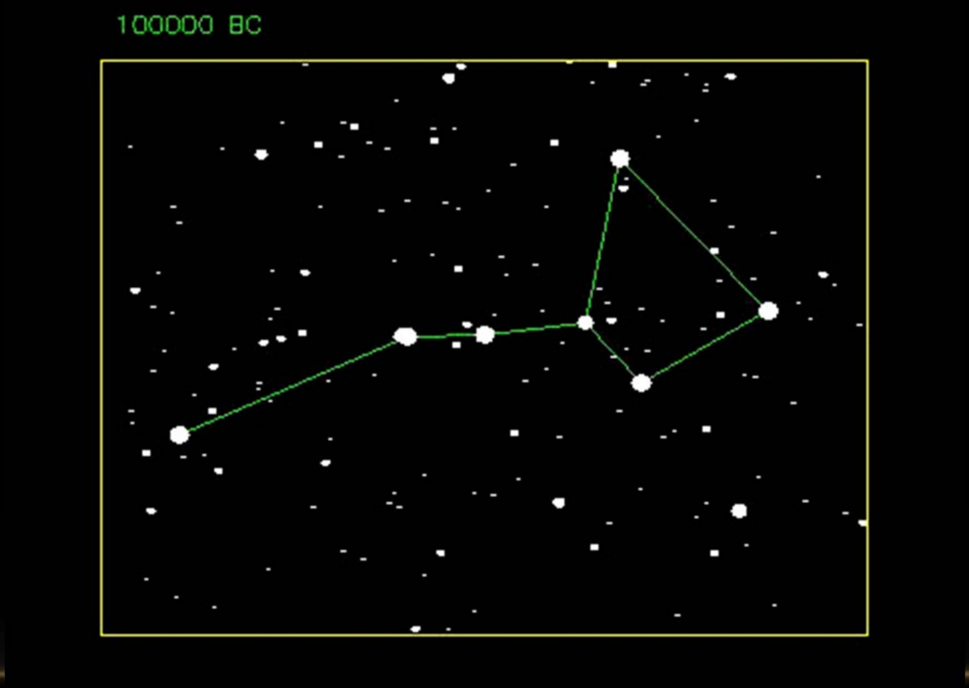
OTHER MOTIONS

- The position of a nearby star changing over a year gives us parallax
- Stars can also move on their own
  - "Real" motion, not just our point of view
- They are just balls of gas and are moving around too
  - Just so far away they appear to move very slowly

PROPER MOTION

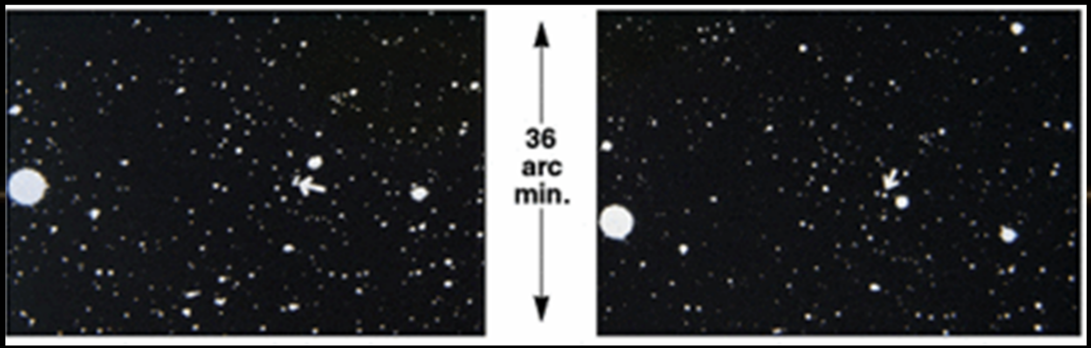
- A star's own movement is called "Proper Motion"



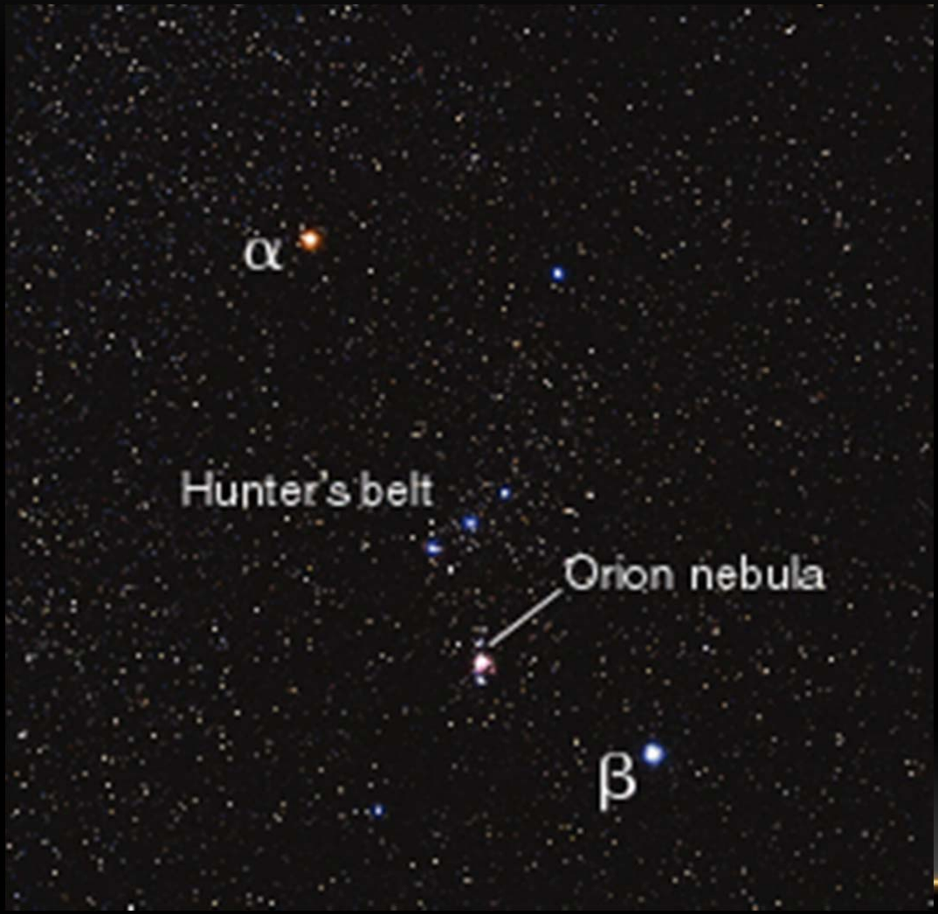
Animation by Richard Pogge, Ohio State

BARNARD'S STAR

- 2nd closest star to the Sun
  - 1.82 pc
  - Close by things appear to move more quickly
- Has rather large velocity
  - 142 km/s total, 89 km/s "Tangential" (sideways)
- Photos below taken 22 years apart



COLORS



- Again, look at Betelgeuse and Rigel
  - Betelgeuse is very red
  - Rigel is very blue
- Spectra!
- Temperatures, composition, etc.

SPECTRAL CLASSES

- Annie Jump Cannon cataloged many stellar spectra around the turn of the (last) century
  - Based on which absorption lines they had
  - Each class had a letter name

Back in the days when "computer" was a job title!

