Astronomy 102: Stars and Galaxies

Fall, 2003

Sample Review Examination 4 Solutions

1. (a), (b) and (d) :

(a) A Nova. A nova happens when a white dwarf pulls mass from a companion, and the compressed shell on the surface of the white dwarf explodes. This requires a binary system.

(b) A Type Ia (thermonuclear) supernova Progenitor systems are just like nova progenitor systems, only here the white dwarf pulls enough mass into itself that it exceeds the $1.4\,M_\odot$ mass limit; it compresses enough that runaway fusion of the carbon in the white dwarf can proceed. Since the white dwarf needs a mass source, this too comes from a binary system.

(c) A Type II (core collapse) supernova. This is a massive star going foom when its core can no longer hold itself up. That's a function of the structure of the star itself, and doesn't require a companion; thus, these don't require binary systems.

(d) A star whose mass we can measure without resorting to theories of stellar evolution. We talked about measuring the mass of binary stars a while back; by observing the speed and separation of the orbit, we can figure out the mass of the binary stars.

(e) A star whose luminosity we can measure without resorting to theories of stellar evolution. Flux you can measure from any object. You can measure the distance to a star via parallax, and that doesn't require the star to have a companion. Put those two together to get luminosity. Thus, this doesn't require a binary system.

(f) A pulsar. This is a rotating neutron star, which is left behind by a Type II supernova (see (c) above). Since those can happen to isolated stars, isolated pulsars can be left behind. (Some pulsars are in binary systems, but they don't need to be.)

(g) A white dwarf. This is what's left behind when a low mass star finishes its evolution. That evolution will happen even if the low mass star is all by itself, so you can find white dwarfs left behind all by themselves.

(h) The Sun has planets. The Sun is not in a binary star system…

2. (e) None of the above. Let's go through these in order:

(a) You didn't have the numbers necessary to *calculate* the moon's event horizon radius, so reasoning another way might be necessary. You might remember that a black hole of the mass of the Sun would be 3 km in radius. You might remember that a neutron star is typically several km in radius, and that if it's about as small as a star can get (modulo the exotic possibility of "quark stars") before it is a black hole. Neutron stars are typically within a factor of a few of the Sun's mass. Referring to the equation on the front of the test that tells you the event horizon radius of a black hole is proportional to its mass, since the moon is a whole lot less massive than the Sun, a moon-mass black hole will have an event horizon a whole lot less than the "few kilometer" size typical for star mass black holes. As such, 3 km is way too big for the event horizon of a moon mass black hole.

(b) Tides on the Earth are due to the difference between the affect of the Moon's gravity on one side of the Earth and the effect on the opposite side of the Earth. (The Sun plays a role too, but we're only talking about the Moon here.) A black hole *of the same mass as the Moon* and *at the same distance as the Moon* would have the *same* gravitational effect... thus, the size of the tides wouldn't change. How do we reconciles this with the discussion in class about the huge tidal forces of black holes? That happens because you can get so *close* to a black hole. The closest you can get to the center of the Moon is its surface. If you tunnel down into the surface, some of the Moon will now be higher than you, and the full mass won't be pulling you towards the center with gravity. In contrast, you can get within centimeters of a moon mass black hole and have the full mass still pulling you towards it. Because gravitational force gets stronger as you get closer, this is why tides are so extreme near black holes: because you can get so close.

(c) This is a very common misconception about black holes. Black holes are not cosmic vacuum cleaners that suck down everything in the universe. Yes, something that crosses the event horizon is "sucked down" in the sense that it will never come back out. But the Earth isn't being pulled closer to the Moon right now (the speed of the orbit keeps us nicely apart), and thus there's no reason why the gravity of a Moon-mass black hole at the same distance as the Moon would be any more effective at pulling the Earth towards it.

