1 Binary Stars

Most of the stars in the galaxy are binary or multiple star systems

Binary stars are of tremendous importance, they allow astronomers to determine masses of stars

Recall Kepler's 3^{rd} Law of Planetary Motion

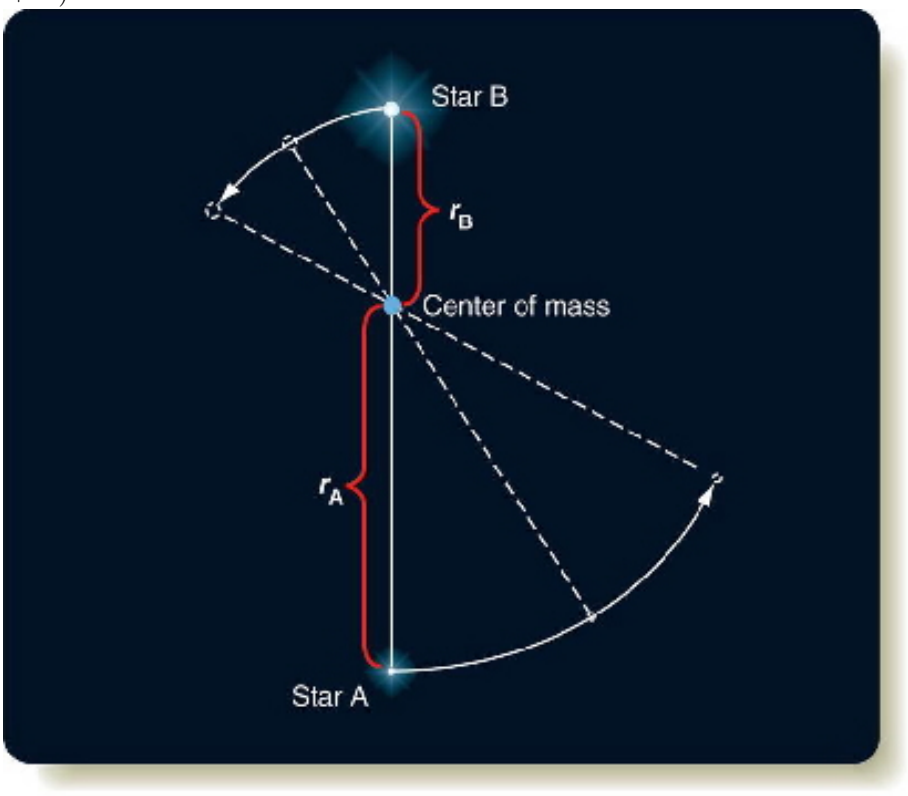
$$P^2 = \frac{4\pi^2}{G(M+m)}a^3$$

The astronomer watches the binary star system, making a plot of the positions of the two stars

Eventually the period of one orbit is known

Also, the separation of the two stars must be determined, either by the small angle formula along with knowing the distance to the system so that the semimajor axis can be determined

Then its an easy calculation to determine the total mass of the binary system $(M+m)$



Astronomers measure the position angle of the fainter star as it orbits around the brighter star

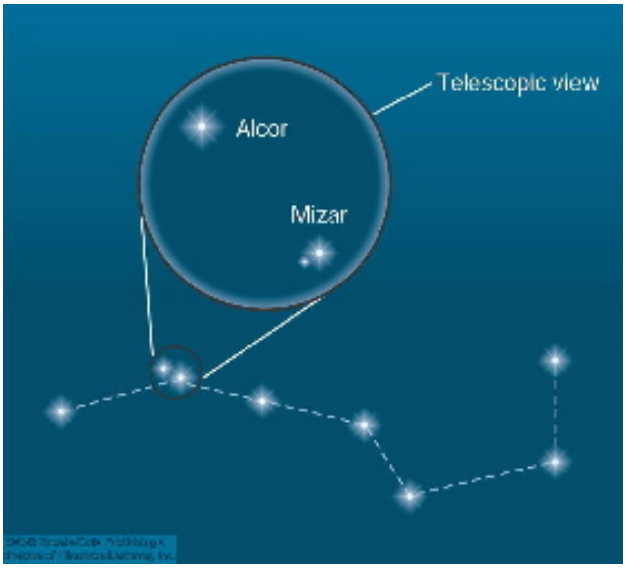
Position angle is the number of degrees that a line drawn through the two stars makes with the true north-south line

