PHYSICS 113
Assignment #9
SOLUTIONS

Chapter 17

13. Starting with the determination of the size of the Earth, outline the sequence of steps necessary to calculate the distance to a remote cluster of galaxies. (Hint: Review Chapter 18.)

(i) The Earth's diameter can be determined by the methods used by Erastothenes. The distances to the nearest planets (and the Sun and the Moon) can be measured using radar ranging. This allows us to measure distances up to several A.U.'s.
(ii) The distances to the nearest stars (up to 100 parsecs) can be measured using stellar parallax (obviously this first requires an accurate measurement of the astronomical unit).
(iii) By measuring the spectrum of a star in our Galaxy, we can determine its spectral type and by using the HR diagram we can deduce its luminosity (assuming that the star is on the main sequence). By next measuring the star's apparent brightness, we can then deduce its distance. We can measure distances in excess of 10,000 parsecs using this method. This method is known as spectroscopic parallax (also known as main sequence fitting). Distances to globular clusters (in the halo of our galaxy) can also be determined by measuring the apparent brightnesses of RR Lyrae stars (we know their absolute brightnesses).
(iv) The distances to nearby galaxies (up to 10 Mpc=10,000,000 parsecs) can be determined by measuring the light curves of Cepheid Variables. By establishing the period (in days) of their brightness changes, we can deduce their luminosity. By measuring their apparent brightness, we can thus determine their distance. Note that Cepheids can also be used to measure distances within our own galaxy as well. In fact, the absolute luminosity of Cepheids in our Galaxy was only established after their distances were determined by some other method.
(v) The distances to more remote galaxies can be determined by observing the apparent brightnesses of Type I supernovae, or by measuring the apparent brightnesses of the brightest supergiants and/or globular clusters in the galaxy (we assume that the brightest ones are similar from galaxy to galaxy). These methods work for distances up to and including 100 Mpc.
(vi) Distances to remote clusters of galaxies can be established by measuring the apparent brightness of the brightest of the galaxies within that cluster and by assuming that the brightest galaxies in clusters all have approximately the same absolute brightness (i.e. luminosity). These methods work up to distances of nearly one Gpc (= 1,000 Mpc).
(vii) The distances to the most remote objects in the universe (e.g. quasars) are found by measuring the redshift of those objects and then by converting the redshift to a velocity of recession using Doppler's formula. Once this is calculated, Hubble's law can be used to calculate the distance.
All of these steps make up the *cosmic distance ladder*.

21. Suppose a supernova explosion occurred in a galaxy at distance of 10^8 light years. If we are only now detecting it, how long ago did the supernova actually occur? According to Hubble's law, what is the velocity with which this galaxy is moving away from us? (Assume a Hubble constant of 20 km/second per million light years.)

Since the distance to the supernovae is 10^8 light years, the supernovae explosion occurred 10^8 years ago. Hubble's law tells us that $v = H\,d$ where v is the velocity of recession, H is Hubble's constant and d is the distance to the object. If the Hubble constant is 20 km/sec per million light years (H =

20), and $d = 10^8$ light years = 100 million light years, then the speed of the galaxy is $v = (20)(100) =$ 2000 km/second. Note that d had to be expressed in millions of light years since H was expressed in terms of millions of light years.

Chapter 18

11. A friend of yours who has watched many *Star Trek* episodes says, "I thought that black holes pulled everything into them. Why then do astronomers think that black holes can explain the great outpouring of energy from quasars?" How would you respond?

Since black holes have mass, they have gravity and thus they attract matter towards them. When this matter moves inside the event horizon (also known as the Schwarzschild radius), it is no longer observable. This is because even light is trapped inside the event horizon and thus no information can get out to the rest of the universe. However, as the matter falls towards the black hole (far outside of the event horizon), it is accelerated to ever higher speeds by the gravitational force of the black hole. Collisions of atoms in the gas ionize and heat it, and the acceleration of the charged particles in the gas causes the gas to radiate energy at all wavelengths in the EM spectrum. It is this radiation from the hot gas that we see as the tremendous outpouring of energy from quasars.

Chapter 19

14. Why do we know less about the formation of galaxies than about the formation of stars?

Stars can be seen forming nearby, and we can make detailed observations of what goes on when stars form. Most, if not all, galaxies formed when the universe was young. In order to study how they form, we must look at very distant galaxies (i.e. galaxies for which it has taken light many billion years to reach us [and was emitted by the galaxy when it was young]). Since we must look at objects that are billions of light years away from us, it is difficult to obtain detailed information about their shapes, stellar content, amounts of gas and dust, and composition. Obviously with new technology and better telescopes, we may be able to resolve the detailed features of these very distant (and young) galaxies.

Chapter 20

11. Suppose the universe expands forever. Describe what will become of the radiation from the primeval fireball. What will the future evolution of galaxies be like? Could life as we know it survive forever in such universe? Why?

The radiation leftover from the big bang fireball will become ever more redshifted (as the universe ages), and thus have lower and lower energy. Thus, this cosmic background radiation (and universe) is becoming increasingly cooler. Assuming that the universe expands forever (i.e. an open universe) and given that all the stars in galaxies will eventually burn themselves out (leaving behind black holes, neutron stars, and [mostly] cold white dwarfs), we would expect that the Universe to eventually cool to nearly absolute zero (Kelvin) in temperature. Thus the universe would become a very cold, dark place where no life could possibly exist.