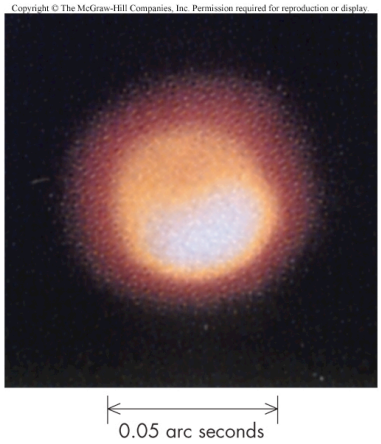
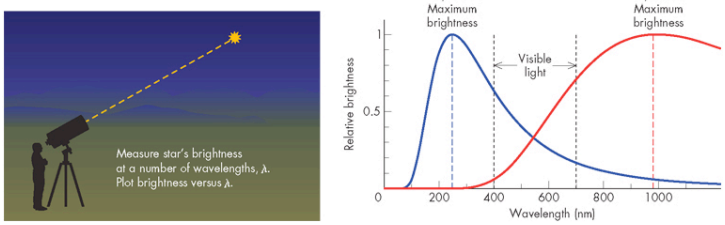
How big are stars? How do we know?

Interferometry

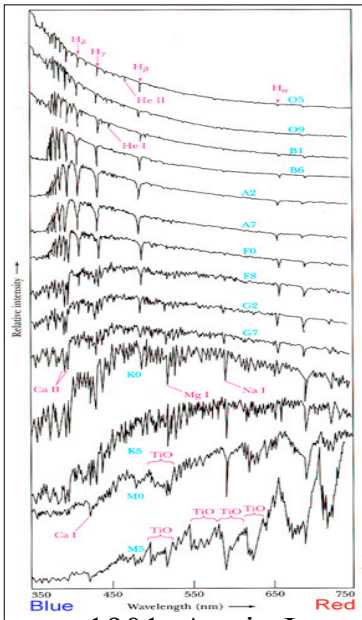
- Stars are simply too far away to easily measure their diameters!
  - Atmospheric blurring and telescope effects smear out the light
- Can combine the light from two or more telescopes to pick out more detail – this is called *interferometry*
  - Two telescopes separated by a distance of 300 meters have almost the same resolution as a single telescope 300 m across!

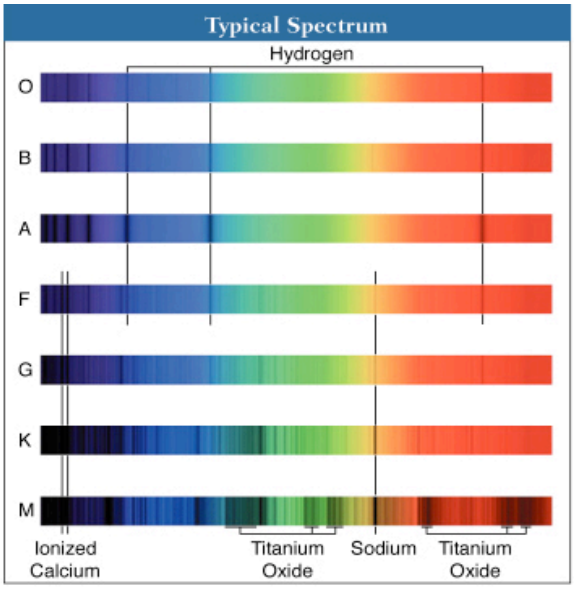


Measuring Temperature using Wein's Law



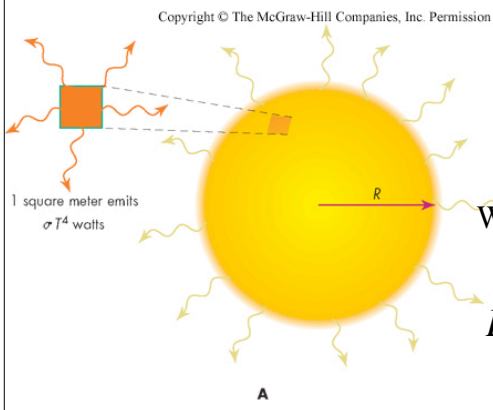
$$T = \frac{2.9 \times 10^{6}\,\mathrm{K \cdot nm}}{\lambda}$$