Study of the star system may take many years

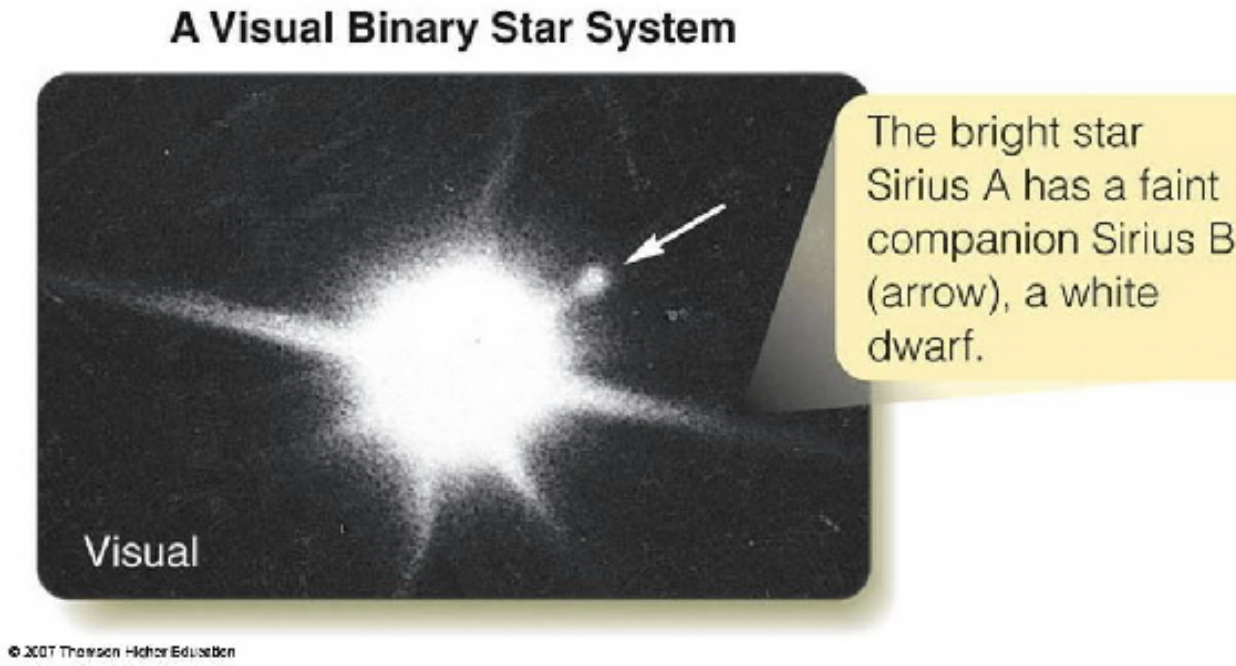
1.0.1 Types of Binary Star Systems

Binary star systems are described by the method of discovery

Optical Doubles These are not binary stars
Two stars just happen to lie along the same line of sight
One star is at a larger distance than the other
Example: Mizar and Alco - middle star in the handle of the Big Dipper



Visual Binaries These are pairs of stars that do orbit around each other
Both stars are visible through powerful telescopes



Example: Castor in Gemini - actually a triple double, six stars

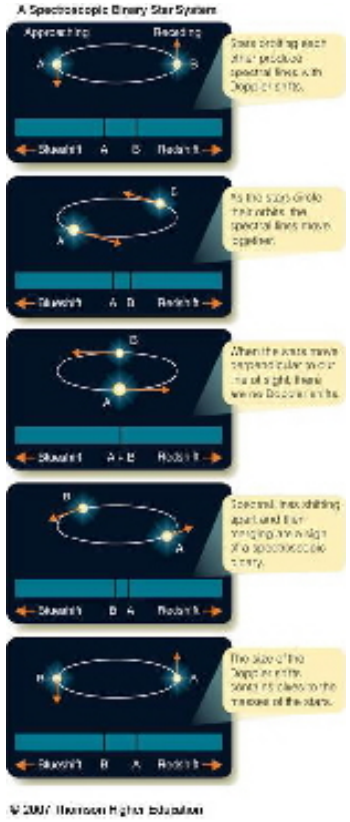
Astronmetric Binaries Only one of the star is visible

The path of the bright star through the sky wobbles as it orbits the center of mass

Example: Sirius - 1844 by Friedrich Wilhelm Bessel discovered Sirius was a binary

Sirius is now a visual binary - since 1862

Spectroscopic Binaries - Double Line Spectroscopic The Doppler Shift of the two stars as they orbit the center of mass periodically move toward us for part of the orbit and then away from us



The spectra will have both blue shifted and red shifted lines of the respective stars

