Astronomy 122

This Class (Lecture 17):

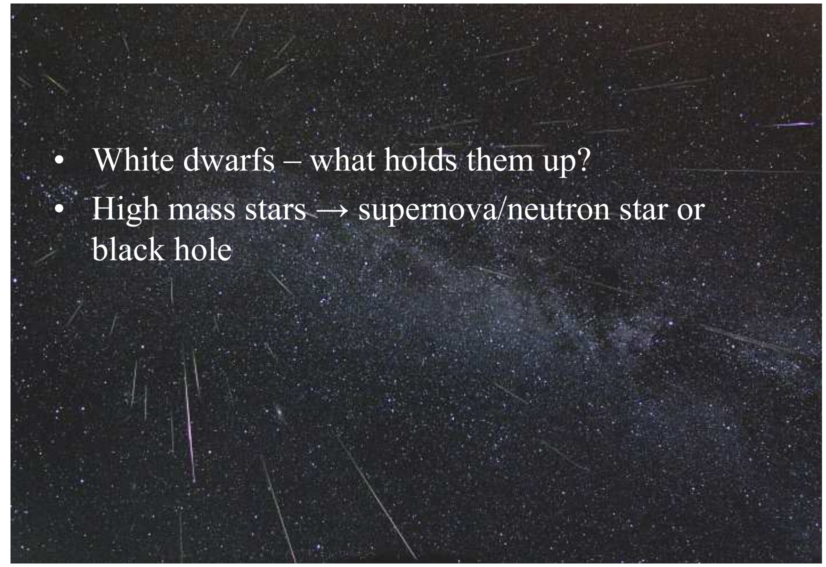
Stellar Evolution:
Dying in Space

Next Class:

Stellar Evolution:
Neutron Stars

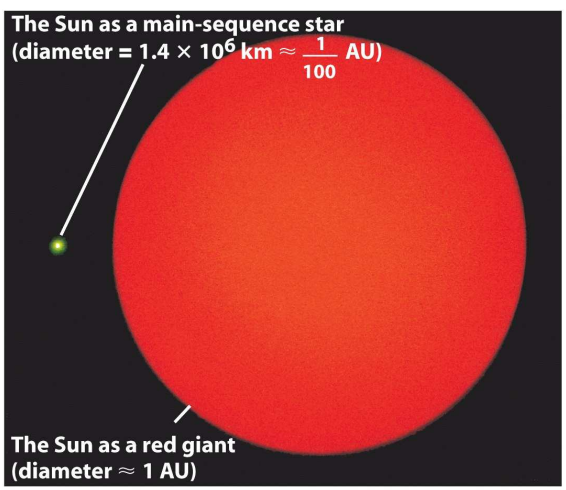
Music: *We Are All Made of Stars* – Moby

Outline



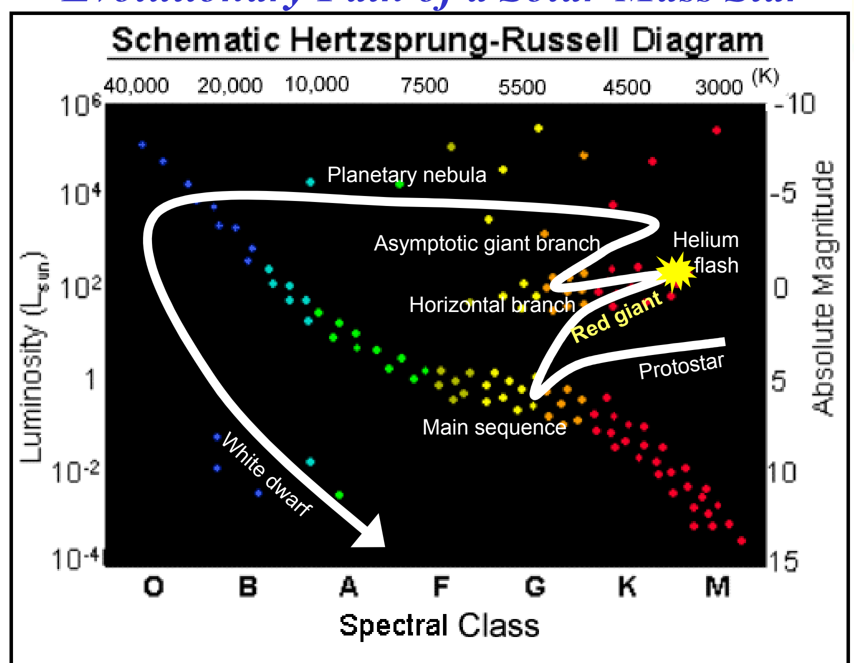
- White dwarfs – what holds them up?
- High mass stars → supernova/neutron star or black hole

