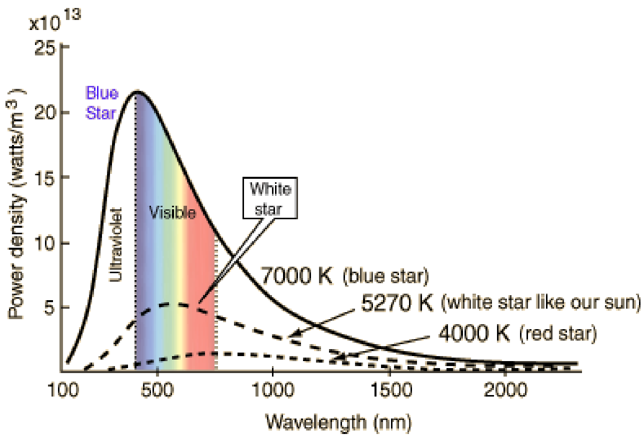
XIII. ASTRONOMY: IT'S FULL OF STARS

A. The main property used to observationally classify stars is their surface temperature.

1. Wein's law tells us that hot objects appear blue, and cool objects appear red.



a. Measurement of the wavelength of the peak of spectrum provides a better approximation to the surface temperature.

b. Analysis of the **strength** of absorption lines yield, the most accurate temperature.

2. The spectral classification scheme based on surface temperature (T) is as follows:

a. Type "O" stars have T>25,000 K.

b. Type "B" stars have 11,000 <T< 25,000 K

c. Type "A" stars have 7,500 < T < 11,000 K

d. Type "F" stars have 6,000 < T < 7,500 K

e. Type "G" stars have 5,000 < T < 6,000 K

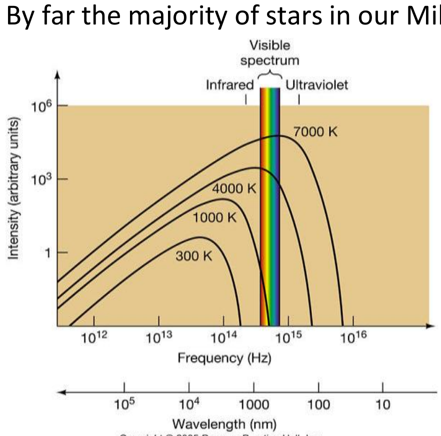
f. Type "K" stars have 3,500 < T < 5,000 K

g. Type "M" stars have T < 3,500 K.

3. Each spectral type is divided into 10 subtypes ranging from hottest (0) to coldest (9): e.g., G0 through G9. The Sun is a type G2 star, with a surface temperature of 5,800 K.

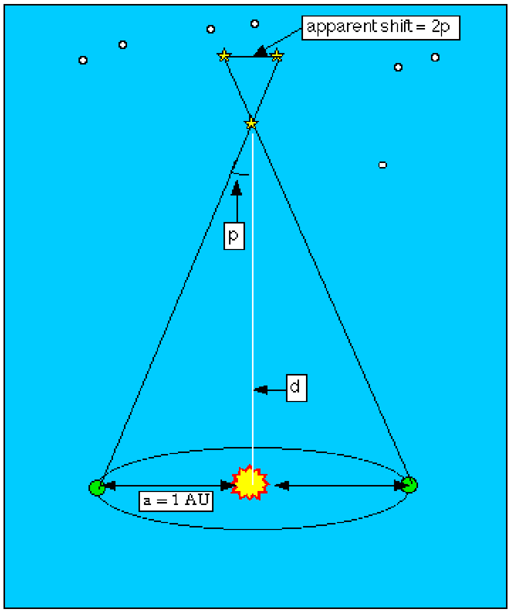
4. Type O and B stars appear blue, type A-G stars are basically white, and types K-M are orange/red.

a. By far the majority of stars in our Milky Way galaxy are K and especially M-type stars.