Another example: Mizar is a visual binary

Here are two spectra of Mizar and its companion taken at different times

Single-line spectroscopic binaries Only one star's spectra is seen

Eclipsing Binaries The orbital plane of the two stars is tipped at a small angle to our line of sight

Edge-on view of the orbital plane

There are two eclipses during each orbit

Light Curve

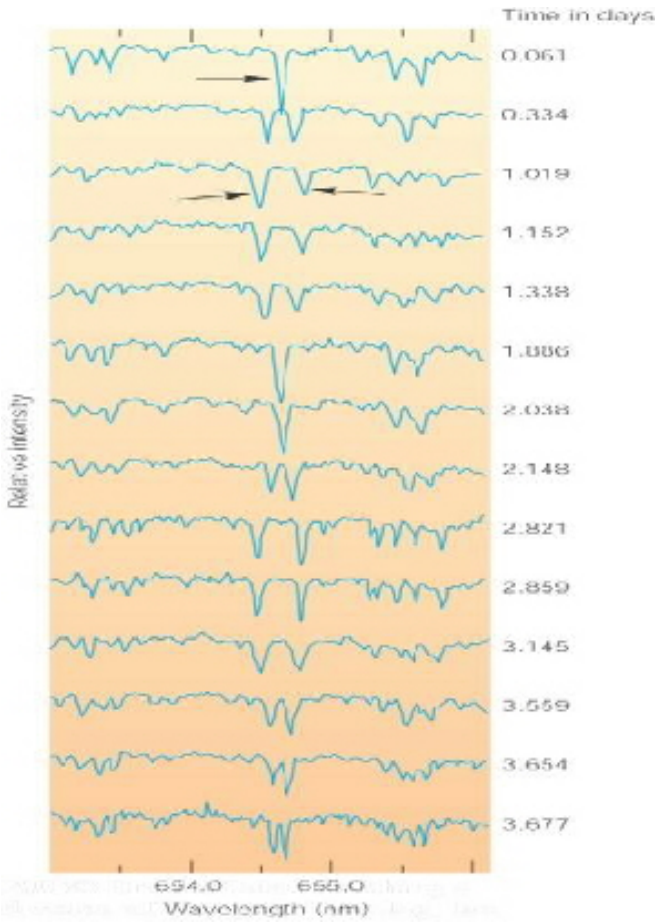
Primary minimum

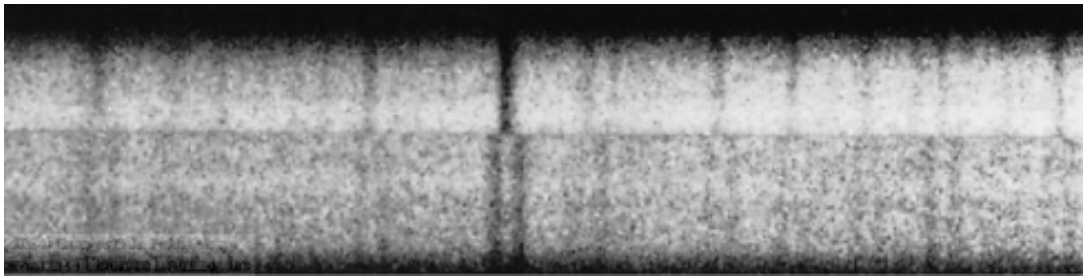
Secondary minimum

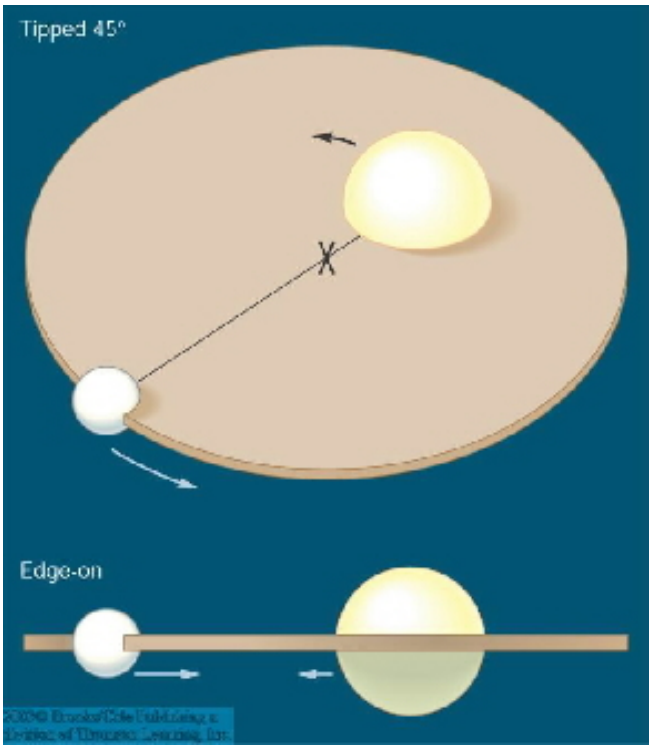
These light curves allow astronomers to measure the sizes and shapes of stars

