Astronomy 122

<u>This Class (Lecture 16):</u>

Stellar Evolution:
Post-Main Sequence

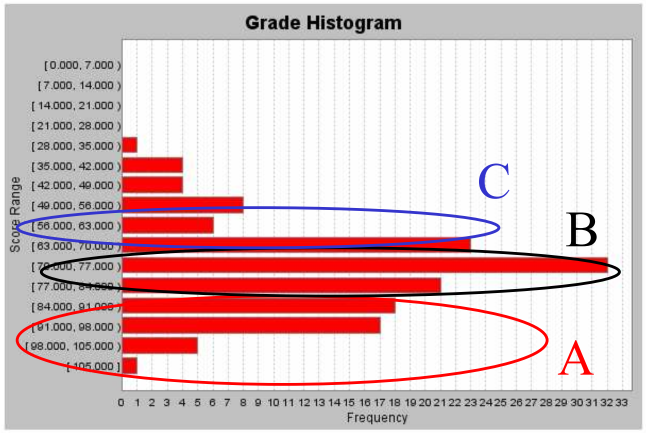
<u>Next Class:</u>

Stellar Evolution:
Post-Main Sequence

Music: *Supernova* – Liz Phair

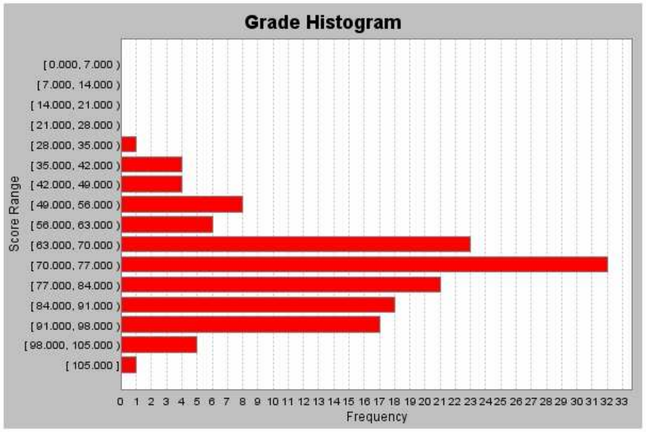
Midterm

- Pretty standard distribution.
- Average score of 75%
- Median score of 76%



Midterm

- If we assume scores of
  - 95% HW
  - 95% Class
  - 95% on Night obs
- Then
  - >71 is A-
  - >38 is B-
- If you don't have those grades on your other assignments, then…



Question

I have attended night observations:

a) Yes

b) No

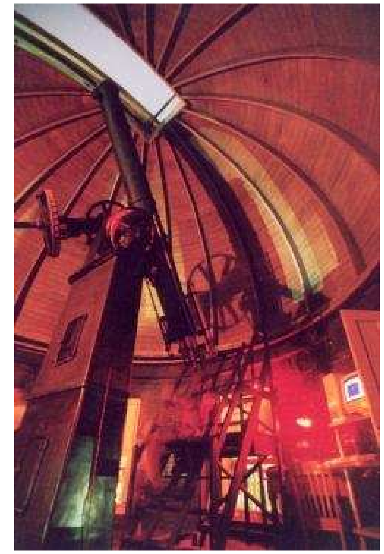
Question

Do you think it would be better if the night observing was extra credit (1%) instead of graded?

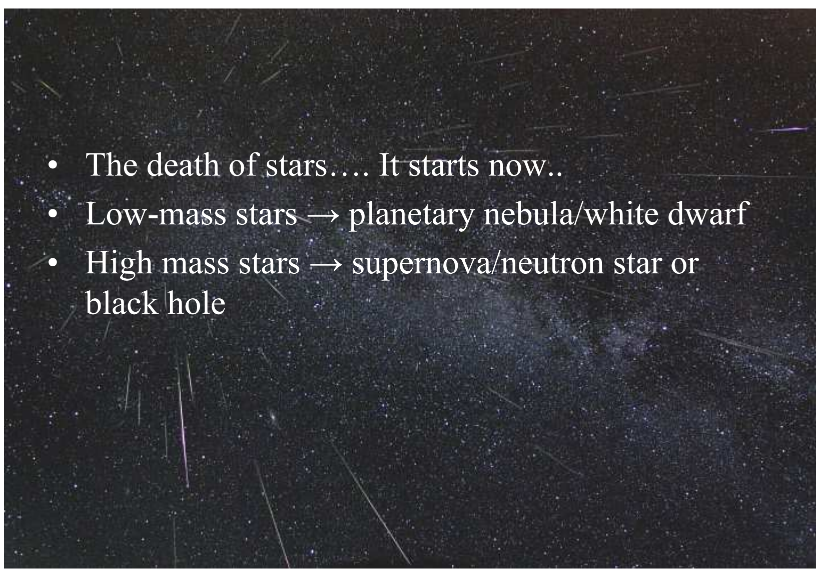
a) Yes
b) No
c) Don't know

Night Observing

- Nearly at the end!
  - .. so far we have had 4 nights.
  - Two LAST nights: tonight and Wednesday!
- Observing sessions are from 8:00pm-10:00pm (allow 45 mins to complete)