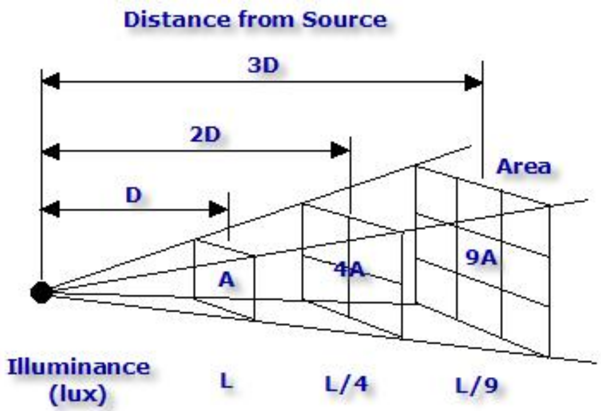
B. The distances of nearby stars are of fundamental importance and can be determined by triangulation ("trigonometric parallax"). [This was explained in section I of this course].

1. The measurement of a parallax, p (units: seconds of arc). This procedure works only with sufficiently nearby stars.
2. To determine the distance in parsecs for the equation d = 1/p. Then convert parsecs to cm. (The conversion factor is 3.09×10^{18} cm/pc).



C. The apparent brightness of a star is also an important quantity. The magnitude scale was explained in section II of this course. However, since the magnitude scale is rather arbitrary and counterintuitive, we will generally not use it in this course. However, those of you who read astronomy magazines will see it often.

1. Here we will use the apparent brightness itself, b; it's units are energy received per unit area, per unit time.
   a. For example, b can be measured in ergs/cm^2/s, where an "erg" is a small unit of energy.
   b. Formally, an erg is one g- cm^2/s^2.
   c. An erg is roughly the energy it takes a fly to do a pushup.
2. Apparent brightness is related to intrinsic brightness (power, or luminosity L: the amount of energy an object emits per unit time).
   a. The mathematical relationship is $b = L/(4\pi d^2)$, where d is the object's distance.
   b. The units work out correctly: b is in ergs/cm^2/s, L is in ergs/s, and d is in cm.
   c. This equation is just the well-known inverse-square law of light.
   d. For example, if the distance to an object is doubled, it appears four times fainter, because a given amount of light has spread over a surface area four times larger.



e. Basically, the relationship says that for a constant source emitting light uniformly in all directions, a given number of emitted ergs go through a sphere of radius d each second. Since the surface area of a sphere is given by $4\pi d^2$, each unit area of the sphere (e.g. 1 cm^2) intercepts only a fraction $1/(4\pi d^2)$ of the total L.

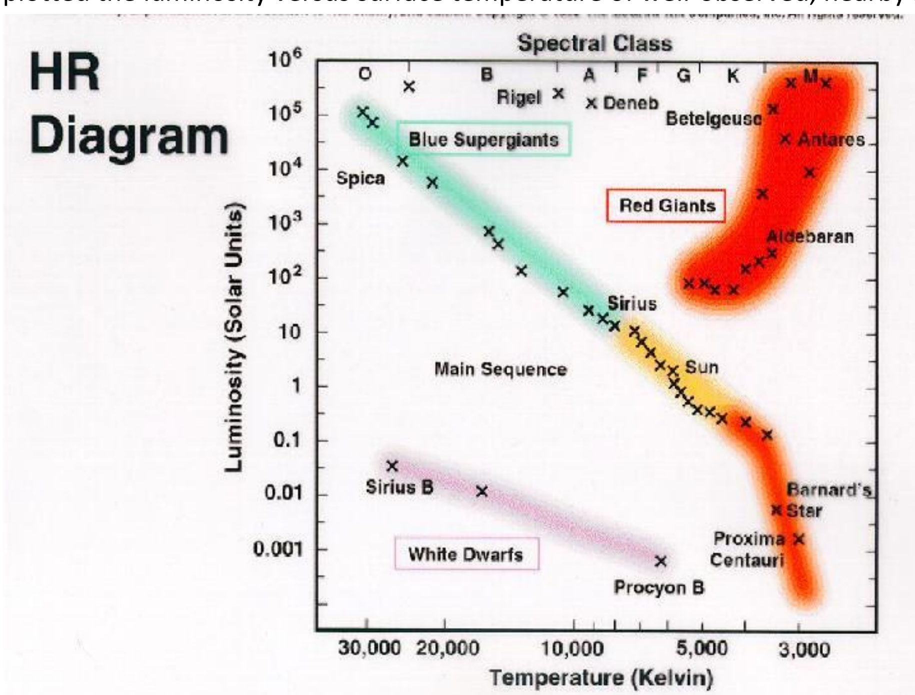
f. You can compute $L = 4\pi d^2 b$.