Fig.12.5

SPECTRAL CLASSES

- It was later realized that these could be put in temperature order
  - Both based on blackbody curve…
  - …and on which elements could survive the heat
  - "Oh Be A Fine Girl/Guy Kiss Me" is the order
    - Book proposes a more modern one:
      "Only Bungling Astronomers Forget Generally Known Mnemonics"

SPECTRAL CLASSES

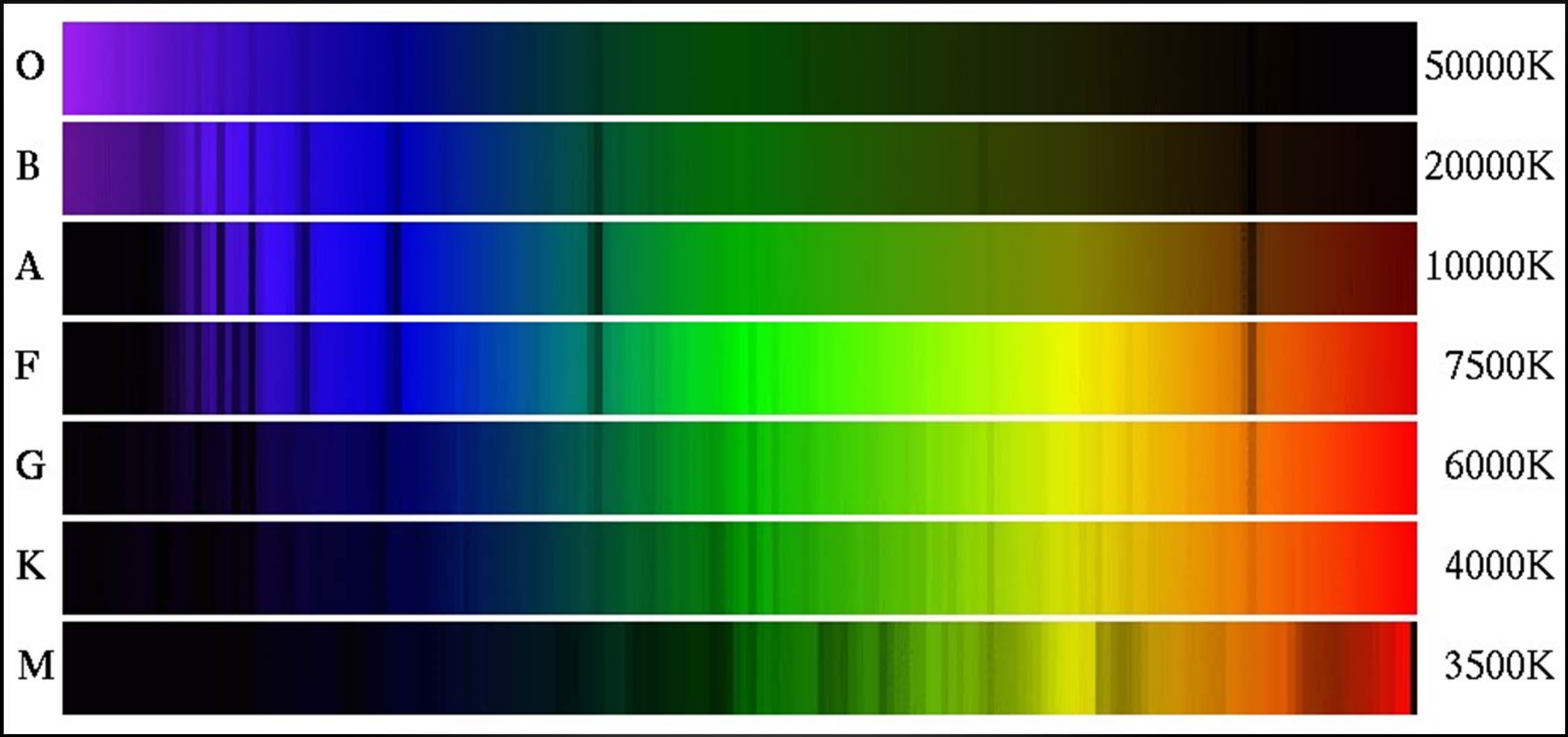


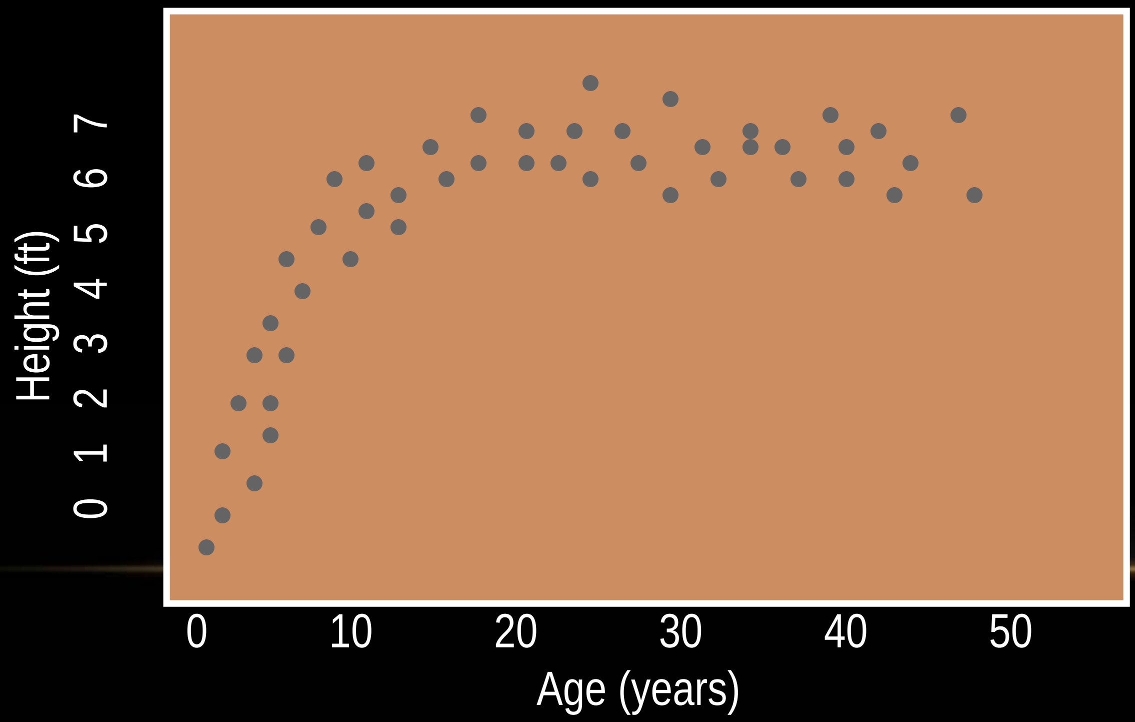
Figure from Lemke & Jefferey

SOME EXAMPLES

- Within a class, ordered from “0 to 9”
- Some stars you might know:
  - Mintaka (O9)
  - Rigel (B8), Vega (A0), Sirius (A1)
  - Canopus (F0)
  - Sun (G2), Alpha Centauri (G2)
  - Arcturus (K2), Aldebaran (K5)
  - Betelgeuse (M2), Barnard's Star (M5)

HOW TO USE THIS INFO

- Say you made a graph of people's height vs. age, with a dot for everyone in the neighborhood:

