Astronomy 122

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

Stellar Evolution:
Post-Main Sequence

Make-up Nightlabs!

Nightlabs due in discussion class on March 29th.

<u>Next Class:</u>

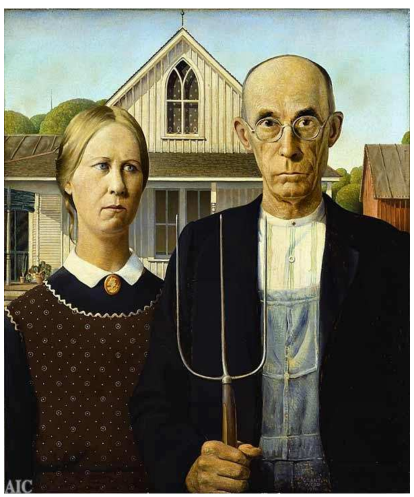
Stellar Evolution:
Post-Main Sequence

Music: *Supernova* – Liz Phair

Outline

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

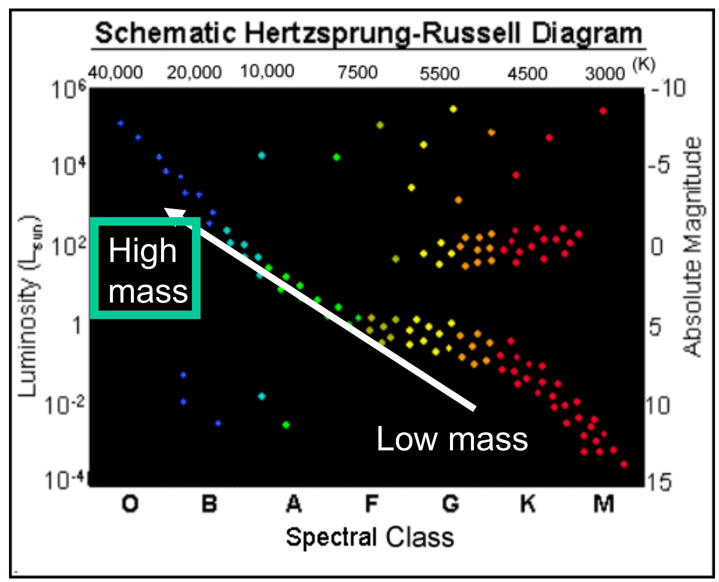
Stellar Lifestyles



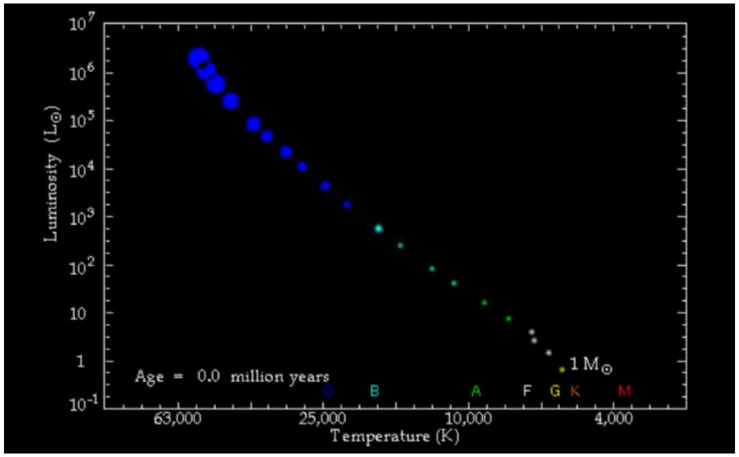
Low-mass stars

Massive stars

Main Sequence Mass Relation

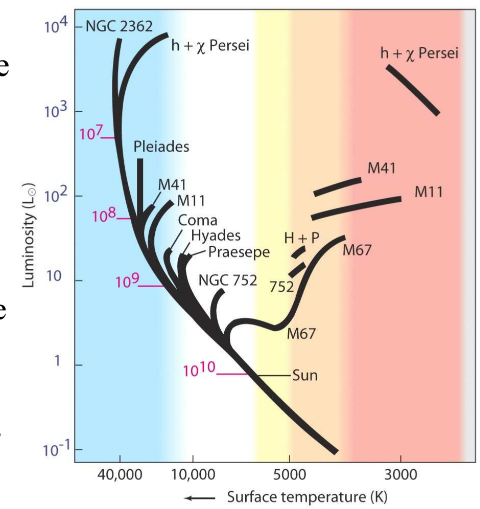


Main Sequence Lifetimes

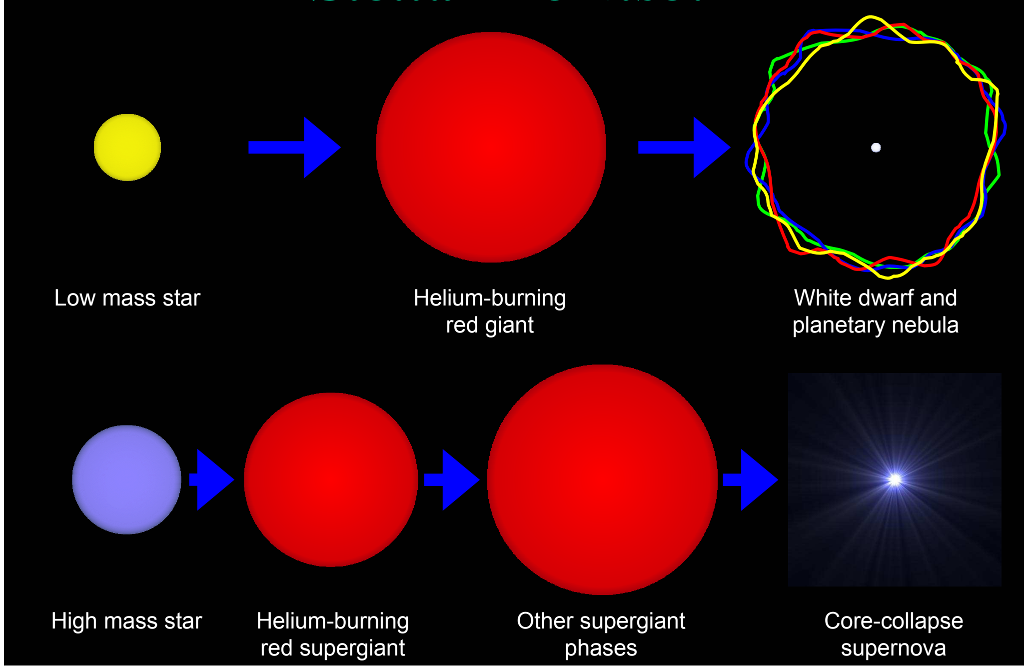


Guess The Cluster's Age!

- 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!

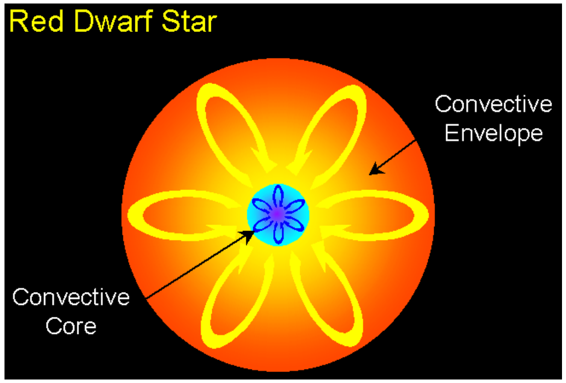


The Evolution of Stars

- A star's evolution depends on its mass
- We will look at the evolution of three general types of stars
  - Red dwarf stars (less than 0.4 M_{Sun})
