Chapter 17 Red Giants and White Dwarfs

The Solar Neighborhood

We live in the Milky Way galaxy. It contains over 100 billion stars in a disk that is 100,000 ly across. The center of the galaxy is some 28,000 ly from the Earth. Looking out from our home we can see billions of galaxies, which are home to well over 10^{18} stars (quintillion). And yet if you look at them, you will find that they all undergo the same processes. They are born, they live and they die. WE are able to discern several stellar quantities: luminosity, temperature, chemical composition, size and mass. Knowing the distances to the stars is essential to calculating many of the stars properties.

Stellar Parallax

Parallax is used to determine the distance to near-by stars. DO DRAWING. What is done is a picture of a star is taken against the background stars and then months later another picture of the star is taken. You will see that the star has shifted position among the distant stars. You can measure the angle and take half of it and that is the parallax angle for that star. The angles are measured in *arcseconds*, which is 1/3600th of a degree. The distance that a star must be at for us to see 1" of parallax is 206,265 AU. This is called a *parsec*. The formula is: d (parsecs) = 1/parallax angle. Thus if the parallax angle is .5", then the distance would be 2 parsecs. Also 1 parsec is equal to 3.26 ly.

Our Nearest Neighbors

The closest star to us other than the Sun is called Proxima Centauri. Since it is the closest it has the largest parallax angle, .77". That means that the distance from us is 1.3 parsecs or 4.3 ly. Imagine that the Earth is a grain of sand orbiting a marble 1 m away, then the closest star, also marble sized, would be 270 km away. The next closest star which is called Barnard's star has a parallax angle of .55" which gives a distance of 1.8 pc or 6 ly. Figure 17.2 shows us our 30 or so closest neighbors. We can see parallax angles of about .03" which is about 30 pc or 100 ly, but that is about it. Why? This takes in several thousand stars. In the 1990's the Hipparchus satellite was put up by the ESA to do parallax work. It measured parallaxes out to 200 pc, which measured well over a million stars.

As well as the apparent motion in the sky due to our movement, most stars have a real spatial motion. A star can have a *radial velocity*. This is a motion towards or away from us. We can do Doppler measurements to determine how fast the star is moving. There is also the *transverse motion*. This is perpendicular to our line of sight. To see this we must look over a period of years to see the motion in the sky. Figure 17.3 shows Barnard's star over a 22 year period. This kind of motion is called *proper motion*. This describes the transverse component of the stars movement. In 22 years Barnard's star moved 228" so it is moving at 10.4"/year. That is an actual displacement of 2.8 billion km. From all of this we can calculate that it is moving at 89 km/sec. Some stars may be moving at hundreds of km/sec, but because of their distances they move very little in the sky.

Luminosity and Apparent Brightness

The luminosity of a star refers to its total energy output and this can be referred to as the *absolute brightness* of the star. But when we look at a star we see its *apparent brightness*. This is a measure of its *energy flux* (energy per unit area per unit time). The energy flux is affected by the distance that the star is away from us. The farther away, the less energy we receive.

Another Inverse Square Law

If you have a light source at some point, you can measure its energy flux. As you move away from the light, the amount of light that you can measure becomes less and less. That is because the light is spreading out in all directions. The formula is called the inverse square law and it is: Apparent brightness (energy flux) = luminosity/distance^2. So if you were to double the distance from the light source, you would measure only 1/4th as much light as you did before. To determine the stars luminosity we measure the apparent brightness and the distance from us to determine how bright the star actually is.

The Magnitude Scale

Astronomers measure the brightness of an object in terms of its *magnitude*. It dates back to Hipparchus in the second century B.C. He grouped stars together in groups according to how bright they appeared. All of the brightest stars went into the 1st group, the next brightest went into the 2nd group and so on until the 6th group. This idea has been maintained throughout history. But that means that the larger the number, the dimmer the object, just opposite what would think. The brightness difference between a first magnitude star (magnitude replaced the word group) and a sixth magnitude star is about 100 times. That means that for every magnitude of difference you have it is 2.5 times brighter or dimmer. So to determine the brightness difference between 2 stars you would use the following: 2.5^n where n is the magnitude difference. So a star that is 2 magnitudes different would be 2.5^2 which is 6.25 times. Since Hipparchus was looking at the stars with his eyes, this is called the *apparent magnitude*. The Moon has a magnitude of about -12.5 and the Sun is -26.7. That means that the Sun is $2.5^{14.2}$ or almost 450,000 times brighter than the Moon. The dimmest that the Hubble Space Telescope can see is to about 30th magnitude. That would be about as bright as a firefly seen at the distance of the Earths diameter.

