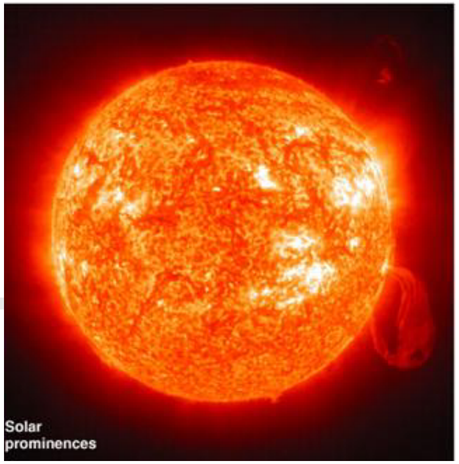
A Star Becomes a Star

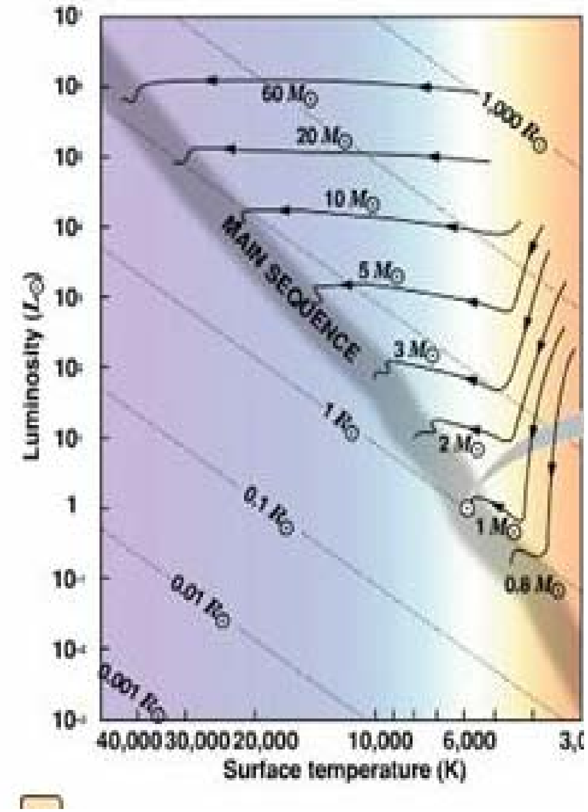
October 28, 2002



1) Stellar lifetime
2) Red Giant
3) White Dwarf
4) Supernova
5) More massive stars

Review

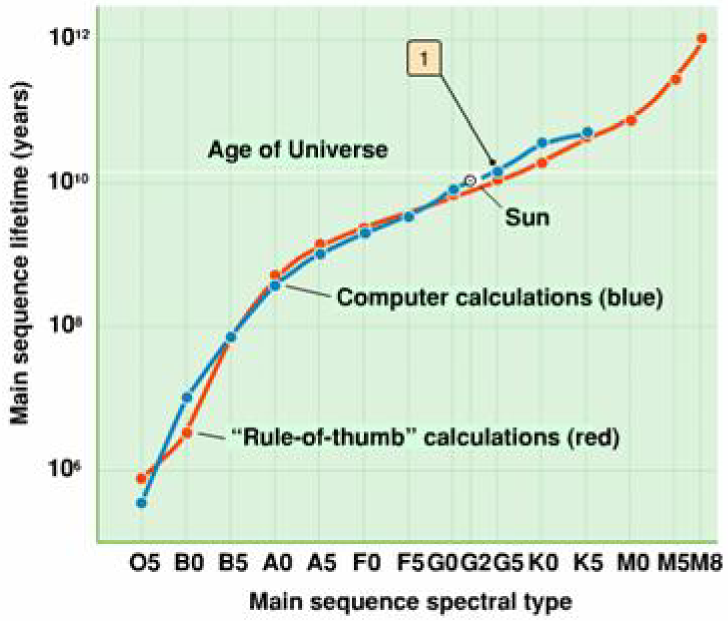
- Solar winds/sunspots
- Gases and Dust
- Molecular clouds
- Protostars/Birth of a Star
- Stellar Lifetime



$$\tau_{MS} = 1\text{x}10^{10}\ (\text{years})\ \text{x}\ \frac{\text{amount of hydrogen (solar mass)}}{\text{rate of hydrogen burning (luminosity)}}$$

How Luminous, How Long?

