ASTR101 Ch 17-18

Ch 17 - Analyzing Starlight

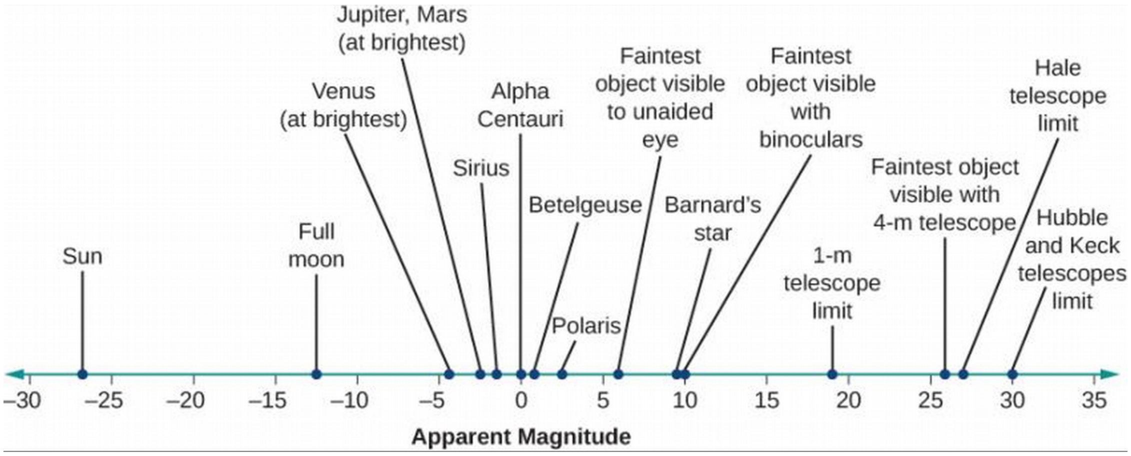
The Brightness of Stars

Luminosity and Apparent Brightness

- Recall that *luminosity* is the total energy, at all wavelengths, emitted by a star per second.
- *Flux* is the luminosity per unit area. Stars emit the same amount of energy in all directions (isotropy).
- The *Apparent brightness* measures, for a given area, the amount of incident energy.
- To make comparisons easier, we use units of $L_\odot$ or L_{Sun}, the Sun's luminosity.
- If stars were the same brightness, we could find how far away they are based on their apparent brightness. (How does energy scale with distance?)

The Magnitude Scale

- *Photometry* is the process of measuring apparent brightness of stars.
- Recall Hipparchus' magnitude scale, with 1^{st} magnitude brightest and 6^{th} magnitude dimmest.
- This is now quantized such that a difference in scale magnitude of 5 corresponds to a factor of 100 difference in brightness.
- We even have negative stars for stars brighter than 1^{st} magnitude, and fractional magnitudes (eg, 2.4). Eg, Venus has magnitude -4.4, the Sun -26.8.
- If a star is one magnitude higher than another star, how many times brighter is it?
- $$m_1 - m_2 = 2.5 log(b_2/b_1)$$



Other Units of Brightness

- A more robust measurement than magnitudes, which are convenient, is SI units (Watts for luminosity, Watts/m^2 for flux).

Colors of Stars

Color and Temperature

- Unlike brightness, color doesn't change if you're farther away, so the colors we observe represent roughly the colors of stars.
- Recall that the peak wavelength is related to the temperature of a star through Wien's law;

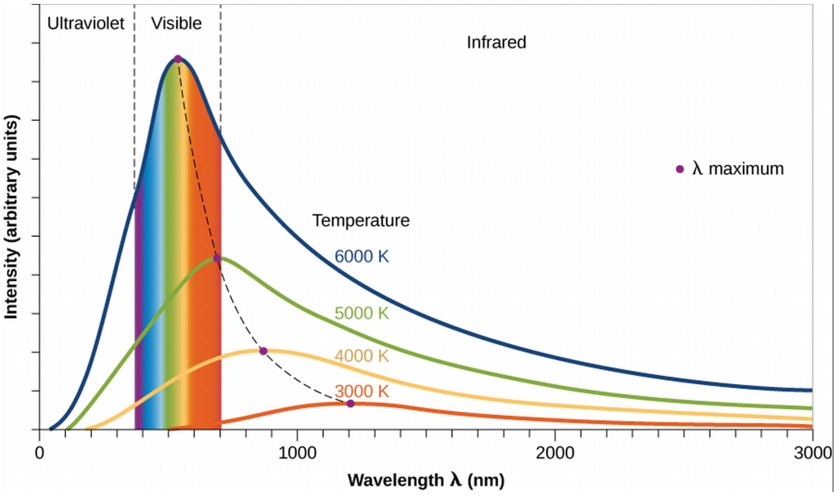
$$\lambda_{max} = \frac{3 \times 10^6 nm \cdot K}{T}.$$

- Blue corresponds to a surface temperature of approximately 25,000 K, white 10,000 K, yellow 6000 K, orange 4000 K, red 3000 K.

Color Indices

- A *filter* is like stained glass; it only allows its own color to pass (filters can also be devised for non-visible light).
- To quantitatively measure color, we take three measurements through the common filters, UBV: ultraviolet, blue, and yellow (v stands for "visual"); around 360 nm, 420 nm, and 540 nm respectively.
- If you subtract any two of these measurements, you get the *color index* of that measurement. Eg, a bluer star would have a negative B-V color index (magnitude of blue minus magnitude of red).
- These are normalized so that Vega (T=10,000 K) has a color index of 0.
- Color index is calculable from temperature and vice versa, using Wien's law.

Figure 1: Hubble image of stars in direction of Milky Way center.