g. It is convenient to express the luminosity in terms of the Sun's luminosity, $L_{sun} = 3.83 \times 10^{33}$erg/s.

i) For example, a star whose luminosity is 7.66×10^{33}erg/s then it is $2L_{sun.}$

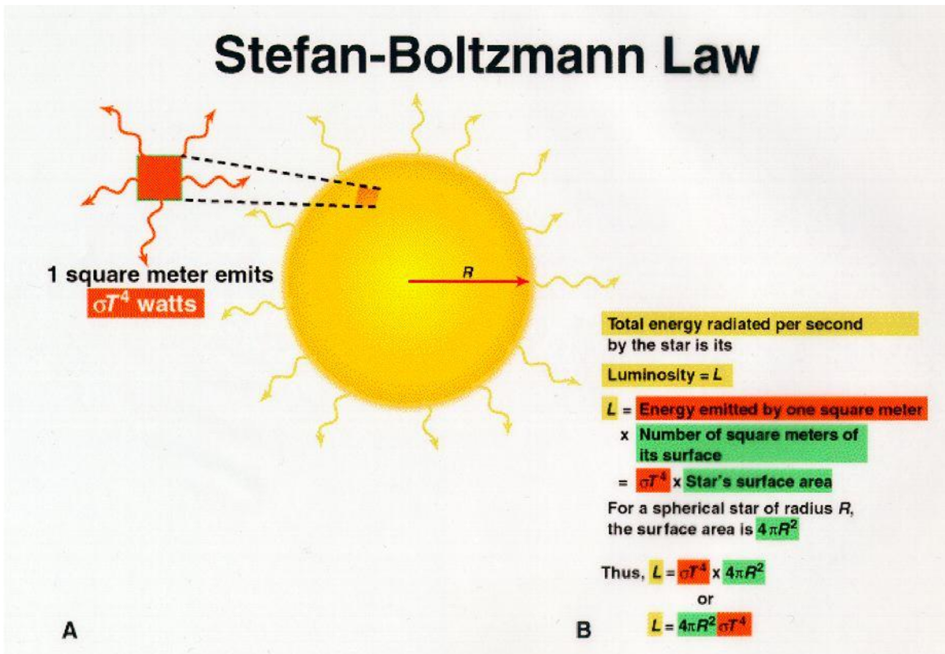
h. The luminosity is a fundamental property of a star --- it tells us the power of the star. As we will see, this turns out to be determined by the star's mass and the evolution.

3. Around 1910, you will recall, Ejnar Hertzsprung and Henry Norris Russell independently plotted the luminosity versus surface temperature of well-observed, nearby stars.



a. They found that stars are not scattered uniformly throughout this plot.

