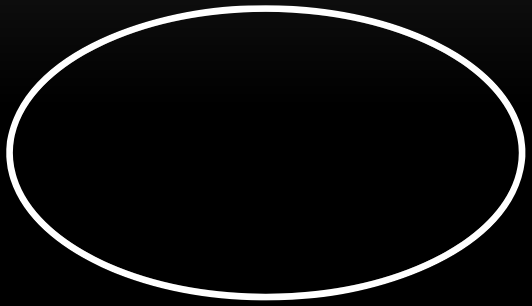
MULTIPLE SYSTEMS

- Actually, more stars than not are part of a multiple-star system
  - Binary (just two) stars the most common
- Single stars like our Sun are less common
- Tells us about star/solar system formation:
  - What if Jupiter had been a little bigger eddy during formation? It could have become large enough to form a second star?
- Another nice feature of our solar system – a binary system would have made it hard to keep the Earth a nice, even temperature for life

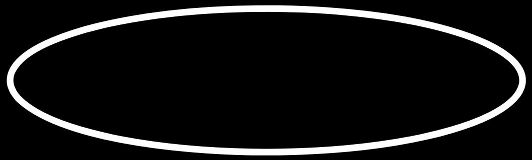
CALCULATE THE ORBITS

- To find the masses, we need to time the orbits, and either:
  - Measure separation or measure velocity
- This gives us the total mass
  - How close the star stays to the center of mass tells us how much of that total mass belongs to it
- For a visual binary we can figure many things out and crosscheck
- Can’t get separation for a spectroscopic binary, but can get the velocity

VIEWING ANGLE



From above
(face-on)



In-between

From the side
(edge-on)

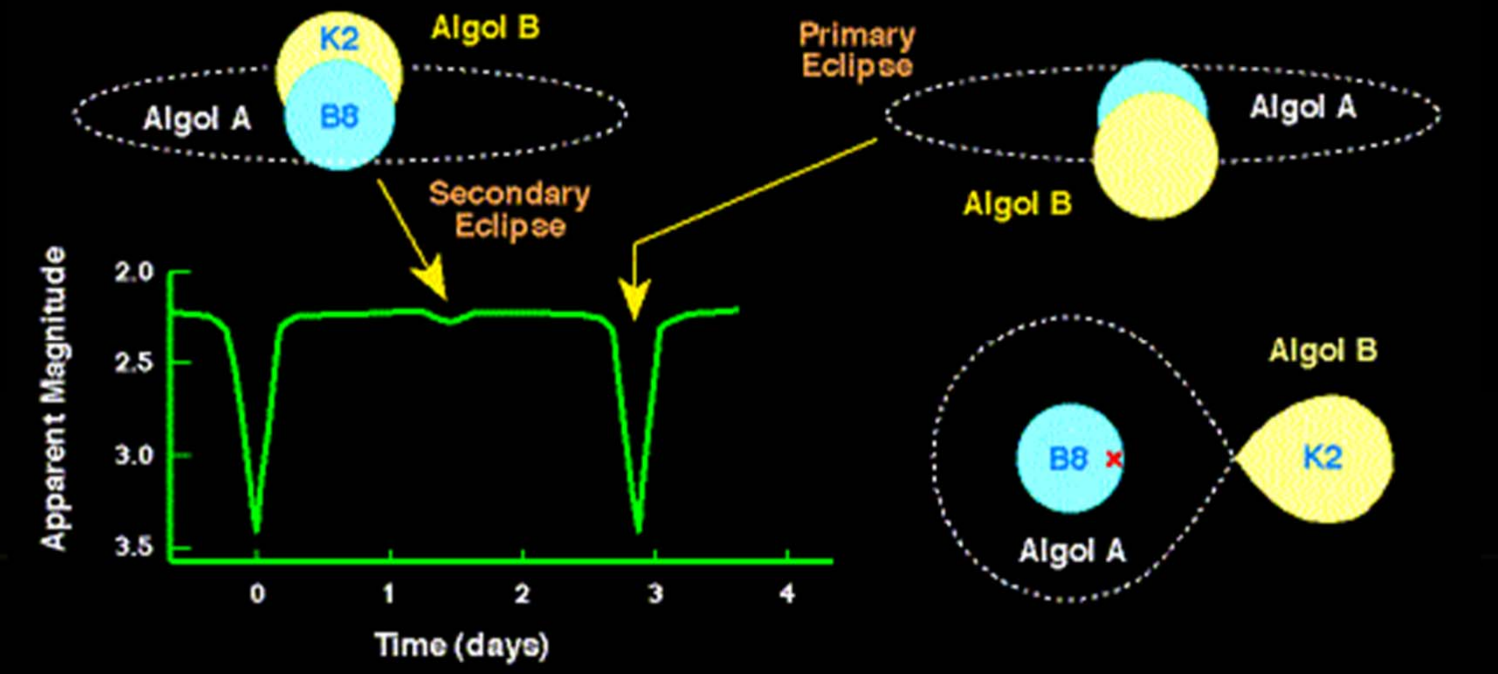
- Problem – at what angle are we looking at things?
- From above, we would see no Doppler shift
- From the side, we'd see all the motion there is
- In between – our velocity measurement is guaranteed to be low, and we don't know how low
- …makes measurements on individual systems uncertain