The Spectra of Stars (and Brown Dwarfs)

Formation of Stellar Spectra

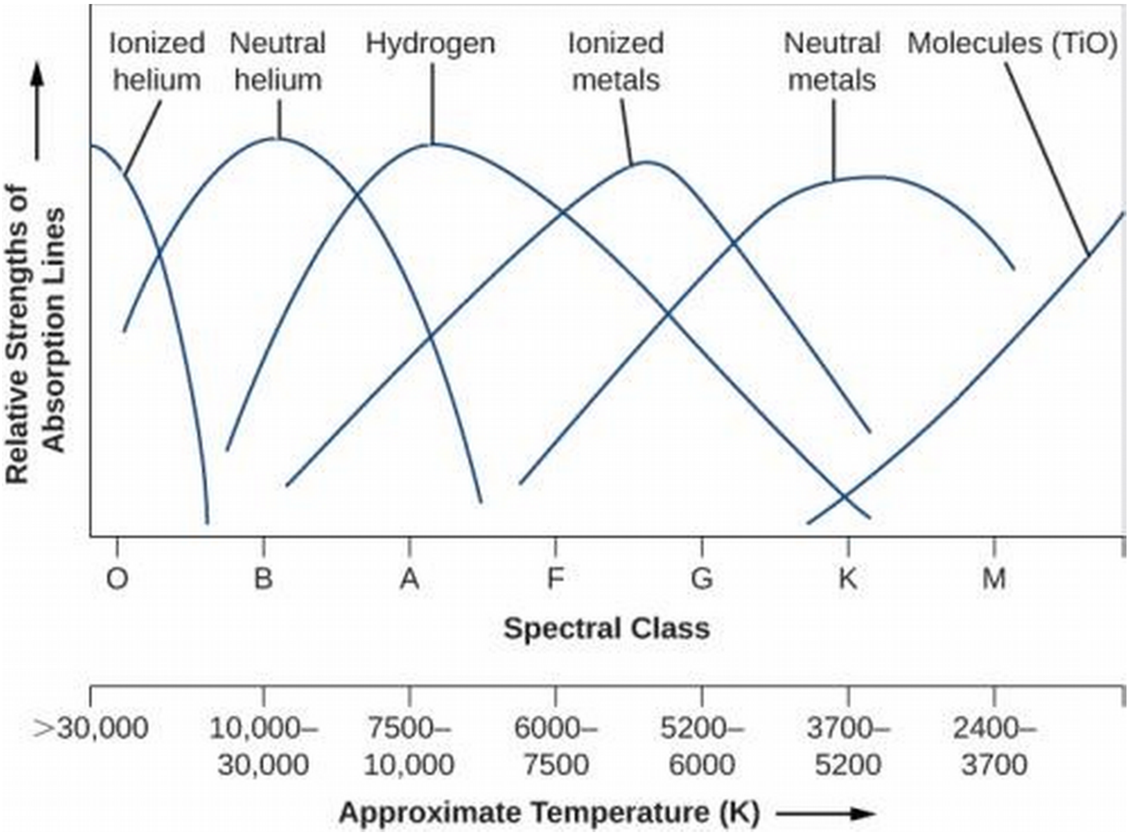
- Spectra from different stars are different. So they're made of different material, right?
- Wrong! Turns out they're nearly the same as the Sun. The temperature, it turns out, is the cause of the different spectra.
- Are we talking about absorption or emission spectra?
- But we understood spectra to reflect the material, and not the temperature—what gives?
- The material actually changes; eg., hydrogen fully ionizes (the electron leaves the atom), and the spectrum corresponding to ionized hydrogen is different from hydrogen's.

./Images/17_HydrogenSeries.gif

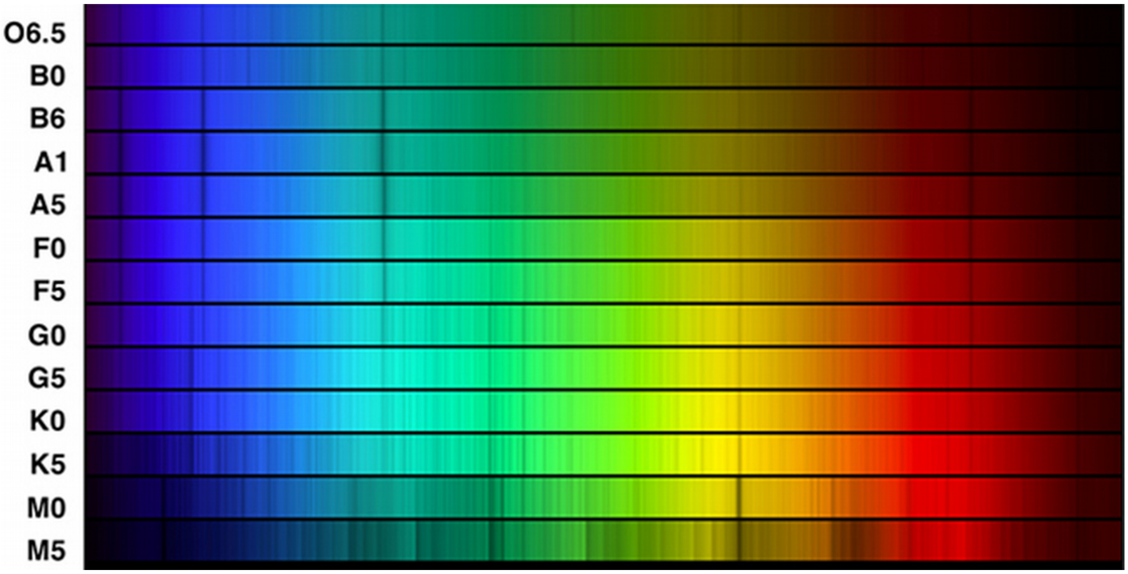
- Another issue is that cooler stars have unionized hydrogen at the lowest (n=1) energy level (*Lyman series*), meaning they absorb and emit in the ultraviolet wavelengths, which are not prevalent in cooler stars.
- A hotter star of 10,000 K produces the most visible hydrogen lines, since many electrons at this temperature are in the n=2 before getting excited by a photon.

Classification of Stellar Spectra

- Stars are sorted into *spectral classes* according to their spectral patterns.
- The seven spectral class, from hottest to coldest, are O, B, A, F, G, K, and M, with recent colder additions L, T, and Y.
- Why the letters? History (sorry). Used to be A-O, based on hydrogen spectrum, but as discussed these are weak and sometimes not in the visible regime, and here we are.
- Actual suggested textbook mnemonic: "Oh, Be A Fine Girl/Guy, Kiss Me Like That, Yo!".
- Each class is subdivided 0-9 (eg, B0 is hotter than B9). The Sun is G2.
- Astronomers refer elements heavier than helium *metals*, for no good reason (they are not metals).
- What spectral patterns are observed for different temperatures?



- See Table 17.2 for more details on classification.



Spectral Classes L, T, and Y

- Why did we recently add L, T, and Y?
- Astronomers began to discover objects even cooler than M9 in 1988.
- A *star* is defined by the fusion that occurs in its hydrogen nuclei into protons, releasing energy.

