Astronomy 102, Spring 2003
Homework Set 4 Solutions

1. Chapter 14, Question 5: *If you placed your hand in boiling water (100° C) for even one second, you would get a very serious burn. If you placed your hand in a hot oven (200° C) for a second or two, you would hardly feel the heat. Explain why this is so, and how it relates to million-Kelvin regions of the interstellar medium*

The key difference between the boiling water and the air in the hot oven is density. The water is at higher density, so many, many more fast particles hit your hand each second. Even though the particles are moving faster in the oven's air (because of the higher temperature), enough fewer of them hit your hand per second that much less energy gets imparted into your hand.

In the million-Kelvin ISM, the density is many, many billions of times lower than even the air in the oven. So, even though the gas is extremely hot, if you were out there there would be so few (though not zero!) collisions per second with your body that it would not heat you up very fast. Indeed, you would radiate away heat (because you aren't at a temperature of absolutely zero yourself) faster than you'd gain heat from collisions with the hot interstellar particles.

2. Chapter 14, Question 7: *Stellar radiation can convert atomic hydrogen (H I) to ionized hydrogen (H II).*

(a) Why does a B8 main sequence star ionize far more interstellar hydrogen in its vicinity than a K0 giant of the same luminosity?

(b) What properties of a star are important in determining whether it can ionize large amounts of nearby interstellar hydrogen?

(a) Because the B8 star is putting out far more ultraviolet radiation than the K0 star, and it takes at least an ultraviolet photon to have the energy necessary to ionize a hydrogen atom. Note that the K0 doesn't put out *no* UV radiation: it just doesn't put out very much. Also, both the B8 and the K0 star are putting out a good quantity of visible light. However, the B8's spectrum is bluer, and given that the two stars are the same luminosity you can be very sure that the B8 star is putting out *more* UV than the K0 star.

(b) Temperature and luminosity. The former controls what fraction of the energy output of a star is in the ultraviolet (i.e. where photons have enough energy to ionize hydrogen). The latter controls the total energy output. It's not enough to be hot; if you're going to ionize a lot of gas, you need not only to emit UV, but you must emit a lot of it.

Many of you indicated "mass" as a property. This isn't quite right. Yes, one way to make a very high-temperature and high luminosity star is to make a massive main sequence star. However, it's really the temperature and the luminosity that matters. Consider, for example, a post-AGB star: the mass is less than $1.4\,M_\odot$, yet it's got enough ultraviolet radiation to ionize a planetary nebula.

3. Chapter 14, Question 4: *Coinsider a hypothetical star similar to our Sun being one of the first stars that formed when the Universe was still very young. Would you expect it to be surrounded by planets? Explain your answer.*

No. The very first generation of stars must have been made only from Hydrgoen and Helium (and a little bit of Lithium). The process of building planets from the disk of material around a protostar involves dust clumping together to make rocky cores. That dust and those rocky cores require heavy elements— and heavy elements are synthesized inside stars and in supernovae. The first generation of stars come before any supernovae, and there are no previous stars to make heavy elements.

A number of you indicated that if the Universe is 13 billion years old, then a star like the Sun (which only lives 10 billion years) would have gone through its red giant phase, including mass loss. You indicated that the nearer planets would be enveloped, and the further planets would drift away due to the decreased gravity from the mass loss. This latter statement is wrong! The star loses mass, but not *all* of its mass. As the star spews mass out into the ISM, yes, there is less holding the planets there, so the planets will go out into larger orbits. But there still is *something* holding the planets there. When the Sun becomes a white dwarf, approximately half of its mass will be left behind in that white dwarf.

A few of you also mentioned something about things moving too fast in the early universe due to the expansion. This is a misconception of how the universe's expansion works. We will talk more about this during the last week of the course when we get to cosmology.

4. Chapter 16, Question 11: *In 1841, the 150 $M_\odot$ star, Eta Carinae, was losing mass at the rate of 0.1 $M_\odot$ per year. Let's put that into perspective.*

(a) *The mass of the Sun is* 2×10^{30} kg. *How much mass (in kg) did Eta Carinae lose each minute?*

(b) *The mass of the Moon is* 7.35×10^{22} kg. *How does Eta Carinae's mass loss per minute compare with the mass of the Moon?*

(a)

$$\left(\frac{0.1\,M_\odot)}{\text{yr}}\right)\left(\frac{2\times10^{30}\,\text{kg}}{M_\odot}\right)\left(\frac{1\,\text{yr}}{5.26\times10^{5}\,\text{min}}\right)$$

$$= 3.80 \times 10^2 3\,\frac{\text{kg}}{\text{min}}$$

Eta Carina was losing $\boxed{4 \times 10^{23}\ \text{kg each minute}}$.