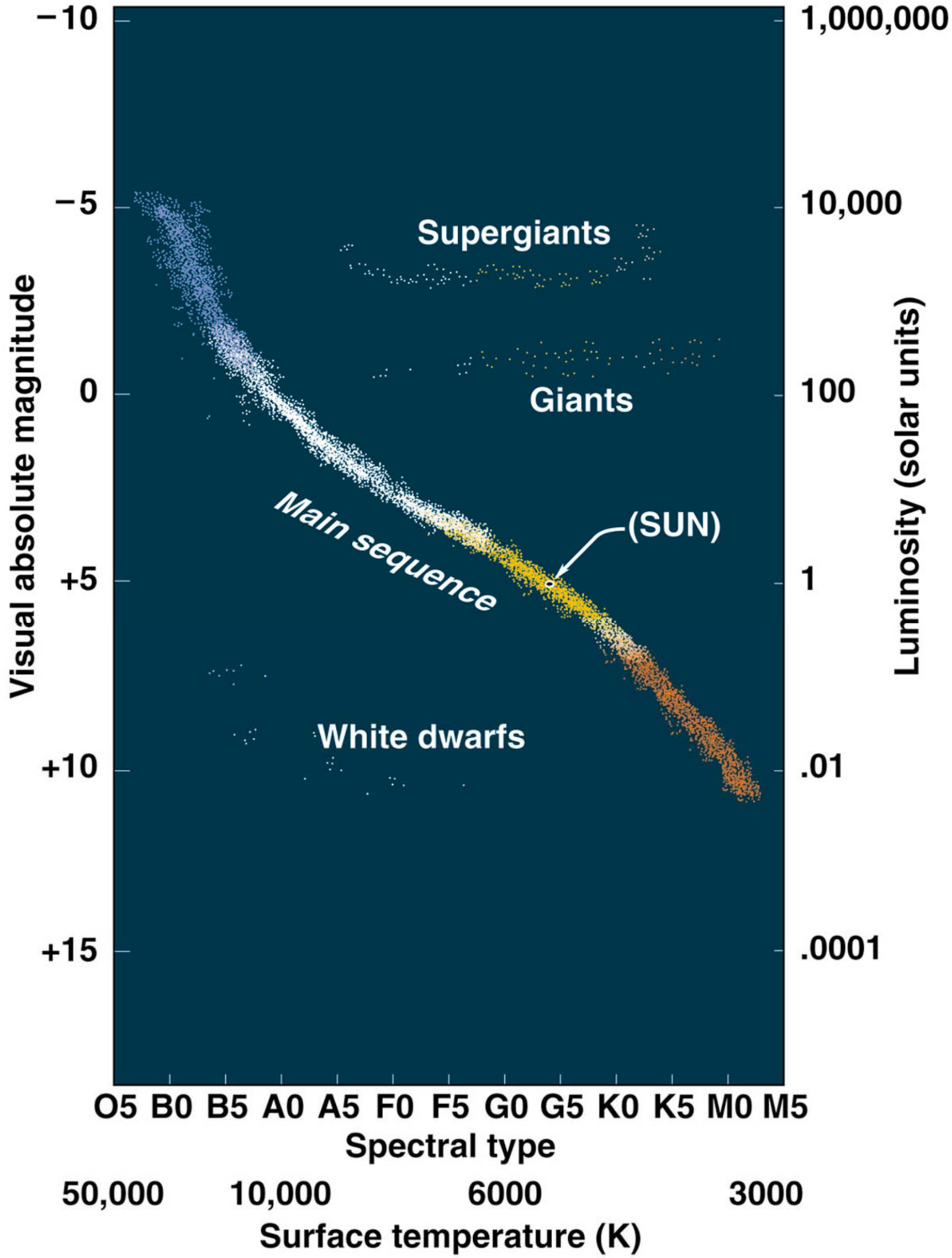


Without watching any one person grow up, you can get a good idea as to how humans change over time: early growth, then stay the same size

HERTZSPRUNG-RUSSELL DIAGRAM

- We know stars' temperatures (from their spectral class)
- We know some stars absolute magnitudes (thus their luminosities) because we know their distances
- Plot one vs. the other

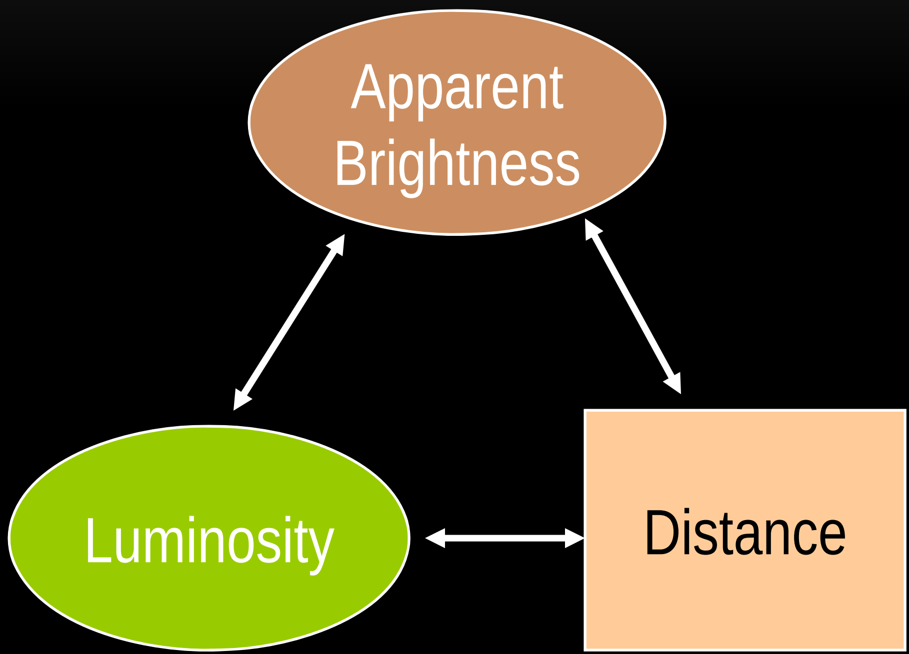
PLAY



H-R DIAGRAM

- Each dot is a star
- Most stars line up on the "Main Sequence"
  - Interpretation – an average star spends most of it life at this combination of temperature and luminosity