  - Low mass stars (0.4-8 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

Red Dwarf Stars

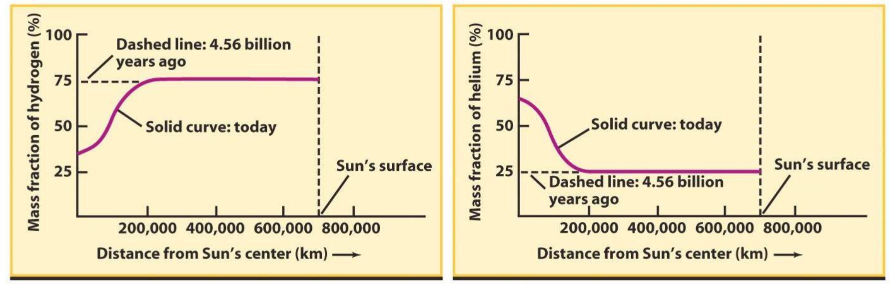
- 0.08 M_{Sun} < Mass < 0.4 M_{sun}
- Fully convective interior
- The star turns all of its hydrogen to helium, then all fusion will stop
- Live hundreds of billions to trillions of years
- The Universe is only about 14 billion years old, so none of these stars have yet made it to the end of their life



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

Low-Mass Stars (Sun-like)

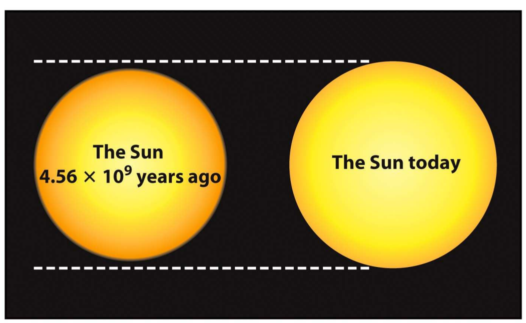
- On the main sequence for ~10 billion years.
- The core is where fusion occurs- H ⇒ He
- Eventually, runs out of hydrogen.



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

Life of a Low Mass (Sun-like) Star

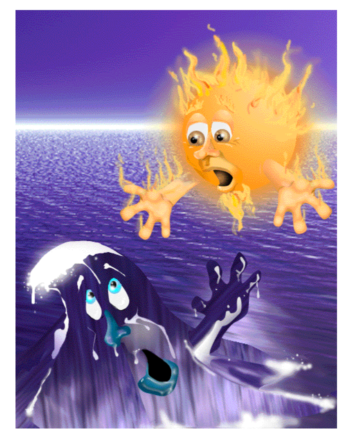
- Most of its life is spent in the happy pursuit of burning H ⇒ He
- With time, luminosity and temperature evolve gradually in response
- The Sun is now 40% brighter and 6% bigger than zero age MS.



