ASTR 220 Homework #8
Spring 2005

1. *Ch. 11, Review Problems, #14.*

   Open clusters and globular clusters are opposites in many properties. Open clusters have a few thousands stars or less, while globular clusters have tens of thousands or even millions of stars. Open clusters are usually pretty young, a couple billion years old or younger, but globular clusters are very old, often over 10 billion years old. Open clusters orbit in the plane of the Milky Way galaxy, while globular clusters orbit in the halo of the galaxy.

2. *Explain why there are almost no old open clusters in our galaxy.*

   Open clusters, like all star clusters, are held together by the mutual gravitational force between all the stars in the cluster. The stars in an open cluster orbit around the center of the cluster. Their orbits do not have to be in a flat disk, but can be in any direction, similar to the orbits of stars around the bulge of the Milky Way galaxy. As stars pass each other on their orbits, their mutual gravitational forces alter their orbits. In particular, stars with high mass (therefore large gravitational force) can greatly change the orbits of lower mass stars that pass by. Over time, the high mass stars fling lower mass stars out of the cluster one by one: the high mass stars transfer some of their kinetic energy to the lower mass stars, so that the lower mass stars have high velocity and can escape the cluster, but since the high mass stars now have less energy, they can't move very fast and "sink" to the center of the cluster. Eventually, the high mass stars eject all of the lower mass stars from the cluster and the cluster has "evaporate": almost no stars are left.

3. *Ch. 13, Sensible Statements, #16.*

   This statement does not make sense. We know that if mass is added to a white dwarf, their radii actually get smaller. The extra weight of the added mass causes the white dwarf to compress to a smaller size.

4. *White dwarf supernovae.*

   (a) *Explain how a white dwarf supernova happens.*

   For a white dwarf supernova to occur, a white dwarf must have a companion star that is only a few AUs away (a close companion). When the companion star hits the end of its adult lifetime and evolves into a red giant, some of its mass is pulled over onto the white dwarf. The gas from the red giant spirals in to the white dwarf, forming an accretion disk. Gas in the disk eventually accumulates on the surface of the white dwarf. The gas that accretes onto the white dwarf is adding mass to the white dwarf, so the white dwarf is compressing to a smaller size. The interior is getting hotter. Eventually, if the mass of the white dwarf hits the Chandrasekhar limit of 1.4 times the mass of the Sun, the white dwarf is compressed enough that its interior temperature becomes high enough to start carbon fusion. The temperature of the white dwarf is the same throughout its interior, so that means that carbon fusion can start in the entire white dwarf simultaneously. The sudden release of so much energy causes the white dwarf to explode in a supernova.

   (b) *Why do they all have the same luminosity?*

   All white dwarf supernovae have the same luminosity because they are all caused by the same thing: a mass of carbon equal to 1.4 times the mass of the Sun fusing into oxygen. Fusion changes rest-mass potential energy into radiative energy. Since the same amount of mass is always fused, the same amount of radiative energy will always be produced, so the luminosity will always be the same.

5. *We learned in class that white dwarfs, neutron stars, and black holes can all be in close binary systems with another star.* ***Explain*** *why the accretion disks around the white dwarf, neutron star, or black hole heat up. Which type of object will have the hottest accretion disk?*

   The accretion disks around white dwarfs, neutron stars, and black holes get hot because as gas falls into the disk, the gravitational potential energy of the gas is being changed into thermal energy, which increases the temperature of the accretion disk. The amount of gravitational potential energy the gas has available to change into thermal energy depends on the gravitational force between the gas and the object that's pulling it in (a white dwarf, neutron star, or black hole). Since a black hole has the largest mass, the gravitational force on the falling gas will be the strongest if it's falling into the accretion disk of a black hole. That means that gas falling into the accretion disk of a black hole has the most gravitational potential energy to change to thermal energy – the accretion disk around a black hole will be the hottest. A neutron star has less mass than a black hole, and so gas falling into the accretion disk of a neutron star will have less gravitational potential energy to change into thermal energy. A white dwarf has the least mass, so gas falling into its accretion disk has the least gravitational potential energy available.

6. *Ch. 15, Review Questions, #1.*

   The three major types of galaxies are spiral, elliptical, and irregular. Spiral galaxies are like the Milky Way: they have a bulge, a disk, and a halo. Generally spiral arms are also visible, although the number of arms can vary. Usually the disk of a spiral galaxy looks bluish from the newly-formed stars, while the bulge looks yellowish because it has only older stars.

   Elliptical galaxies have shapes that are spherical or elongated-spherical. They do not have a disk or spiral arms: they are similar to the bulge of a spiral galaxy. Elliptical galaxies usually do not have new stars forming in them, so they look yellowish overall.

   Irregular galaxies have well-defined shape. They may or may not have new star formation, so they can look bluish (with new stars) or more yellowish (only old stars).