- They need to be greater than about 7.5% of the Solar mass (.075 $S_\odot$) for this to happen.
- "Failed stars" that don't quite reach this threshhold are termed *brown dwarfs*.
- Brown dwarfs emit mostly IR and are cool and hard to detect; 2200 have been discovered since 1988.
- Brown dwarfs are so close to M-type in spectrum that spectrum alone doesn't distinguish them.

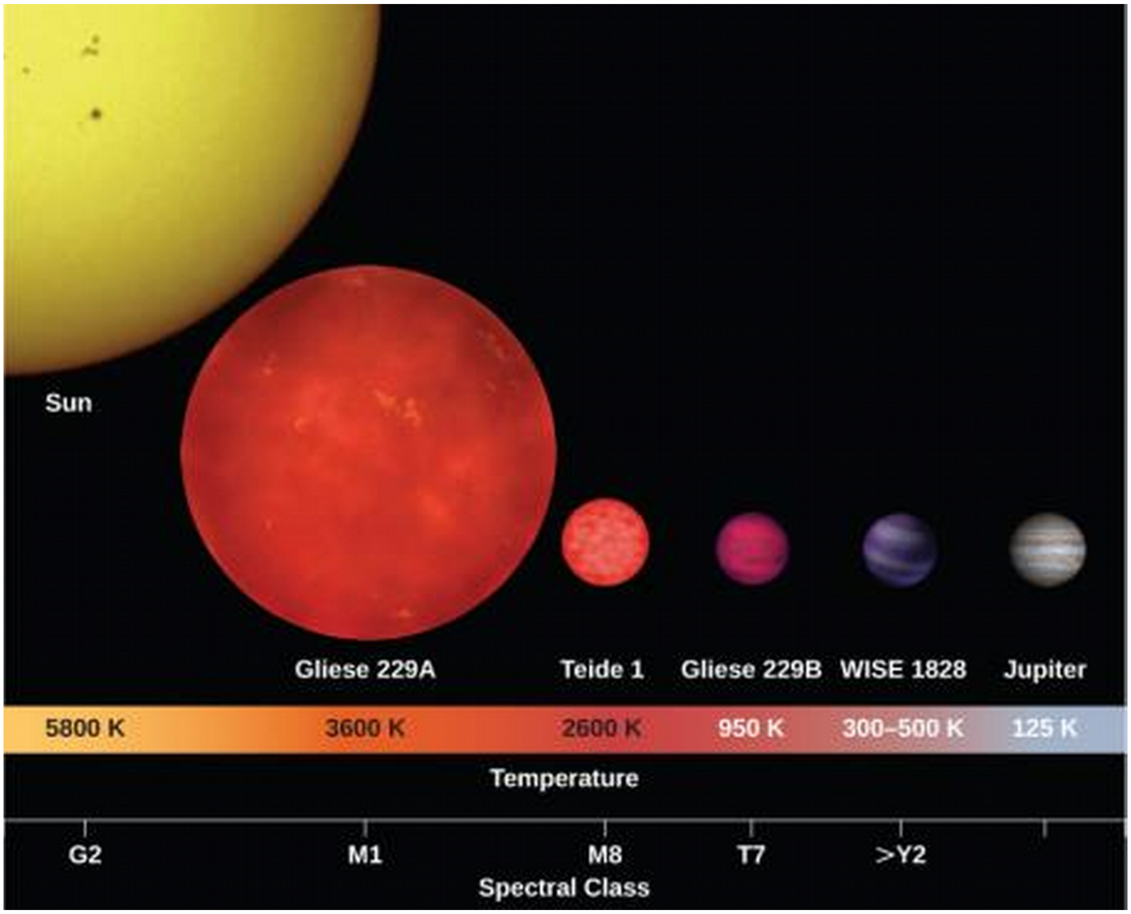


Figure 2: Some brown dwarves in relation to Sun and Jupiter.

Low-Mass Brown Dwarfs vs. High-Mass Planets

- They are difficult to distinguish!
- Brown dwarfs, regardless of their mass (which ranges 13-80 M_J), are close in radius to Jupiter.
- *Deuterium fusion* distinguishes brown dwarfs from high-mass planets;
- While brown dwarfs can't perform proton-proton (hydrogen fusion), they can sustain deuterium fusion.