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

Life of Our Sun

- At 10 Byr old will be 2x 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….



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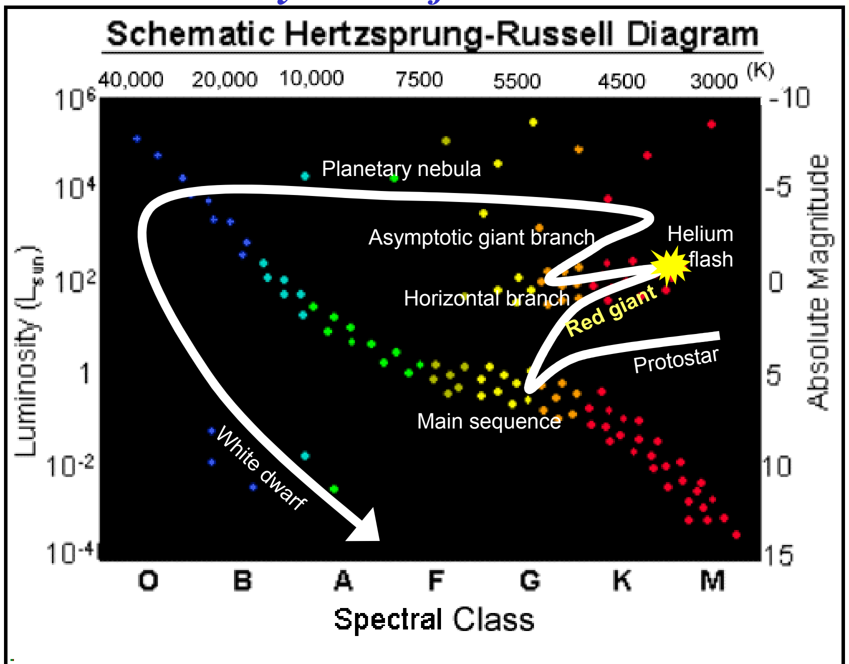
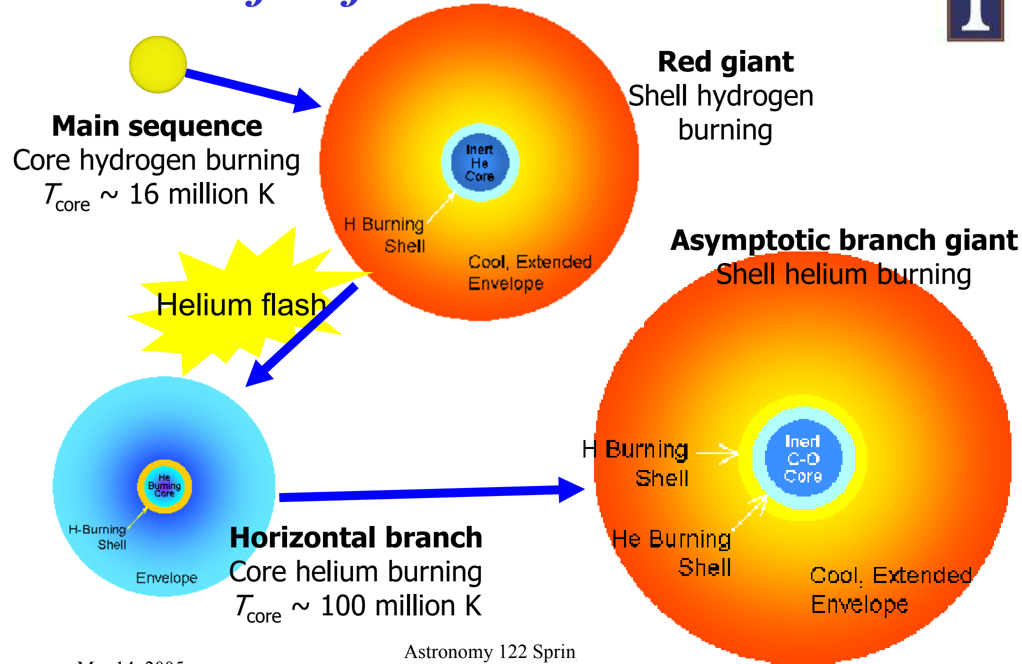
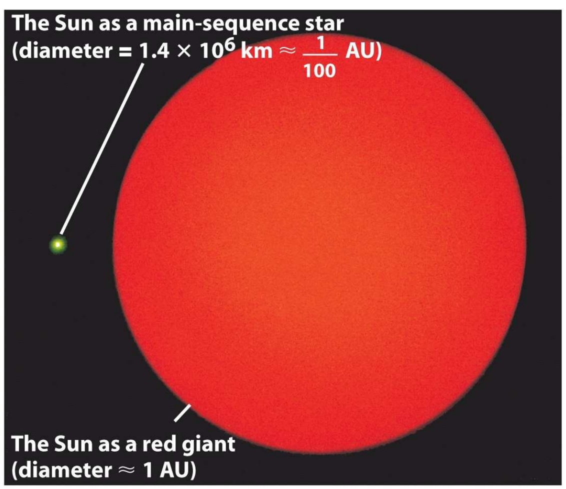
Evolutionary Path of a Solar-Mass Star



