A102 Exam 4 Solutions

2004-December-10

1. **(a)** Zero. The Big Bang made just Hydrogen and Helium; all other heavy elements are made in stars and supernovae. The first stars are by definition formed from gas that hadn't yet been enriched by star formation.

(b) Almost right after the Big Bang. The Universe is 13.6 billion years old, and globular clusters must come from gas that had already been enriched by the first stars, since they have *some* heavy elements. As such, the first batch of first-generation stars must have formed no more than a few hundred million years (or perhaps a billion years) after the Big Bang.

(c) Look to very great distances. When you look far away, it takes time for light to get to you. Thus, you're looking back in time. If you look far enough away, you are looking far enough back in time in so that you may be seeing the time of the first stars. (This will require very impressive telescopes, as the distance is huge. Learning about the first stars will probably be one of the major focuses of the Webb Space Telescope, the successor to the Hubble which should be launched sometime in the 2010's.)

2. **(a)** They must have been at least moderately high. If there are no stars left with the masses of the first stars, it means that enough time must have elapsed for the first stars all to have died. If there were any low-mass stars that lived longer than 13 billion years, there should still be some hangning around.

(b) There may be some white dwarfs, neutron stars, and black holes left over from the first stars.

3. In a core-collapse supernova, gravity wins over the degeneracy pressure of the iron core. The core gets massive enough that the core collpases down to a neutron star, releasing a huge amount of gravitational energy in the supernova.

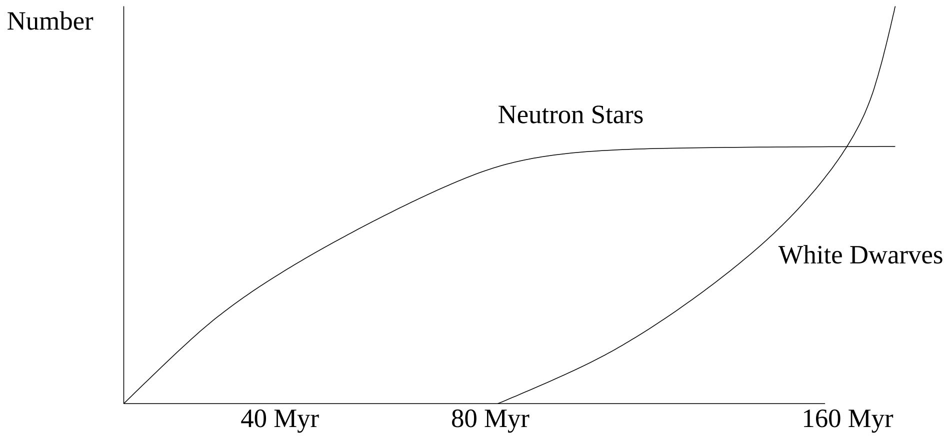
At the very end of a lower mass star's lifetime, it throws off a planetary nebula. The star is unstable and pulsates, and for a short while motion wins enough to eject the outer layers of the star into the expanded gasses that make up the nebula.

In a thermonuclear supernova, first gravity wins, then pressure wins. A white dwarf gets so massive that electron degeneracy pressure can't hold it up any more, and the star starts to collapse. However, that makes the Carbon and Oxygen that form the white dwarf start to fuse. This generates so much energy and motion that the entire star is blown away, representing a final triumph of motion over gravity for this star.

4. It's the only energy source that can work; all other possible energy sources don't provide enough energy to keep the Sun shining at anything like its current luminosity for as long as we know it's been shining.

Second, we've observed neutrinos from the Sun, which are predicted to be there if fusion at the core is what is powering the Sun.

5.



6. (a) If the orange star is the same luminosity as the blue star, it must be much bigger. (The blue star is hotter, so if it were the same size it would be more luminous.) On the main sequence, redder stars tend to be a bit smaller than bluer stars (and much less luminous). Therefore, it's possible that the blue star is a main sequence star, while the orange star is a giant. In this case, the orange star must be more massive. The binary star will have formed together, but the orange star is further along in its evolution (already being a giant). More massive stars live through their lives faster.

Another possibility is that the blue star is a white dwarf, and the orange star is a main sequence star. If you look at an HR diagram, it's possible to both kinds of stars at the same luminosity. Still, the blue star is much smaller than the orange star. In this case, it's hard to say which star is more massive, but the blue star must have *started* as a more massive star, since it's lived through more of its life than the orange star. However, since a lot of mass can be lost when you go from the red giant to the white dwarf stage, the blue star now has less mass than it did when it started out, and it's possible that it is now lower mass than the other star.

(b) No. See above: for the two stars to be the same luminosity, the orange one must be much bigger.

There is one way out of this. The assumption I've implicitly made above is that the two stars are close together, and the planet is orbiting at a some distance from the pair of stars. It's possible that the planet is orbiting around the blue star, and the orange star is much farther away and orbiting the blue-star/planet system. In this case, the orange star could be a giant and appear the same size as the closer blue star. However, in this case, the orange star would be much less bright than the blue star (same luminosity, but at a greater distance). Although I didn't say this in the question, in the movie the two stars are depicted as being equally bright. (Of course, the movie didn't strictly tell us anything about the luminosity. From what the movie told us, it's possible that the orange star is a supergiant that's much more luminous than the blue star. It's much farther away than the blue star, far enough to make both its size and brightness match that of the blue star. In this case, the whole thing would be realistic, but that wasn't the question that I asked on the test.)