Now if we really want to compare different stars together we can’t use the apparent magnitude since it doesn’t take what into consideration? To truly compare stars they theoretically place them all at a distance of 10 pc from the Earth and compare the brightness. This is the absolute magnitude. At 10 pc the Sun is only 4.38 magnitude which is 2.3 trillion times dimmer than it appears to us now. So if you think about it, any star that is farther away than 10 pc will get brighter when we look at it s absolute magnitude and any star that is less than 10 pc will get dimmer.

Stellar Temperatures

When you go out and look up and see the stars, you can approximate the stars temperatures. Temperatures are a measure of the surface temperatures of the stars that we see. Cool stars are redder and the hot stars are bluer.

Color and Blackbody Curves

To determine the actual temperature of a star we will measure the apparent brightness and match the data up with a blackbody curve. We will do this through a visual filter and a blue filter and compare them. Figure 17.9 If you look at curve a you can see that you get almost twice the energy through the blue filter than through the visual filter. This is a 30,000 K emitter. Curve b shows the Blue and visual filters being about the same, which corresponds to about 10,000 K and finally curve c shows the visual filter with 5 times more energy than the blue filter which is a temperature of 3000 K. The V and B fluxes are enough to allow astronomers to calculate the surface temperature of a star.

Stellar Spectra

Color is a very useful way to describe a star. Astronomers though have put together a more detailed way of classifying stars. When you look at the spectra of different stars, you will see different things. In figure 17.10 you can see how temperature affects it. At the high temperatures you see few spectral lines, while at lower temperatures you see more lines. The main differences are:

- Stars hotter than 25,000 K show strong lines of singly ionized hydrogen and multiply ionized heavier elements
- Hydrogen lines in hot stars are very weak
- Hydrogen lines are the strongest in stars with temperatures around 10,000 K.
- Below 4000 K the hydrogen lines are again weak because there is not enough energy to boost the electrons in the atom.

Spectral Classification

Taking the spectra of stars has been going on for many years, long before the 20th century. Even though they were taken, why they occurred wasn't understood. Soon they put together a listing using A, B, C, D, etc. where the A stars had the strongest hydrogen lines, the B stars next and so on. It was thought that this was due to the stars having more hydrogen. The list extended out to the letter P. We now know that this is not true. In the 1920's the structure of the atom became better understood and they began to realize why we had the spectral lines that we did. They realized it was better to classify the stars by temperature. Using the stars that they had already classified, they rearranged the stars. The first category was the O class stars. The stellar classification from hot to cool is O, B, A, F, G, K, M. The hottest stars, O, are in the range of around 30,000 K while the M class stars are around 3,000 K. Each of the classes is broken down into 0 – 9, so you have 10 parts in each class. For example, the Sun is a G2 star.

Stellar Sizes

Direct and Indirect Measurements

Most stars are small enough that we can't directly measure their diameters. But you will find that there are some stars out there that are large enough to do this. One of the ways is *speckle interferometry*. Here you take very short exposures of the star so that they aren't blurred out by the atmosphere and then combine the images to produce a high resolution image of the star. This allows for some surface features to become visible. This also allows us to measure the angular diameter. If we know the angular size and the distance from us we can calculate the diameter of the star. Betelgeuse, the brightest star in Orion, has an angular size of .045" and a distance of 130 pc. That means that Betelgeuse is 630 times larger than the Sun. Most stars can't be done this way, so we use indirect methods. We can infer size from the radiation laws. It is governed by the Stefan-Boltzman law. Luminosity _ radius^2 x temperature^4 If we know the energy output and the temperature (from the color), we can calculate, within reason, the radius of the star.

Giants and Dwarfs

Let's discuss the star Aldebaran in Taurus. It is orange-red and has a surface temperature of about 4000 K and a luminosity of about 1.3 x 10^{29} W. That means that the temperature is about .7 and the luminosity is 330 times our suns. If we use the previous formula, then Aldebaran is about 40 times larger than the Sun. Stars like this are known as *giants*. Since it is cool, it is called a *red giant*. There are some stars out there that are 1000 times as big as our Sun and these are called *supergiants*.

If we looked at Sirius B, we find a star that has a surface temperature of about 27,000 K and a luminosity of 10^{25} W, which is about .025 of the Sun. Using the Stefan-Boltzman law we gat a diameter of .007 of the Sun. This means that it is a *dwarf star*. Because of the temperature, it is white in color and is called a *white dwarf*.