In 5-7 Billion years

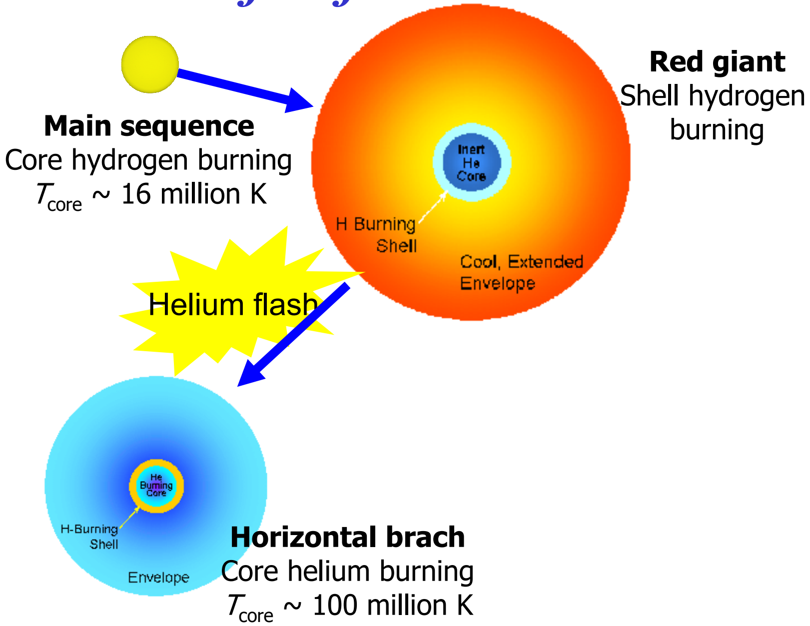


The Sun today and as a red giant

Evolutionary Path of a Solar-Mass Star

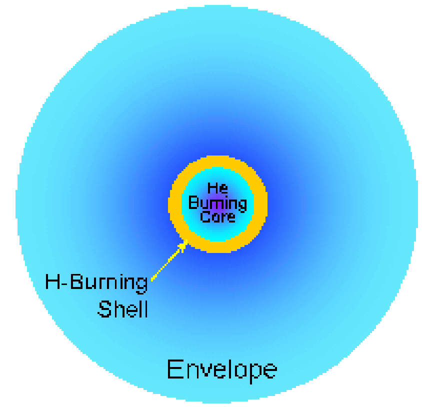


Life of a Low Mass Star

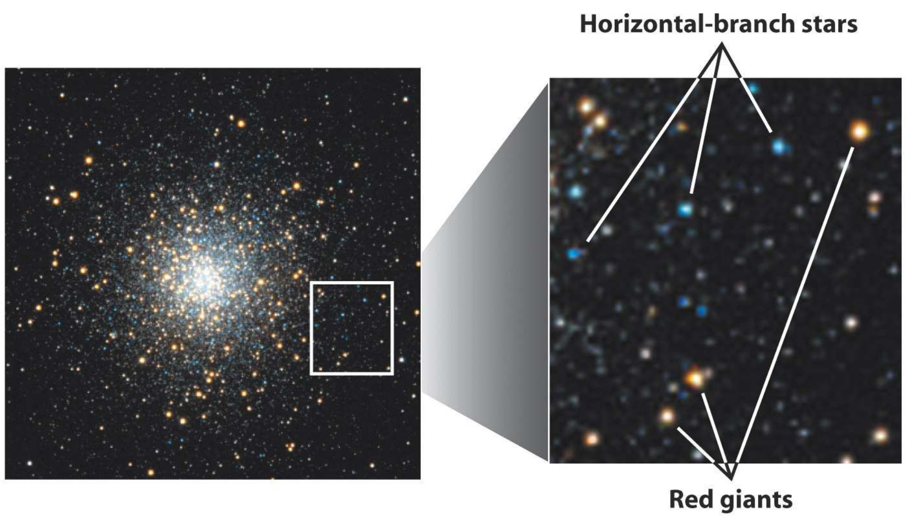


The Horizontal Branch

- 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

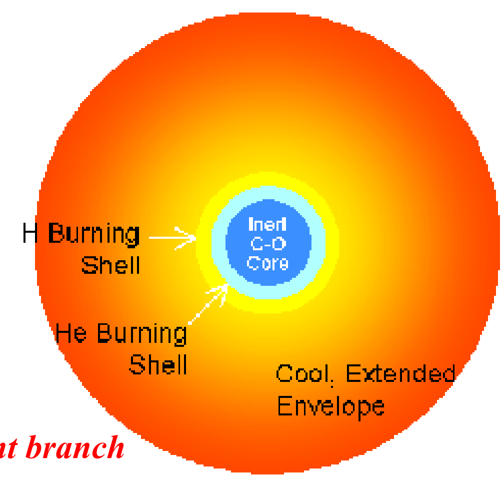


Aging Stars

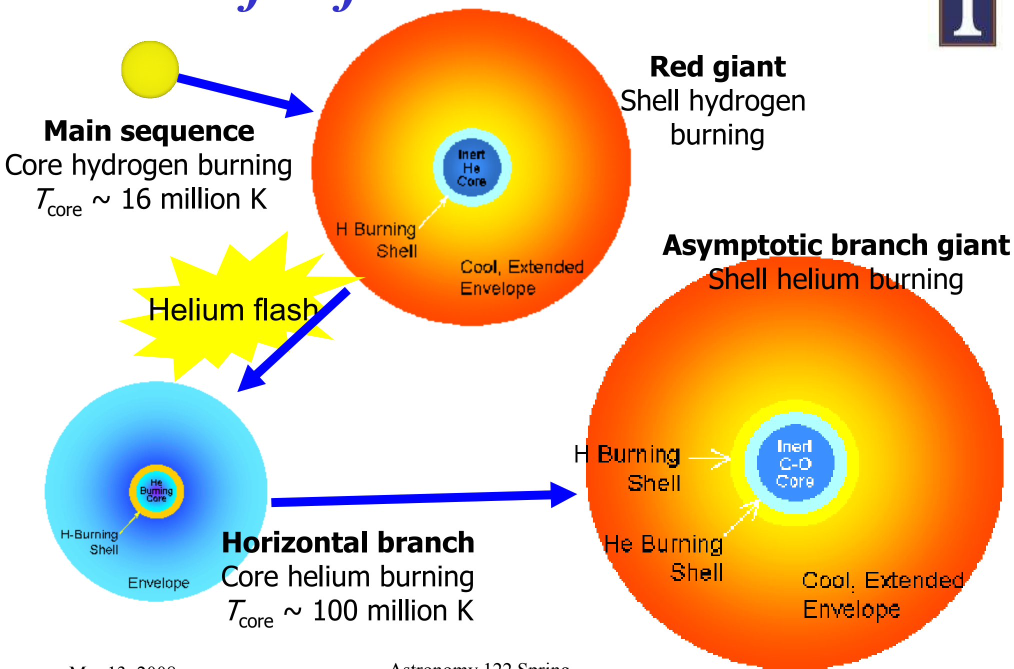


When Helium Runs Out…

- 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***



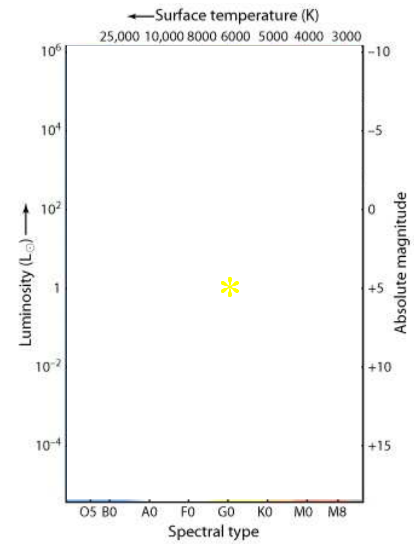