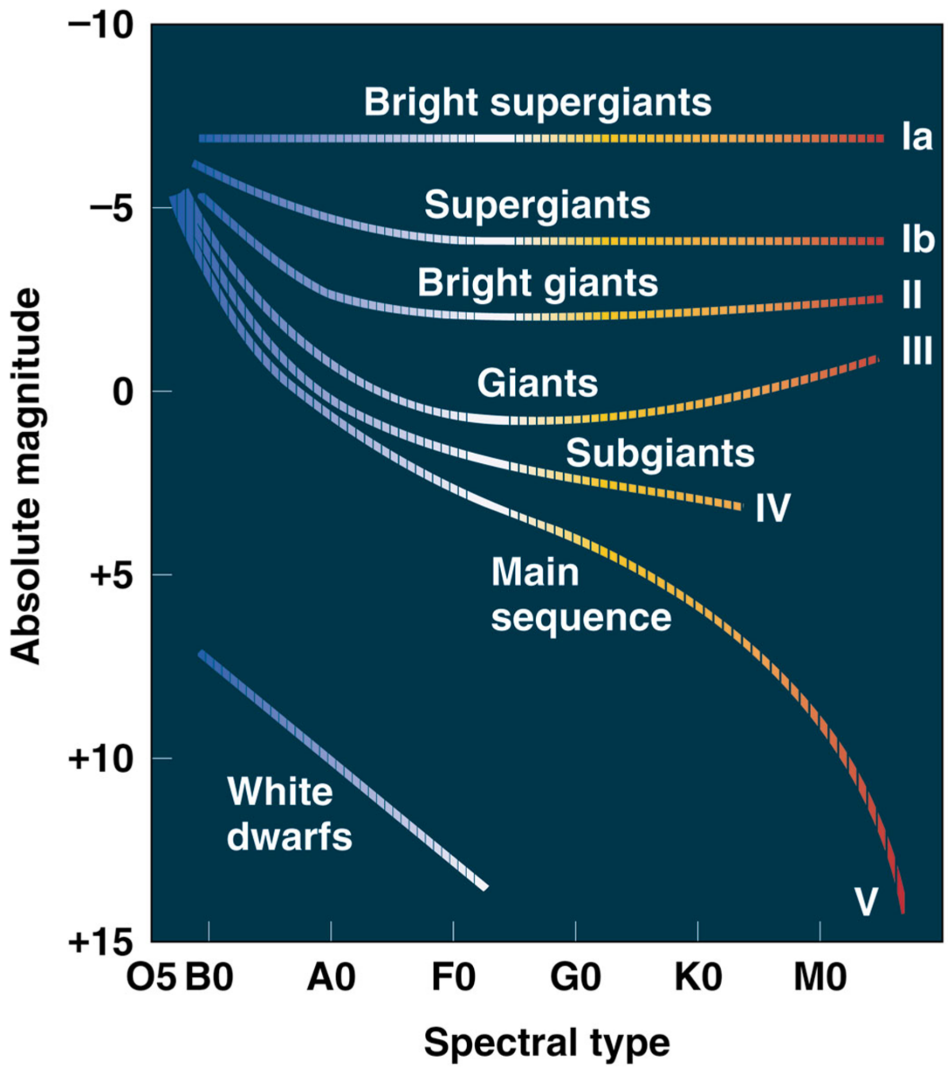
SPECTROSCOPIC PARALLAX



- Has nothing to do with parallax
- But is a way to measure distance, if the star is too far away to get a real parallax
- Measure its temperature, look up the Luminosity on the H-R diagram

Find any two of the three,
You can calculate the third!

LUMINOSITY CLASSES

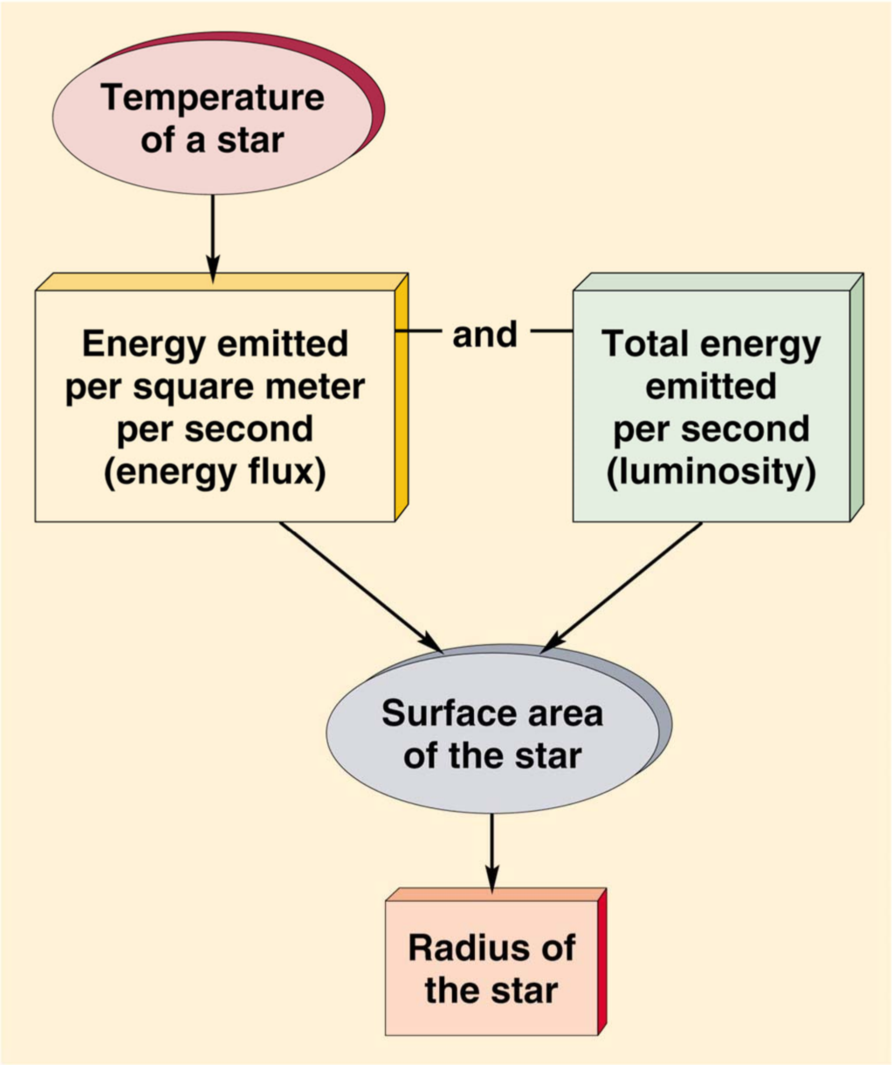


- There are some stars not on the Main Sequence
- Divided into “Luminosity Classes”, with roman numeral
- Absorption line shape helps classify
  - Thin, narrow lines in giant’s atmospheres
  - Higher pressure in more compact stars broadens the lines

DIFFERENT LUMINOSITIES?

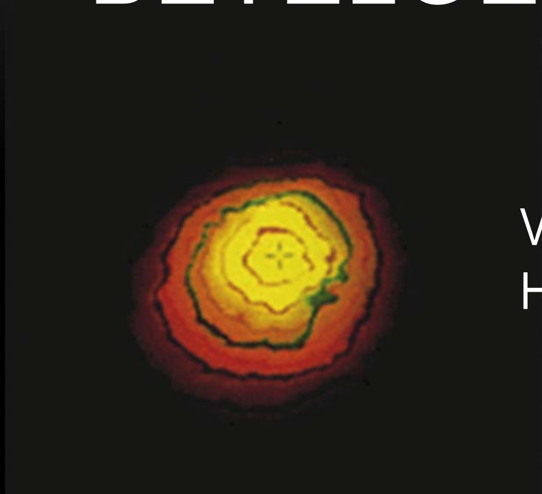
- If the Stefan-Boltzmann law says $I \sim \sigma T^4$, how do you get different I's for the same T?
- I is intensity – power per square meter
- L is total power – so multiply I by the surface area of the star
  - Betelgeuse – M2Ia Supergiant
    - ~1000 R_o (5 AU!), surface area 1 million x the Sun
  - Barnard's Star, M5V Main Sequence
    - 0.12 R_o, surface area 1.5% the Sun's
  - Both stars about the same T. Betelgeuse has 69 million times the surface area, so is that much more luminous

A WAY TO FIND A STAR'S SIZE!