(d) If nothing else, we could use the tides on the Earth to figure out where the Moon-black-hole is.... There are a number of other ways (e.g. the gravitational lensing effect of the black hole). Even though a black hole emits no light itself (modulo Hawking radiation), it does still have gravity, and we could feel the effects of that gravity to figure out where it is.

(e) **None of the above**. That's all that's left.

3. (c) Ultraviolet radiation from the hot star at the center. That's what's ionizing the planetary nebula.

4. Answer: (b). Red giants are huge, and thus have low surface gravity. It's hard for them to hold on to their outer layers. This is even more true as the star throws off its planetary nebula. Note that (a) is wrong: there is hydrogen fusion in a shell around a helium nucleus.

5. Answer: (e)

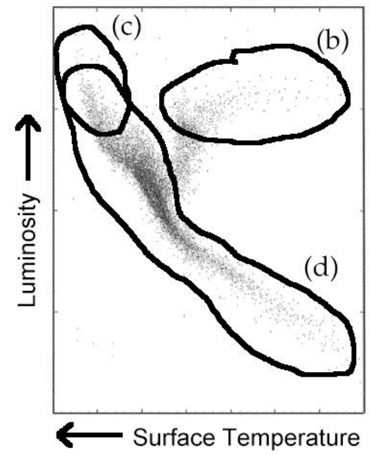
6. Answer: (a) If the stars were all formed at the same time, then stars that were more massive at the time of formation will be farther along in their evolution. Stars evolve from main sequence stars to red giants and on to white dwarves. **Note!** This is *not* necessarily the right comparison of masses *now*! Because stars lose a lot of mass during their red giant stage, and because they lose even more throwing off a planetary nebula, a star will be less massive as a white dwarf than it was when it started the main sequence.

7. Answer: (b)

8. (b) and (c). This is the H-R diagram of a globular cluster. You can tell that it's the H-R diagram of a group of stars all formed at once because it has a well defined main sequence turnoff; stars above a certain specific mass have used up their Hydrogen fuel, but the ones using it slower haven't. You can tell that it's an old group of stars because that turnoff is at relatively low mass, and the red giant branch proceeds *upwards* (whereas the "supergiants" that result from short-lived high mass stars just move to the right when they leave the main sequence). As for heavy elements, there's no reason to suspect that; moreover, this is a globular cluster H-R diagram and those don't have many heavy elements. This can't be the H-R diagram of either the nearest or the brightest stars, because both of those sets will include stars at lots of different ages.

8. (b) and (c). This is the H-R diagram of a globular cluster. You can tell that it's the H-R diagram of a group of stars all formed at once because it has a well defined main sequence turnoff; stars above a certain specific mass have used up their Hydrogen fuel, but the ones using it slower haven't. You can tell that it's an old group of stars because that turnoff is at relatively low mass, and the red giant branch proceeds *upwards* (whereas the "supergiants" that result from short-lived high mass stars just move to the right when they leave the main sequence). As for heavy elements, there's no reason to suspect that; moreover, this is a globular cluster H-R diagram and those don't have many heavy elements. This can't be the H-R diagram of either the nearest or the brightest stars, because both of those sets will include stars at lots of different ages.

9. (a): the Galaxy. It's not the nearest stars, because of the oversupply of high luminosity stars. The nearest stars (or any group of random stars in the Galaxy's disk) will have many more low mass main sequence stars than high mass luminous main sequence stars. It's not a globular cluster or an open cluster because there's no well defined main sequence turnoff: this is a group of stars all at a different age.



10. (1) A post-AGB star (or, less jargonly, an exposed hot core of a low mass star that is basically a newborn white dwarf) at the center of the cloud. In this case, the cloud is a planetary nebula; the hot core is ionizing the nebula with its UV radiation. (2) Hot young massive stars. In this case, the cloud is an HII region, or a star forming region. The hot young massive stars put out enough UV to ionize the cloud. (Other possibilities include a supernova; supernovae put out a lot of UV, and the shocks have enough energy to ionize the gas. We haven't talked much about this, but if you had listed a supernova as one of your options and said something intelligent about why, that would have been good enough. If you listed an active galactic nucleus, then you're way ahead of the rest of us; we'll talk about that sort of thing probably the Friday after the test.)