Life of a Low Mass Star



Question

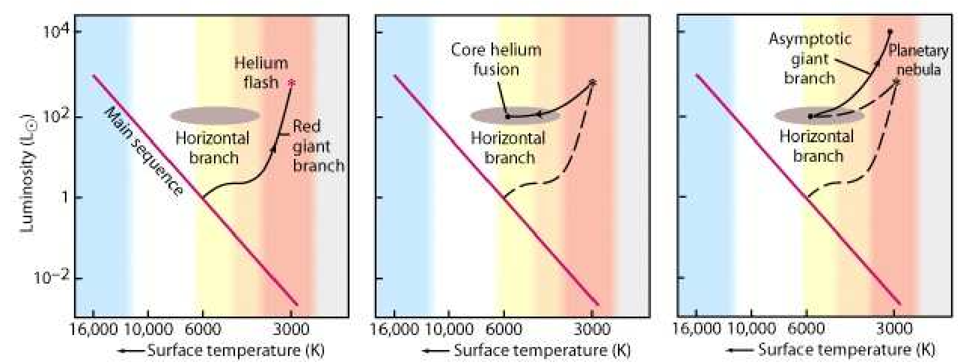
As a one solar mass star evolves into a red giant, its position on the H-R diagram will move…

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



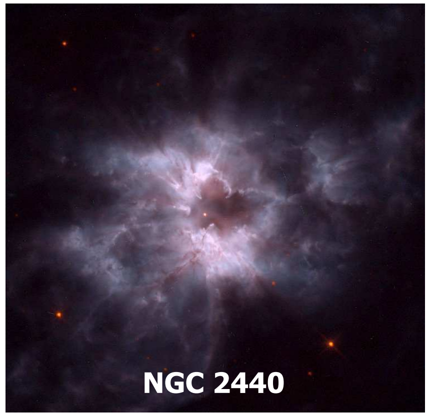
Evolutionary Path of a Solar-Mass Star

Evolutionary Path of a Solar-Mass Star



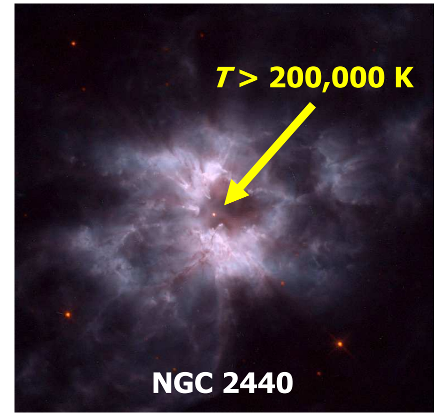
End Game

- "Superwind"
- Outer layers of the red giant star are cast off
  - Up to 80% (at least 50%) of the star's original mass