Outline



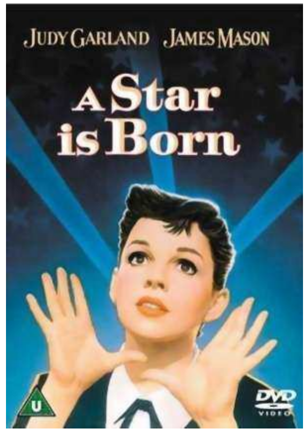
- The death of stars…. It starts now..
- Low-mass stars → planetary nebula/white dwarf
- High mass stars → supernova/neutron star or black hole

Star Formation?

- Our idea of how stars form seems reasonable, but there are many aspects that do not seem to work for the exoplanets
- Who's weird– us or them?

Stars: After Middle Age?

- A star is born, moves to the main sequence.
- Happily burns H into He…



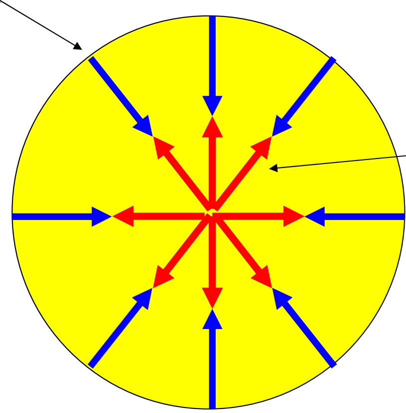
Important Questions

A star remains stable and on the main sequence as long as it has hydrogen to fuse in the core…

- **How long will the fuel last?**
- **What happens when the fuel runs out?**

The Battle between Gravity and Pressure

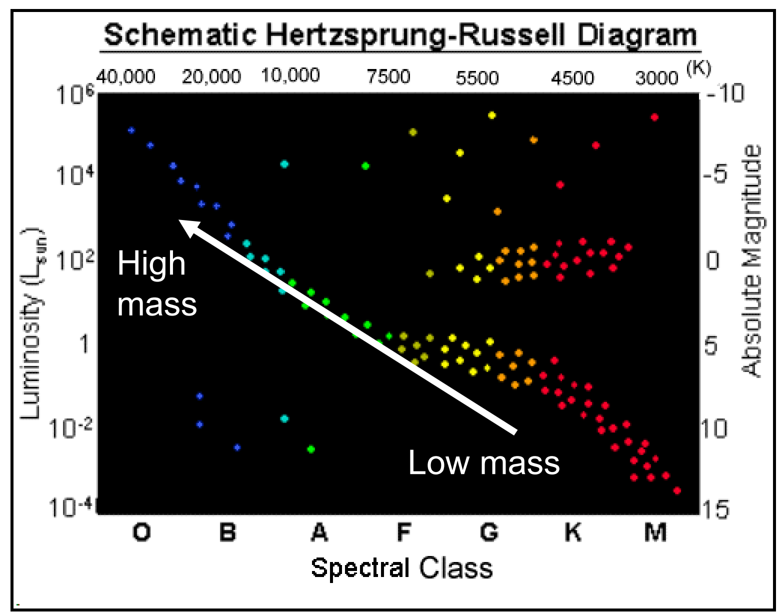
Gravity pushes in



Heat pressure from H→He fusion pushes out.

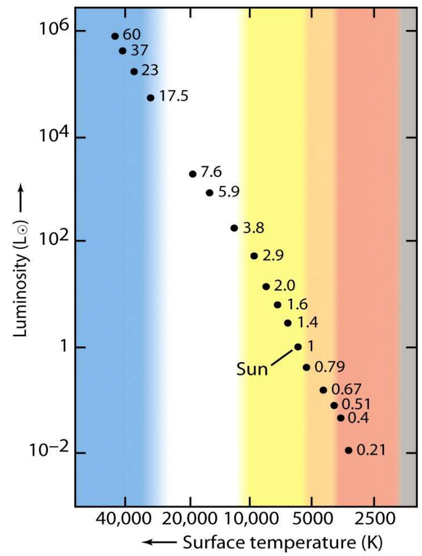
Hydrostatic equilibrium: Balanced forces

Main Sequence Mass Relation



Main Sequence Lifetimes

- The mass-luminosity relation has a big effect on the lifespan of stars.
- The problem is that even though a 60 solar mass star is has 60 times the mass of our Sun, it is a million times brighter!



Question

What I am saying is that the more massive the star, the much, much, much more brighter the star. How do you expect this to affect the life of a star?

a) No real difference.