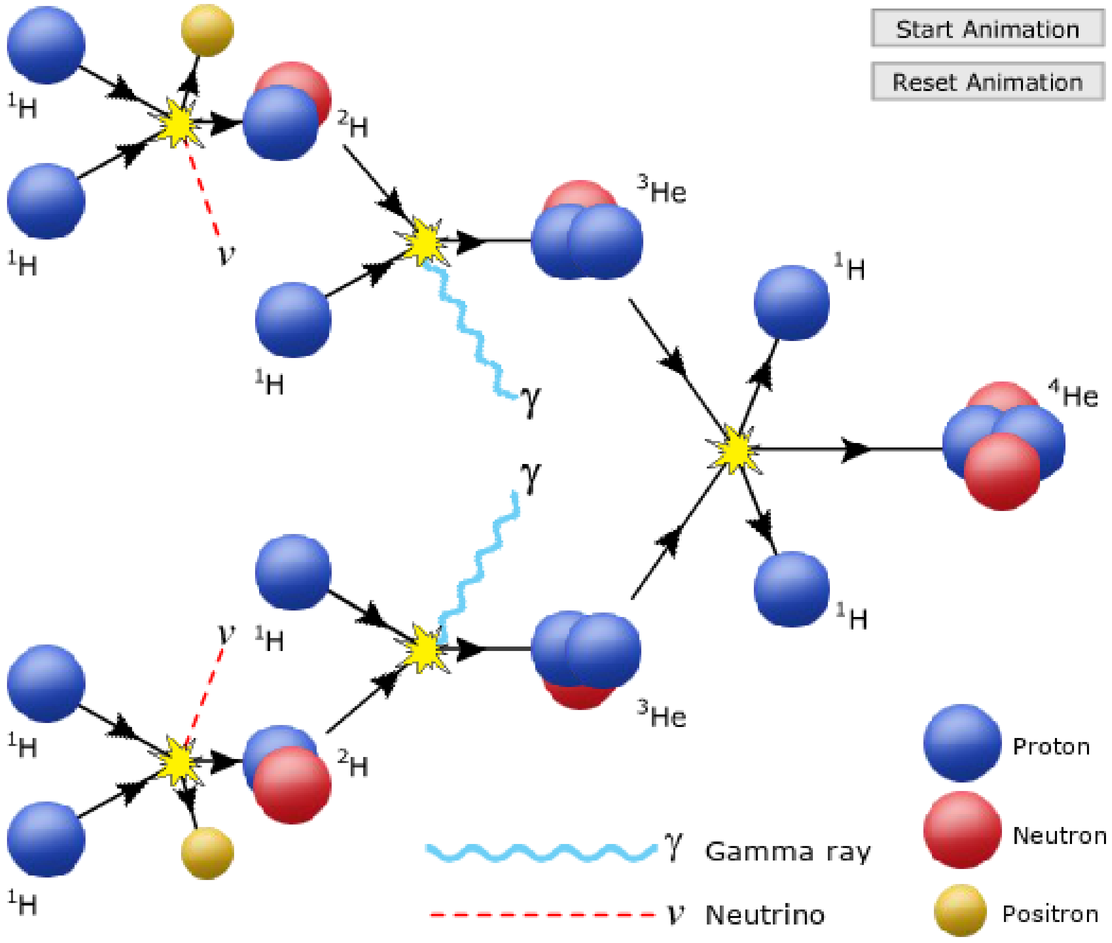


Figure 3: http://astro.unl.edu/classaction/animations/sunsolarenergy/fusion01.html

Using Spectra to Measure the Stellar Radius, Composition, and Motion

Clues to the Size of a Star

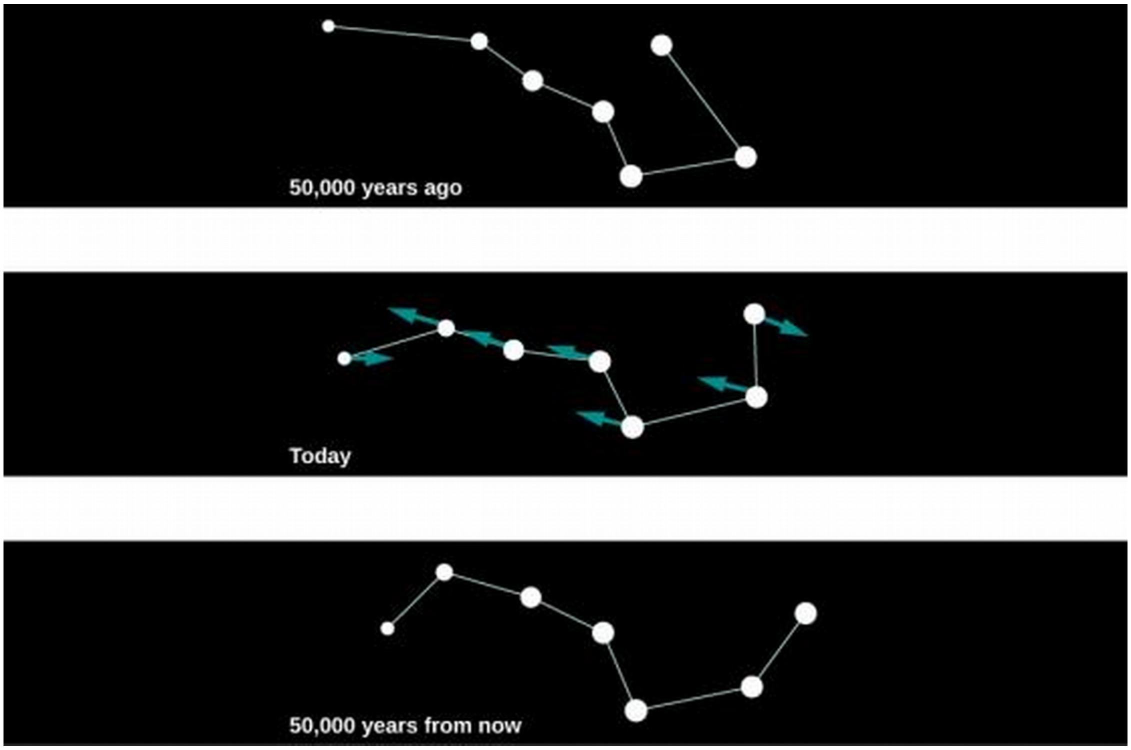
- The biggest stars are called *giants*.
- Spectral lines of giants are narrower due to the lower density of the atoms (less broadening from collisions).

Abundances of the Elements

- We can approximate the ratio of elements by the intensity of their spectral signatures.
- *Metallicity* describes the fraction of a star's mass composed of metals (as defined in Astronomy, not actual metals).
- Recall that metals in Astronomy refer to elements heavier than helium (for no good reason).

Radial Velocity

- If a star moves away from us, all of its spectral lines are red-shifted through the doppler effect (same with blue shift if it moves towards us).



Proper Motion

- *Proper motion* is motion that is transverse (side-to-side, as we see it).
- Of course, too slow to notice just by staring.

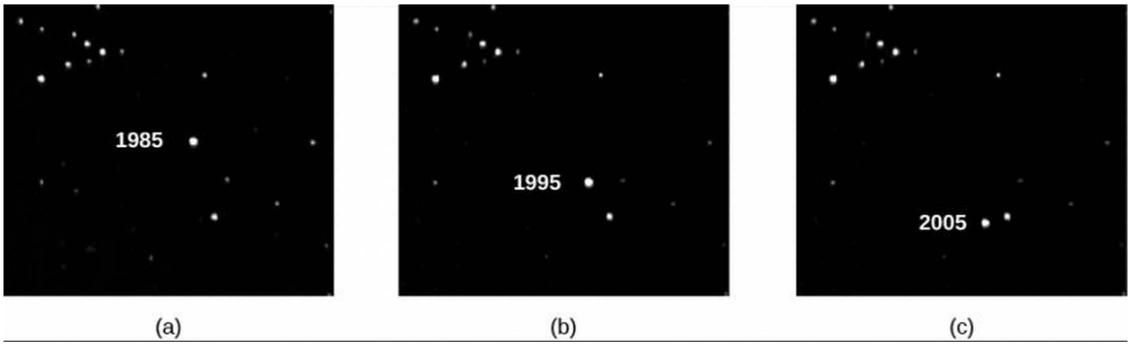
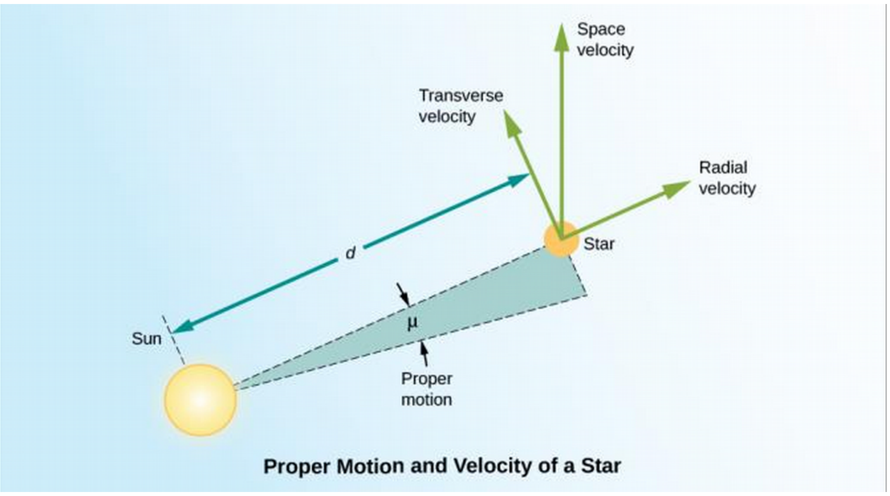