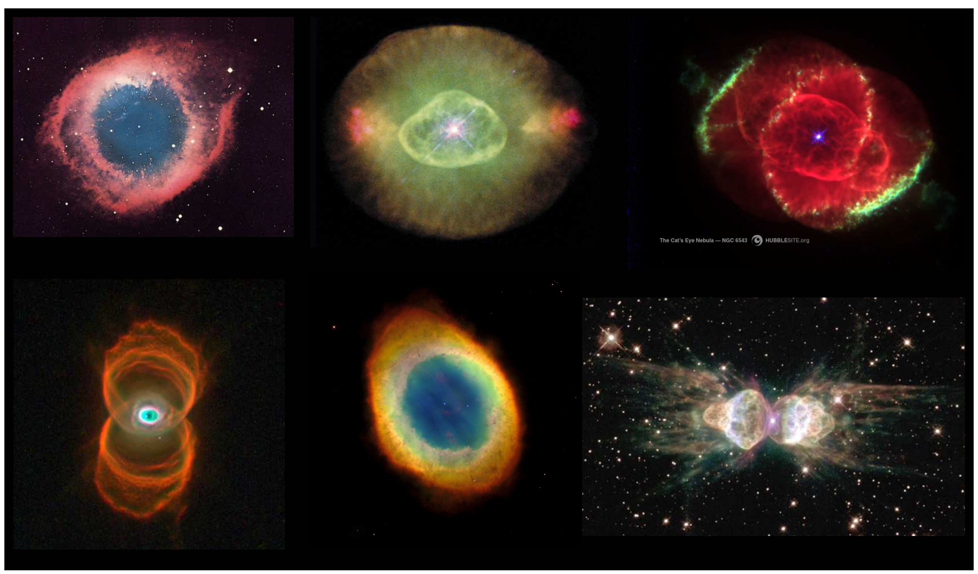


End Game

- "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.*



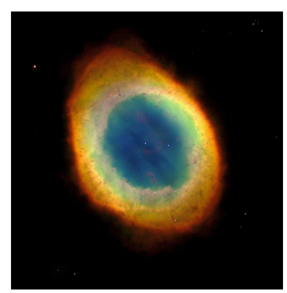
Planetary Nebulae



Planetary Nebulae

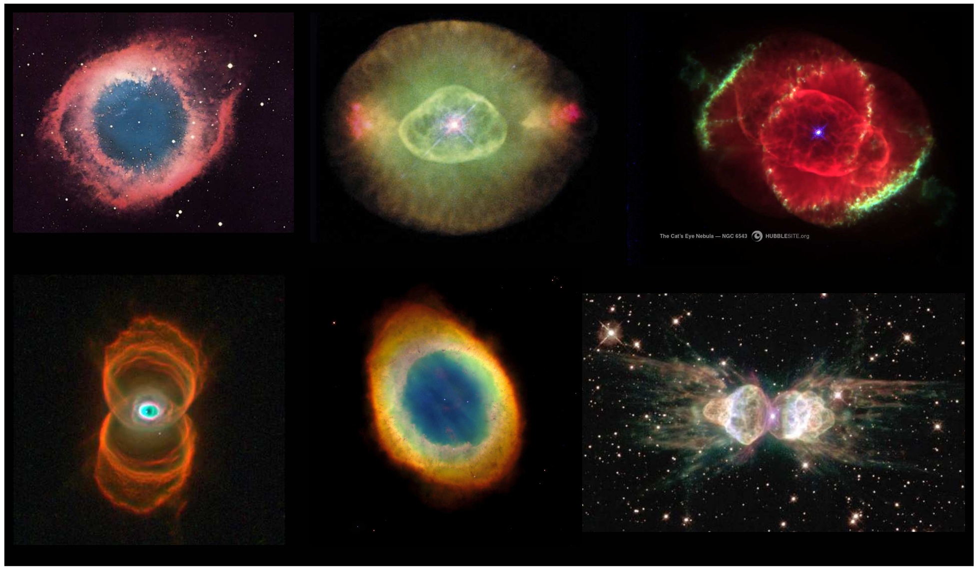
- Note the emission lines ⇒ vibrant colors (somewhat enhanced)
- Ring: approx true color, He=blue, O=green, N=red
- Cat's eye: H=red, O=blue, N=green
- Also note: rarely spherical: rotation, mag fields, ejected gas, and companion can all make axial from spherical.

Ring Nebula



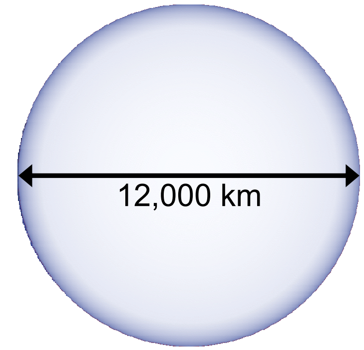
Cat's Eye Nebula

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

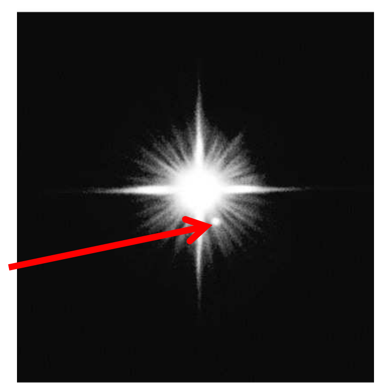


but will usually weigh about 0.6 Solar masses

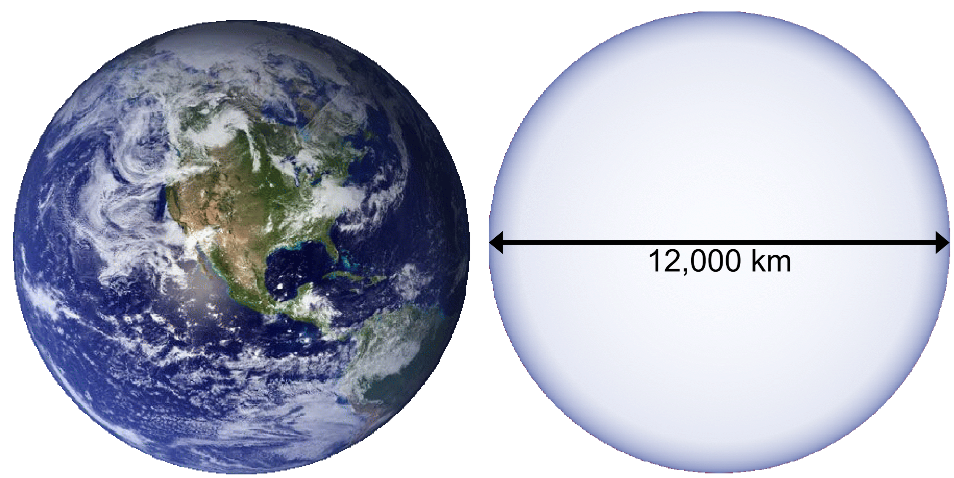
What About the Core?