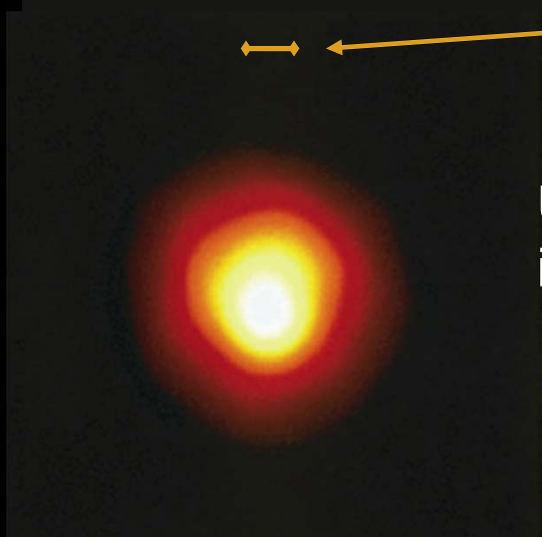
- By this line of reasoning, we can figure out a star's physical size
  - Note that stars are mostly too far away to actually see a disk
- Measure T, L (from distance), get R

BETELGEUSE'S DISK



Visible light HST image

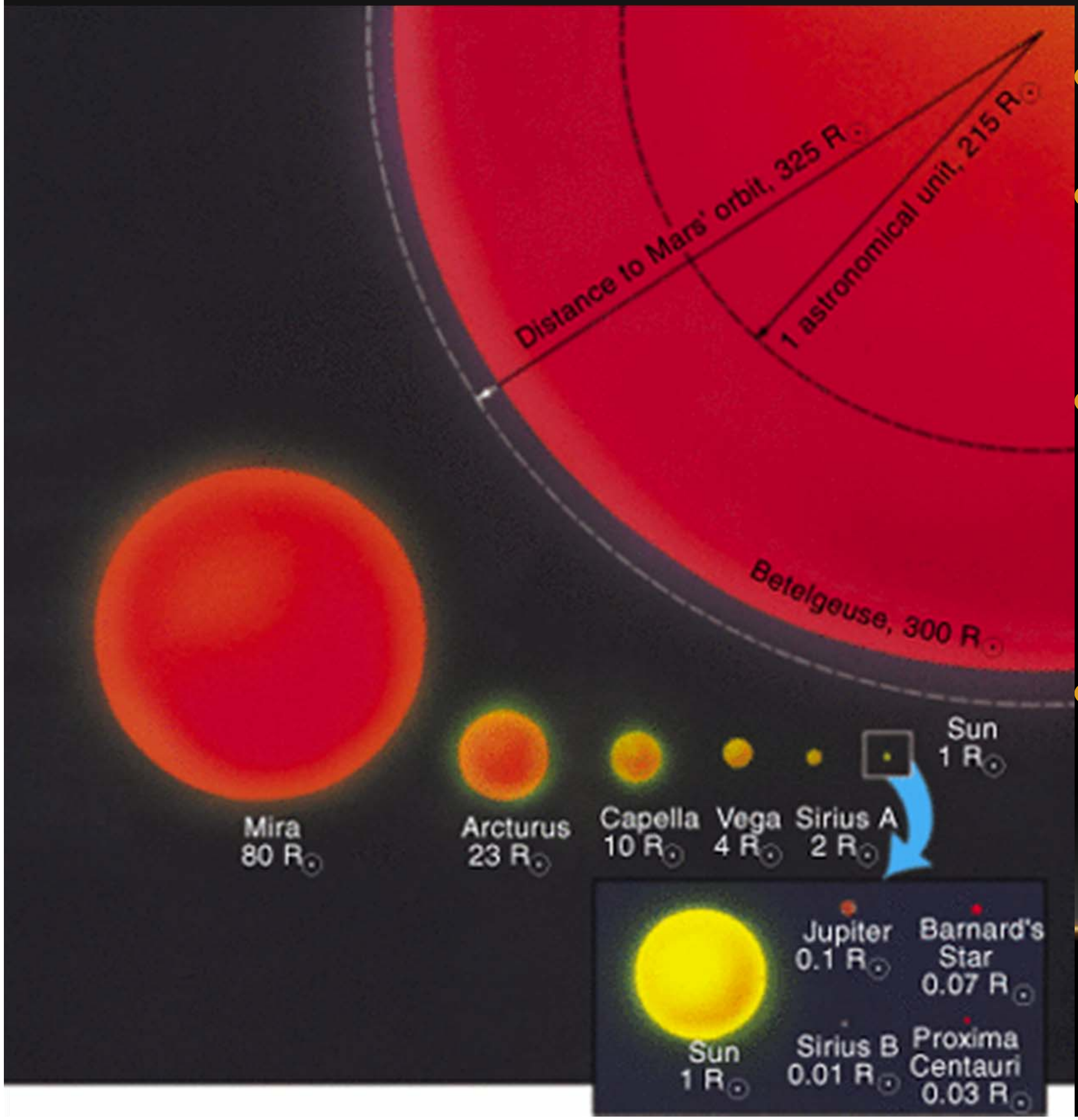
Size of Earth's Orbit!