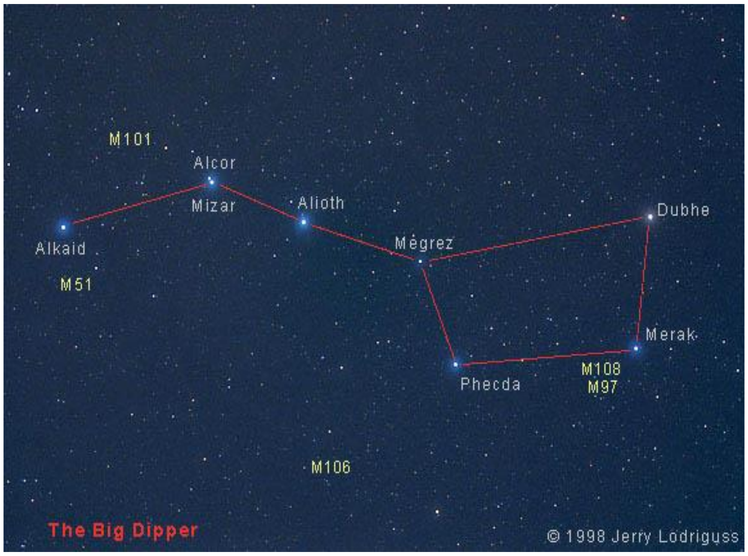
b. Most stars fall in a relatively tight diagonal, from upper left to lower right. This is called the "main sequence." Later we will see that the mass of a star determines it's position on the main sequence.
c. Hot stars are very luminous, cool stars are intrinsically faint, and other stars are in between these extremes.
d. The Sun is a main-sequence star, roughly in the middle of the range.
e. Main-sequence stars are also called "dwarfs"—but they are normal-sized stars.
f. Some stars have surface temperatures below that of the Sun, but are more luminous, typically by a factor of about 100.
   i) Given their lower temperatures, the Stefan-Boltzmann law tells us that per unit surface area, they radiate less light than the Sun.



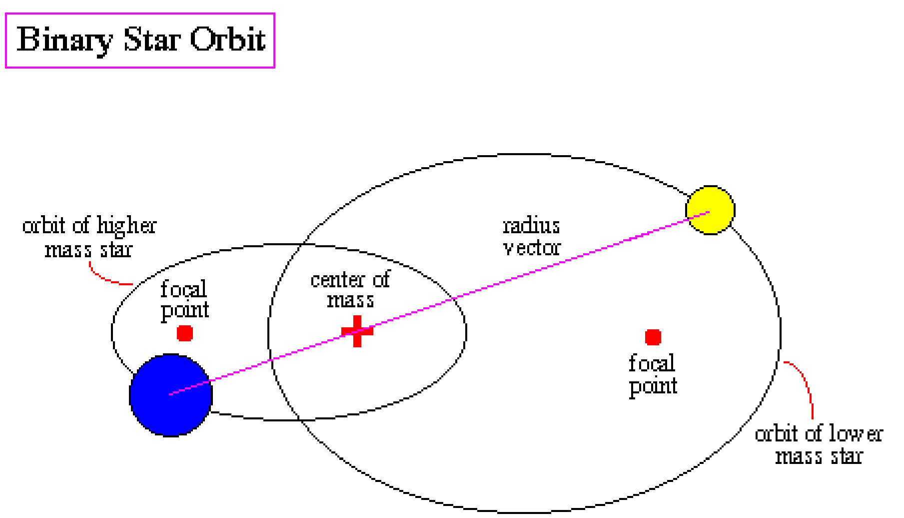
   ii) Thus, they must have surface areas (and radii) much larger than that of the Sun. They are called red giants ("red" because of their low surface temps.)
g. Some stars have surface temperatures comparable to those of red giants, or perhaps even lower, yet they are a factor of about 100 more luminous. They are called red supergiants.
h. There are also stars much less luminous than the Sun (by a factor of 10^{-4} to 10^{-2}), but of comparable or even somewhat higher surface temperatures.
   i) We conclude that they must be very small. In fact, they are about the size of the Earth.
   ii) They are called "white dwarfs", but are actually much smaller than the "dwarfs" on the main sequence. Although the Sun is white, and a dwarf, it is certainly not a "white dwarf".