- Final fate - **White dwarf**
  - Slowly cools off over billions of years

Sirius B



Relative Size of White Dwarf



White dwarf– but will usually weigh about 0.6 Solar masses

Electron Degeneracy

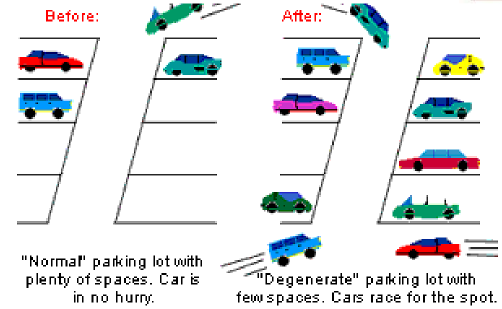
- The electrons get so squashed together that they get pushed into *degenerate states*
  - This creates **pressure** to counteract gravity (Pauli exclusion)
  - Stops contraction

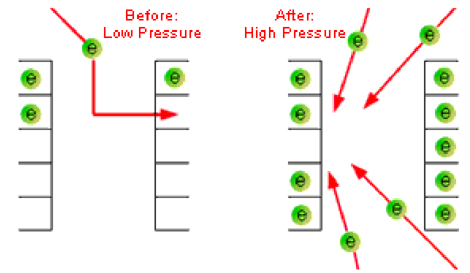
Matter in the core of a normal star

Electron-degenerate matter
1 ton per cubic cm

Degeneracy Pressure

- Electrons are forced into higher energy levels than normal – all of the lower levels are taken
- Effect manifests itself as pressure





NASA

Chandrasekhar limit

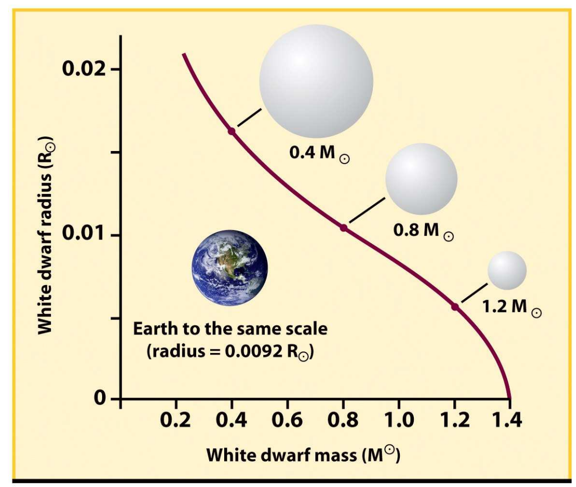
- Maximum mass of a white dwarf.
  - 1.4 solar masses!
- No white dwarf observed is over this.
- If mass is higher, the white dwarf can not support itself with electron degeneracy, and it collapses more!
- Gravity is a harsh mistress!
  - More of this latter.

Subrahmanyan Chandrasekhar 1910-1995

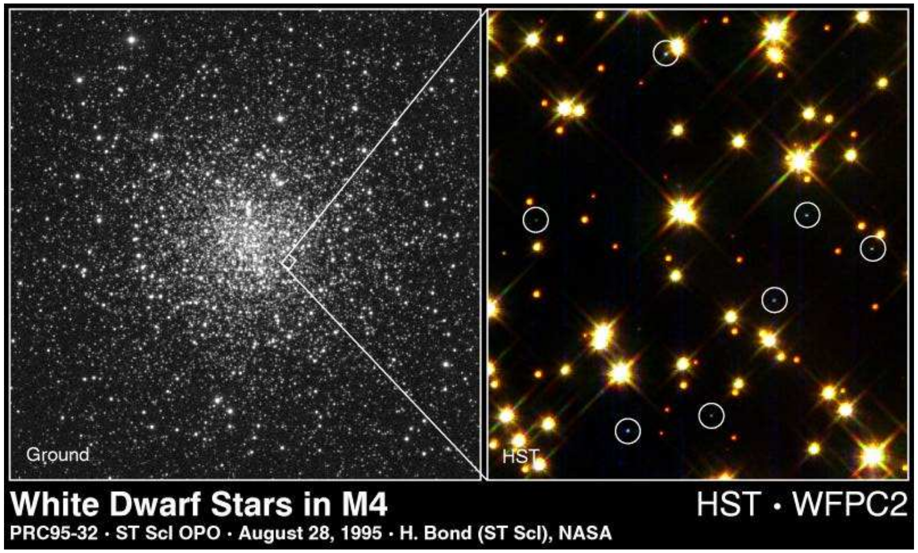
White Dwarfs are Weird

The more massive, the smaller!