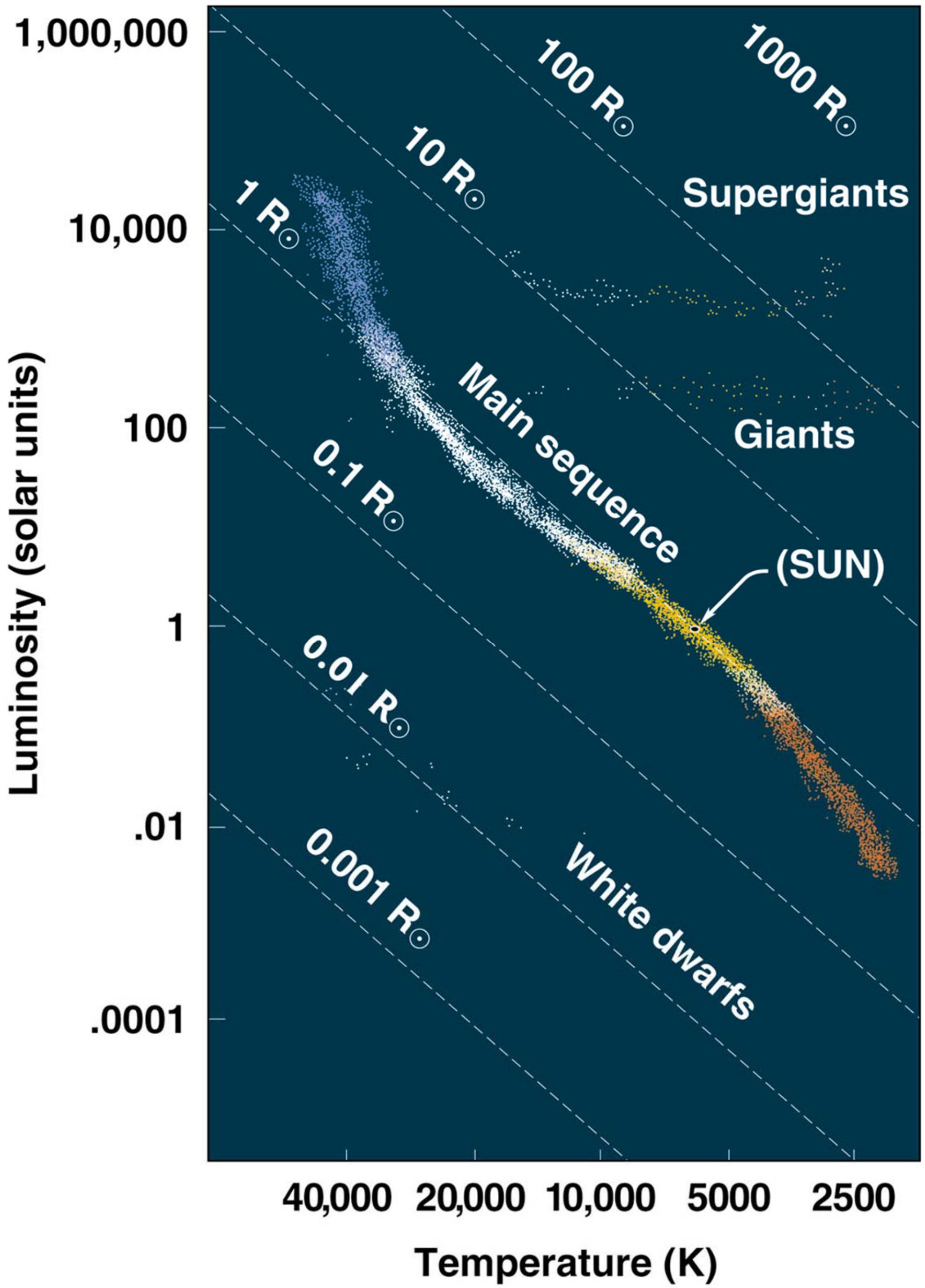
UV HST image

- Betelgeuse is one of only a few stars where the disk has been resolved
  - Fairly close + huge
- HST only telescope accurate enough to do the job
- Note – Betelgeuse is a variable star, it also changes sizes rather dramatically

STELLAR SIZES



- Comparative sizes
- Giants such as Arcturus, Mira ~10's of $R_\odot$
- Supergiants like Betelgeuse ~100's of $R_\odot$
- Most (super)giants pulsate in size and thus in brightness



ADD TO H-R DIAGRAM

- Use the previous calculation to mark the sizes of stars on the H-R diagram
- Most main sequence stars are about the same radius as the Sun
- Giants, supergiants much larger

WHITE DWARFS?

Sirius A & B in X-Rays
Chandra X-ray obs.

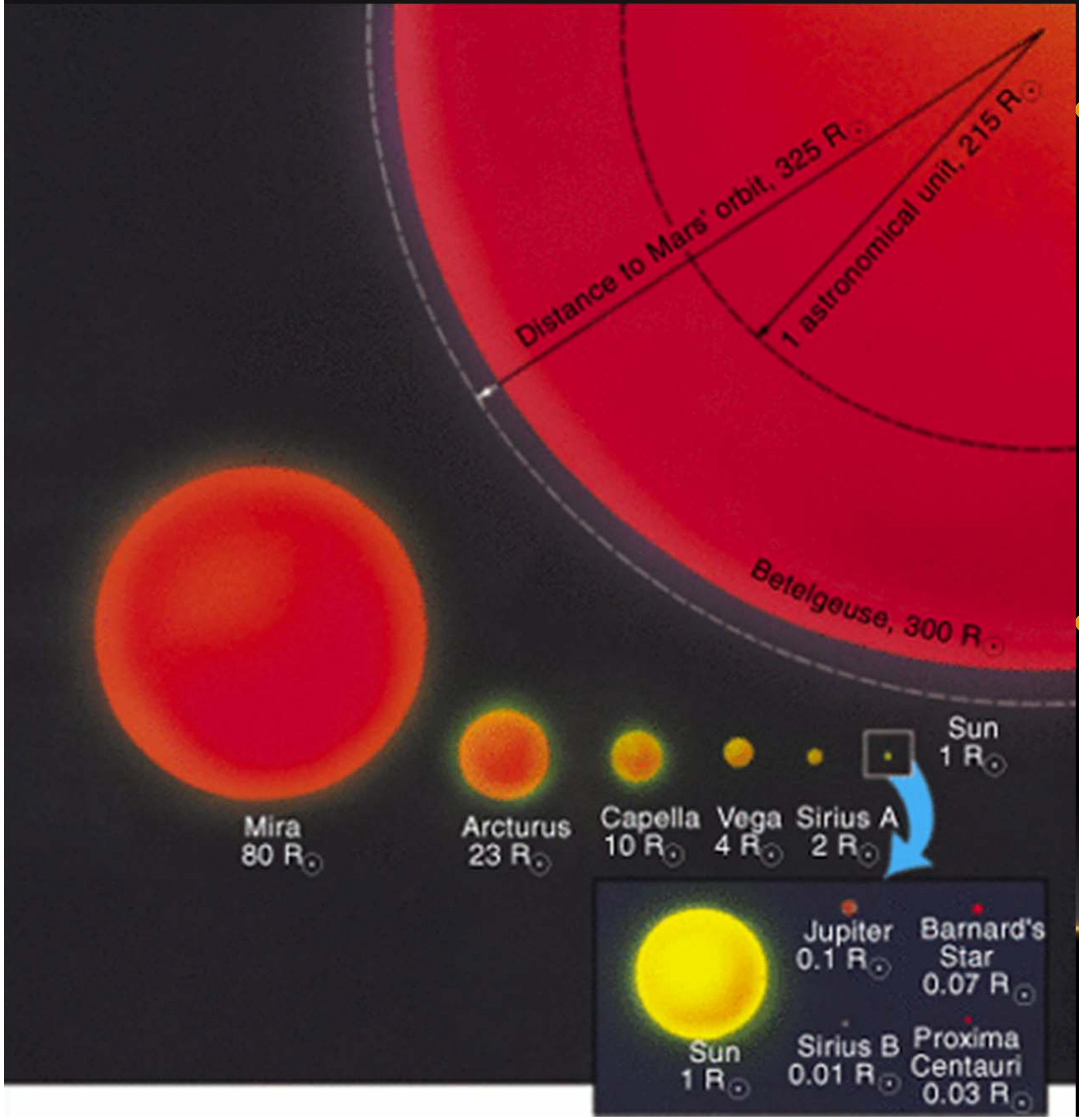
- A white hot yet faint star*
- Must be very small (small area)
  - ~earth sized!
- Burnt out cores of old stars

*Also the name of the Indiana Astro department's grad student intramural basketball team

H-R DIAGRAM SUMMARY

- A graph of Temperature vs. Luminosity
- Each star is a dot on one
- Shows overall trends of how stars work
- A very important tool – go over it again tonight, figure it out. It will make repeat appearances in this class