1901, Annie Jump Cannon > spectral classification

The Stefan-Boltzmann Law



$$flux = \sigma T^4$$

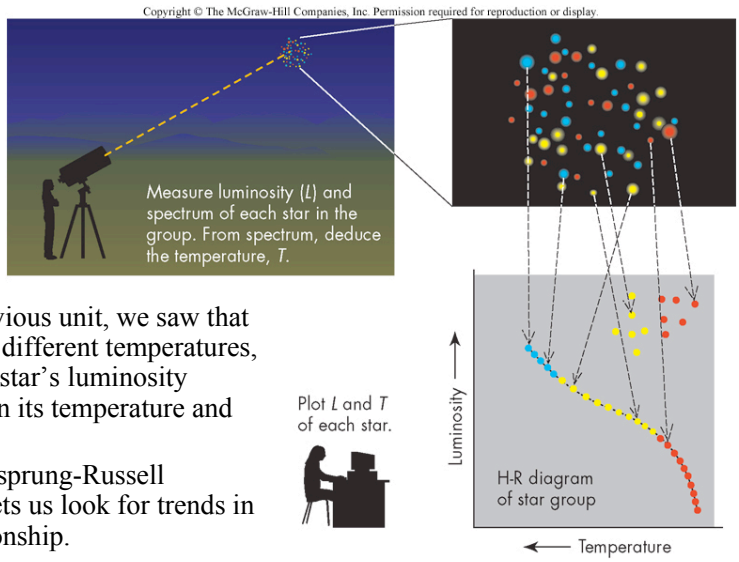
Flux is energy / unit area

Where, $\sigma = 5.67 \times 10^{-8}$ W·m^{-2}·K^{-4}

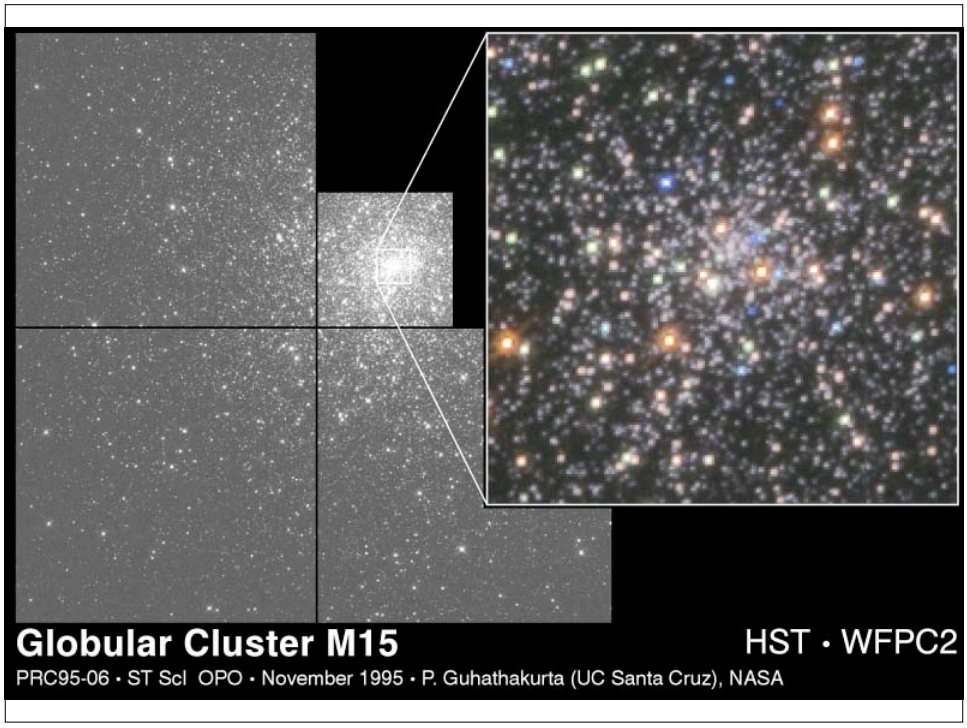
$$L = flux \bullet Area = \sigma T^4 \bullet 4\pi r^2$$

- The Stefan-Boltzmann Law links a star's temperature to the amount of light the star emits
  - Hotter stars emit more!
  - Larger stars emit more!
- A star's luminosity is then related to both a star's size and a star's temperature
- We need an organizational tool to keep all of this straight…

A convenient tool for organizing stars

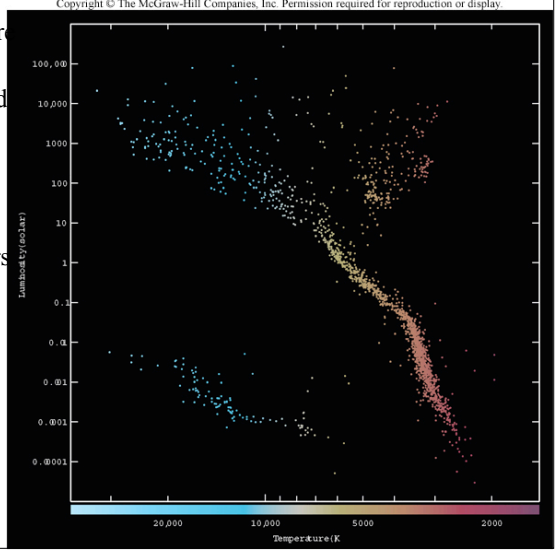


- In the previous unit, we saw that stars have different temperatures, and that a star's luminosity depends on its temperature and diameter
- The Hertzsprung-Russell diagram lets us look for trends in this relationship.