- Most luminous stars live shortest lives
  - also, largest (most massive) stars
- Less luminous stars live longer
  - less massive stars
  - no star less than 0.8 solar masses has ever burned all its hydrogen

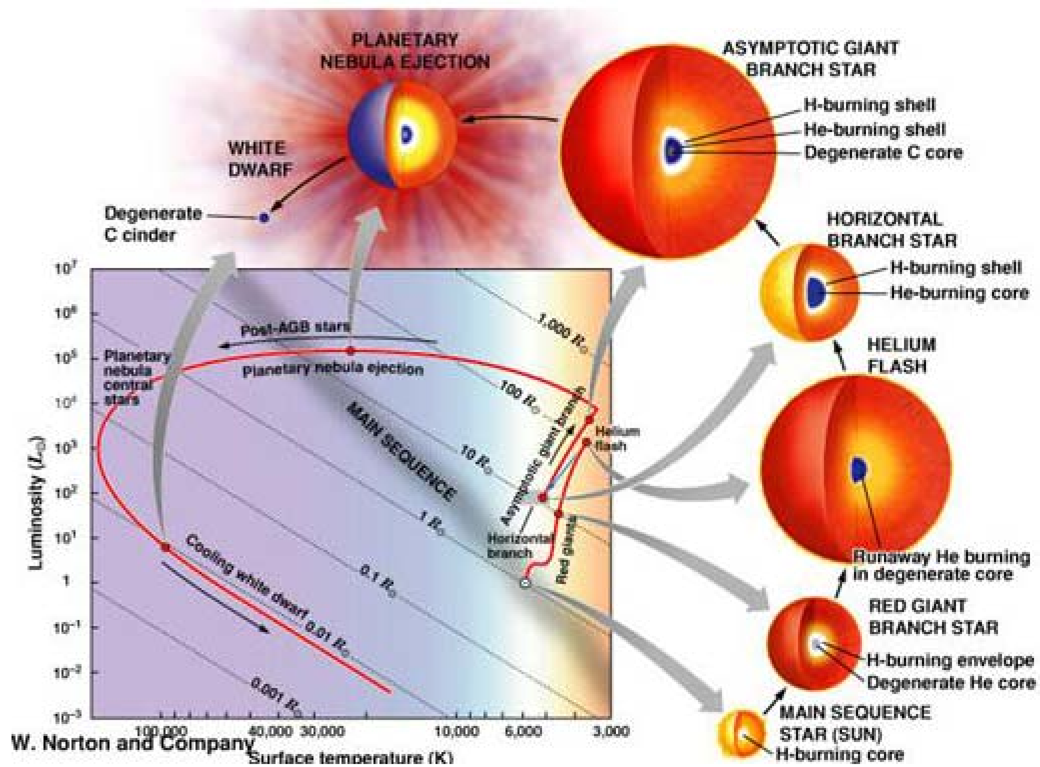


Luminosity & Temperature

- Luminosity depends on
  - surface temperature
  - size
  - can increase luminosity by increasing surface temperature or size
- Temperature
  - surface temperature
  - internal temperature
  - hydrogen burning occurs at 10 million K

