Astronomy 102, Exam 2 Solutions 2006/10/09

1. **(a)** You can just look these up by comparing the top and bottom labels of the horizontal axis on the H-R diagram. The bluish star is a B-star, the reddish star is a K-star.

(b) If the yellow star has the same luminosity as the Sun, then you know that the only thing that will affect brightness is distance:

$$B_G \;\propto\; \frac{1}{{d_G}^2}$$

So:

$$\frac{B_G}{B_\odot} \;=\; \frac{\frac{1}{{d_G}^2}}{\frac{1}{{d_\odot}^2}} \;=\; \left(\frac{d_\odot}{d_G}\right)^2$$

Thus:

$$d_G \;=\; d_\odot\sqrt{\frac{B_\odot}{B_G}}$$

We know that $d_\odot \;=\; 1\,\mathrm{AU} \;=\; 1/206265\,\mathrm{pc}$, so:

$$d_G \;=\; \frac{1}{206265}\,\mathrm{pc}\,\sqrt{\frac{1}{2.4\times10^{-13}}}$$

$$d_G \;=\; 9.9\,\mathrm{pc}$$

NOTE: Several of you failed to make the units consistent. Be sure to do this! Also, a few of you made the mistake of saying that $1/2.4\times10^{-13} \;=\; 2.4\times10^{13}$, which isn't correct.

Finally, a *lot* of you came up with an answer that made no sense whatsoever, but made no comment about that. Many of you had the star billions of light-years away, which should have raised some alarms. Others had it a small fraction of a pc away, which also should have raised your eyebrows. The most extreme had the star $2.6\times10^{-19}\,\mathrm{m}$ away.... A star that is just like the Sun, but much less bright, is hardly going to be a tiny fraction of a meter (smaller that the diameter of an atomic nucleus, in fact) away. If you get an answer like that, which is clearly absurd, think about it; if you can't find a mistake in what you did, at least comment about it.

(c) We have a star that's the same brightness as a Sun-like star, but 10 times farther away. (From (b), we know the G-star is about 10pc away.) It must be 100 times more luminous to have the same brightness. Looking at the H-R diagram, a B star that is 100 times the luminosity of the Sun falls squarely within the main sequence.

NOTE A lot of you said that supergiants must be red. A quick perusal of the H-R diagram in the test shows you that while giants tend to be red, and the vast majority of post-main sequence stars (giants and supergiants) are red, there are some B-type supergiants.

(d) We have a reddish star that's the same brightness and the same distance as a bluish star. Since it's got the same brightness and same distance, it has the same luminosity. If it has the same luminosity, but a much lower temperature, it must have a much bigger radius, making it a giant. Indeed, if you look at the H-R diagram, you see that a K-type star with a luminosity that's 10^2 that of the Sun falls squarely within the giant blob.

2. Elliptical galaxies are usually redder than spiral galaxies. The reason is that the brightest blue stars— the ones that dominate the blue light— in spiral galaxies are the hot main sequence stars. However, those stars only live up to a few tens of millions of years. If stars were last formed a few million years ago in an elliptical galaxy, they won't be there contributing their bluer light to that elliptical galaxy, so the elliptical will be redder.

NOTE: It's not enough to say that "because the stars in the elliptical galaxy are older, they're in the process of becoming red giants." This oversimplifies, and misses a couple of points. First, they're not all older than all the stars in the spiral galaxy; some of the stars in the spiral galaxy are very old. It's just that there are no young stars in the elliptical. Second, lots of stars in both galaxies will have become or have been red giants. However, the very low mass, dim stars that live longer than the age of the Universe will still be main sequence in both galaxies. The key point is that the more massive stars live faster, and it's only the more massive stars that are both luminous and blue. Thus, you have to have had recent star formation to have any luminous and blue stars hanging around.

NOTE: There *will* be evolved stars in both galaxies. There will be some stars in the last 10% of their lifetime in either galaxy. There will also be white dwarves in either galaxy; the main sequence stars that only live hundreds of millions of years will all have died off (and left behind white dwarves) in the elliptical galaxy, and most of them (all but those formed in the last few hundred million years) will also have died off in the spiral galaxy.