ECLIPSING BINARIES

- If we see one of the two stars passing in front of the other, we can figure out a lot:
  - We know that this is an edge-on system, so can calculate masses well
  - By comparing brightness's vs. time, we can learn which star is brighter
  - Timing the eclipse tells us the stellar diameters
  - Careful study can tell us about the stellar surfaces

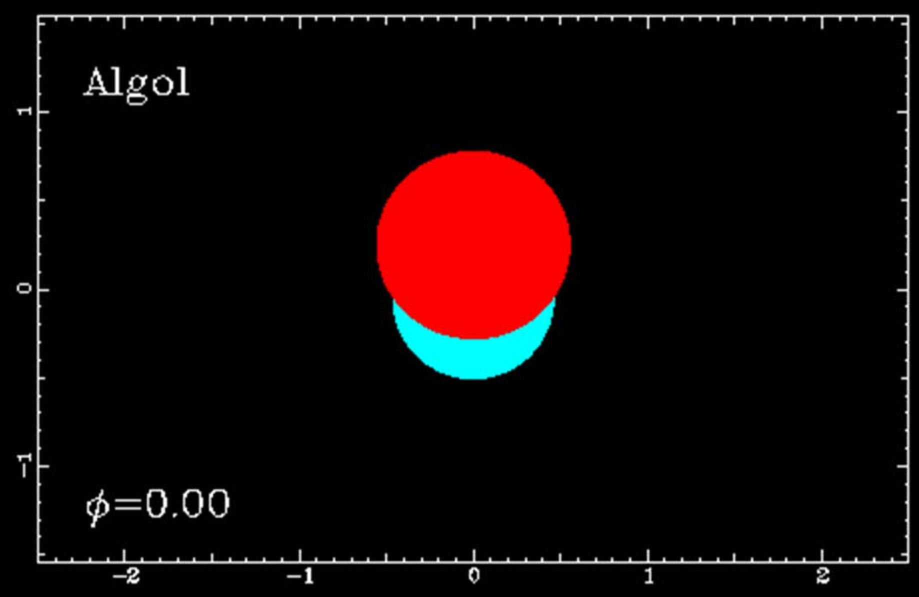
ALGOL

- Algol is such a star
- Eye of the Gorgon in Perseus
  - Name means “demon”



PLAY

ALGOL



- The stars are a 3.5 $R_\odot$ K2 star and a 3$R_\odot$ B8 star
  - Primary eclipse is when you can't see much of the hot B8
- Note tidal distortion of larger star: it's pulled into a teardrop shape