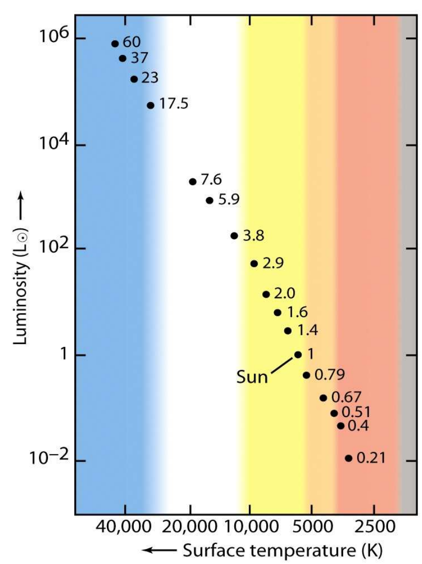
b) High mass stars will move off the HR diagram first.

c) Low mass stars will move off the HR diagram first.

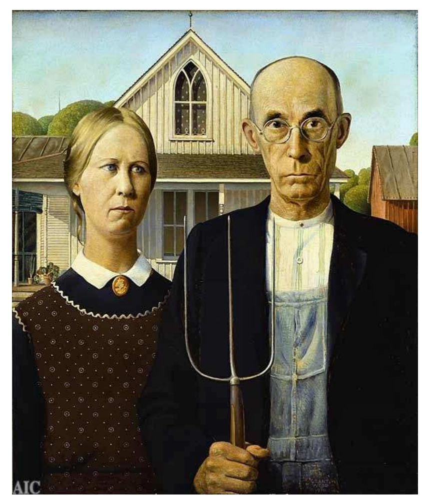
Why?

Main Sequence Lifetimes

- The mass-luminosity relation has a big effect on the lifespan of stars
  - Mass ⇒ amount of fuel available
  - Luminosity ⇒ rate at which fuel is being consumed
- Lifetime = $t \propto M/L$
  $\propto M/M^{3.5} = 1/M^{2.5}$
- **High-mass stars have dramatically *shorter* lifespans!**



Stellar Lifestyles



Low-mass stars

Massive stars

Life Fast, Die Young

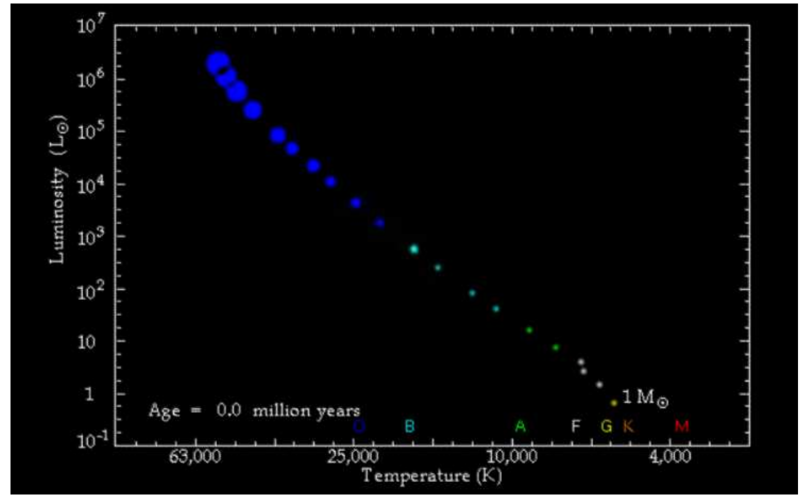
- High-mass stars: "gas guzzlers"
  - Very bright
  - Live short lives, millions of years
- Low-mass stars: "fuel efficient"
  - Dim
  - Long-lived, tens to hundreds of billions of years

table 21-1 Approximate Main-Sequence Lifetimes

Mass ($M_\odot$)	Surface temperature (K)	Spectral class	Luminosity ($L_\odot$)	Main-sequence lifetime (10^6 years)
25	35,000	O	80,000	4
15	30,000	B	10,000	15
3	11,000	A	60	800
1.5	7000	F	5	4500
1.0	6000	G	1	12,000
0.75	5000	K	0.5	25,000
0.50	4000	M	0.03	700,000

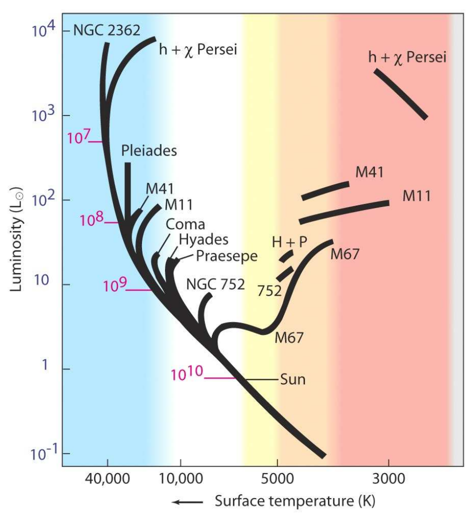
The main-sequence lifetimes were estimated using the relationship $t \propto 1/M^{2.5}$ (see Box 21-2).