The H-R Diagram

- A star's location on the HR diagram is given by its temperature (x-axis) and luminosity (y-axis)
- We see that many stars are located on a diagonal line running from cool, dim stars to hot bright stars
  - The Main Sequence
- Other stars are cooler and more luminous than main sequence stars
  - Must have large diameters
  - (Red and Blue) Giant stars
- Some stars are hotter, yet less luminous than main sequence stars
  - Must have small diameters
  - White Dwarf stars



The Family of Stars

Hertzsprung—Russell diagram
(1910)

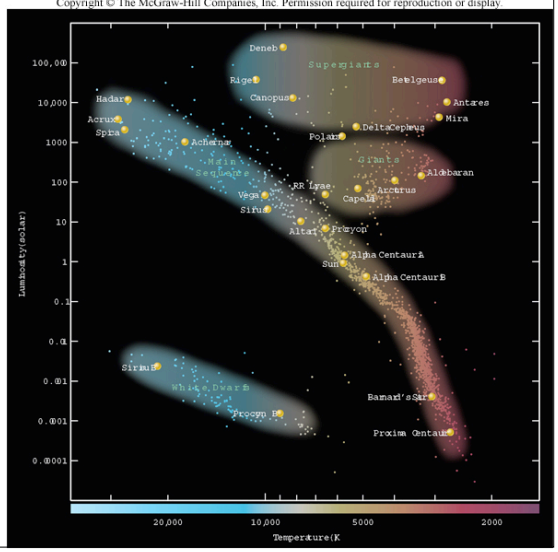
1. temps (= colors = spect type)
   OBAFGKM
2. luminosities

   NOTICE:
   same T → bright or faint ?!

3. same temp , diff Lum

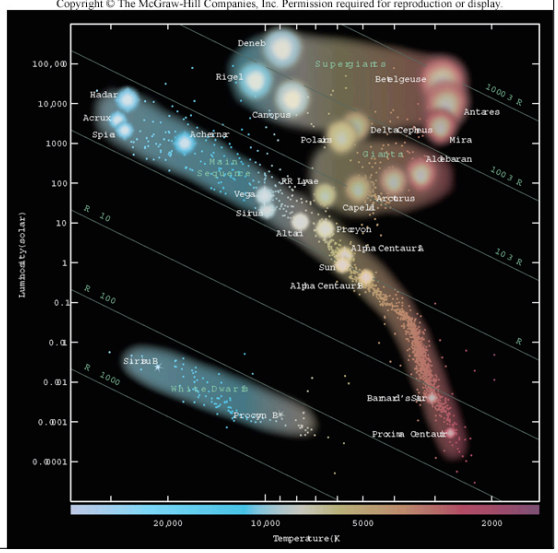
   → different radii !!!

   $L = \sigma T^4 \, 4\pi R^2$



Stars come in all sizes…

- A star's location on the HR diagram is given by its temperature (x-axis) and luminosity (y-axis)
- We see that many stars are located on a diagonal line running from cool, dim stars to hot bright stars
  - The Main Sequence
- Other stars are cooler and more luminous than main sequence stars
  - Must have large diameters
  - (Red and Blue) Giant stars
- Some stars are hotter, yet less luminous than main sequence stars
  - Must have small diameters
  - White Dwarf stars
- So what's going on here?