Example: Algol - β Persei

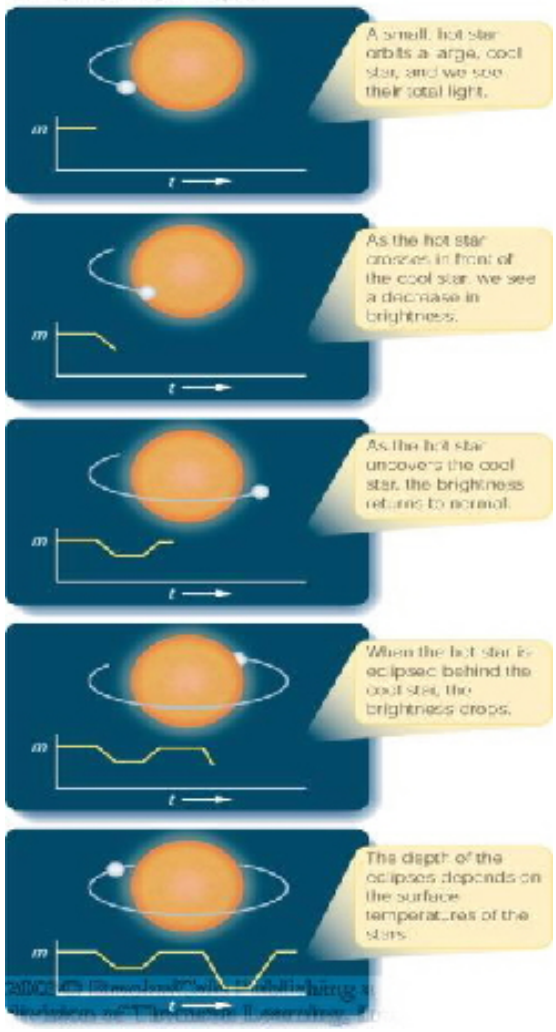
Mass and Density After enough stars have had their masses determined then they can be plotted on the HR diagram

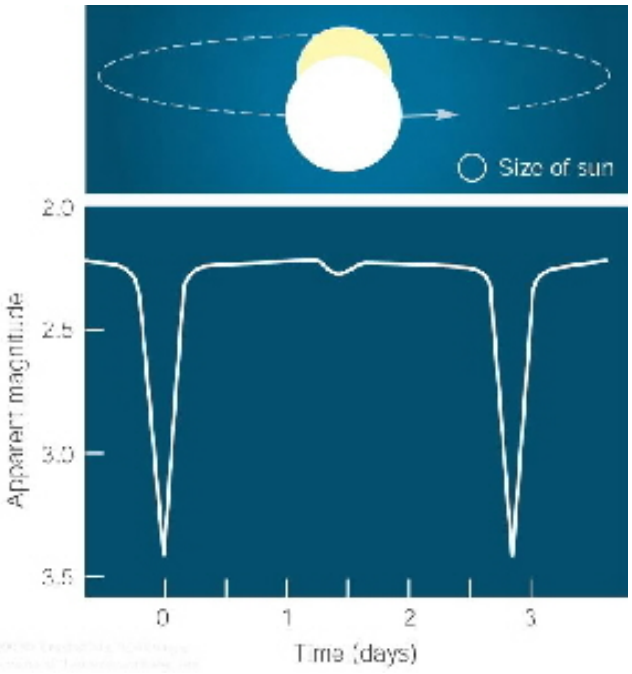

Time in days
0.061
0.334
1.019
1.152
1.338
1.886
2.038
2.148
2.821
2.859
3.145
3.559
3.654
3.677
Relative intensity
654.0
656.0
Wavelength (nm)




Tipped 45°
Edge-on

An Eclipsing Binary Star System





There is a pattern for the main sequence stars

This ordering of main sequence stars by their masses is a clue to how stars work

If instead, stars are plotted comparing their luminosity to their mass we see another pattern

We see the luminosity increases as mass increases

In fact it increases approximately as the mass raised to the 3.5 power

$$L = M^{3.5}$$

This is known as the Mass - Luminosity Relation and is fundamental to our understanding of stars