Their radius *decreases* with mass!

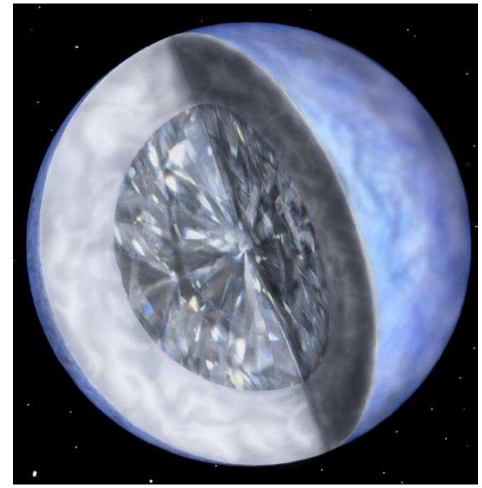


White Dwarves!



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!

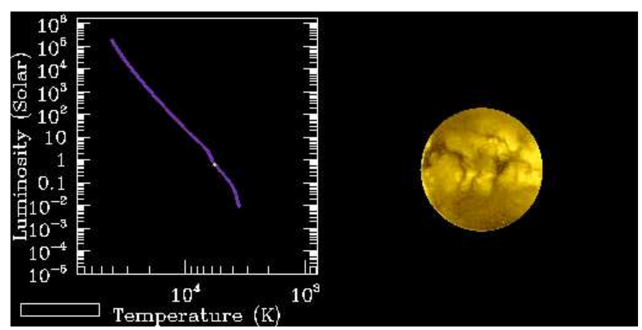


Question

This is the way the Sun ends. This is the way the Sun ends, not with a bang but a

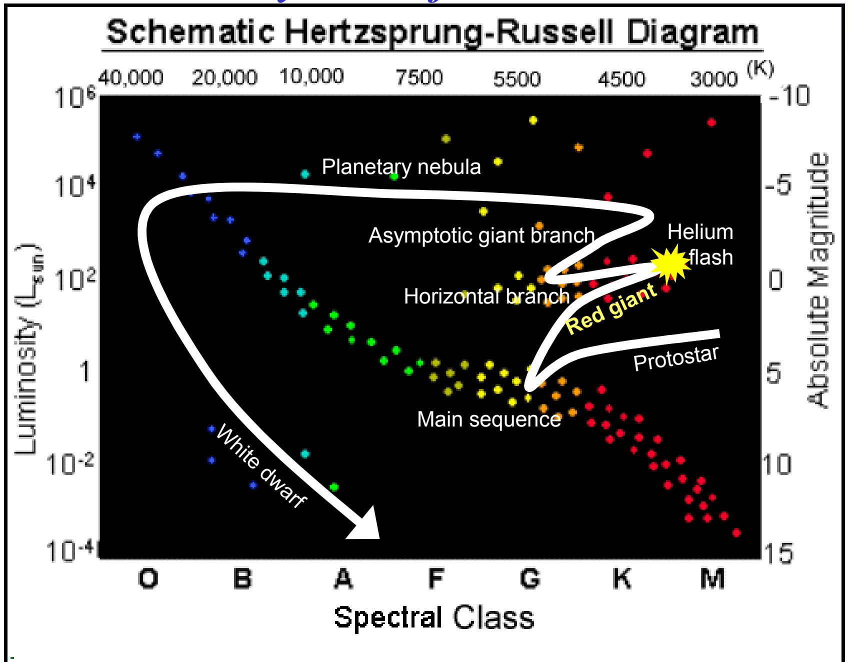
a) whimper; it just cools down over time.
b) supernova blasting heavy elements into space.
c) blackhole.
d) planetary nebula and a white dwarf.
e) a helium flash.

The Life and Times of a Low-Mass Star



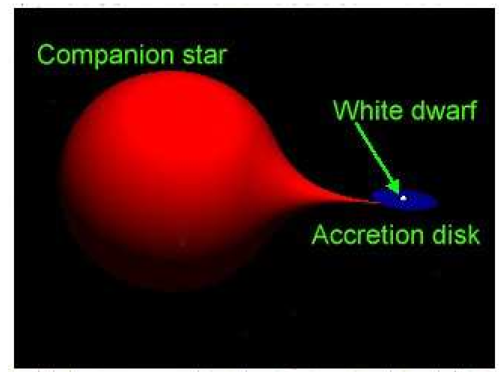
http://rainman.astro.uiuc.edu/ddr/stellar/beginner.html

Evolutionary Path of a Solar-Mass Star

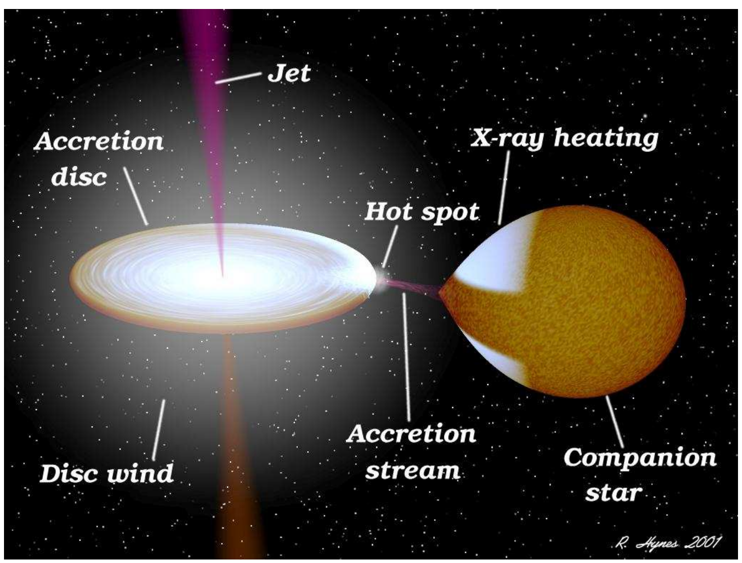


Binary Systems?