WHAT WE KNOW SO FAR



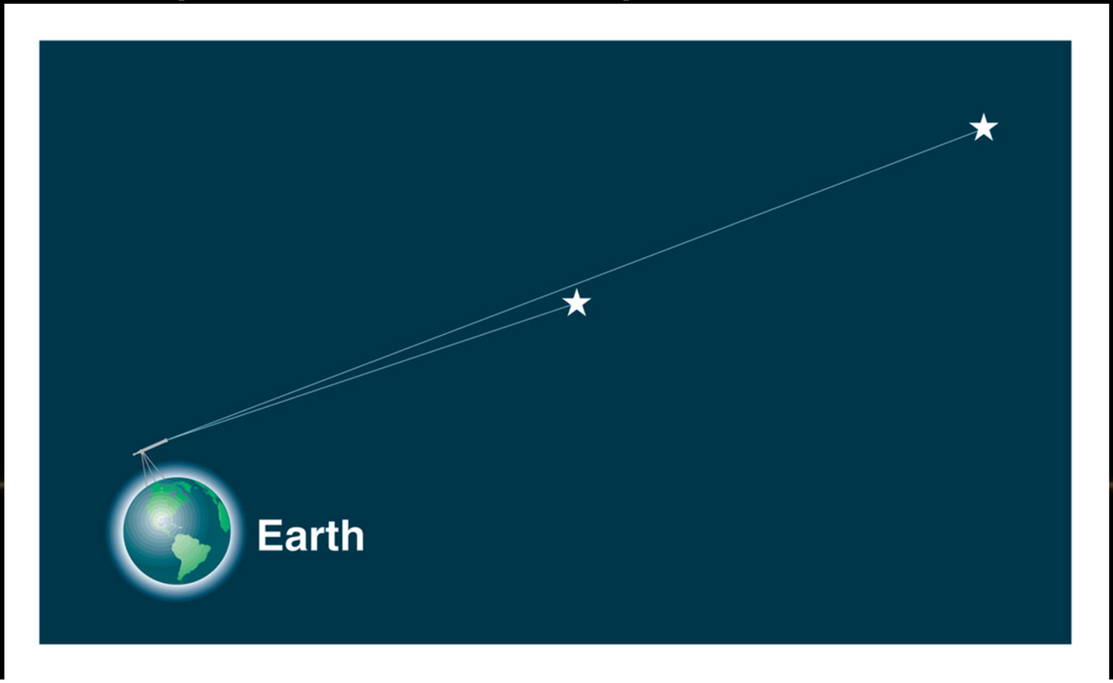
- A surprising amount:
  - Distance
  - Temperature
  - Luminosity
  - Radius
  - Composition
- A big missing piece:
  - Mass!
  - As in solar system, need to watch things orbit, use Kepler's laws

MULTIPLE STAR SYSTEMS

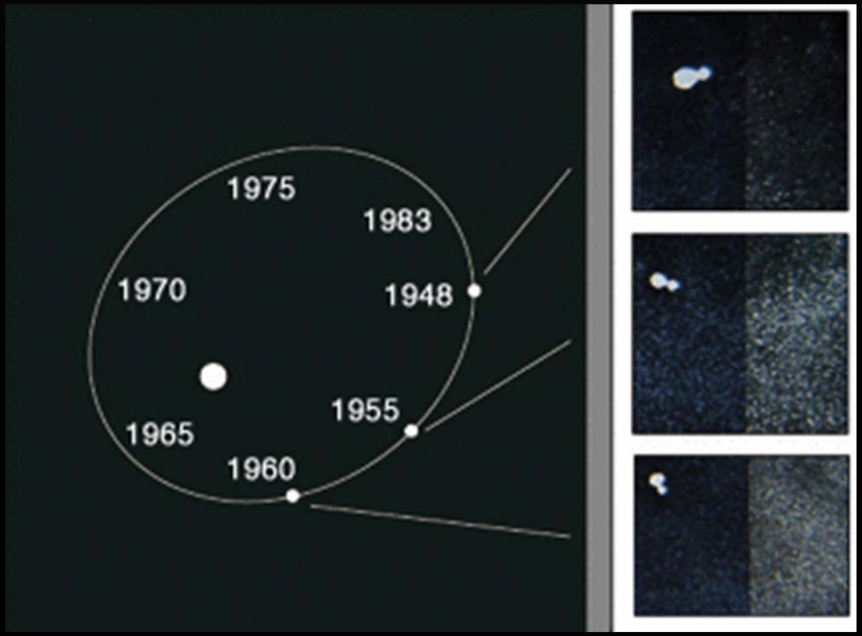
- Finding planets is hard (only recently done for a few thousand stars)
  - Very small, dim
- But we can see other stars
  - Stars orbiting stars would let us figure out their masses
  - Use Kepler's, Newton's laws to figure out the masses of the two stars

OPTICAL DOUBLES

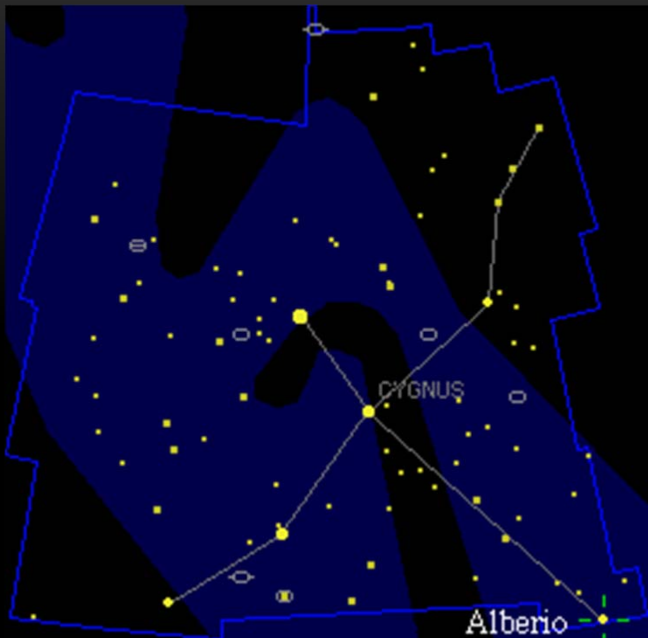
- Just because 2 stars appear next to each other does not make them a gravitationally bound *binary* (double) star system
- Chance lineups are called "Optical Doubles"



VISUAL BINARIES



- If we can see two stars going about each other, that's a visual binary
- Measure separation, orbital period
  - Work out the masses
  - Only possible for nearby stars

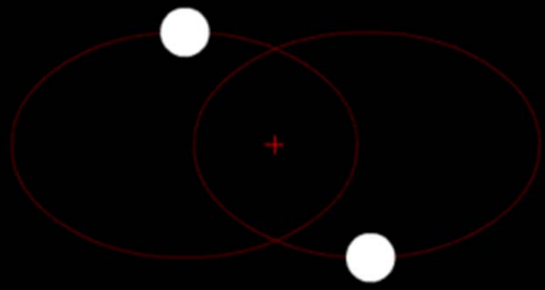


- β Cygni (*Alberio*)
  - The “beak” star of the swan
- An easy, impressive visual binary
  - Can see in binocs, small telescope
  - One yellow, one blue
- Polaris also a visual double

Photos by Jack Schmidling

ORBITS

- We are used to light things orbiting around heavy things
- What if both things are about the same size – who goes around what?
  - Both go around the Center of Mass (c.o.m.)
  - True of all objects – even Earth/Sun, but the c.o.m. is very close to the Sun so it's hard to tell
- Kepler's laws apply
  - c.o.m. is at a focus of the ellipse
  - Things move slower further away from c.o.m.