11. What we're looking at that is emitting the light must be expanding. Since it's cooling off, the only way for it to get more luminous if it's emitting thermally (which is implied since we assign a temperature to it) is for it to be getting bigger. This is no surprise... a supernova is the result of an exploding star, complete with shock wave traveling outward and sweeping up the gas. It would be surprising if it *weren't* expanding.

12. (a) If Betelegeuse doesn't lose too much mass and stays "high mass", it would explode in a $\boxed{\text{Type II (core collapse) supernova}}$ and leave behind a $\boxed{\text{neutron star}}$ which we could potentially observe as a $\boxed{\text{pulsar}}$. On the other hand, if it loses enough mass, it might alternatively throw off a $\boxed{\text{planetary nebula}}$ and leave behind a $\boxed{\text{white dwarf}}$. (Betelgeuse is high enough mass that that white dwarf would be a little different than the ones we talked about, composed of Oxygen and Neon rather than Carbon, but it would otherwise be similar, an electron degenerate star cooling off.) *Both* can't happen; only one of the other. What's more, there's no reason to suspect this white dwarf would turn into a nova or Type Ia supernova, since both of those events require a companion star, which the problem didn't mention.

(Given current best estimates, Betelgeuse will almost certainly one day go supernova.)

(b) This is a binary system. If Sirius B pulls mass from Sirius A (more likely once Sirius A becomes a red giant and has less of a grip on its outer layers), it might become a *nova* (possibly more than once), or even maybe (though it's not necessary, nor even likely) a *Type Ia Supernova*. In any event, eventually Sirius A will throw off a *planetary nebula* and become a *white dwarf*. **Note:** Sirius A won't go supernova! Not unless yet another star with a weak grip on its outer layers comes along to supply it with mass, and that's extremely unlikely.

For both parts of this problem, you wouldn't have had to list everything boxed above. For instance, in part (a), if you got both the alternatives of a supernova and *either* planetary nebula or white dwarf, you would get full credit.

13. (a) All stars currently known have at least some heavier elements, which were synthesized in the stars and supernovae of a previous generation of stars. Thus, this star would be from the first generation of stars; such a star has yet to be directly observed, and so it would be very exciting to find one.

Note: This was a test question last year. On the test, a few people said this was a star just like the Sun. That wouldn't be all that exciting, because we already do know of a number of the stars very much like the Sun. What's more, it's wrong: the Sun *does* have some heavy elements (about 2% of its mass).

(b) No. Planets need to have a rocky core to form in the first place. They form from bits sticking together. Indeed, the Earth is made most of rocky stuff. That's all heavier elements; if this is a first-generation star, which formed from a cloud of only Hydrogen and Helium, there aren't any heavier elements around to make planets.

(c) This star can *not* be more massive than the Sun. If it is one of the first generation of stars, to still be on the main sequence it must be very old— older than the globular cluster or halo stars, some of which are already almost as old as the universe. If such a star were more massive than the Sun, it would already have lived out its life and either have exploded as a supernova or become a white dwarf; in any event, it would no longer be on the main sequence.

Note: On last years test, a few said that it can't be a high-mass star because one needs heavy elements to become a heavy star. This is wrong! The mass of the constituent elements doesn't control the mass of the star; the total amount of stuff there is what controls the mass of the star. What's more, some people you incorrectly said that a star gets more massive over time as it fuses heavier elements. Remember that it takes *four* Hydrogen atoms to make *one* Helium atom. To first approximation, the star's mass doesn't change. In fact, since one Helium atom masses a little bit less than four Hydrogen atoms, the star's mass actually *decreases* (though as we saw earlier, only by a very small amount); that change in mass is released as energy according to $E = m\,c^2$, and is why stars can generate energy through fusion.