- 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

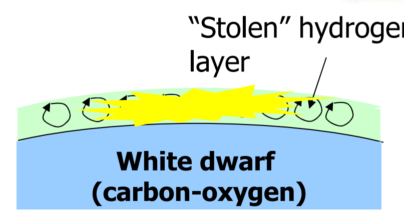


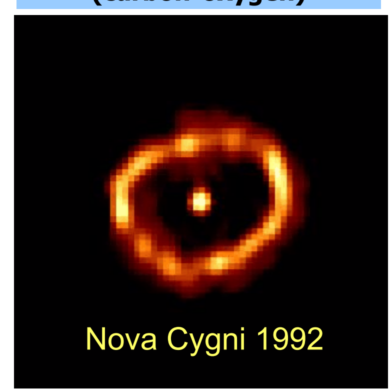
Binary Systems?



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





Life Fast, Die Young

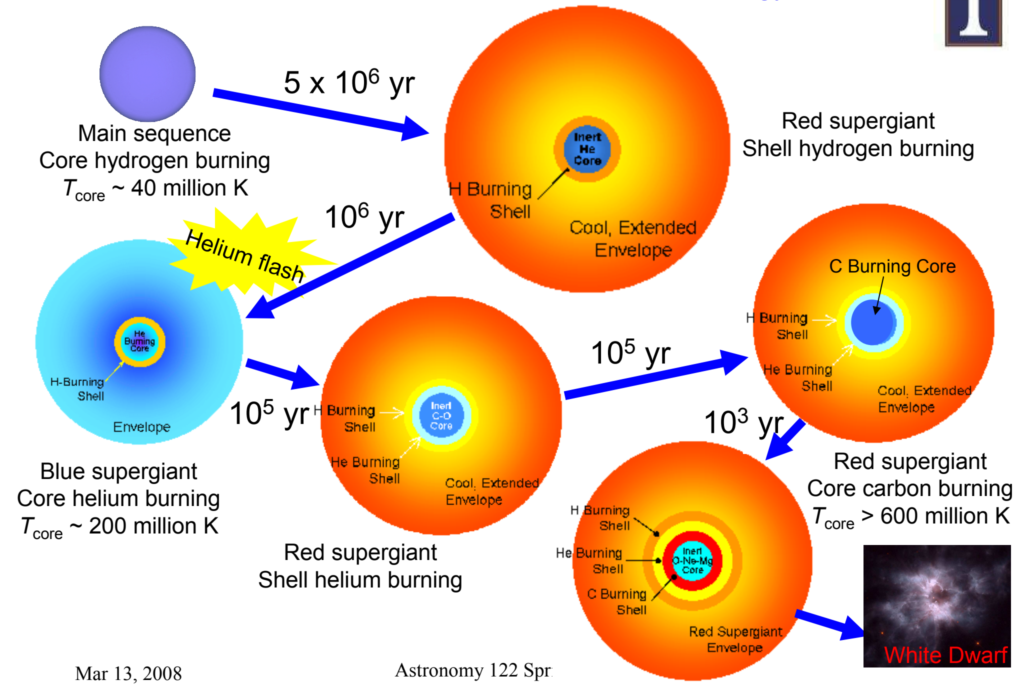
- High-mass stars: "gas guzzlers"
  - Very bright
  - Consume hydrogen fuel supply very quickly
  - Only live for millions of years on the main sequence

table 21-1 Approximate Main-Sequence Lifetimes

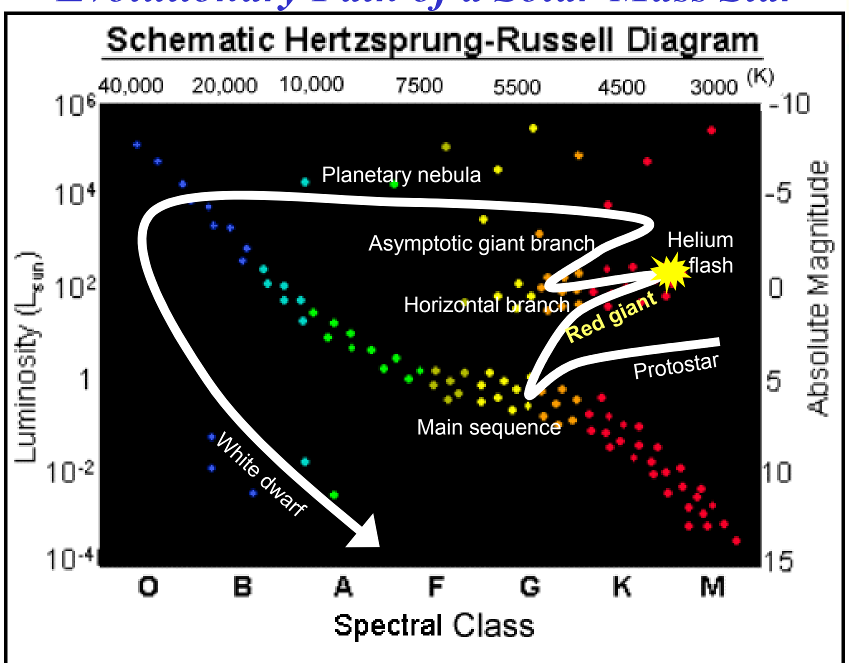
Mass ($M_\odot$)	Surface temperature (K)	Spectral class	Luminosity ($L_\odot$)	Main-sequence lifetime (10^6 years)
25	35,000	O	80,000	4
15	30,000	B	10,000	15
3	11,000	A	60	800
1.5	7000	F	5	4500
1.0	6000	G	1	12,000
0.75	5000	K	0.5	25,000
0.50	4000	M	0.03	700,000