The Hertzsprung-Russell Diagram

In the 1920's a Danish astronomer named Ejnar Hertzsprung and an American astronomer named Henry Norris Russell independently worked on a luminosity vs. temperature plot. What they developed was so close that it was combined and both men were given credit for the work. It is more often called the H-R Diagram. DO THE H-R DIAGRAM.

The Main Sequence

The main part of the H-R diagram is the *main sequence*. This is where a star will spend 85% of its life. Once it turns on to burn hydrogen fuel, it is on the main sequence. You find that there are hot blue giants and blue supergiants as well as cool red dwarfs.

White Dwarf and Red Giant Regions

Upper right from the main sequence you find the *red giant region* of the H-R diagram. They are brighter, cooler stars. These stars are now burning their helium fuel which has caused them to swell greatly and their surface cools off. Due to the fact that they have swollen up in size, they are very bright. Lower left from the main sequence you find the *white dwarf region* of the H-R diagram. Some red giant stars blow off their outer atmosphere and expose the core of the star which is quite hot. There is no nuclear fusion going on here. They are small, dim and very hot. IN our solar neighborhood the proportion of the stars is about 90% on the main sequence, 9% are white dwarfs, and 1% are red giants.

Extending the Cosmic Distance Scale

Let's talk about pushing out the distance scale. In the solar system we can use radar imaging. After that we have been able to use stellar parallax. Now we are going to talk about *spectroscopic parallax*. We understand that if a star is dim that it might be that it is bright and far away or dim and close. We don't know so it makes things a little more difficult. But there are ways around this:

1. we measure the star's apparent brightness and spectral type
2. using the spectral type we estimate the star's luminosity
3. and we can then apply the inverse square law to calculate the distance

This can be used to determine the distances out to a few thousand parsecs. It allows us to determine the spectral class and use the H-R diagram to tell us what the real luminosity is. Since the main sequence line has some thickness to it there is some uncertainty. It may be as much as 25%.

Luminosity Class

We know that the width of the spectral lines on the spectrum can be due to the density of the atmosphere of the star. Astronomers have developed a classification using the width of the spectral lines as its basis. It has come to be known as the *luminosity classification.* This allows us to distinguish supergiants from giants and so on.

Ia	Bright Supergiants
Ib	Supergiants
II	Bright Giants
III	Giants
IV	Subgiants
V	Main sequence stars and dwarfs

Our Sun is a G2V star. What does that tell you? Vega is an A0V star and Betelgeuse is a M2Ia star.

Stellar Masses

You will find that ultimately everything about a star is determined by its mass. The other thing that determines things for the star is composition. The ability to measure these 2 properties is of the utmost importance. Measuring the mass is very difficult for a star like our Sun. We want to use Newton's laws to determine the mass. To do this we must look towards a binary star system.

Binary Stars

Most stars are members of a *multiple star system*. This is where there are several stars orbiting a common center of gravity. Alpha Centauri is one such system where you have 3 stars orbiting each other. Most of the multiple star systems are *binary star systems*. This is where you have 2 stars orbiting each other. Binary stars are classified by how they are seen. A visual binary is simply that, you can see both stars because they are widely separated. Spectroscopic binaries are so close that you can't separate them visually, but when you take the spectra of them you see 2 distinct spectra due to the Doppler shift as the stars come towards us then away. One other type of binary is the eclipsing binary. This is where one star passes in front of the other and it is eclipsed. Eclipsing binaries have very distinct light curves. Sometimes you will see 2 stars very close together and say that it is a binary star. The problem is that it is a line of sight double or in other words they only look like a double star. These are called *optical doubles*.

Determination of Stellar Masses

By watching the actual orbits or looking at the spectra of the stars astronomers can determine the orbital period of the 2 stars. If we know how far away a binary star is then we can determine the separation between the 2 stars by simple geometry. If we know the period and separation we can determine the masses using Newton's laws. This is not easily done for spectroscopic binaries. We can measure the radial velocities of the stars and from that the combined masses, but since we don't know the angle of inclination of the orbit we can have large errors in our calculations. Usually the brighter star can be seen as a main sequence star and its intrinsic properties are know, like mass, and we can go from there. Regardless of this we have done mass calculations for many stars that are near-by.

Mass and Other Stellar Properties

As you can see, there is a clear progression up the main sequence line on the H-R diagram due to mass. Masses range from .1 to 20 times the mass of the Sun. As you can see the radius and luminosity is determine by the mass. Knowing these things we can determine the stellar lifetime with the following:
stellar lifetime _ stellar mass / stellar luminosity We can rewrite the formula to the following: stellar lifetime _ 1/(stellar masses)^3 For example a 10 solar mass star would have a lifetime of 1/10^3 or in other words 1/1000 of the Sun's life.