Main Sequence Lifetimes

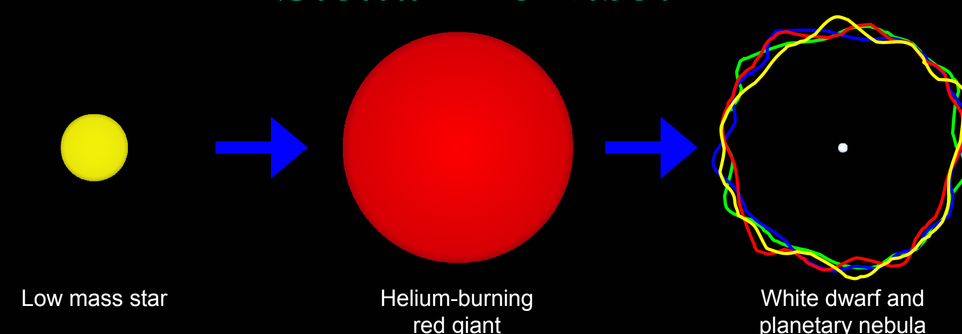


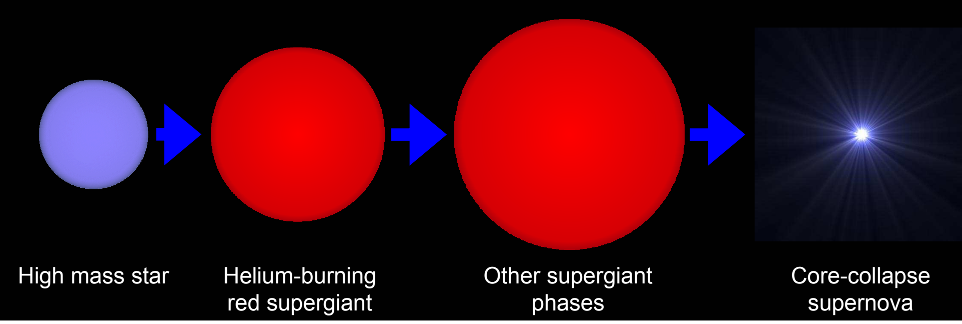
Guess The Cluster's Age!

- We can estimate the age of a cluster from its main sequence stars
  - Massive stars **age** faster than low mass stars
  - The cluster can't be any older than its most massive stars' main sequence lifetimes
  - We call the point where a cluster's main sequence ends the *main sequence turnoff*



Stellar Demise!





Question

You are observing a very large cluster of stars in the optical, you notice that there are no O or B stars, which means

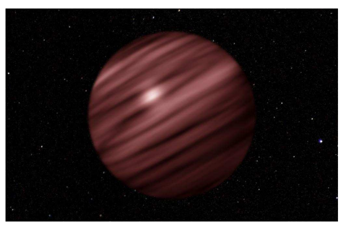
a) your telescope is too small to detect them.
b) they are so hot, you need to observe them with x-ray telescopes.
c) it is an old cluster because the most massive stars were scattered out.
d) as these are the most massive stars, they have not yet formed. The cluster is too young.
e) it is an evolved cluster becuase the most massive stars have already gone supernova.

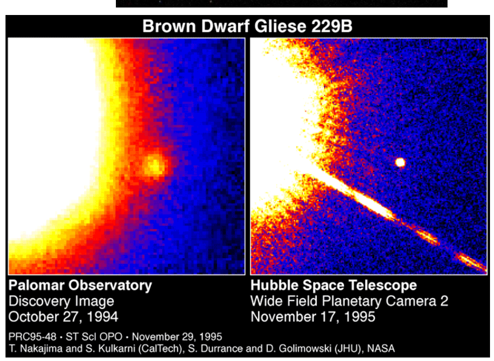
The Evolution of Stars

- A star's evolution depends on its mass
- We will look at the evolution of three general types of stars
  - Red dwarf stars (0.08 to 0.4 M_{Sun})
  - Low mass stars (0.4 to 8 M_{Sun})
  - High mass stars (more than 8 M_{Sun})
- We can track the evolution of a star on the H-R diagram
  - From main sequence to giant/supergiant and to its final demise

Brown Dwarfs are not Stars: $M < 0.08\ M_{sun}$

- These are objects that are below 80 Jupiter masses.
- The central density and temperature **do not** get large enough for nuclear fusion to occur.
- These failed stars, gradually cool down and contract.
- Recently, there have been a number of discovered brown dwarves.