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

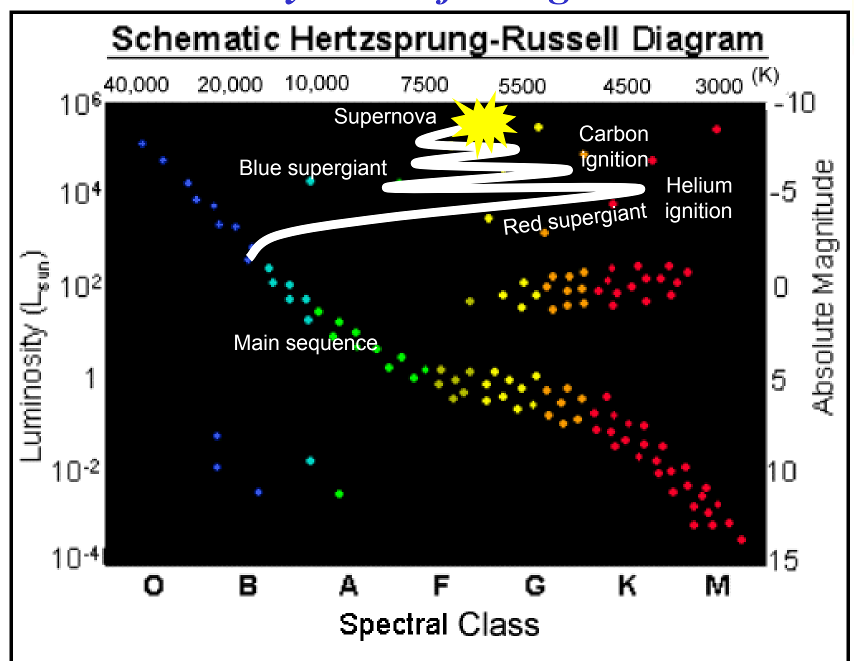
Evolution of an Intermediate-Mass (4 M_{Sun}) Star



Evolutionary Path of a Solar-Mass Star

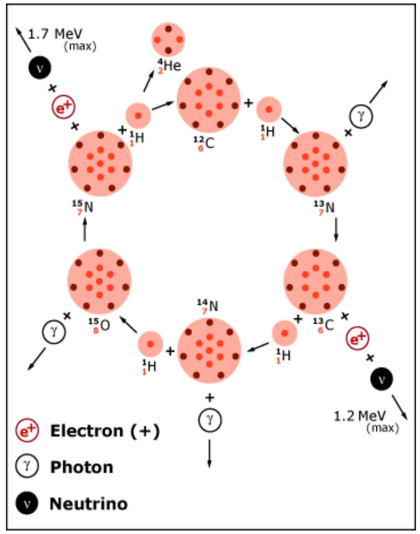


Evolutionary Path of a High-Mass Star



More than one way to fuse

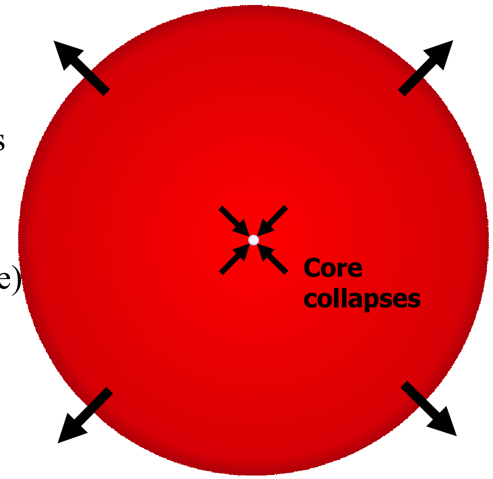
- High-mass stars do fusion by a second process
- Called the *CNO cycle*
  - Still converts 4 hydrogens into 1 helium
  - Uses a carbon nucleus as a catalyst
- Requires very high temperatures in the core
  - More than low-mass stars (like the Sun) can produce



The CNO Cycle

When the Hydrogen Runs out?

- Similar to lower-mass stars in the first few stages
- When the hydrogen supply runs out the core starts to contract
- Hydrogen shell burning (around the helium core) starts
- The outer envelope expands quickly becoming a **red supergiant**



The Supergiant Phase

- Outer envelope of the star grows larger and cooler
  - Up to 5 AU in size!
  - Unlike a low mass star, brightness does not increase dramatically
- Eventually, core is hot enough that it can fuse helium atoms together (non-degen gas, so no flash)
  - Star contracts and heats up
  - Now a **blue supergiant**