Life of a Low Mass Star



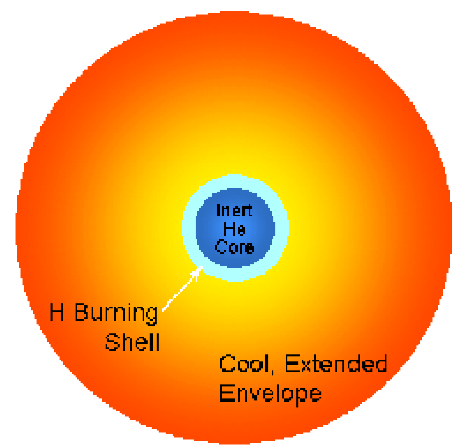
In 5-7 Billion years



The Sun today and as a red giant

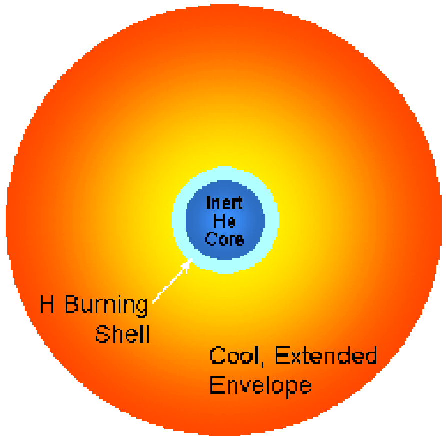
The Red Giant Phase

- 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



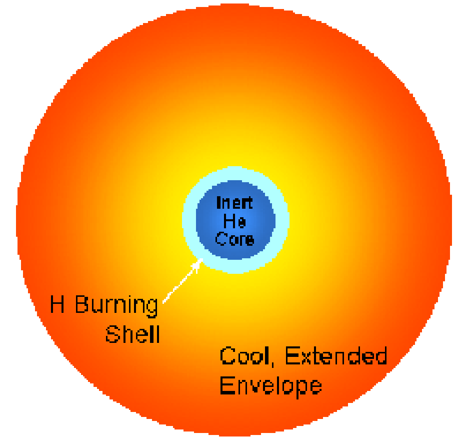
Contraction Junction

- In core, contraction increases density
- Core temp increases
  ⇒ He fusion ignites
- Two ways:
  - < 2-3 solar masses Helium Flash
  - > 2-3 solar masses gradual burn



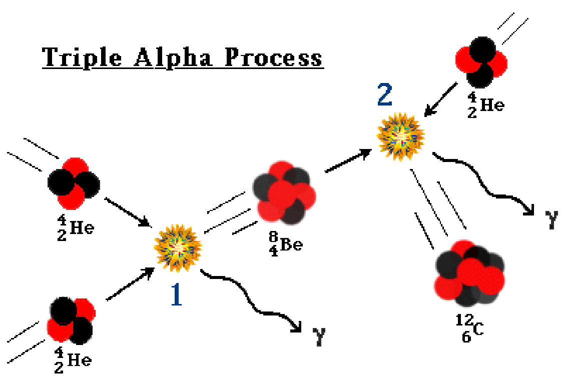
Helium Flash

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



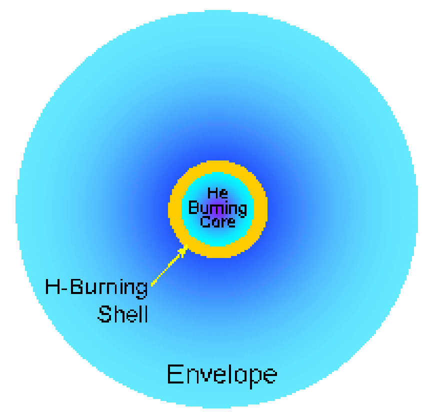
Helium Burning

- 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
  - As side effect, carbon & helium can fuse into oxygen



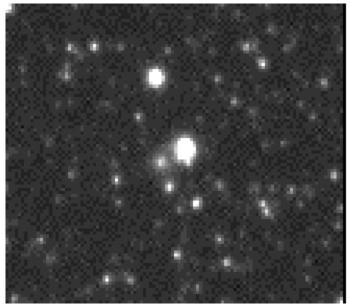
The Horizontal Branch

- 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



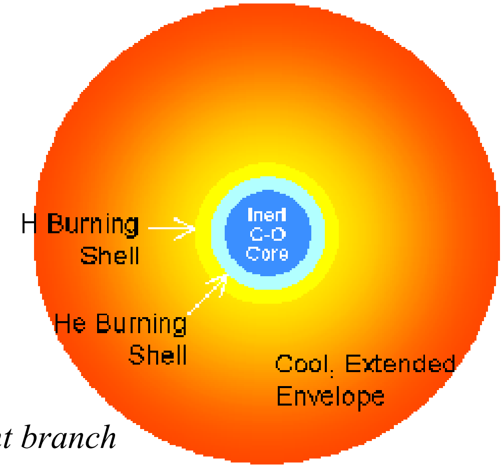
Cepheid Variables

- 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!