Animation by Larry Molnar

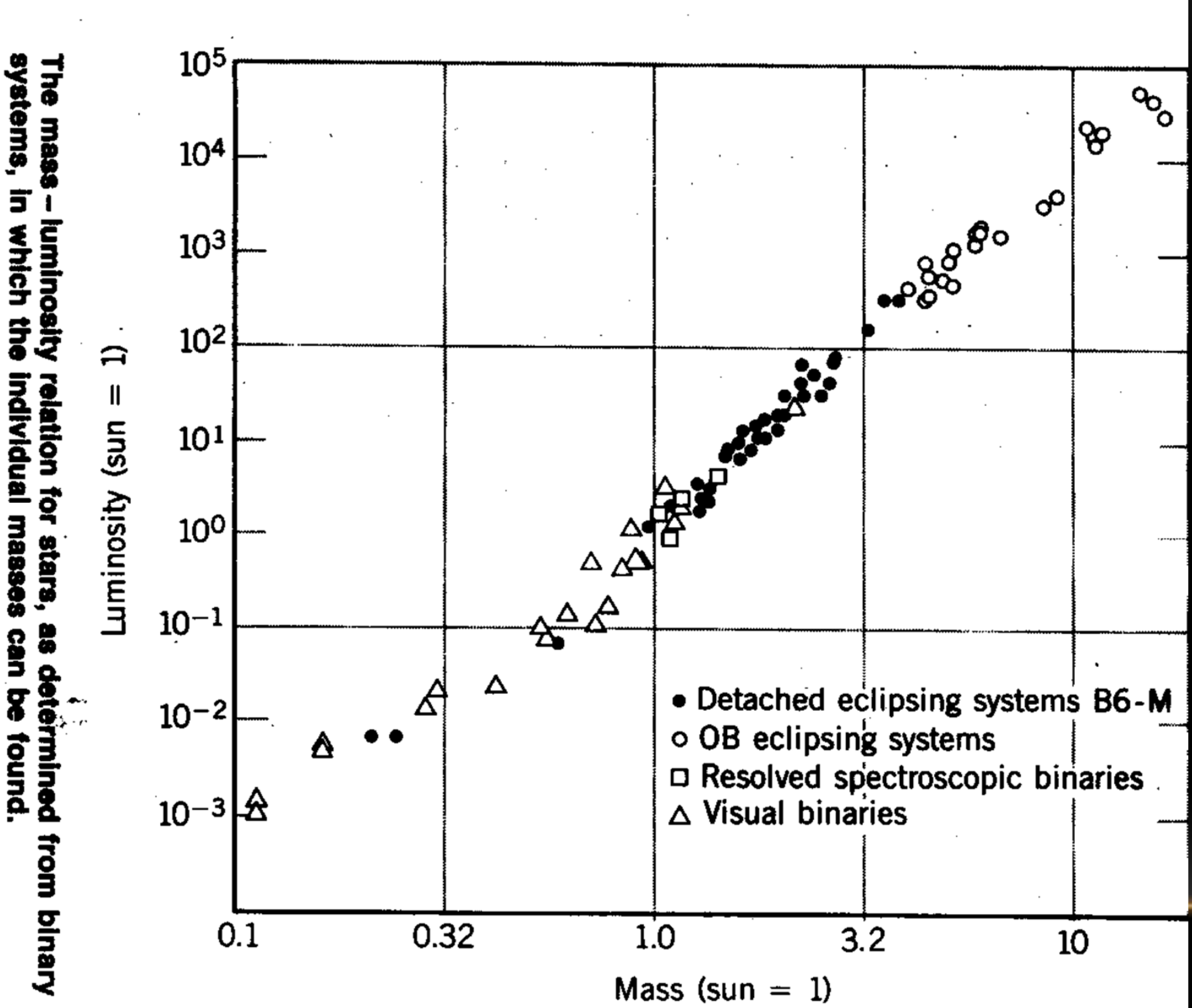
OTHER BINARIES

- Astrometric Binary
  - We see a star moving around about an unseen companion
- Composite Spectrum Binary
  - We see a star that has a spectrum which is two different spectral classes mixed together

MASSES

- We can calculate good masses for the following systems:
    - Visual binaries
    - Eclipsing binaries
    - Resolved spectroscopic binaries
- How does mass relate to other things we have measured?

MASS-LUMINOSITY RELATIONSHIP



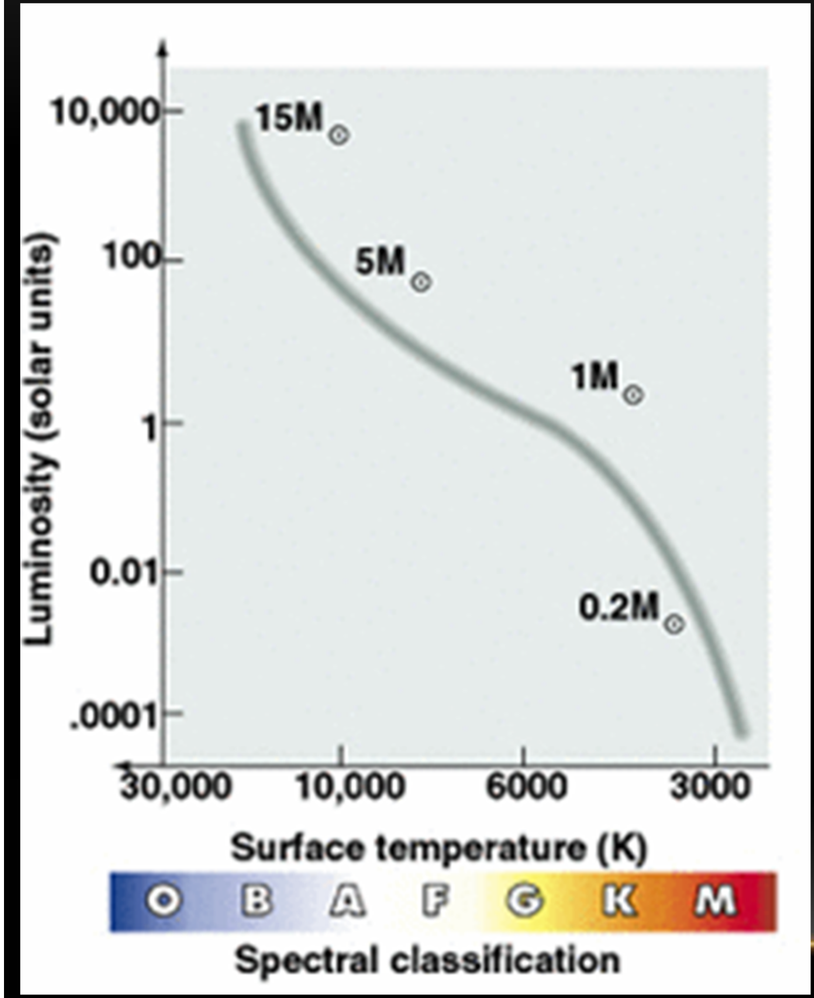
The mass – luminosity relation for stars, as determined from binary systems, in which the individual masses can be found.