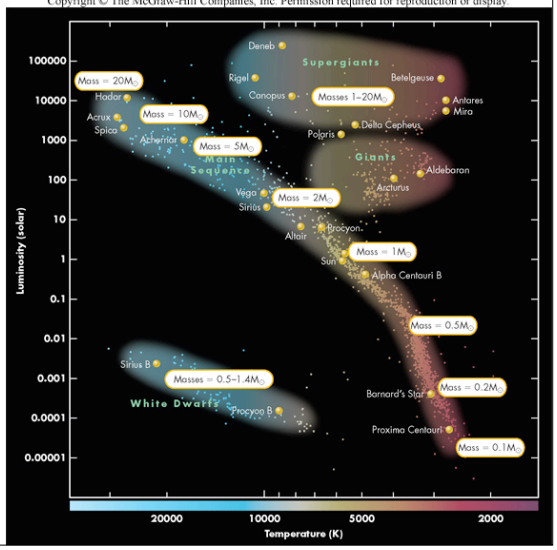


The Mass-Luminosity Relation

- Some of these stars are binaries.
- Newtons formulation of Keplers 3rd law > Mass!
  - Low mass main sequence stars tend to be cooler and dimmer
  - High mass main sequence stars tend to be hotter and brighter
- The Mass-Luminosity Relation:

$$L \approx M^{3.5}$$

Massive stars burn brighter!

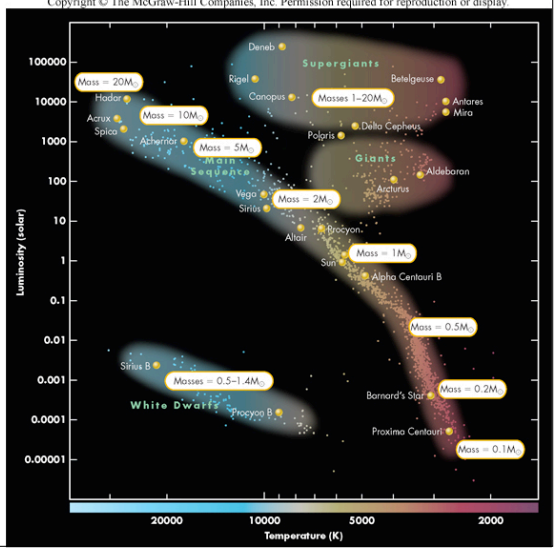


The Mass-Luminosity Relation

Stellar Luminosity Classes

Class	Description
I	Supergiants
II	Bright giants
III	Giants
IV	Subgiants
V	Main sequence

B0.. B1… B9
larger number, cooler star.



Most of the brightest stars in the sky are

a) relatively hot main-sequence stars that are relatively close to the Sun.

b) relatively cool giant stars that are relatively close to the Sun.

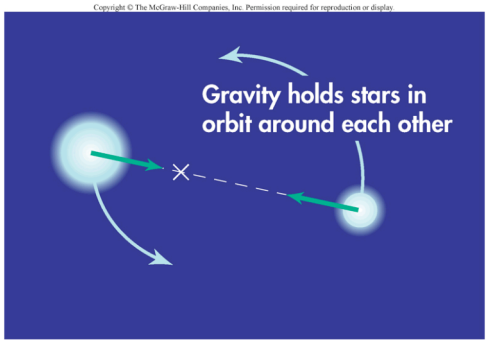
c) relatively cool main-sequence stars that are relatively far from the Sun.

d) relatively cool main-sequence stars that are relatively close to the Sun.

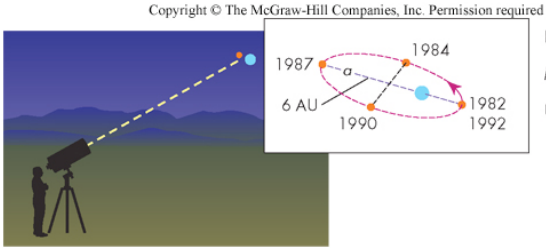
e) giant stars and relatively hot main sequence stars.

The Types of Binary Stars

- Many stars are found orbiting another star. These star systems are called binary stars.
- Three types:
  - If we can see from pictures taken over time that the stars are orbiting each other, the system is a *visual binary*
  - If the stars are so close together (or distant from Earth) that their spectra blur together, the system is called a *spectroscopic binary*
  - If the stars are oriented edge-on to the Sun, one star will periodically eclipse the other star in the system. These are called *eclipsing binaries*



