of 0.7 $M_\odot$. (hint: 1 gram of carbon contains $N_A/12$ carbon ions where $N_A = 6.02 \times 10^{23}$). b) What is the total energy in this 0.7 $M_\odot$ of carbon nuclei if the temperature is 10^8 K? c) How long could this energy provide a luminosity of 0.01 $L_\odot$? d) of 0.001 $L_\odot$? This is where white dwarfs get their energy. They are the cooling "embers" of helium burning.

2) Big and bright as a supernova is, it still radiates like a blackbody not much hotter than the solar photosphere. It must therefore have an enormous radius. Calculate the radius of a Type IIp supernova when it is at its brightest and has a luminosity of 5×10^{42} erg s^{-1} and an emission temperature of 5500 K. Express your answer in AU. [You may need to go back and review your blackbody radiation formulae from earlier in the quarter].

3) The *observable* universe contains about 100 billion (10^{11}) galaxies. Most of these galaxies are much smaller and fainter than the Milky Way, which has a total luminosity of about 10^{44} erg s^{-1}. So let us estimate the luminosity of a typical galaxy to be 10% of that, i.e., 10^{43} erg s^{-1}. What is the approximate luminosity, in starlight, of the observable universe in erg/s? Compare this to the energy released in neutrinos by a proto-neutron star during the first 3 seconds of its life - 3×10^{53} erg. [Note this answer is only good to about a factor of 10. Not all galaxies are the same and the number is uncertain, galaxies evolve, their light gets redshifted, etc.]

4) Carbon burning in a massive star occurs in a state of balanced power with neutrino losses from each gram of matter balancing energy released by nuclear fusion. If carbon fusion at 10^5 g cm^{-3} develops a power of 5×10^9 $(T/10^9 K)^{23}$ erg g^{-1} s^{-1} and neutrino losses by the pair process carry away a power of $4 \times 10^8 (T/10^9 K)^9$ erg g^{-1} s^{-1}, at what temperature will carbon burn in balanced power? [nb. in the notes the neutrino losses are given by a slightly different expression that is more accurate at higher temperature. Don't use the expression in the notes for this problem.]

5) If the net gravitational binding energy of a white dwarf just before it explodes as a Type Ia supernova is -3×10^{50} erg and if the nuclear fusion reactions release 10^{51} erg and the mass of the dwarf is 1.4 solar masses, what will be the average velocity - in km/s - of the ejecta in the explosion?

Shorter Questions and lists

1) Define and discuss each of the following with two or three sentences.

a) Babcock model b) Solar corona c) Solar wind d) Neutrino flavor mixing

2) Define and discuss each of the following with two or three sentences.

a) Helium flash b) Planetary nebula c) Horizontal branch of the HR diagram d) On the horizontal branch are more massive stars bluer or redder than less massive ones - only one word needed here e) Asymptotic giant branch star

3) Define and discuss each of the following with two or three sentences.

a) Chandrasekhar mass b) Carbon burning c) Pulsar d) The r-process e) Classical nova

4) What is the relevance of each of the following masses in stellar evolution? That is, what happens above or below this mass that is different?

a) 0.08 $M_\odot$ b) 0.5 $M_\odot$ c) 1.44 $M_\odot$ d) 2 $M_\odot$ (two things) e) 8 $M_\odot$ f) $\sim$130 $M_\odot$ (what happens and why?).

5) What are the chief differences with respect both to mechanism and observations between a Type Ia and a Type II supernova? Give 5 characteristics of each - "what kind of stars give each, how often do they occur, what does the spectrum look like, how bright are they, how long does each last, what velocities are seen, what elements do they make, what do they leave behind, how does each explode", etc. are questions you might consider.