D. Over 50% of the apparently single "stars" you see in the sky are actually *multiple* systems bound by gravity.

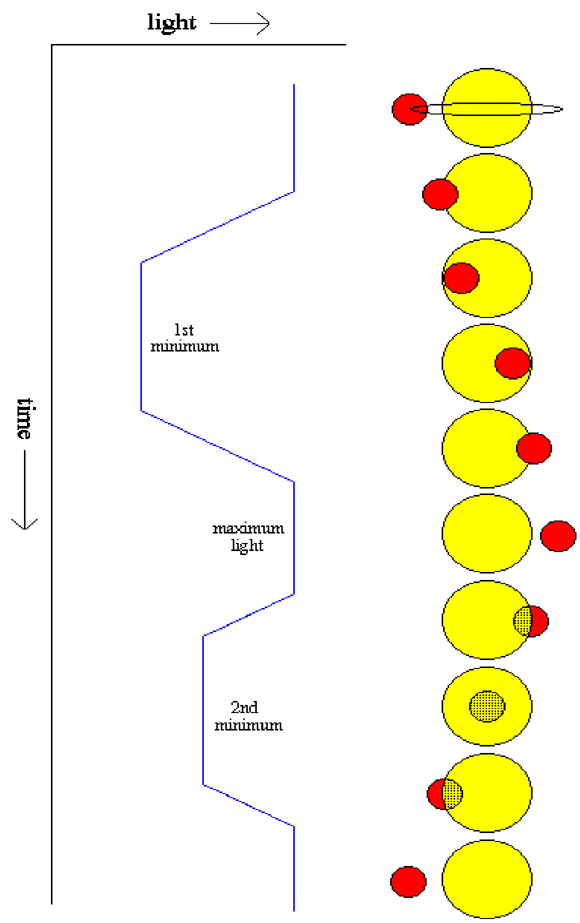
1. Most multiple systems are double stars (binary stars), but some consist of three or more stars. The famous "double star" Alcor and Mizar in the Big Dipper (the second "star" from the end of the handle) is actually a seven-star system.



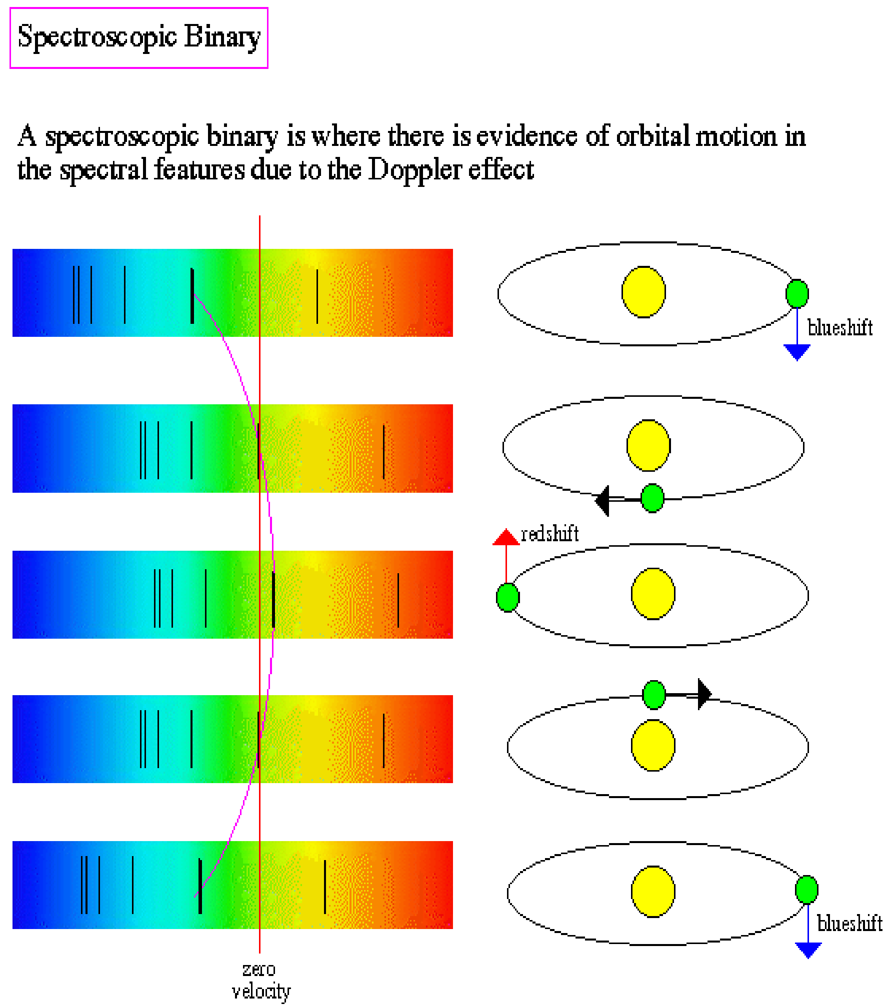
2. Consider the simplest possibility, a binary star (or binary object) with circular orbits.
   a. One can define the center of mass of the system with the equation $m_1r_1 = m_2r_2$, where r_1 and r_2 are the distances of stars 1 and 2 (respectively) from the center of mass. Note that the center of mass must be along a line joining the two stars.
   b. If the two stars have equal mass, they are equidistant from the center of mass. Their orbits have equal size, the stars move with equal speed, and their orbital periods are equal.
   c. If $m_1>m_2$, then star 1 is closer to the center of mass than star 2 is. The orbit of star 1 is smaller than that of star 2, and star 1 moved around the center of mass with a lower speed than star 2. Their orbital periods remain equal.