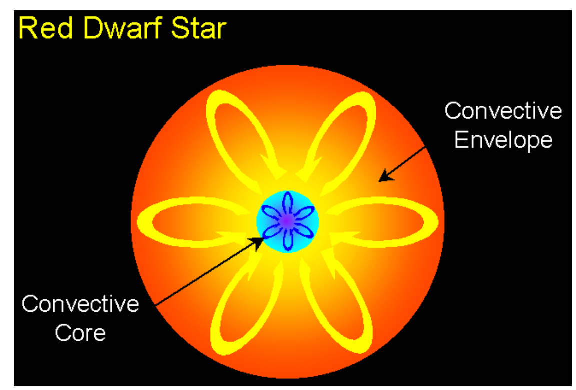




http://www.ast.cam.ac.uk/HST/press/gl229b.html

Red Dwarf Stars

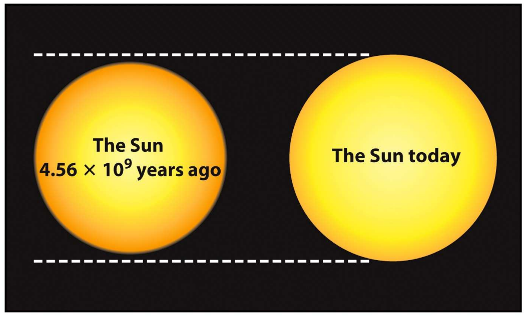
- $0.08\ M_{Sun} < \text{Mass} < 0.4\ M_{sun}$
- Fully convective interior
- The star turns **all** of its hydrogen to helium, then all fusion will stop
- Live hundreds of billions to trillions of years
- The Universe is only about 14 billion years old, so none of these stars have yet made it to the end of their life



http://www-astronomy.mps.ohio-state.edu/~pogge/Ast162/Unit2/RedDwarf.gif

Life of a Low Mass (Sun-like) Star

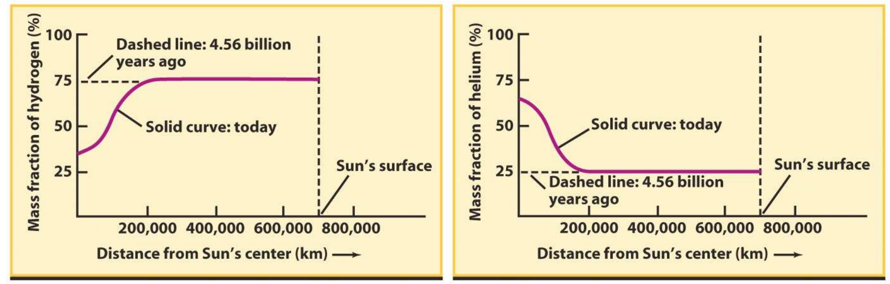
- Most of its life is spent in the happy pursuit of burning H ⇒ He
- With time, luminosity and temperature evolve gradually in response
- The Sun is now 40% brighter and 6% bigger than zero age MS.



http://wings.avkids.com/Book/Myth/Images/ocean_sun.gif

Low-Mass Stars (Sun-like)

- On the main sequence for ~10 billion years.
- The core is where fusion occurs- H ⇒ He
- Eventually, runs out of hydrogen in the core.



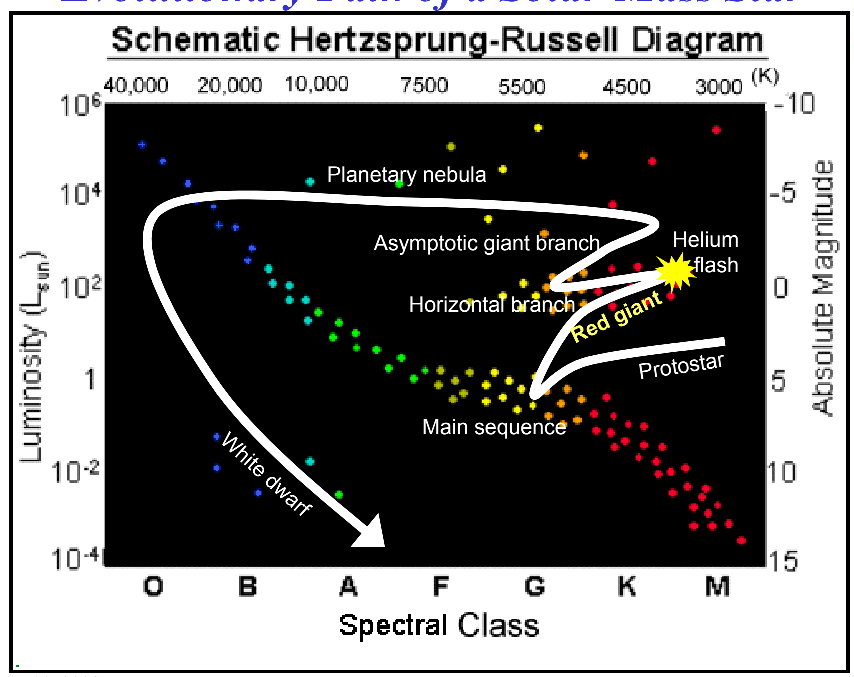
(a) Hydrogen in the Sun's interior (b) Helium in the Sun's interior