Figure 4: Barnard's Star exhibits the largest known proper motion.

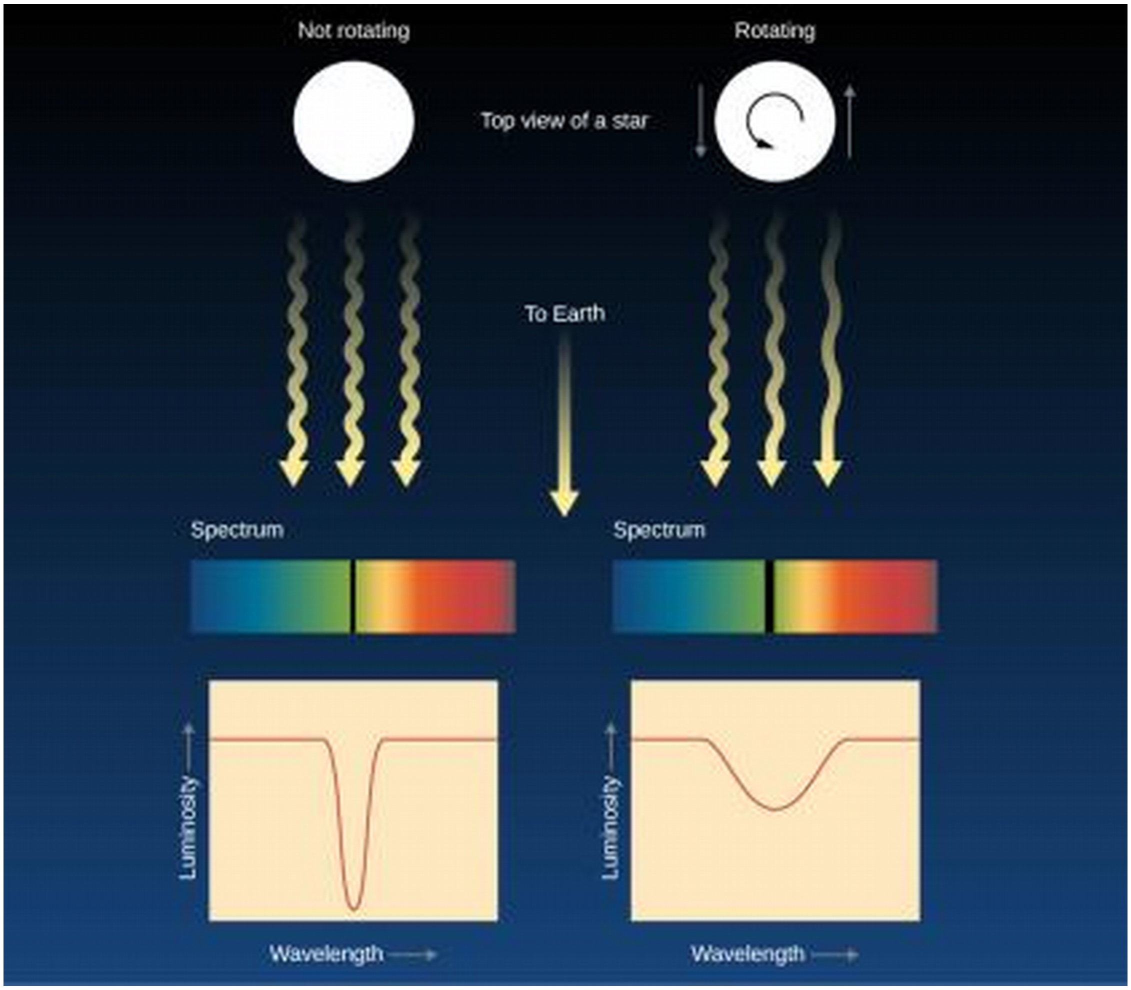
- Then to know the full velocity (*space velocity*) of a star, we need to know its radial velocity, proper motion, and distance.

- Why distance?



Rotation

- Recall we can observe doppler broadening to see how fast the star is rotating.



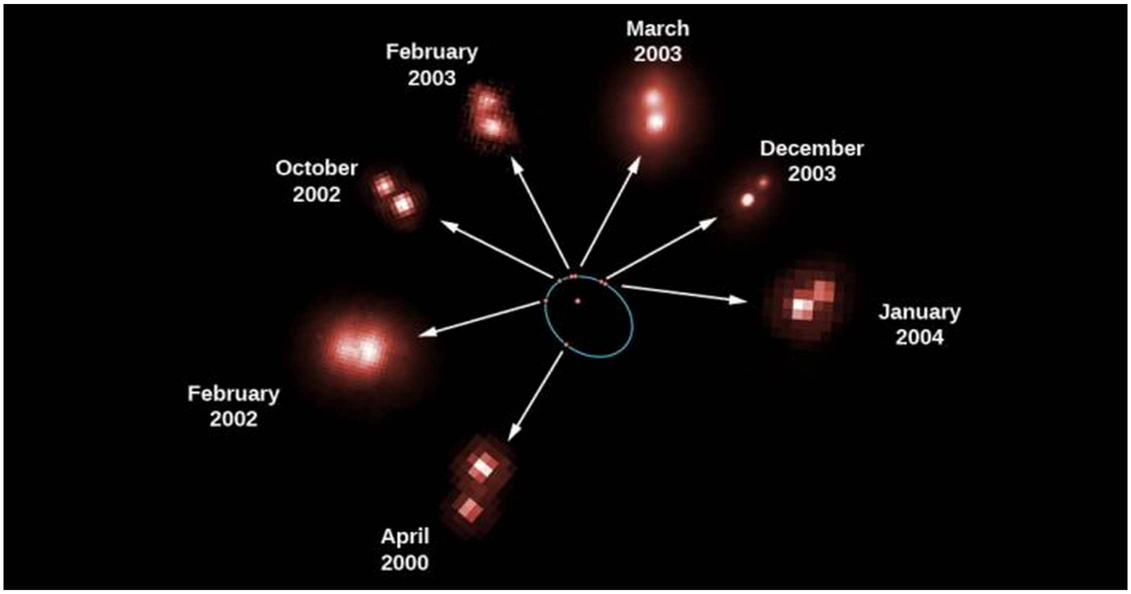
- Many stars rotate faster than the Sun, which has a rotation period of 24-30 days.
- Their rotation can change their shape.
- Stars decrease their rotational speed as they age.