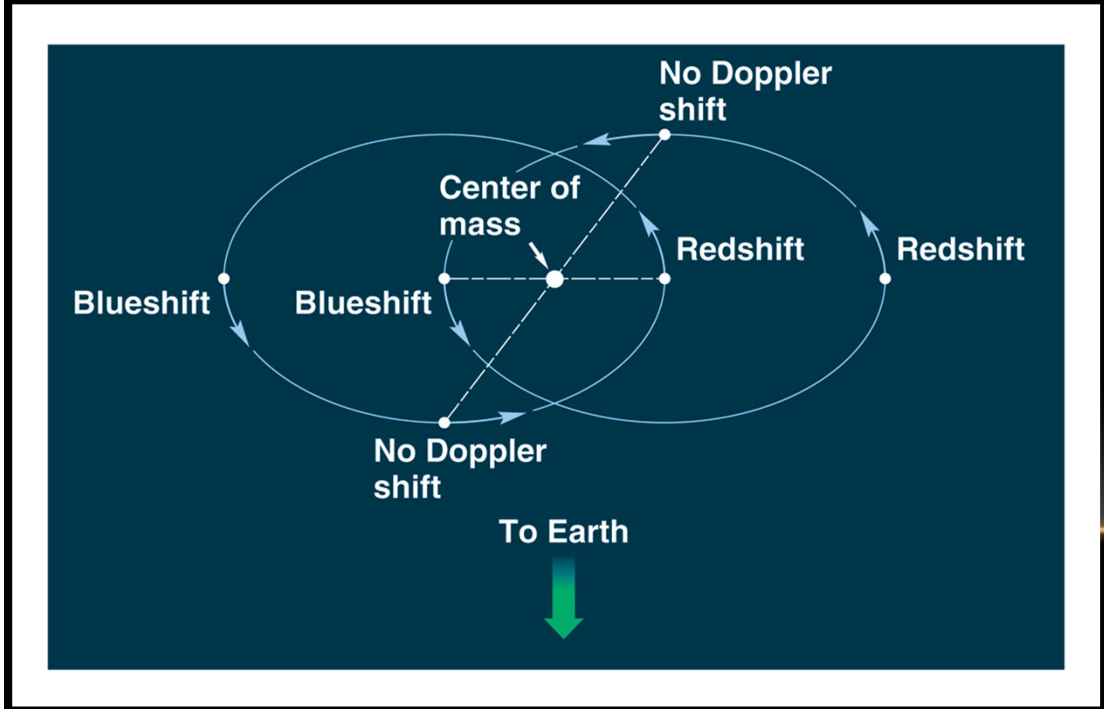
Procyon animation
by Bruce McClure

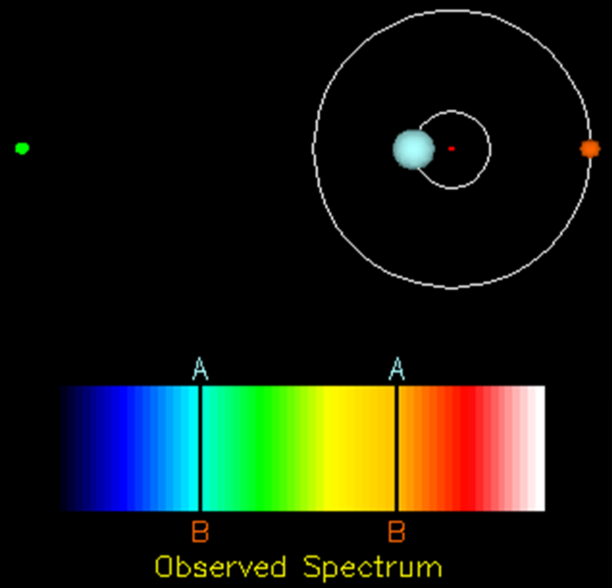
SPECTROSCOPIC BINARIES

- What if the stars are too close together to tell apart?
  - Especially a problem unless they are very close to us!
- Their light is combined, we see one “star”
- Only way to tell it’s not really a single star is to look at the spectrum

SPECTROSCOPIC BINARIES

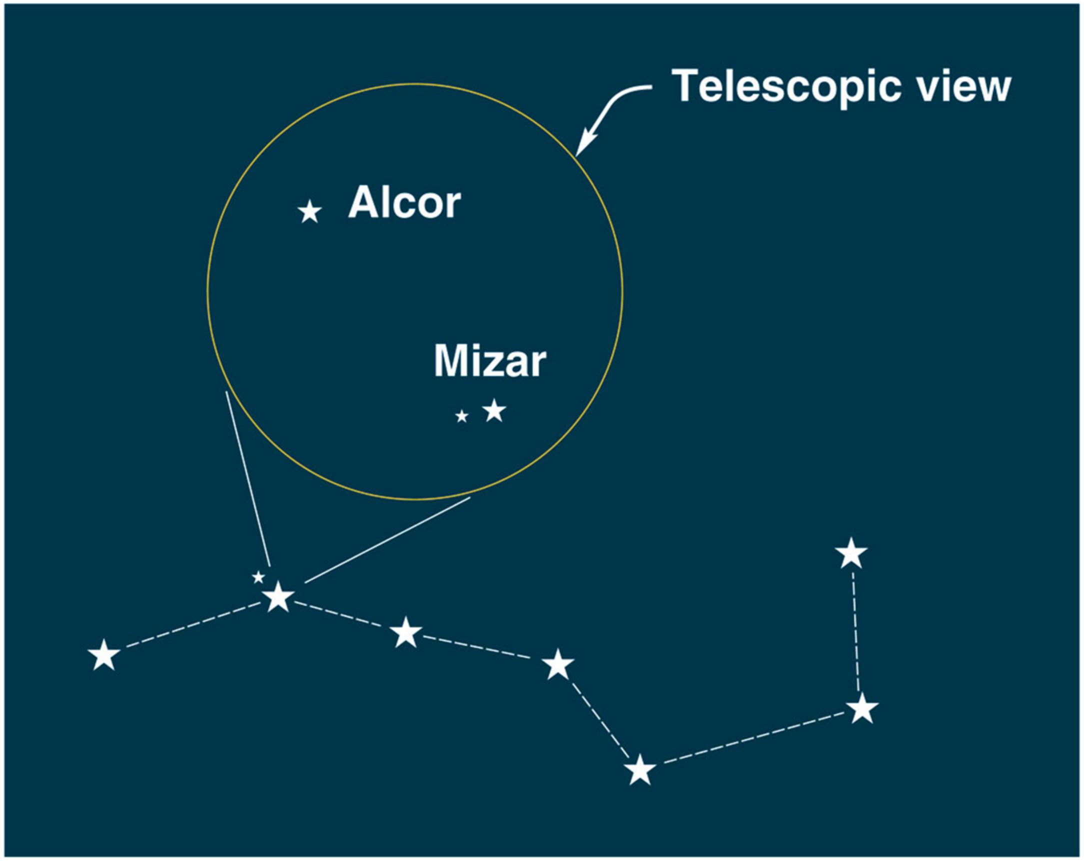
- As the stars orbit, they are moving
- Movement towards or away from us Doppler shifts the spectroscopic lines
- Split lines can mean a binary star





Animation from
Unione Astrofili Italiani.

ALCOR & MIZAR



- Big Dippler handle stars
- A visual binary to the naked eye
  - A traditional vision test
- Mizar is also a telescopic visual binary!

ALCOR & MIZAR

- Turns out that each “star” is actually a spectroscopic binary too!
- 3 binary stars orbiting each other, a six-star system