(b)

$$\left(3.80\times10^{23}\,\text{kg}\right)\left(\frac{M_{\text{Moon}}}{7.35\times10^{22}\,\text{kg}}\right)$$

$$= 5.17\,M_{\text{Moon}}$$

Eta Craina was losing $\boxed{\text{5 times the mass of the Moon each minute}}$.

Note that we only have one significant figure here, even though the Moon mass was given to three; the *other* number is only good to one figure. Notice also that I kept an extra couple of digits for intermediate calculations to avoid errors due to repeated rounding.

5. Chapter 16, Question 13: *In our Galaxy, there are about 50,000 stars of average mass (0.5 $M_\odot$) for every main sequence star of mass 20 $M_\odot$. But stars with 20 $M_\odot$ are about* 10^4 *times more luminous than the Sun, and 0.5 $M_\odot$ stars are only 0.08 times as luminous as the Sun.*

(a) *How much more luminous is a single massive star than the total luminosity of the 50,000 less massive stars?*

(b) *How much mass is in the lower-mass stars compared to the single high-mass star?*

(c) *What does this tell you about which stars contain the most mass in the Galaxy and which stars produce the most light?*

(a)

$$\frac{10^4\,L_\odot}{(50,000)(0.08\,L_\odot)} = 2.5$$

The single 20 $M_\odot$ star is $\boxed{\text{3 times as luminous}}$ as all 50,000 average stars put together!

(b)

$$\frac{(50,000)(0.5\,M_\odot)}{20\,M_\odot} = 1250$$

The average stars have $\boxed{\text{1000 times the mass}}$ of the 20 $M_\odot$ star. *NOTE!* This ratio does *not* have units! The units of $M_\odot$ cancelled out in the quotient aboe.

(c) All you can really conclude is: although average stars have much more of the Galaxy's mass than luminous main sequence stars, those luminous main sequence stars put out more light than all those average stars put together.

A lot of you concluded far too much, although I did not take points off for this. Some things you should not have been able to conclude:

Most of the light of the galaxy comes from high-mass stars. We haven't considered all types of stars here. Even if we assume that the problem gives accurate result for high mass versus low mass main sequence stars, we haven't considered giant stars. In fact, low mass stars do get a chance to contribute significantly to the luminosity of a galaxy when they are briefly giants, and much more luminous. (How much red giants versus massive main sequence stars contribute depend on the type and age of the stellar population.)

Most of the Galaxy's mass is in low mass stars. We now know from what we've done in class since this homework set was due that in fact most of the Galaxy's mass is in dark matter! All this problem really tells us is that the low mass stars use up more of the mass than the main sequence stars that put out the most light; or, equivalently, the low mass stars have a much higher percentage of the mass of the galaxy, but the high mass stars put out more light. You might also say that most of the *stellar* mass of the Galaxy is in low-mass stars.

6. *Type Ia and Type II Supernovae are each explosions that signify the death of a star and which are briefly as luminous as an entire galaxy. However, they are very different sorts of objects. What is the original source of the energy which powers each type of explosion? (I.e. where did the energy come from that allowed the energy in the explosion to be released?)*

Type Ia: fusion of carbon to heavier elements

Type II: gravitational potential energy released as the core collapses to a much smaller size

Notes: That's all that this problem needed. Many of you who got this also embellished your answer with a page of exposition about what happens in each sort of supernova. That's fine, but if you're on a test, you should conserve your time by answering the question which was asked.... If something helps you elucidate the answer, then it's great, but extraneous information isn't necessarily useful.

However, many more of you simply *didn't answer the question which was asked*! A lot of you answered the question "Please describe a Type Ia and a Type II supernova each in a paragraph or two." A few answered the question "What is the difference between a Type Ia and a Type II supernova?" A few more answered the question "What sort of star or star system do you have to have in order to get each type of supernova?" These answers resulted in a lot of (sometimes) very nice text saying what goes on in each type of supernova, but which never identified where all the energy which is released in each event comes from. I did give a point of partial credit for these nice descriptions, but no more than that since you didn't answer the question which was asked.

Take note of this as a strategy for answering problems. Sometimes, a huge information dump may accidentally spit out the right answer somewhere in the middle of everything else. Make sure, however, that you've thought about what the question is asking, and that you've actually addressed that in your answer.