Topics: Nucleosynthesis and stellar evolution, part 3 (review)

Reading:

- Re-read key sections of Ch. 6 (and even some earlier chapters), as needed, according to this week's problems and discussion topics; otherwise, no new reading.
- Take a (re-)look at the charts of nuclides linked from the class website (and think about them with respect to the liquid drop model).

Summary of work to be produced:

- Your solutions to QW2 and QW10 should be handed in by 4pm on Friday.
- Bring solutions to the numbered problems assigned below to seminar on Monday. Bring a xeroxed copy to give to me at the beginning of class, and expect to take notes on your original solutions. And be ready to discuss the ideas/questions that are stated below, but before the first numbered question. *Note that some problems are more wordy, multi-part, and less mathy than usual; you should provide written answers to all parts of these numbered problems.*

Questions etc.:

Note: The numbered questions for which you have to hand in solutions include just the stuff in each continuous paragraph associated with each number. Paragraphs without a number do *not* require written solutions.

Also note: There are a few more questions than usual this week both because you have, presumably, already thought about and written down some notes for the questions below that came from last week's assignment and also because there's no new reading for this week. Finally, Ostlie and Carroll is on reserve in Cornell.

Refer back to Fig. 6.10 to look at differences in the evolution of stars of different masses (what are the key differences, compared to the Sun, of very massive stars? very low mass stars?).

Q1 What happens to the heavy elements in an end-stage massive star, as it is collapsing? What are those reactions on p. 246? Is energy released or consumed? Compute the amount of energy either released or consumed in the reaction given in eq. 6.67. How much energy is 10^{51} ergs – how long would the Sun have to shine to produce that much energy? Where does that supernova energy come from? What back-of-the-envelope calculation could we do to see if that energy is actually available (assuming, say, that a neutron star of $M = 3\ \mathrm{M}_\odot$ and $R = 10$ km is produced in the core-collapse)?

QW2 Main sequence lifetimes are discussed and then shown in Fig. 6.23. If we could determine a relationship between the mass of a star and its luminosity on the main sequence, we could express the main-sequence lifetime as a function of a star's mass. Do this (both the $L(M)$ derivation and the expression of t_{life} as a function of M, by first deriving a scaling relation for $L(M)$. This can be done by looking at the stellar structure equations: HSEQ and radiation transport and cast them as *scaling relations* (i.e. proportions, not equations; drop all constants; express differentials as quotients) and combine these two equations to derive the relationship between mass and luminosity (L as a function of M)) for stars that transport energy primarily by radiation.

Rapidly rotating neutron stars: are you comfortable with the centrifugal force vs. gravity balance to, in this case (p. 261), derive an upper limit to the density of a neutron star? More fundamentally, this puts a limit on the rotation rate of a self-gravitating spherical object.

Q3 How many times faster than once-per-24-hours could the Earth rotate before the centrifugal force flings it apart? (What would the length of the day be in this case? You may assume that the Earth maintains its spherical shape.)

Q4 Eq. 6.70 is the *distance modulus*. Show that it's just the inverse square law in magnitude form. Show just the proportionalities.

Do you see how Fig. 6.26 is a way to use that equation for a whole cluster of stars? (Does the interstellar medium have an effect on this? – that's not discussed in the reading at all.)

Q5 The mass-radius relationship for white dwarfs is very different than for regular stars (supported by gas pressure). Why is this, physically (ask yourself: does a more massive star require more pressure? How can a degenerate gas produce more pressure)? Use the equation of state for (non-relativistic) degenerate matter and the equation of HSEQ to derive a scaling relation between the mass and radius of a white dwarf. How is this mass-radius relationship modified for a relativistically degenerate white dwarf? This should give you a hint that there is an upper mass limit to white dwarfs. Why are more massive white dwarfs the ones that are described by the *relativistic* degenerate equation of state?

Q6 Show that the beta-decay reaction given by eq. 6.89 is the inverse of the reaction given by eq. 6.67.

Find the part of the chart of nuclides shown in Fig. 6.36 in one of the interactive charts linked from the website. Show/describe step-by-step the s-process path denoted by the solid line in the figure. Be prepared to describe what is actually happening as nuclei are synthesized along the path (at each step, what reaction is happening). Explain how, if the neutron flux were much higher, ^{116}Cd would be produced instead. What two processes should we be comparing, in terms of their speed, in order to determine if this happens (r- vs. s-process)?

Q7 How do we know which isotopes are stable and which are not? What are the physical considerations behind each term in the *liquid drop* model?

Q8 What does radioactive decay of cobalt have to do with supernovae light curves? How do we know for sure that we're seeing this effect in the light curve? Note that the rate at which a radioactive isotope decays is proportional to the number of such atoms present, and so the luminosity produced by this decay is $L = -dN/dt = kN$. What is the relationship between the constant of proportionality, k, and the half-life of the isotope?

Q9 What is a type Ia supernova? And how is it similar to a recurrent nova? And how is it different?

QW10 Do problem 16.1 in Ostlie and Carroll.

Q11 Do problem 16.11 in Ostlie and Carroll.

Q12 Do problem 16.18 in Ostlie and Carroll.