- Plot Mass vs. Luminosity for stars where we know both well
- There seems to be a connection!
    - Massive stars are brighter

MASS-LUMINOSITY RELATIONSHIP

- The mathematical function which fits that plot:
  - $L = M^{3.5}$
  - … or L = M x M x M x square root(M)
- So, being a somewhat more massive star means you really burn much more brightly

MASS ON THE HR DIAGRAM



- Add this info to the HR diagram
- Work out the hydrostatic equilibrium of a star:
  - Massive star means more gravity, thus more pressure
  - More pressure means hotter core
  - Hotter core fuses Hydrogen faster
  - Faster fusion – more energy – more luminosity!
- How massive a star is the reason behind its temperature and Luminosity

PLAY

STELLAR LIFETIME

- Given the Luminosity (rate at which it puts out energy), how long before a star burns up all the fuel in its core?
- Massive stars burn very brightly
  - Live fast, die young

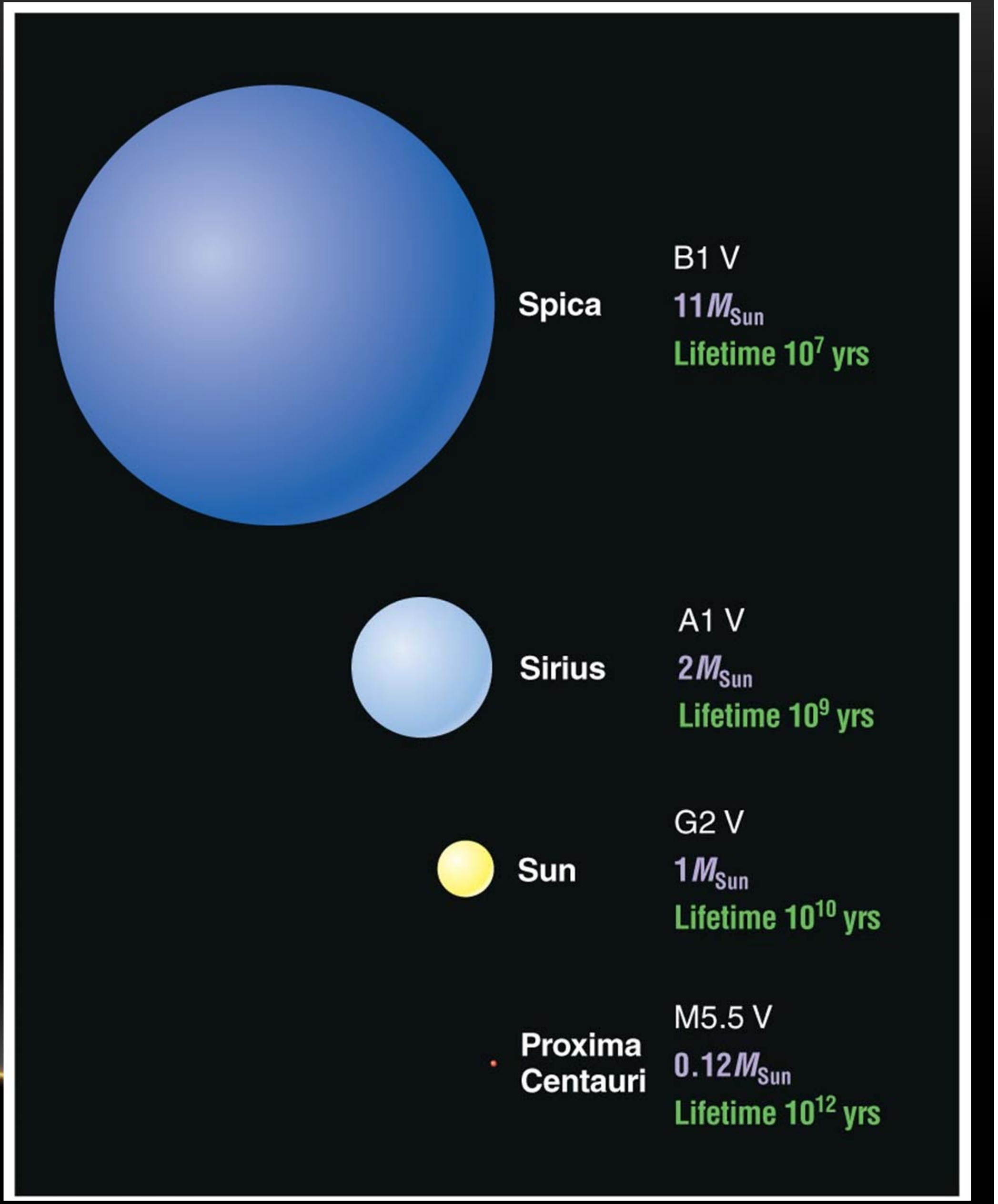


Fig.12.12

LIFETIME ON THE HR DIAGRAM

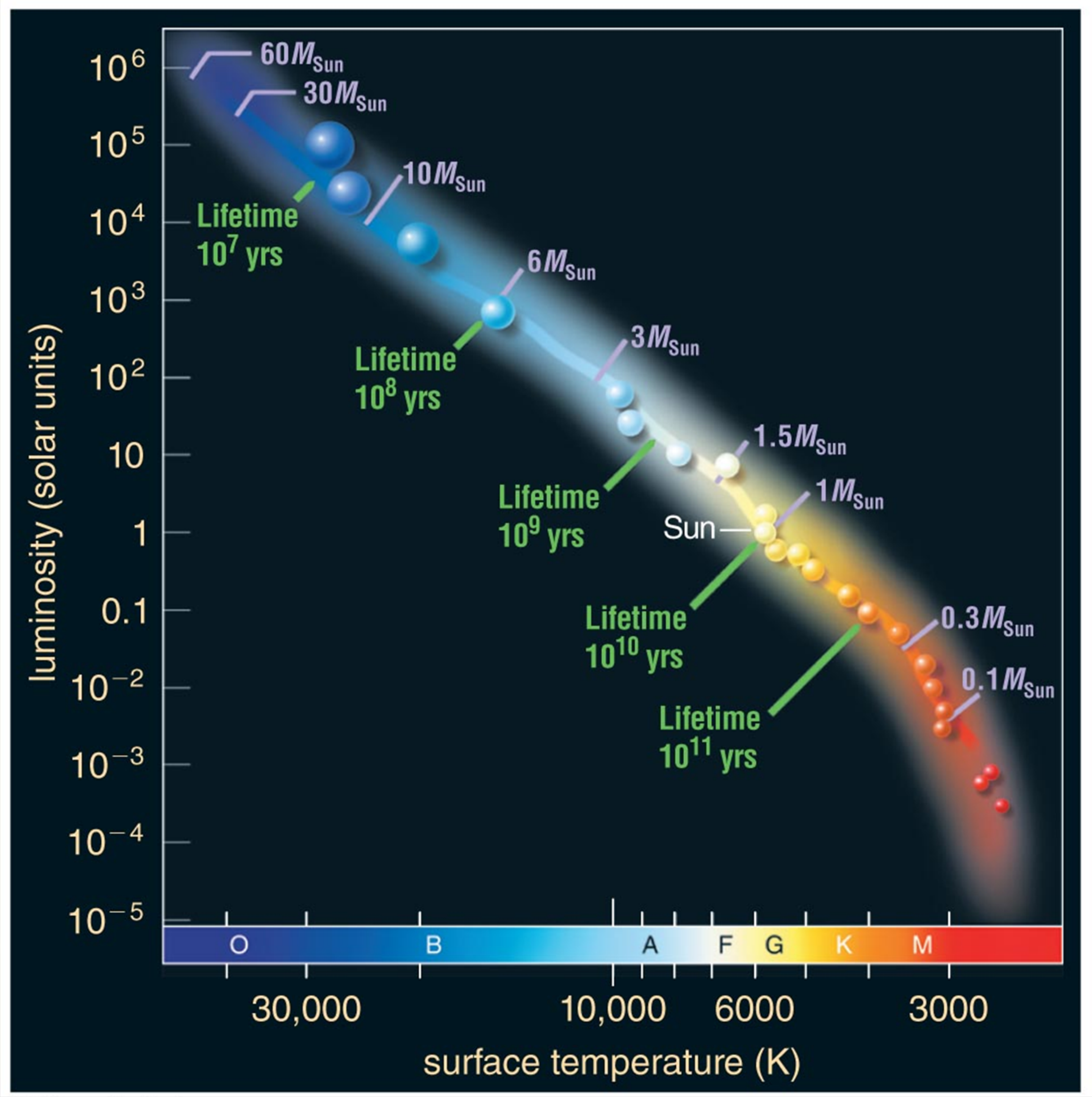


Fig.12.11

STAR CLUSTERS

- Stellar sisters
- Formed from fragments of same cloud

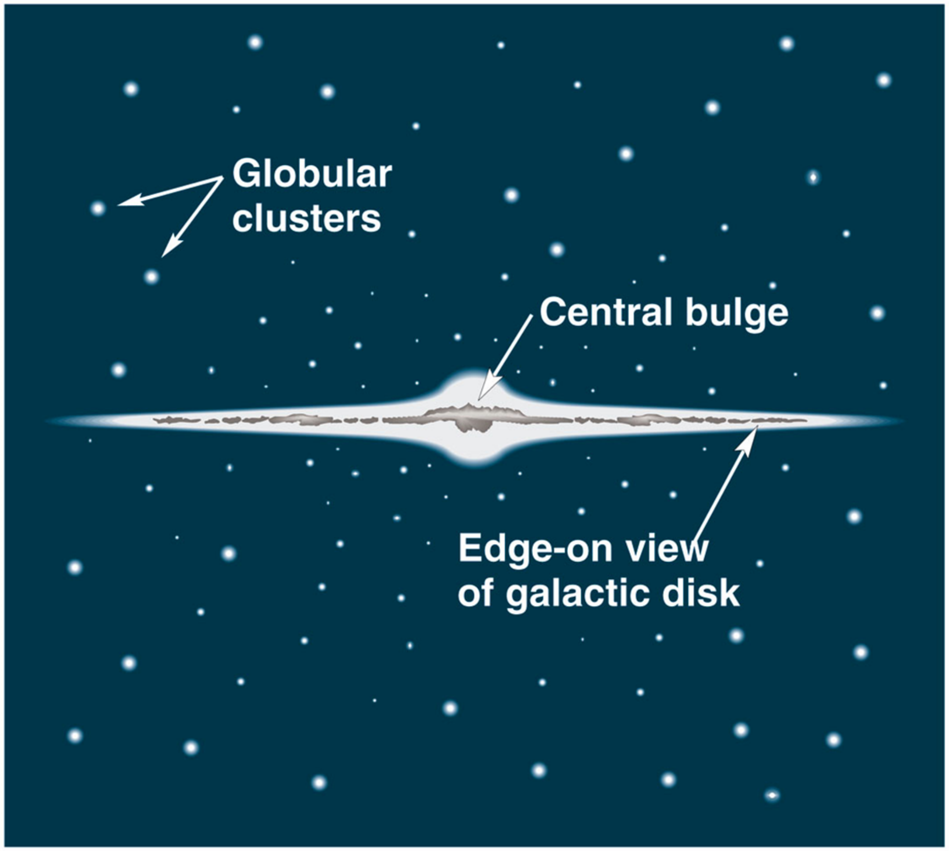
“Open Clusters” the Pleiades
And Hyades

OPEN CLUSTERS

- "Open" or "Galactic" clusters
  - Hundreds of stars
  - Drift apart eventually
- All formed from the same stuff at the same time
  - Handy for evolutionary studies!
- This one is young and compact, ~20ly across