Measuring Stellar Masses with Binary Stars

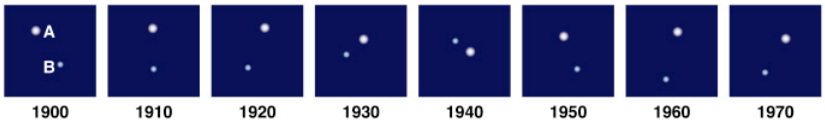


Plot of star positions → Period of 10 years

Measure semi-major axis = a = 6 AU

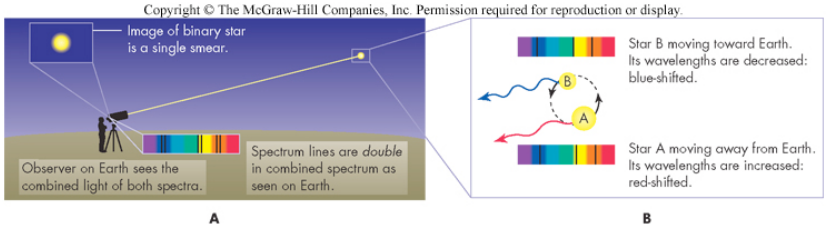
Use modified form of Kepler's third law

$$m + M = \frac{a^3}{p^2} = \frac{6^3}{10^2} = 2.16\ M_\odot$$



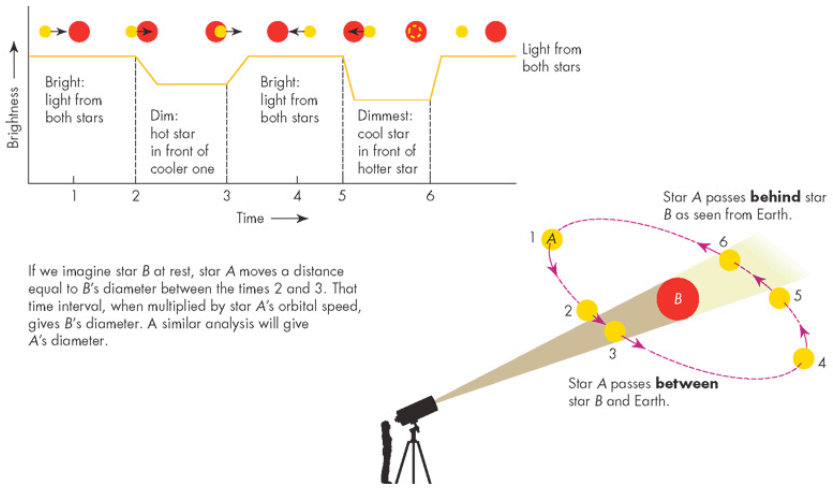
Note that this technique only gives us the combined mass of the two stars…
How do we know the distance?

Using the Doppler Shift to detect binary systems



- As a star in a binary system moves away from us, its spectrum is shifted towards red wavelengths. As it moves toward us again, the spectrum is shifted toward the blue wavelengths
- This Doppler Shift allows us to detect some binaries!

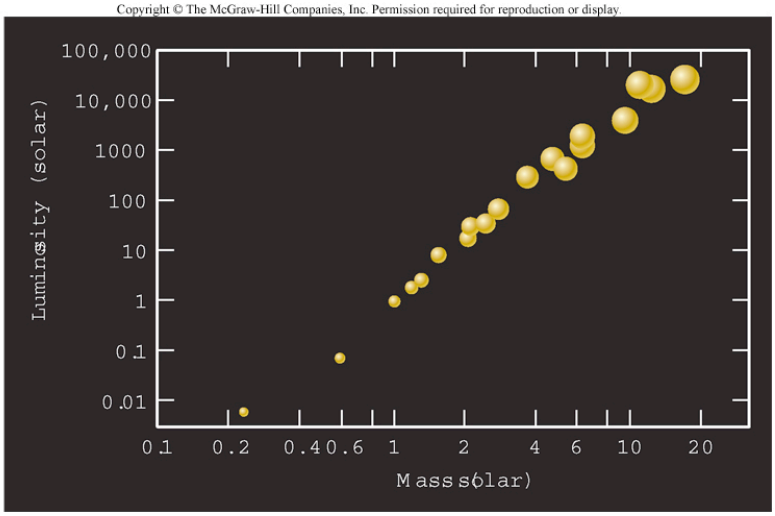
Using eclipsing binary systems to measure stellar diameters



If we imagine star *B* at rest, star *A* moves a distance equal to *B*'s diameter between the times 2 and 3. That time interval, when multiplied by star *A*'s orbital speed, gives *B*'s diameter. A similar analysis will give *A*'s diameter.

Massive stars burn brighter

B



O B A F G K M

- Oh! Be A Fine Girl/Guy, Kiss Me
- Officially, Bill Always Felt Guilty Kissing Monica
- Oh Big And Ferocious Gorilla, Kill My Roommate Now, Sir.
- Only Big Astronomy Federal Grants Keep Money. Research Needs Support!
- Only Bored Astronomers Find Gratification Knowing Mnemonics
- Only Boys Advocating Feminism Get Kissed Meaningfully
- Oh Boy An F-Grade Kills Me
- Oven Baked Ants Fried Gently Keep Moist
- Only Boring Astronomers Find Gratification Knowing Mnemonics Like These