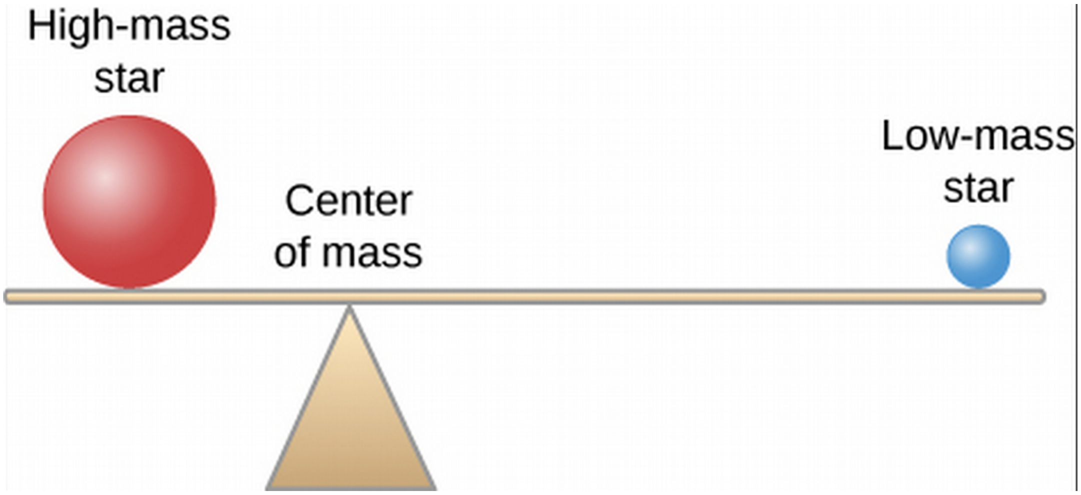
Ch 18 - The Stars: A Celestial Census

Binaries

Visual Binaries

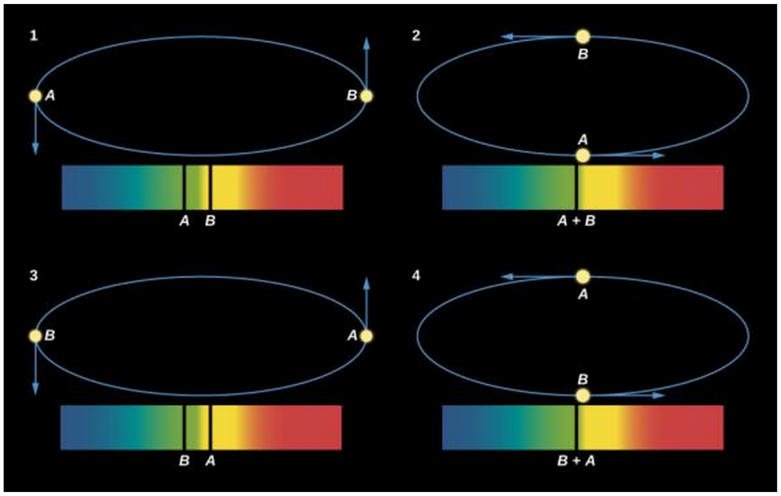
- We can find the mass of stars in *visual binaries,* in which both stars can be seen, by analyzing their motion.

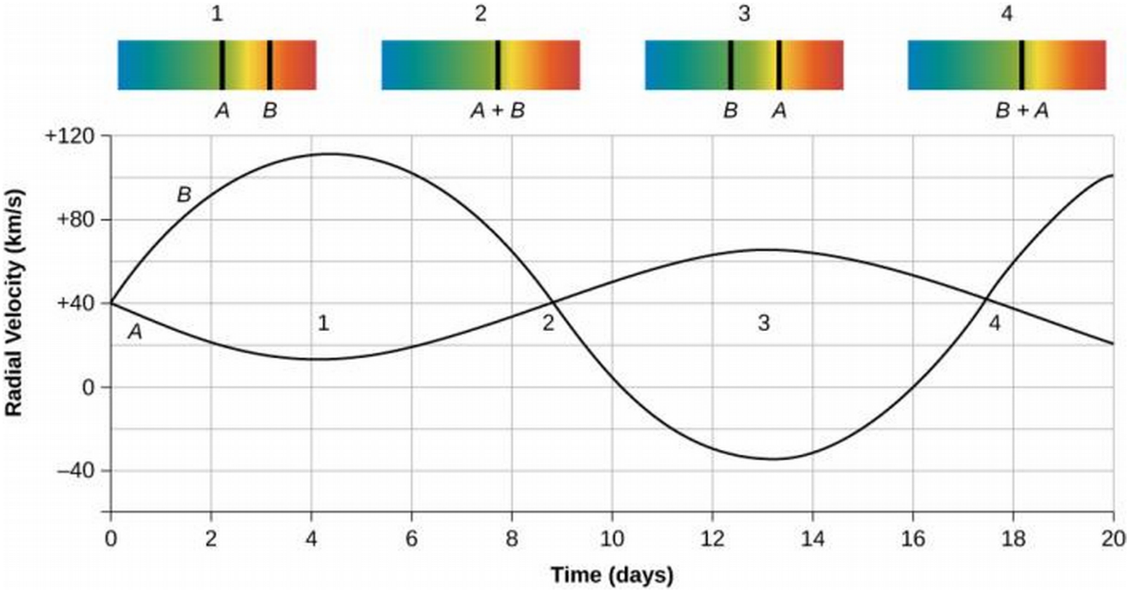




Spectroscopic Binaries

- We don't have this advantage in *spectroscopic binaries*, which are only clearly shown to be binaries through spectroscopic measurements!
- We observe the radial velocity through the periodic doppler shift.