NOTE: Many of you suggested that the low, dim red dwarf stars, being the most common sort of star, were significant in one way or another. However, remember everything we talked about in class and on the homework regarding what are the brightest stars we see in the sky; they tend to be the white or blue main sequence stars, the supergiants, or the red giants. Red dwarfs, despite being numerous, have a low enough luminosity that they don't really contribute that much light to the overall light of a galaxy. The light we see from spiral galaxies is dominated by a mix of supergiants (of all colors), luminous hotter main sequence stars, and red giants. The light we see from elliptical galaxies is dominated by red giants. In the spiral galaxies, the red giants are a wide variety of ages and masses, since stars of all ages are dying right now. In the elliptical galaxy, the red giants are all going to be from stars less than a solar mass or two, since any star larger than that died long ago.

Also, some of you said that the spiral galaxy would be a mix of colors. The problem was asking about the overall colors of the galaxies; as such, you expect spiral galaxies to be whitish or slightly bluish, which is in fact what you see. You do see some small gradient in the color (different colors at different places), but it's not very large. However, as long as you indicated that ellipticals would be redder than spirals, and for the right reasons, I gave you full credit.

3. **(a)** It's approaching, since we see a blueshift— the light is shifted to a shorter wavelength.

(b) Combining the Doppler Shift and Redshift formulae, we get:

$$\frac{v}{c} = \frac{\lambda_{\rm obs} - \lambda_{\rm orig}}{\lambda_{\rm orig}}$$

$$v = c\left(\frac{6556\text{Å} - 6563\text{Å}}{6563\text{Å}}\right) = -0.0011\,c$$

$$v = -3.2 \times 10^5\,\text{m/s} = -320\,\text{km/s}$$

So the Andromeda Galaxy is coming towards us at 320 km/s.

NOTE ON SIG FIGS: Many of you murdered sig figs. Strictly speaking, there is only *one* sig fig in the answer, because the subtraction of 6556 and 6563 (yielding -7) reduced the number of sig figs to 7. If you gave me 2 or 3, I didn't care too much. However, many of you gave me *six* sig figs, and many of you gave me even more in part (c)! That vastly overstates how well you know the answer, given the precision of the information given to you in the problem. I did not take off for sig figs this time, but if you give me an utterly absurd number of sig figs on any future test, I will take off points.

(c) This is a simple distance=speed × time problem:

$$800,000\,\text{pc} = (320\,\text{km/s})t$$

$$t = \left(\frac{800,000\,\text{pc}}{320\,\text{km}\,\text{s}^{-1}}\right)\left(\frac{3.086 \times 10^{13}\,\text{km}}{1\,\text{pc}}\right)\left(\frac{1\,\text{yr}}{3.16 \times 10^7\,\text{s}}\right)$$

$$t = 2.4 \times 10^9\,\text{yr} = 2.4\,\text{billion years}$$

That's before the Sun will die! A recent issue of *Sky and Telescope* had an extensive article about the coming M31/Milky way collision.

There is a much easier way to do this problem; instead of working in km/s and pc, just work in light-years and years. The two galaxies are 2.6 million light-years apart. They are moving at 0.00106 the speed of light (to a few extra sig figs). The speed of light is 1 light-year per year. As such, it will take 2.6 million / 0.00106 years for the two galaxies to collide. . . or 2.4 billion years!

NOTE: Several of you came up with a relatively small number of years; some in the hundreds, some in the tens of thousands. Either way, you've just indicated that the two galaxies will close a 2.6 million light-year distance in less than 2.6 million years. . . which puts the galaxies travelling at faster than the speed of light! Clearly that can't be right. . . .

4. **(a)** This is an *emission* spectrum. Energy is put into the low-density gas by the stars that heat and excite it, and then the low-density gas will emit that energy in specific wavelengths.

NOTE: Many of you figured it was an absorption spectrum, because the light of the star would go through the gas. While this is true, there are two things to consider. First, as the problem says, the gas is spread widely around the stars– several pc in size. Stars tend to be much, much smaller than that, as we discussed the first few days of class (and have referred back to several times since then). As such, most of the gas you see from these regions is around the stars, not in front of the stars. This wouldn't matter if the gas were cold, because you just wouldn't see anything from or due to the gas that's not in front of the stars— but it's not. The gas is heated and excited by the stars. As such, this heated and excited gas will give off emission lines.

(b) The key here is that the light from the gas is an emission spectrum, with very little continuum; it's *not* a blackbody spectrum. As such, there's no real reason to expect that the gas would have the same color as a blackbody at the temperature of the gas. Indeed the problem statement says that the light is dominated by the Hα emission line, which is already a pretty direct statement that the light you're seeing does not make a good approximation to a blackbody.

Refer back to the homework question where I showed you the spectrum of the planetary nebula. Indeed, these star forming regions are in some ways similar to a planetary nebula: low-density gas surrounds a very hot star, and the star excites and heats the gas.