When Helium Runs Out…

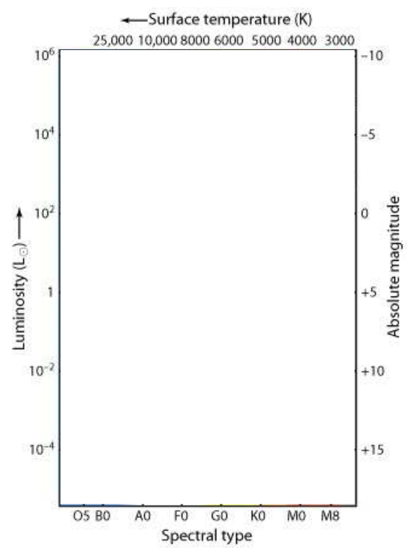
- Fusion in the core stops – the helium has been converted to carbon and oxygen
- Stellar core collapses under its own gravity
- Shell starts fusing helium
- Star starts to grow and cool again
- Called the *asymptotic giant branch*



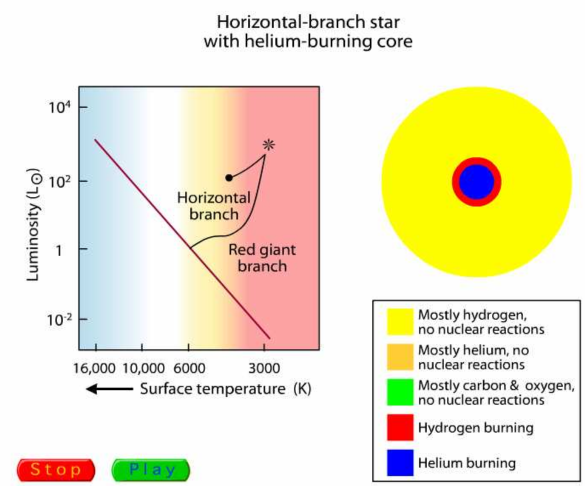
Think-Pair-Share

As a one solar mass star evolves into a red giant, its position on the H-R diagram will move…

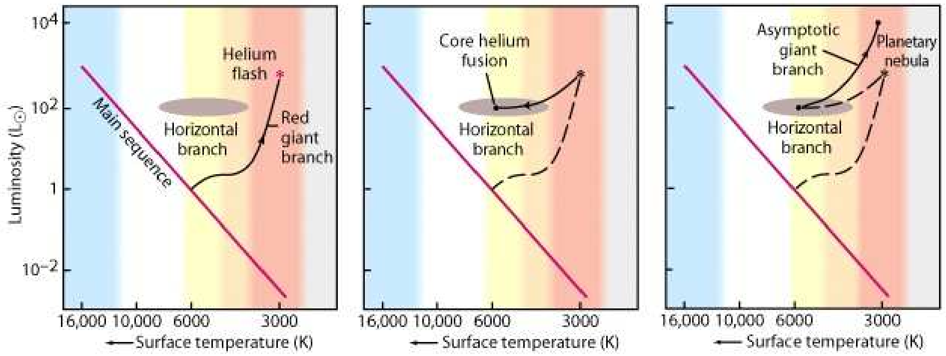
1. Up and to the left
2. Down and to the right
3. Down and to the left
4. Up and to the right