Sharpless 212 photo by
Lise Deharveng *et al*

“GALACTIC” CLUSTERS



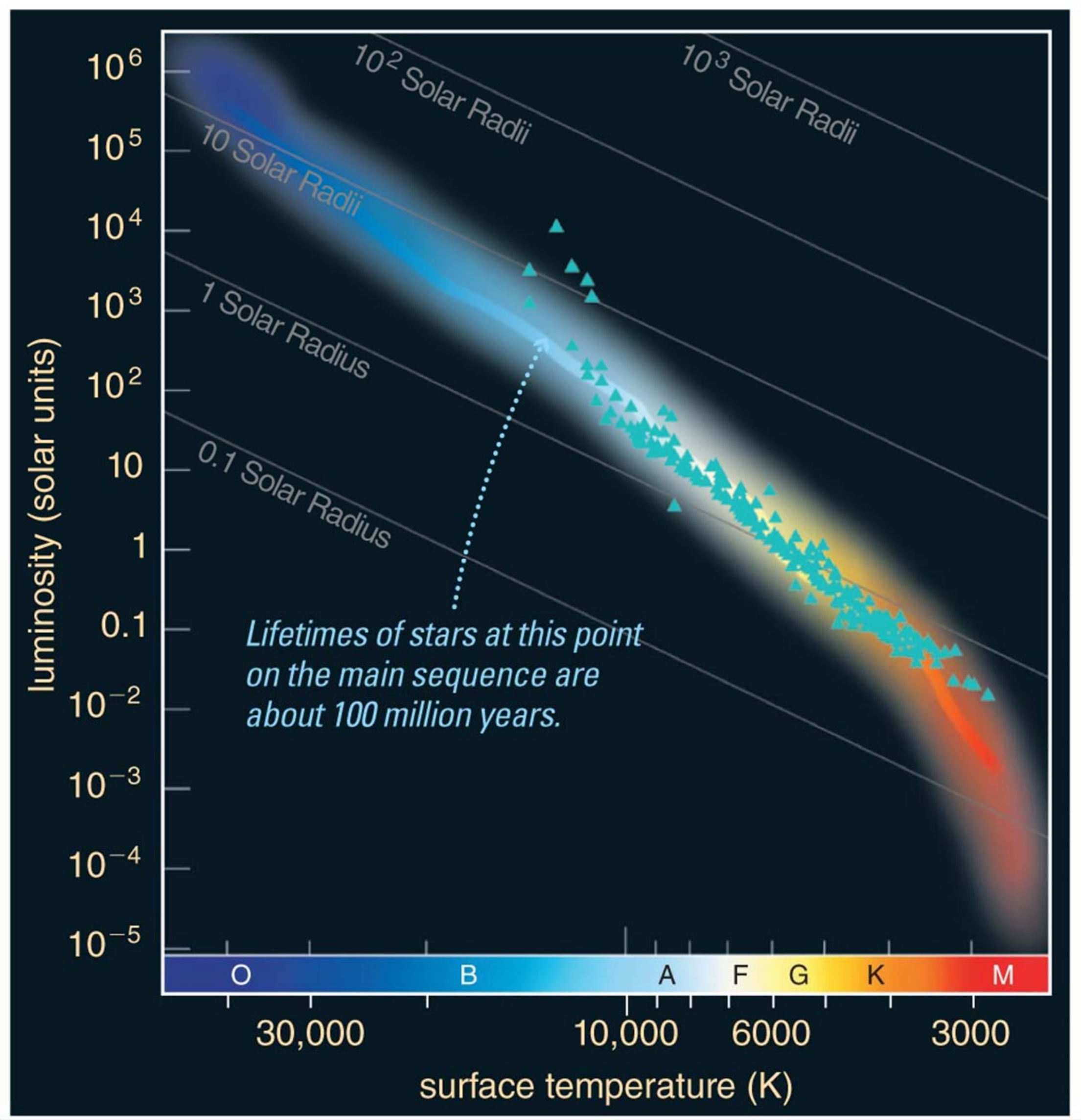
- Sometimes called “galactic” clusters because they are located in our galaxy
  - These are <u>not</u> clusters of galaxies!
- We see them in the plane of the galaxy

GLOBULAR CLUSTERS

M80, by F. R. Ferraro &
M. Shara with the HST

- Spherical groups of very many stars
  - They stick together
  - Many stars very close
- Formed a very long time ago
- Hundreds of thousands of stars
- Outside the plane of the galaxy – but part of our galaxy, they are not other galaxies