Life of Less Massive Stars

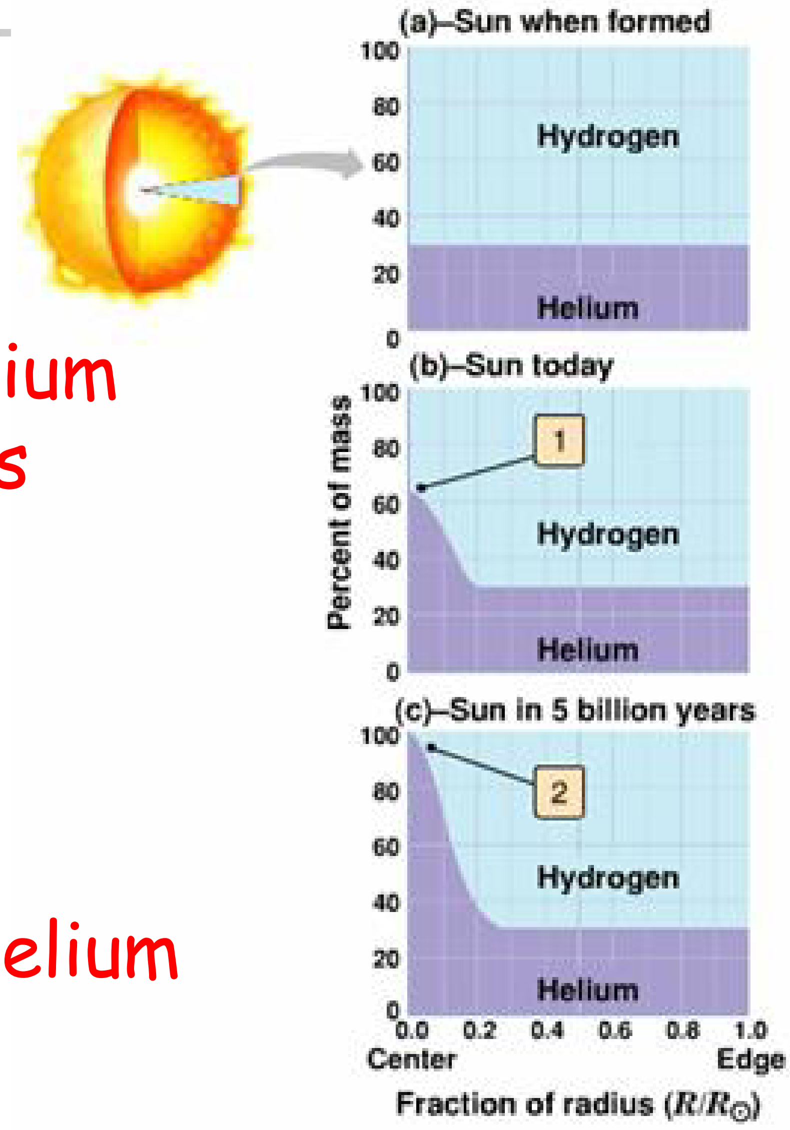
- We will start with stars lower mass stars
  - higher mass stars come later
- Low mass stars follow a pattern
  - protostar
  - main sequence star
  - red giant
  - white dwarf
  - black dwarf



- Other interesting things might happen along the way

Hydrogen → Helium

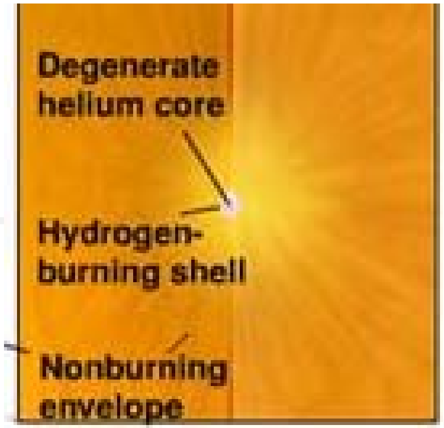
- Fusion in the core turns hydrogen into helium
- Originally hydrogen and helium evenly spread through stars interior
- Core changes
  - hydrogen burned up
  - helium builds up
- Eventually, core is mostly helium
  - helium doesn't burn well



Degenerate Gas

- Helium core becomes degenerate
- Degenerate
  - two electrons can't be in the same state
    - Quantum Mechanics
  - so there is a limit on how closely electrons can be packed together
  - this is why a gas becomes degenerate
- You can not "squeeze" a degenerate gas into a more compact form