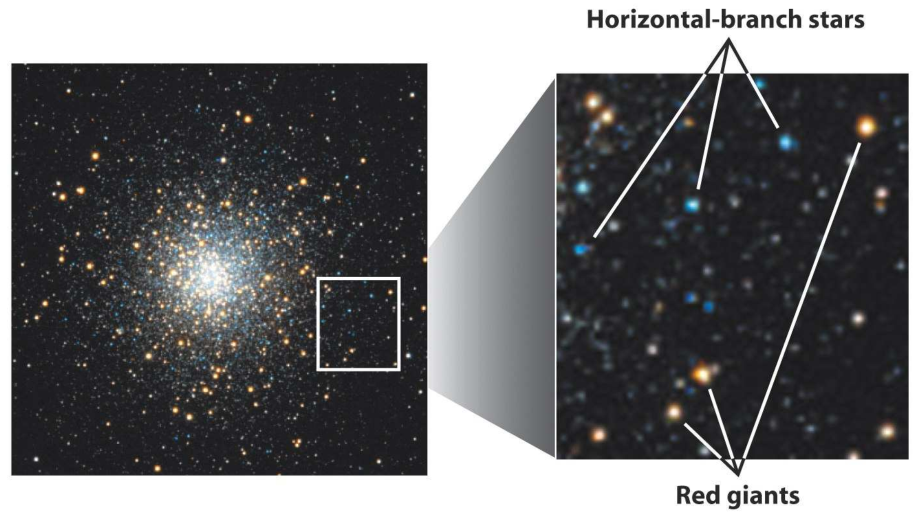
Evolutionary Path of a Solar-Mass Star



Evolutionary Path of a Solar-Mass Star

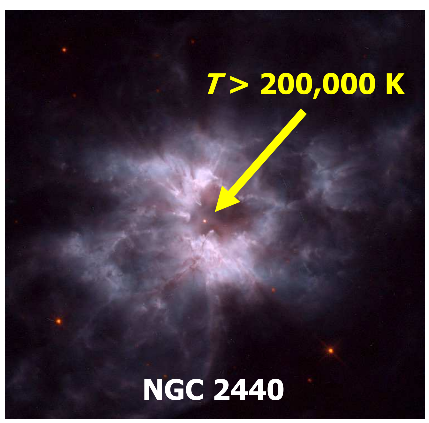


Aging Stars

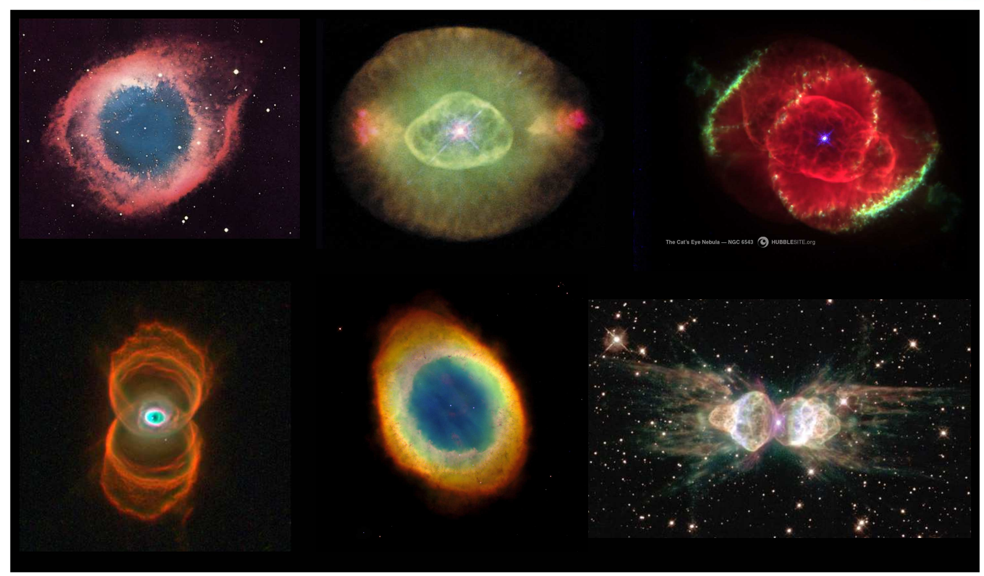


End Game

- “Superwind”
- Outer layers of the red giant star are cast off
  - Up to 40% of original mass
- The core remains, made of carbon/oxygen “ash” from helium fusion
  - The core is very hot, above 200,000 K
- Ultraviolet radiation from the core ionizes the cast off outer layers
  - Becomes a *planetary nebula*
  - *Unfortunate name, but some of the most beautiful objects in the sky.*



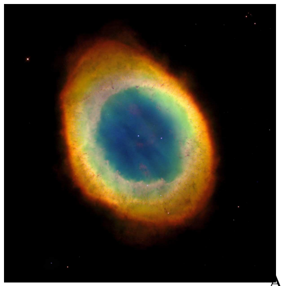
Planetary Nebulae



Planetary Nebulae

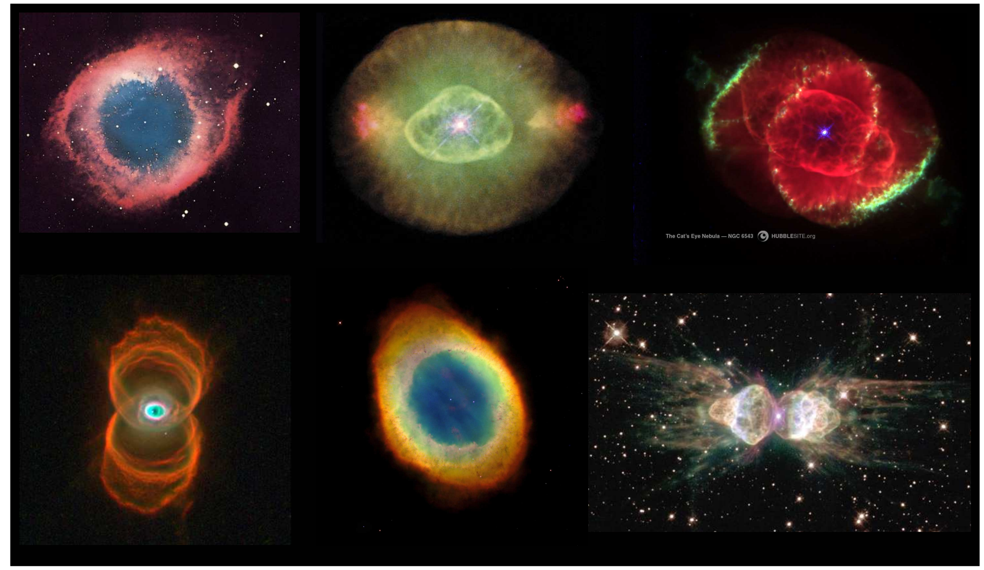
- Note the emission lines ⇒ vibrant colors (somewhat enhanced)
- Ring: approx true color, He=blue, O=green, N=red
- Cat's eye: H=red, O=blue, N=green
- Also note: rarely spherical: rotation, mag fields, ejected gas, and companion can all make axial

Ring Nebula



Cat's Eye Nebula

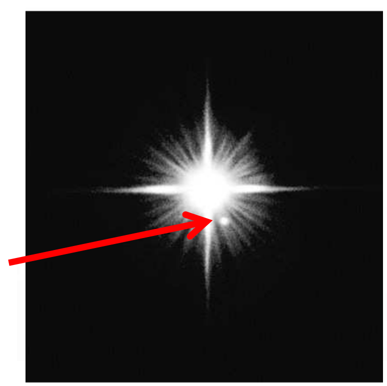
Planetary Nebulae



What About the Core?