3. Binary stars can be detected in a number of ways.
   a. They can appear double when viewed through a telescope.
   b. They can brighten and fade periodically, due to mutual eclipses. (Note that some stars vary in brightness intrinsically, not due to eclipses).



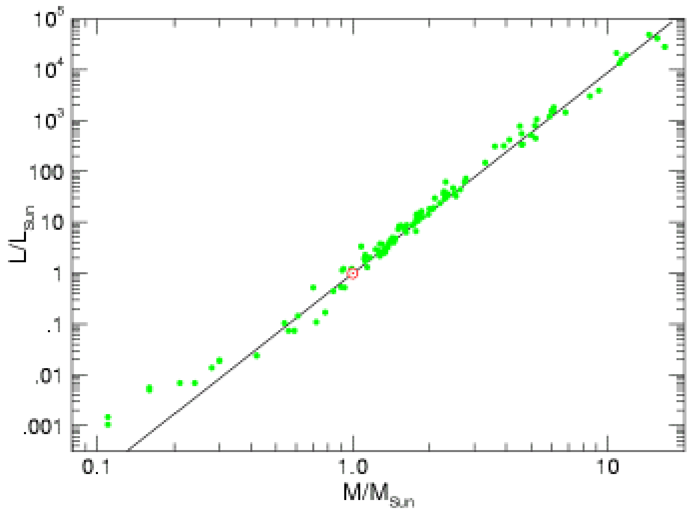
   c. Sometimes a single star moves back and forth very slightly across the sky, due to orbital motion around an unseen companion star.
   d. The most common type is the spectroscopic binary: the star appears single, even through a telescope, but the spectrum indicates that it's a double star.
      i) Two sets of absorption lines are visible.
      ii) The wavelengths of the absorption lines in a given set oscillate back and forth with time, as the star alternately moves toward us and away from us while orbiting a companion.
      iii) The other set of absorption lines also oscillates, but out of phase with the first set; that is, one set is blueshifted while the other is redshifted.



4. The primary use of binary stars is the determination of stellar masses.
   a. Spectroscopic binaries in which both sets of absorption lines are visible, and which are also eclipsing binaries, provide accurate masses and radii.
   b. It turns out that the mass of a star is it's single most important characteristic: essentially everything else depends on it.
   c. To get some feeling for the range of properties, consider main-sequence stars with mass going from 0.2 - 40 solar masses.
      i) Their spectral type goes from M5 – O5. (Remember the Sun is G2)
      ii) Their surface temperature goes from 2,800 K – 40,000 K (5800 K for the Sun).
      iii) Their radius goes from 0.3 – 18 radii where the Sun is 1.
      iv) Their luminosity goes from 0.008 – 5 X 10^5 solar luminosities (1 solar luminosity for the Sun).
5. The range of luminosities given above for main-sequence stars is a manifestation of the important *mass-luminosity relation.*

a. Luminosity is roughly proportional to the fourth power of mass: $L \approx M^4$.

i) The proportionality is only approximate; the exponent of M actually varies to some extent along the main sequence.



ii) Thus, for example, a star with twice the Sun's mass is a factor of $2^4 = 16$ times more powerful (luminous) than the Sun. (This applies only to main sequence stars).