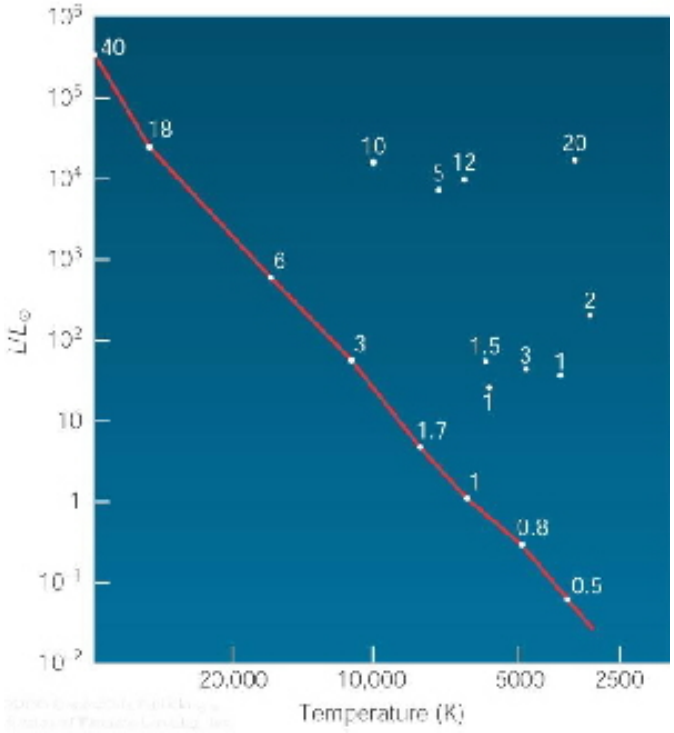
As an example, if a particular star has a mass twice that of Sun, then the luminosity of the star will be 11.3 times the luminosity of Sun

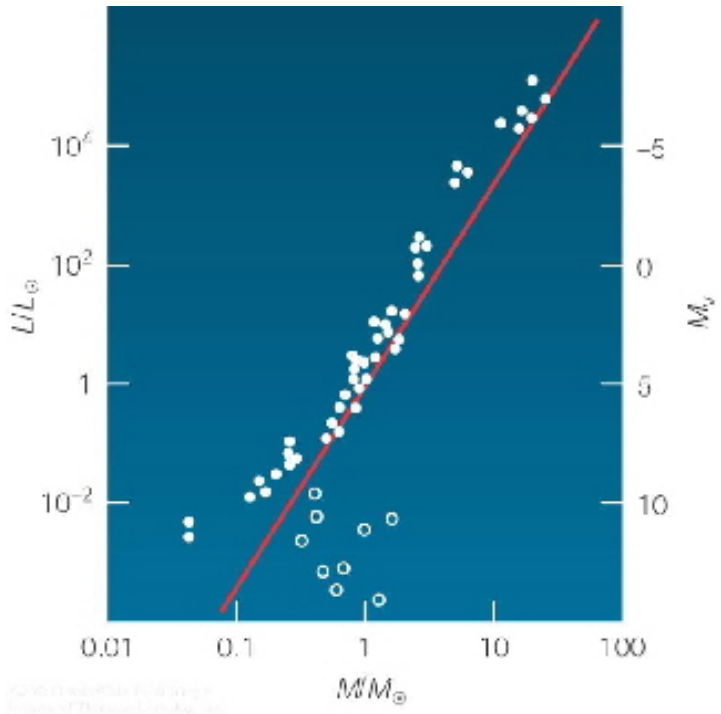
Imagine a star with a mass of 40 times the mass of Sun, it would radiate over 400,000 times more energy

Stellar Densities Once we know the mass of a star and its size, we can then calculate its density

$$Density = \frac{\text{mass}}{\text{volume}}$$

Giant stars have densities ranging from $0.1\,\mathrm{g/\,cm^3}$ to $0.01\,\mathrm{g/\,cm^3}$


40
18
10
5
12
20
6
2
3
1.5
3
1
1
1.7
1
0.8
0.5
20,000
10,000
5000
2500
Temperature (K)


10^4
10^2
1
10^{-2}
$L/L_\odot$
−5
0
5
10
M_v
0.01
0.1
1
10
100
$M/M_\odot$

Supergiant stars have densities still lower; from 0.001 to $0.000001\,\mathrm{g/cm^3}$, which is thinner than the air we breath

White dwarfs have masses of about one solar mass but the size of the star is about the size of Earth

This means the average density is about $2,000,000\,\mathrm{g/cm^3}$ or more

A cubic centimeter would weigh about the same as a Hummer