- Nuclear fusion has stopped, and gravity begins to win the battle
- Core contracts to the size of the Earth
  - But its about 60% the Sun's mass!
  - Material in the core is compressed to a density of 1,000 kg/cm^3!
  - Very hot, surface temperature >100,000 K
- Final fate - **White dwarf**
  - Slowly cools off over billions of years

Sirius B



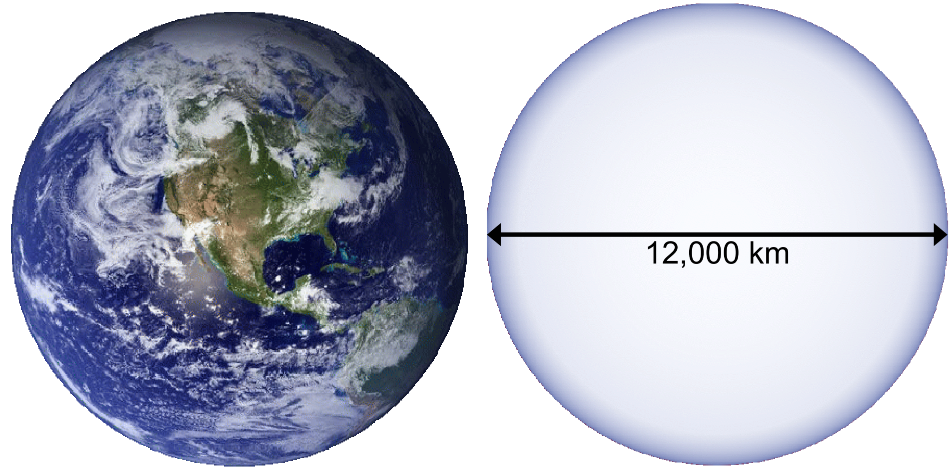
Electron Degeneracy

- The electrons get so squashed together that they get pushed into *degenerate states*
  - This creates pressure to counteract gravity (Pauli exclusion)
  - Stops contraction

Chandrasekhar limit

- Maximum mass of a white dwarf (M $\cong$1.4 solar masses).
- No white dwarf observed is over this.
- If mass is higher, the white dwarf can not support itself with electron degeneracy, and it collapses more! Gravity!

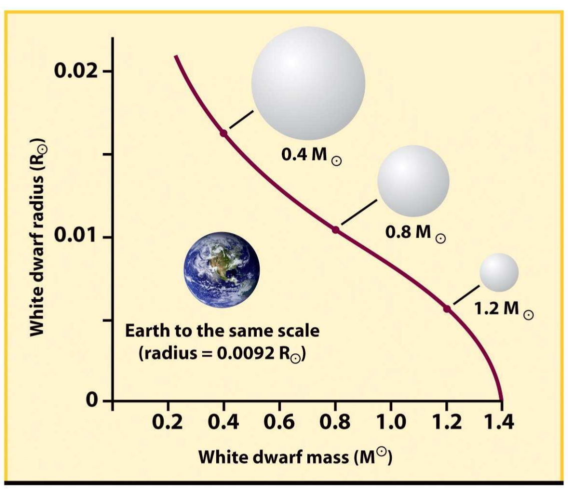
Relative Size of White Dwarf



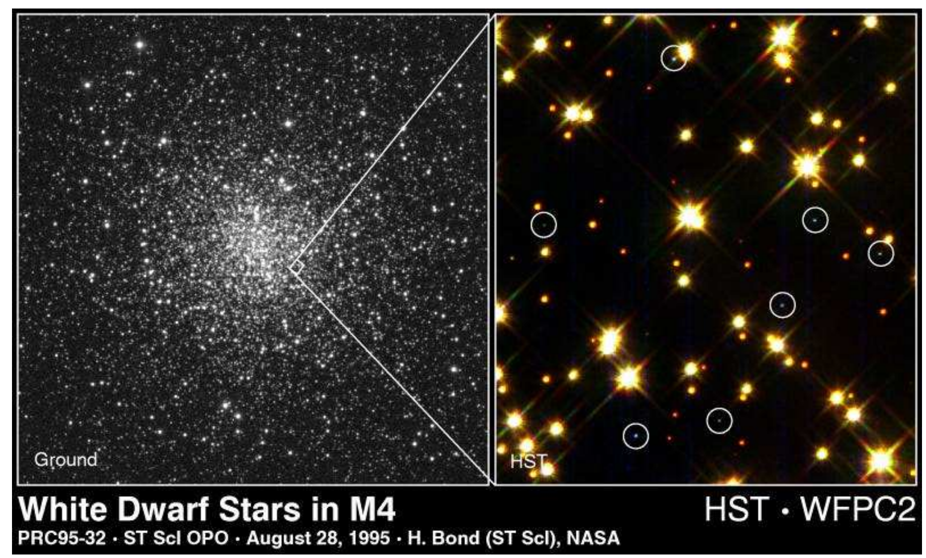
White dwarf– but will usually weigh about 0.6 Solar masses

White Dwarfs are Weird

Their radius *decreases* with mass!