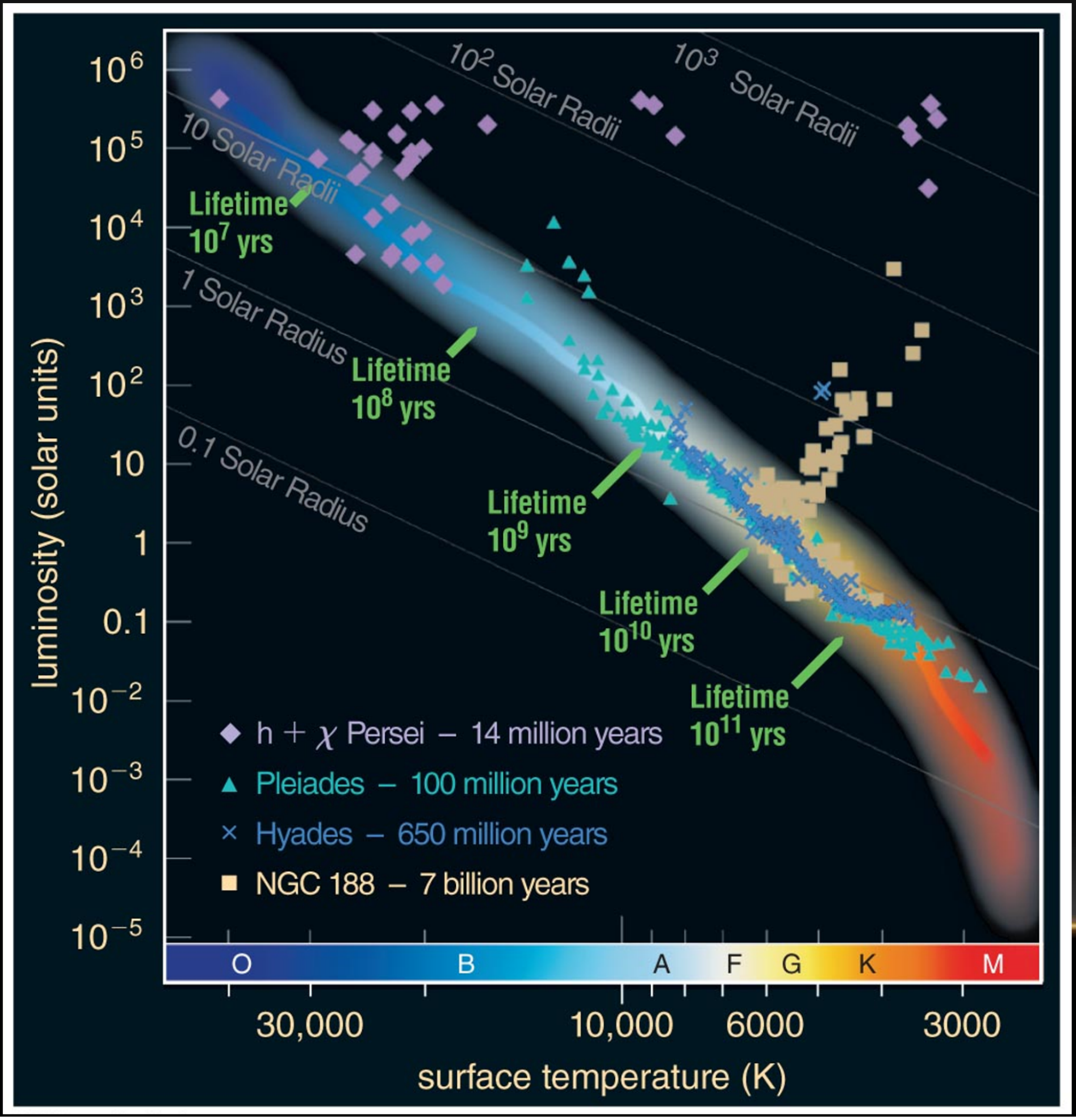
ALL BORN AT THE SAME TIME



- So look at HR diagram of just the stars in that cluster
- Make note of the "top" of the Main Sequence
    - Cluster can't be younger than that

Fig.12.16

CAN NOW DATE WHOLE CLUSTERS OF STARS



- Look for the “turn off” from the main sequence
- Hot blue stars die first, then yellow, then red
- Oldest Globular Clusters are 13by old