Life of Our Sun

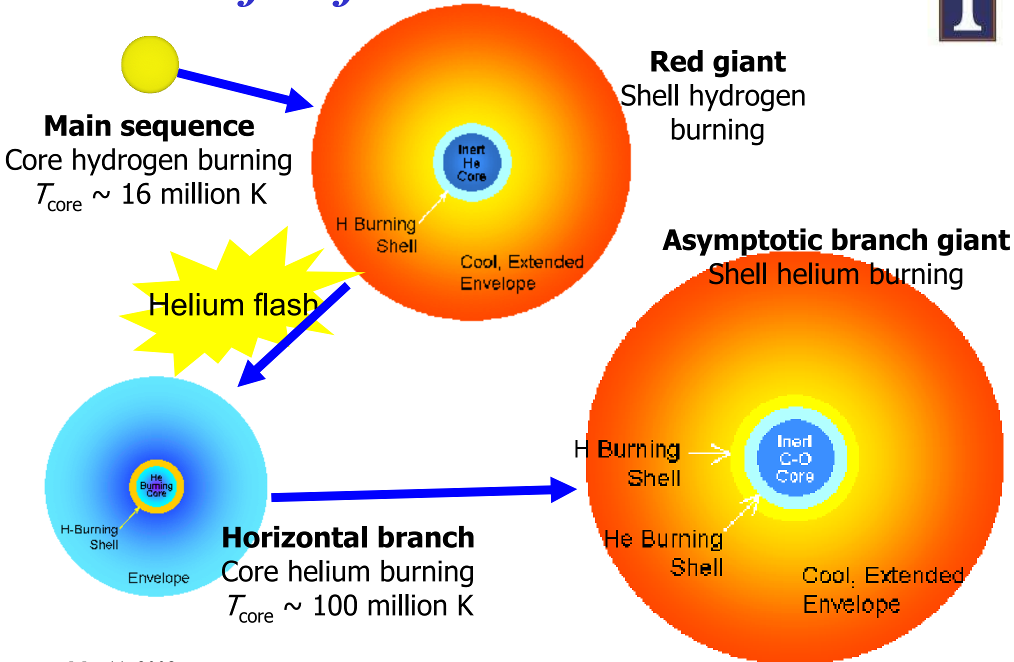
- At 10 Byr our Sun will be twice as bright as now
- This alone will cause a Greenhouse effect on earth!
- But in fact, oceans boil⇒ runaway greenhouse when $L = 1.1L_{\odot}$, which happens in about 1 Byr. So this is when things may hit the fan, not in 5 Byr.
- Model dependent, but still….

http://wings.avkids.com/Book/Myth/Images/ocean_sun.gif

Evolutionary Path of a Solar-Mass Star

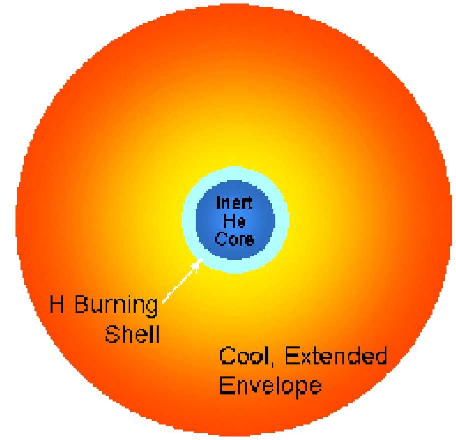


Life of a Low Mass Star

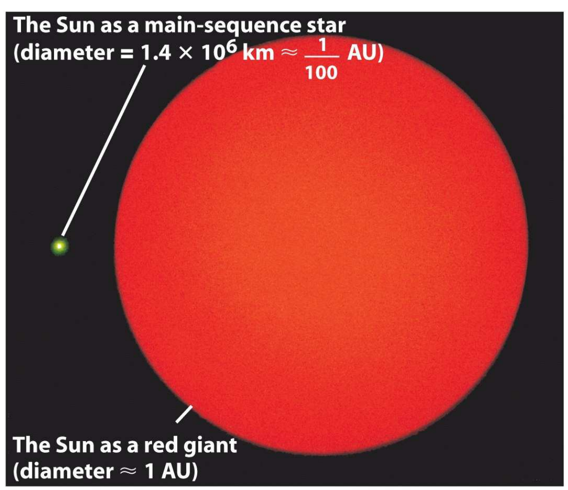


The Red Giant Phase

- When the hydrogen is gone in the core, fusion stops
- Core starts to contract under its own gravity
- This contracting heats the core, and hydrogen fusion starts in the shell around the core
- Energy is released, expands envelope ⇒ Lum increases!
- As the envelope expands, it cools – so it becomes a **red giant**