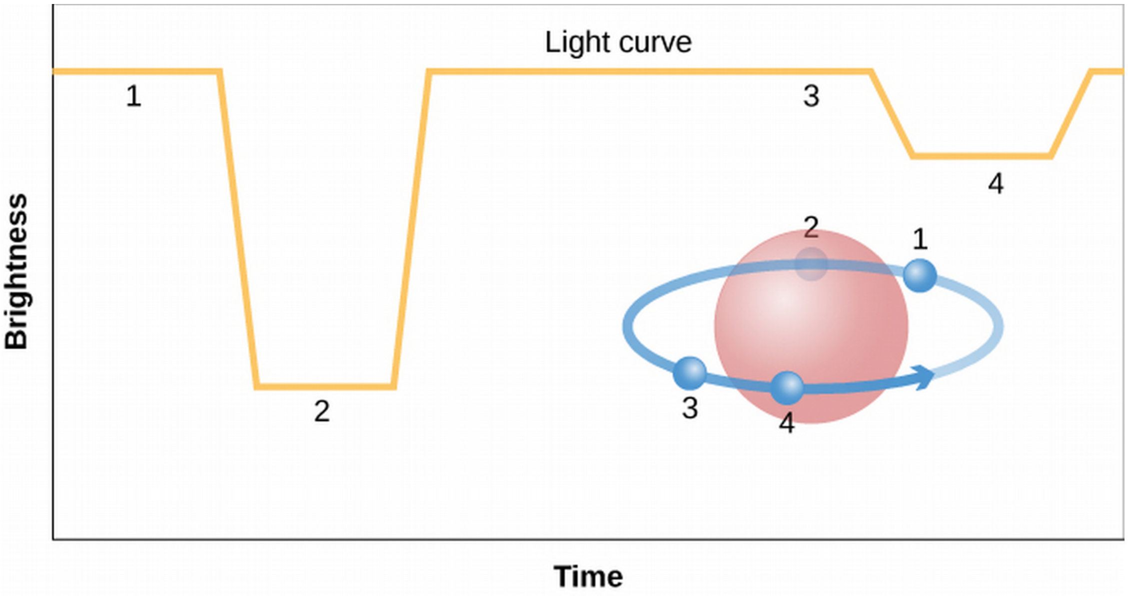


Eclipsing Binary stars

- In cases of eclipsing binary stars (as in the homework), we can find the star diameters and relative velocities, from which the masses can be found!

- We can further use Newton's reformulation of Kepler's third law,

$$D^3 = (M_1 + M_2)P^2.$$


Light curve
1
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Brightness
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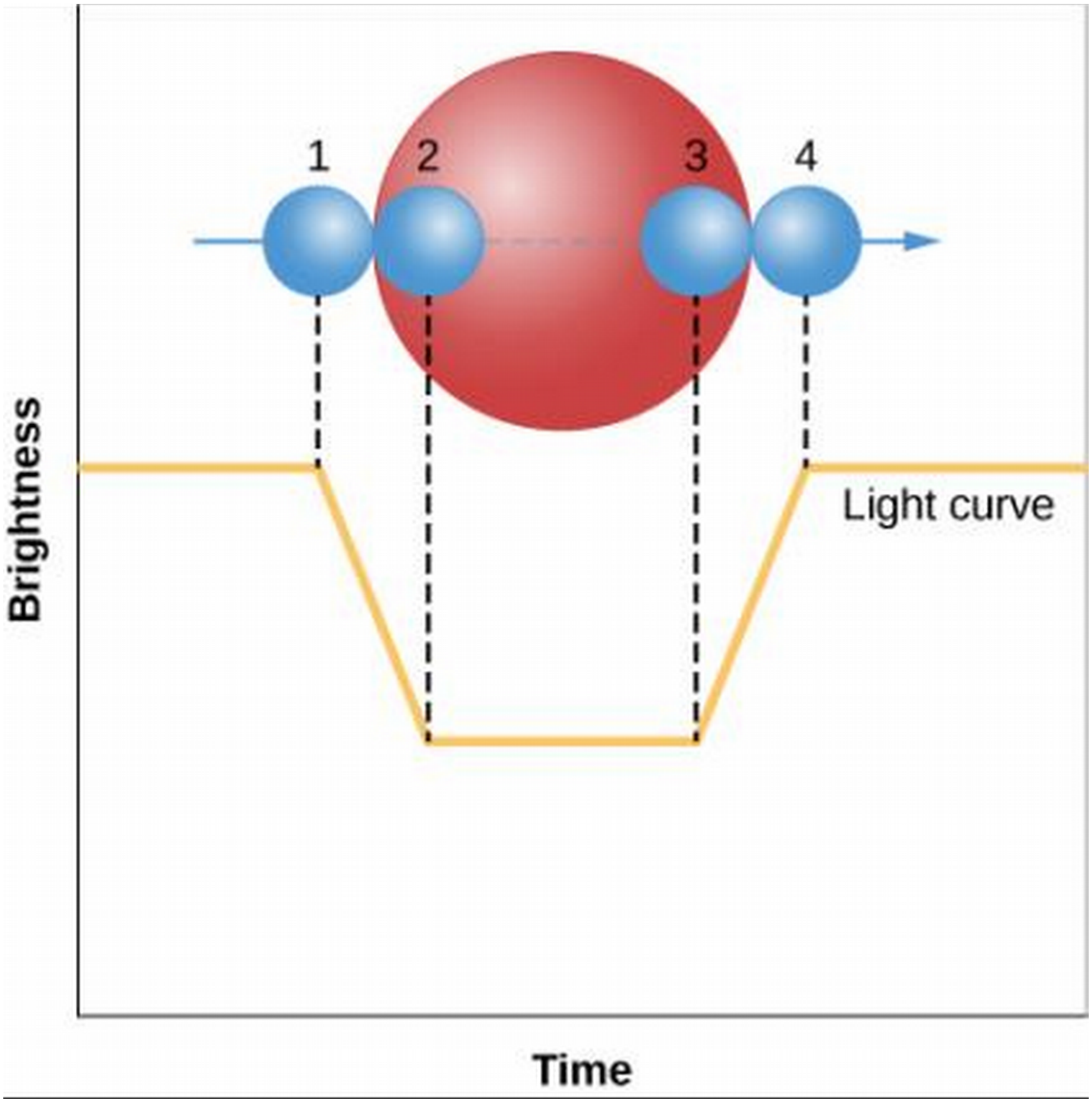


