Astronomy 102 Spring 2003: Exam 3 Solutions and Commentary

1. (c) The dust between us and the center of the galaxy obscures visible light, but infrared light can penetrate it.

2. (e) Dark matter. This question had a trap in it: you remember from the last homework set that you figured out that the more numerous low mass stars have more total mass in aggregate than the stars which are individually more massive. I didn't grade you down if you said that most of the galaxy's mass is in low mass stars, but as was pointed out in the solutions, that was drawing too much of a conclusion, and after that set was due we learned that most of the galaxy's massis in dark matter.

3. (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 explods. 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 rquire 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 wholse luminosity we can measure without resorting to theoreis 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. . .

4. (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 (though you may remember from one of the review problems that it's about a milimeter), 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.

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

6. (b) More massive stars are rare.

7. (a) Easier to find due to shorter period and greater gravitational effect.

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 realtively 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. Nobody got this completely right. In fact, the vast majority of you answered slightly the wrong question, "Can life exist on the planet which was discovered?" Many of you reasoned right that, no, Earth-like life couldn't exist on a Jupiter-like planet. (But, note, see below.) If you read the question carefully, it asks "Is it possible that there is life similar to life on Earth in this *star system*?" Only three or four of you considered the possibility of another planet, and correctly reasoned that if there were a Jupter at the Earth's distance from the Sun, its gravity would prevent there being an Earthlike planet close enough to be the right distance from the Sun to support life. Those people got 2.5 out of 3 points.

Nobody divined the purpose of the hint: as you've observed Jupiter and Saturn in the lab (or even just read about them in the lab descriptions), you've seen that they have *moons*. These moons are a lot smaller than Jupiter and Saturn, and indeed some of them are similar in size to smaller terrestrial planets. Earth-like life could have evolved on a moon around a gas giant at the right distance from a Sun-like star. (Like, say, redwood trees and Ewoks.)

Note: A number of you said things which are wrong about a Jupiter-like planet 1 AU from the Sun. Many said it would be very *hot*. You were probably thinking of the "hot Jupters", many of which are *closer* to their primary than the Earth is to the Sun. If you look back at our thermal equilibrium discussion, except for considerations of the greehouse effect, the surface temperature of a planet depends *only* on its albedo and how far it is from the Sun, *not* on its size. Thus, to first order, you'd expect the surface temperature of a Jupiter 1 AU from the Sun to be similar to the surface temperature of the Earth. Many of you also said that if Jupiter were so massive, it would have to orbit the Sun a lot faster. First, it's not clear why this would inhibit life. Second, this is wrong. The period of any planet's orbit (planets being much less massive than the Sun) depends only on its distance from the Sun; look back at our discussion of Kepler's laws a couple of months ago.

10. (a) If Betelegeuse doesn't lose too much mass and stays "high mass", it would exploed 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, compsed 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.

I noticed that a *lot* of you made a point of mentining that if it did explode as a Type II Supernova, that supernova would be powered by the gravitational energy released as the core collapsed. Clearly you were scarred by missing that on the last homework set, and got the idea that whenever a Type II supernova comes up, you must mention gravitational energy. It didn't hurt you here, but it wasn't necessary. Be careful with this kind of memorization and term regurgitation. While it usually won't hurt you, it can potentially distract you from answering the question which was asked, as happened on the last homework set.

(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 Siris 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, I didn't require you 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 got full credit.

11. (a) The disk, or the bulge. The disk has most of the mass, so that's where we see the most star formation, but it does go on in the bulge. More star formation does happen closer to the center than further out, but it is going on throughout the disk.

(b) Open cluster

(c) Yes. That gas will be ionized because of this very hot young star. (Further away, you'd expect there to be molecular gas which is left over from the cloud this star formed from.)

(d) The best answer is [similar heavy element abundance]. Most of you said "greater" and gave the right reason, and got full credit. (If you wrote the wrong reason I docked some points, but if you gave no reason I didn't dock anything since no reason was asked for.) The heavy element abundance of disk stars varies from a little less than that of the Sun to a little more than that of the Sun; it's not much more. Clouds forming stars now are likely to have been through more generations of star formation than the cloud the Sun formed from. It's not necessary, though; parts of the Galaxy (closer to the center) which are more vigorously forming stars have gone through generations faster than stars farther out.

Note: a small number of you confused heavy element abundance observe in a star with the results of fusion. Yes, ultimately heavy elements come from fusion in a star, but what you see in a star depends on the cloud that the star formed from! Both the Sun and this star are main sequence stars, which means they are fusing Hydrogen to Helium. In other words, they aren't making heavy elements yet. Any heavy elements they have will be what they had when they started out, which will be the same fraction as the cloud that they formed from. (See also the last problem for more misconceptions about heavy elements and stars.)

12. The primary evidence for dark matter comes from observing the orbits of stars in the disk about the galaxy. From looking at where the light of the galaxy is (which traces the stars, and if you use telescopes of the right wavelengths, the gas), you can predict how fast a star a given distance from the center of the galaxy will be orbiting. As you get farther out, they are all orbiting *faster* than that. Thus, there must be more mass than we've seen. That leftover mass— most of which isn't yet identified— is the dark matter.

Many of you identfieid MACHOs observed via gravitational lensing. Yes, this does give evidence for some dark stars (or other compact objects) we hadn't previously realized were there. However, this is not all of the dark matter. What's more, these searches were motivated by the above evidence that there had to be *some* kind of dark matter. If it had turned out that MACHOs were all of the dark matter, it would be fair to say that detection of MACHOs was primary evidence for dark matter. As it is, though, the orbits of stars remains the primary evidence.

A few of you mentioned the gravitational lensing of clusters of galaxies, which allows us to measure those clusters' mass. That is evidence for dark matter in those clusters, not for dark matter in our Galaxy.

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: A few of you 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. See Homework assignment #4, Quesiton 3.

(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: A few of you said it can't be because you need 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 of 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.