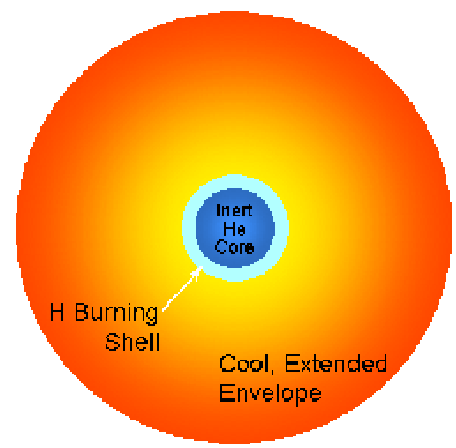
In 5-7 Billion years



The Sun today and as a red giant

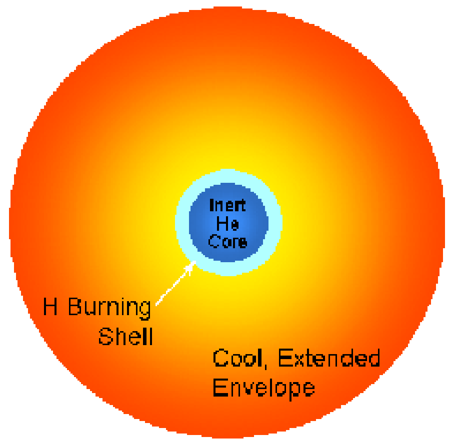
Contraction Junction

- In core, contraction increases density
- Contraction slowed by Pauli exclusion principle: can't put two electrons in same state
- Quantum "degeneracy" pressure.



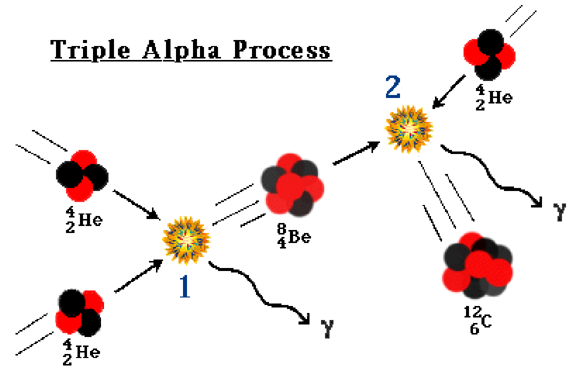
Contraction Junction

- In core, contraction increases density
- Degenerate core and H burning shell
- Core heats ⇒ He fusion ignites



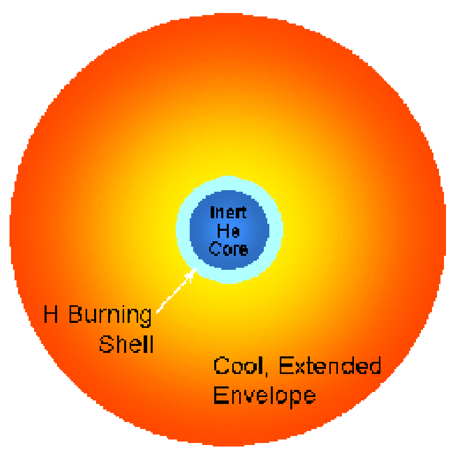
Helium Burning

- When the core of the star reaches 100 million degrees, it can start to fuse helium (the ash of hydrogen burning) into carbon
- Called the Triple-Alpha Process
  - Converts 3 heliums into one carbon + energy