7. *How will collisions between galaxies in a cluster gradually change what types of galaxies are in that cluster?*

   We know that galaxies in a cluster are relatively likely to collide, because there isn't a lot of empty space between them compared to their sizes. When a galaxy cluster forms, there are likely to be many spiral galaxies in it, since we believe spiral galaxies are the basic galaxies that are created by the process of galaxy formation. However, when two galaxies collide and merge, they generally lose their original shape and end up forming an elliptical galaxy. Over time, as more collisions happen in a galaxy cluster, we would expect to see more and more elliptical galaxies and fewer spiral galaxies as a result of galaxy collisions and mergers.

8. *We learned in class that the Milky Way is likely to collide with both the Andromeda Galaxy and the Virgo Cluster in the future.*

   (a) *The Milky Way is heading toward Andromeda at a velocity of* $1.4 \times 10^5 m/s$. *Andromeda is* $2.2 \times 10^6 lyr$ *(*$2.1 \times 10^{22} m$*) away. How long will it be before they collide, assuming the speed is constant? Give your answer in both seconds and years.*

   We can use the basic equation $d = vt$, where d is distance, v is velocity, and t is time. We know the distance is $2.1 \times 10^{22} m$.

   We also know the velocity: $1.4 \times 10^5 m/s$. Now we can find the time.

$$t = \frac{d}{v} = \frac{2.1 \times 10^{22} m}{1.4 \times 10^5 m/s} = 1.5 \times 10^{17} s$$

Now we have the time in seconds. Let's convert it to years to get a better feel for how long this is.

$$t = \frac{(1.5 \times 10^{17} s)}{(60 s/min)(60 min/hr)(24 hr/d)(365 d/yr)} = 4.8 \times 10^{9} yr$$

The Milky Way and Andromeda will collide in 4.8 billion years!

(b) *The Milky Way is heading toward the Virgo Cluster of galaxies at a velocity of* $4 \times 10^5 m/s$. *The Virgo cluster is* $5.5 \times 10^7 lyr$ *(*$5.2 \times 10^{23} m$*) away. How long will it be before they collide, again assuming the speed is constant? Give your answer in both seconds and years.*

We can work this out just like the first part.

$$t = \frac{d}{v} = \frac{5.2 \times 10^{23} m}{4 \times 10^5 m/s} = 1.3 \times 10^{18} s$$

Now convert this to years.

$$t = \frac{(1.3 \times 10^{18} s)}{(60 s/min)(60 min/hr)(24 hr/d)(365 d/yr)} = 4.1 \times 10^{10} yr$$

The Milky Way won't collide with the Virgo Cluster for 41 billion years! That's a long time. Of course, by that time the Milky Way and Andromeda will have merged, so the speed of the combined galaxy may be different.

(c) *Which of these collisions (if any) will occur within the Sun's remaining lifetime?*

We believe the Sun will be fusing hydrogen into helium for another 5 billion years. The collision between the Milky Way and Andromeda will happen just within that timespan. However, the collision between the Milky Way and the Virgo Cluster won't happen until long after the Sun has died and become a white dwarf.

9. ***GalCrash Applet on the Web.*** *For the next problem, you will be using a web applet called Gal Crash at the website: http://burro.astr.cwru.edu/JavaLab/GalCrashWeb/ . You will be testing different initial conditions to see how long it takes galaxies to merge.*

Below are approximate values for the relative velocity during the first pass of the galaxies and the time until the merge.

Red Galaxy Mass	Peri (kpc)	Relative Velocity (km/s)	Time to Merge (Myr)
1	10	550	480
3	10	700	580
4	10	750	650
6	10	825	850
1	1	775	425
1	10	550	500
1	15	500	800

(a) *For the first four experiments when you had the peri value set to 10 kpc, did it take longer for the galaxies to merge if the red galaxy had higher or lower mass? Describe why you think this is the case.*

Looking at the top half of the table, we can see that it took longer for the galaxies to merge when the mass of the red galaxy was higher. You can see why this is the case by carefully watching each simulation. When the red galaxy's mass is higher, the mutual gravitational force between the galaxies is higher, so as they approach each other the accelerate to higher velocities. However, the galaxies miss on the first pass by each other, and since they accelerated to high velocities, they go shooting by each other. It takes a long time for them to slow down, turn around, and make another pass and eventually merge. When the red galaxy's mass is lower, the force of gravity between the galaxies is weaker and so they don't reach such high velocities when they fly by each other. That means they will eventually merge sooner.

(b) *For the last three experiments when you had the red galaxy mass set to 1, did it take longer for the galaxies to merge if the peri value was higher or lower? Describe why you think this is the case.*

Looking at the bottom half of the table, we can see that it took longer for the galaxies to merge when the peri value was higher. The peri value is how close the galaxies come to each other on their first pass. If peri is high, then the galaxies do not pass very close to each other. That means that the gravitational force between the galaxies is relatively weak, and so it takes a longer time for the pull of gravity between them to cause them to come together and merge. When the peri value is low, the galaxies pass close to each other initially and the force of gravity between them is relatively strong, and so they don't shoot by each other as much and merge more quickly.