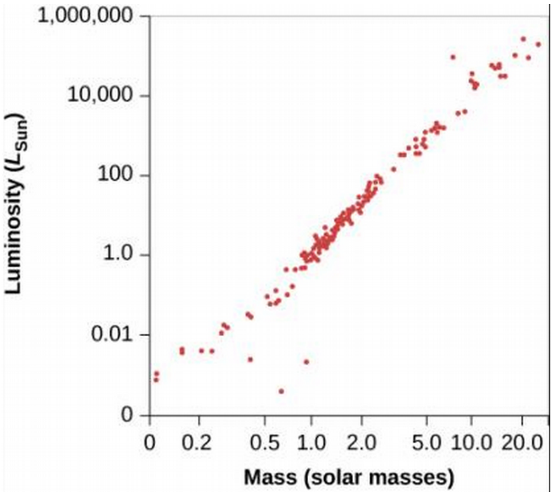
Measuring Stars

-Table 18.2 summarizes how to measure various characteristics:

Characteristic	Technique
Surface Temperature	1. Color (rough) 2. Measure spectrum and get spectral type.
Chemical Composition	Spectral analysis
Luminosity	Measure apparent brightness and compensate for distance.
Radial velocity	Measure Doppler shift.
Rotation	Measure Doppler broadening.
Mass	Measure Period and radial velocity curves of binaries.
Diameter	1. Measure how a star is blocked. 2. Measure light curves and Doppler shifts of eclipsing binaries.

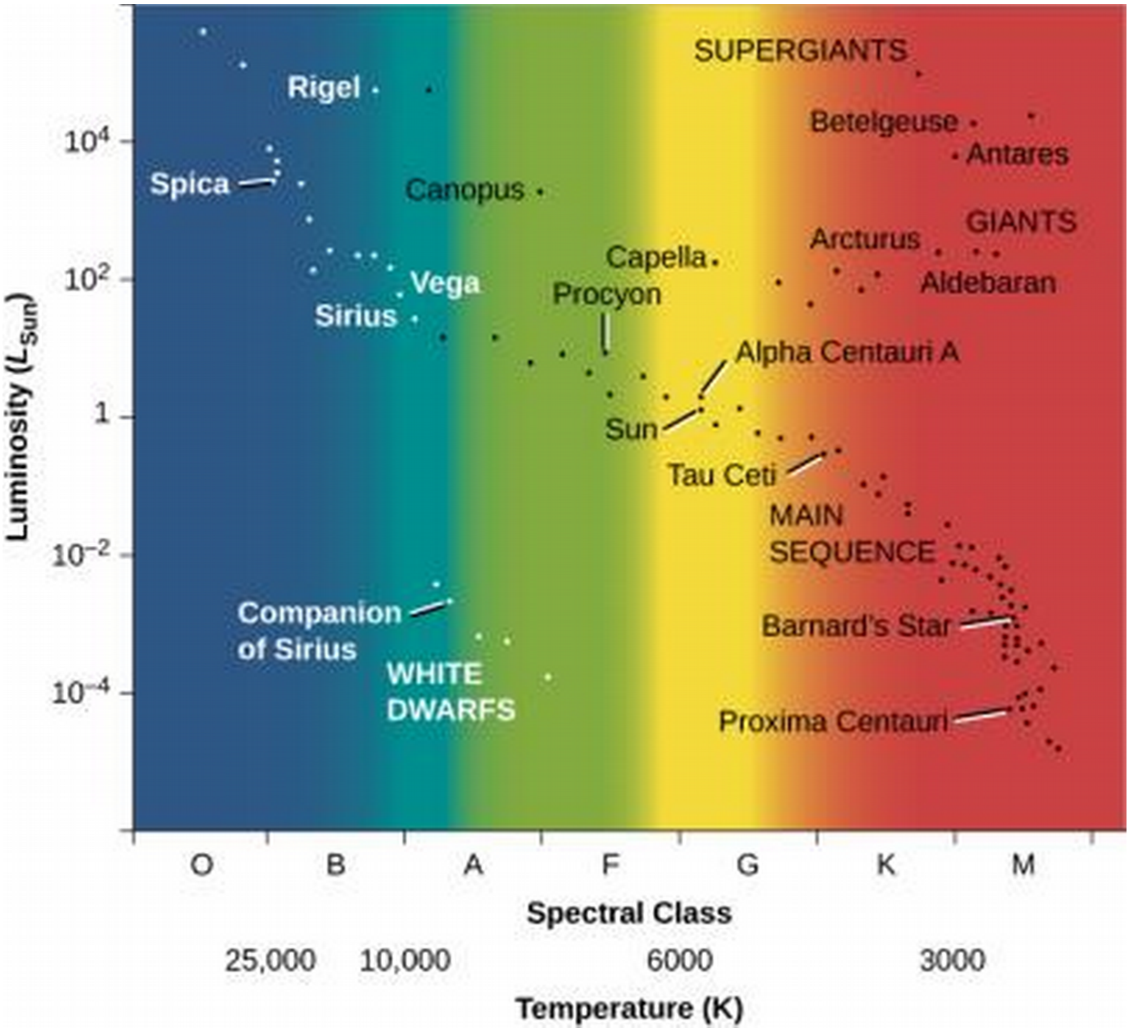
H-R Diagrams

- Plotting Luminosity v. Mass for various stars supports the relationship, $L{\sim}M^{3.9}$.



The H-R diagram

- Hertzsprung-Russell diagram, shows stars in Luminosity v. Spectral class.
- There is a main sequence of stars where luminosity and temperature are related.
- Top right stars are cool and luminous—how? Must be gigantic!
- Bottom left have high temperature, low luminosity, they must have a very small total surface area. These are called *white dwarfs*.



- Keep in mind, we can only plot stars we know the distances to, resulting in observation bias, so the plot doesn't accurately portray relative abundance.
- We estimate from various surveys that outside of brown dwarfs, 90% of stars are along the main sequence, 10% white dwarfs, and less than 1% giants and supergiants.