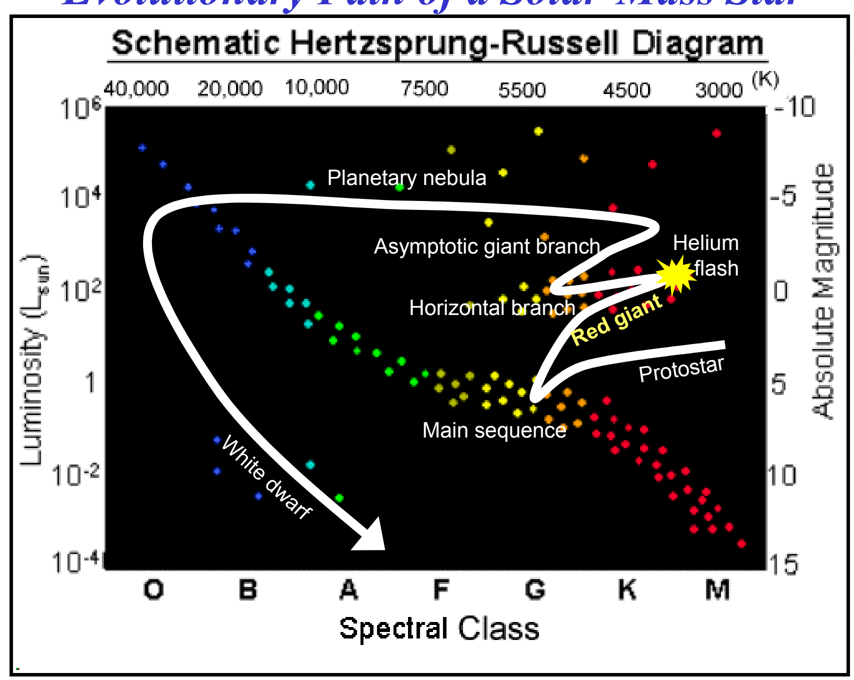


Helium Flash

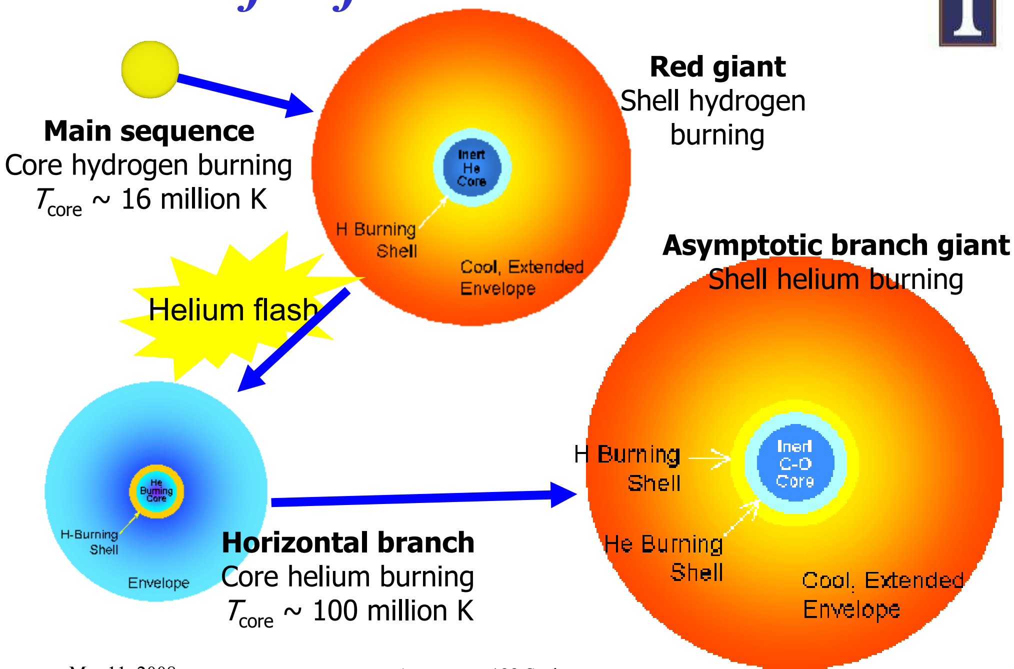
- Helium Flash (few min)
- Note: explosion energy trapped in outer layers so don't see anything special from the outside



Evolutionary Path of a Solar-Mass Star

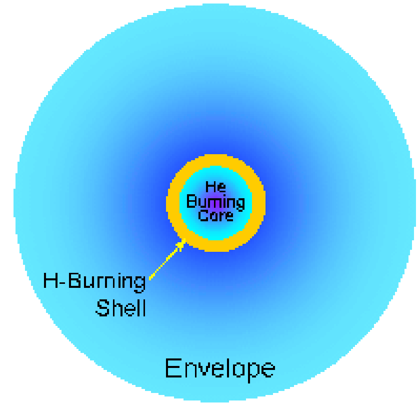


Life of a Low Mass Star



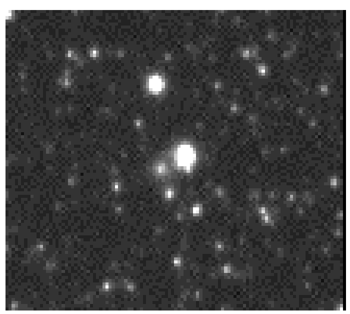
The Horizontal Branch

- Helium burning stabilizes the core
- The outer envelope shrinks, heats up, and dims slightly
- But helium doesn't last very long as a fuel
  - Horizontal branch lifetime is only about 10% that of a star's main sequence lifetime
  - Our Sun will burn helium for about a billion years
  - Also He burning is unstable



Cepheid Variables

- Giants with more than 5 M_{Sun} enter periods of variability as they evolve
  - Become unstable
  - Start to pulsate at a regular pace
  - Pulsation makes them vary in brightness



- The period of pulsation is related to the star's absolute magnitude
  - Excellent way to measure distance!