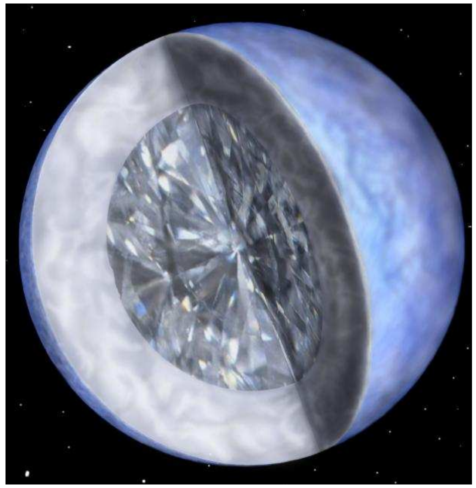


White Dwarves!

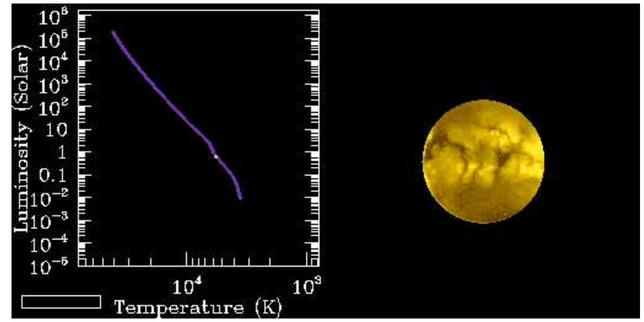


Stellar Diamonds!?!

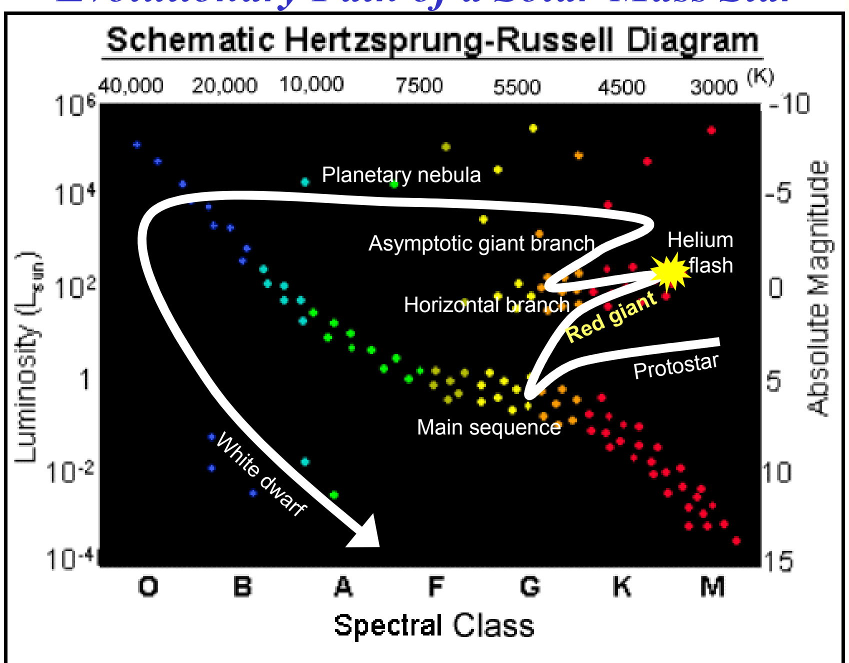
- The interior of the white dwarf crystallizes due to the extreme pressures
- Made mostly of carbon (some oxygen)
- Crystallized carbon = **a diamond**
  - With a blue-green tint from the oxygen
  - 10 billion trillion trillion carats!



The Life and Times of a Low-Mass Star

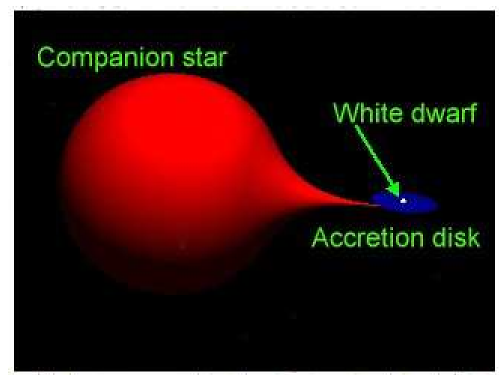


Evolutionary Path of a Solar-Mass Star



Binary Systems?

- In a close binary pair of stars with slightly different masses, the higher mass star evolves into a white dwarf first
- Later, the other star evolves into a red giant
- White dwarf then steals mass from its giant companion!
- Creates a dense layer of hydrogen gas on the white dwarf's surface



Novae

- If enough material piles up onto the surface of a white dwarf, can undergo explosive nuclear fusion
- White dwarf blows off this envelope and brightens by 100 – 1000 times
- Fades over a period of months
- This is called a **nova** (from Latin for "new")
- Common, about 20 per year in our galaxy