Fig.12.17

PLAY

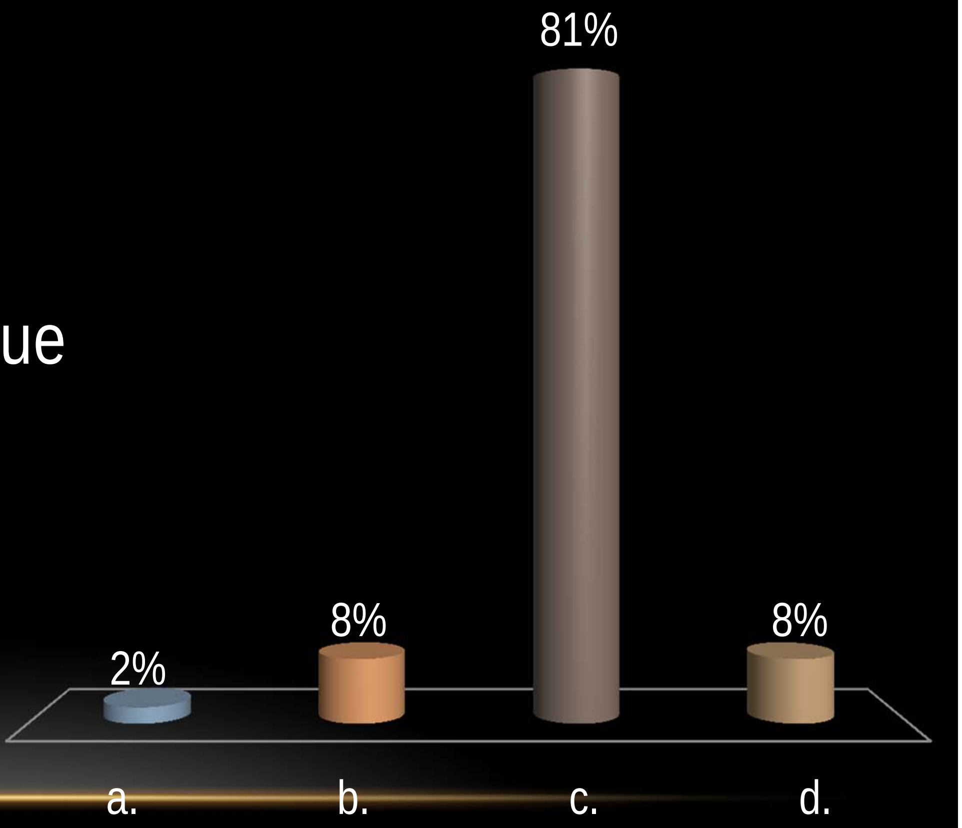
TWO STARS THAT LOOK VERY DIFFERENT MUST BE MADE OF DIFFERENT KINDS OF ELEMENTS.

a. Yes, stars have a wide range of compositions.

b. Yes, stars appear different because of their different composition.

✓ c. No, stars appear different due to their different ages and masses, not composition.

d. No, stars appear different because of their varying distances from us.



STELLAR PROPERTIES

- We can measure from the light:
  - Brightness (apparent magnitude)
  - Position in the sky
  - Color (spectra)
- We can watch for changes in all three of these things
  - Variable stars
  - Parallax, Proper motion, visual binary orbits
  - Spectroscopic binaries

PIECE TOGETHER THE PUZZLE

- Use apparent magnitude and distance to learn absolute magnitude and thus Luminosity
- Spectra tell us the temperature (and chemical composition)
- Together, these tell us the stellar radius

PIECE TOGETHER THE PUZZLE

- Plot T vs. L, make a Hertzsprung-Russell diagram
  - Find out which stars are like others
  - Use this new knowledge of L to find previously unknown distances
- Find masses from binary stars
  - Mass-Luminosity relationship tells us stellar lifetimes

A LOT FROM A LITTLE

- We now know:
  - How big (mass and radius) stars are
  - How far away they are
  - What temperature they are
  - What they’re made of
  - How they glow and how long they’ll live
- All from a little point of light!

STAR FORMATION

Ch.13

STUFF BETWEEN THE STARS

- So stars are out there
- What else? What's between the stars?
- We see nebulae, what are they?
- Where does this stuff come from and where does it go?

Orion Nebula photo
By Robert Gendler

CONTRADICTION

- Space is very very empty
  - Maybe one atom per cubic cm
  - Less there than the best vacuum you could make in a lab on Earth
- But we see all this stuff!
  - Space is also very very big
  - Over light years, a few atoms/cm^3 really adds up

INTERSTELLAR DUST

“Snake” Nebula
Jean-Charles Cuillandre, CFHT

- Stuff between the stars acts like clouds on Earth
- Gets in the way of the starlight
- We see dark areas
  - Holes or clouds?
- “Interstellar Cirrus”
  - After the earthly wispy clouds

DUST, NOT JUST TUNNELS?

- The “Horsehead” nebula certainly <u>looks</u> dusty with a good picture
- Getting tunnels of nothing lined up just right for us to see past is very unlikely

Photo by
Nigel Sharp, NOAO

SEE THE DUST!

- Dust is cold but still warm enough to radiate infra-red
  - So an IR picture picks up dust
- This is the “Horsehead” again in the IR
  - Bright spot is a lot of hot dust where a star is forming

IR picture by
L. Nordh *et al*, ISOCAM

THE INTERSTELLAR MEDIUM

“Omega” Nebula by
K.M. Merrill, SQIID

- An IR view of dust clouds
- In particular, light from polycyclic aromatic hydrocarbons (PAH’s)
  - Little bit of carbon out there, forms hydrocarbons like car exhaust
  - Associated with dust
  - Easy to see

WHAT ARE DUST CLOUDS?

- Mostly hydrogen, helium (*of course!*)
- Tiny amount of carbon, nitrogen, oxygen etc.
  - Bonds with hydrogen
  - Forms molecules
  - Can accumulate into “dust”
- Cold – few tens of K!
- Big – few parsecs to tens of parsecs across
- Comparatively dense – maybe a million molecules per cm^3