$$\left(\frac{L}{L_{Sun}}\right)=\left(\frac{M}{M_{Sun}}\right)^4$$

b. The mass-luminosity relation for main-sequence stars implies that massive stars have much shorter lives than low-mass stars.

i) Massive stars have more fuel, but they consume it at a disproportionately rapid rate.

ii) For example, a star with 2x the Sun's mass has about 2x as much fuel, so if all else were equal it would live 2x as long. But it actually uses it's fuel 16x more rapidly! Thus, it can sustain itself for only 1/8 as long as the Sun.

6. The mass-luminosity relation allows us to determine the age of a *cluster* or stars.

a. Star cluster are beautiful objects that come in 2 main varieties.

b. "Open" star clusters in our Milky Way Galaxy are rather sparse (typically 20-1000 stars in a region of diameter about 10 pc), irregular in shape, often have many massive stars, and are generally found in or near spiral arms.

i) Roughly 1000 open clusters are known in our Galaxy.
ii) Most open clusters are reasonably young.

c. "Globular" star clusters in our Milky Way Galaxy are densely packed (typically 10^4-10^6 stars in a region of diameter about 30 pc), usually spherical or slightly flattened, consist only of low-mas stars, and are generally found in the halo.

i) Roughly 150 globular clusters are known in our Galaxy.
ii) Globular clusters in our Galaxy are very old.

d. A key point is that all stars in a given cluster have essentially the same distance, age, and initial chemical composition.
i) The stars formed from the same cloud of gas and dust, at almost the same time.
ii) The main distinguishing characteristic of stars in a given cluster is their mass; all other variables are equal (e.g., distance, age, composition), or are governed by the mass (e.g., radius).
iii) These properties make clusters enormously useful for measuring the ages of stars, and for studies of the advanced stages of stellar evolution.

e. Right after the formation of a populous cluster, there will be stars on all parts of the main sequence in an H-R diagram of the cluster.
i) However, the most massive main-sequence stars (O-type) will begin to die first, leaving the main sequence after only a few million years. (Super giants)
ii) As the cluster ages, progressively less massive stars will leave the main sequence as they begin to die (becoming red giants): first B, then A, then F and so on.
iii) G-type stars like the Sun leave the main sequence after about 10 billion years.
iv) M-type star last a very long time: 100 billion – 10 trillion years on the main sequence, much longer than the current age of the Universe.
v) Thus, the length of the main sequence on the HR diagram gets progressively shorter: it is like the wick of a candle burning down.
vi) If we know the rate at which stars having different masses evolve off the main sequence, we can determine the age of the cluster by measuring the spectral type of the brightest main-sequence stars.

f. For example, suppose the cluster does not have any type O and B main-sequence stars
i) We deduce that the cluster is about 100 million years old, because that's how long it takes the least massive B-type stars to leave the main sequence.

E. Questions:

1. Explain how the surface temperature of a star is measured.

2. Describe the spectral classification of stars.

3. What is the distance in parsecs and light years of a star that has a parallax of 0.65”?

4. If two G2 stars appear in the same constellation but one of the stars is 9X fainter than the other, how much closer in distance is the brighter star? (Hint: Inverse square law)

5. Summarize the Hertzspring-Russel diagram and the different groups of stars within it.

6. Explain how the radius of a star can be determined from it’s luminosity and surface temperature.

7. Why do you think that the mass of a star determines it’ s position on the main sequence?

8. Define what is meant by a binary star.

9. State the ways in which binary stars can be identified.

10. Describe the main use of binary stars.

11. Summarize qualitatively the dependence of the spectral type, surface temperature, radius, and luminosity of main-sequence stars on their mass.

12. If a G2 star is 3 times the Sun's mass, how much more powerful (luminous) is it than the Sun?

13. Describe the two types of star clusters.

14. Explain how the age of a star cluster can be determined.

15. Why do you think massive main-sequence star use up their fuel much faster than low-mass stars?

16. Are the different types of binary stars mutually exclusive?