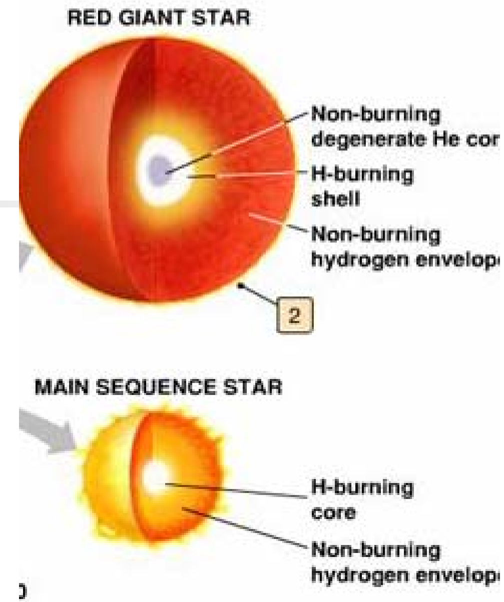
Hydrogen Shell Burning

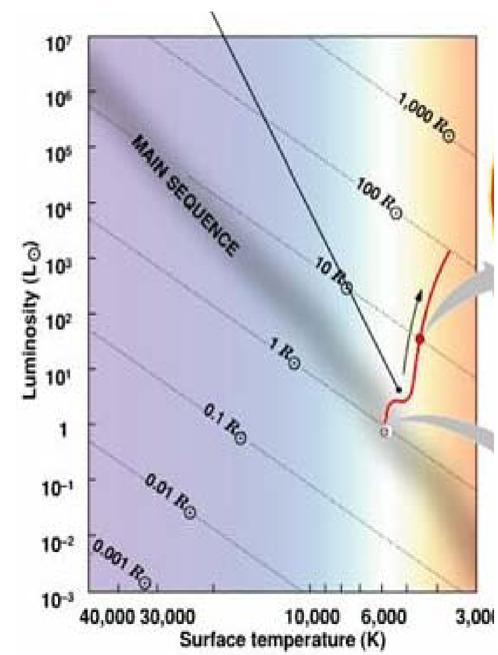


- Helium core becomes degenerate
  - doesn't burn
  - shrinks in size – more compact form of matter
- Hydrogen continues to burn in shell surrounding core
- Star grows more luminous (why?)
  - increased gravity from denser core
  - balance requires increased pressure
  - increased pressure means hydrogen burns faster
  - more hydrogen burning means more light/energy
- The star has entered the next part of its life

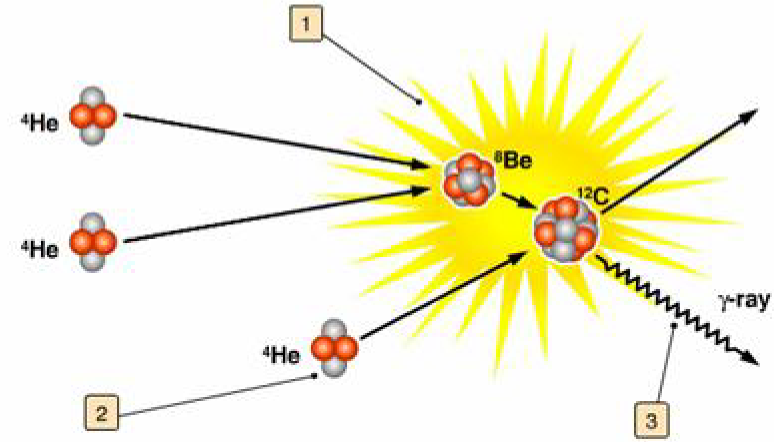
A Red Giant Is Born

- More hydrogen burning causes the star to expand
  - up to 1000 times its original size
  - surface temperature drops
  - luminosity increases dramatically
- Hydrogen is still rapidly burning in a shell around the helium core
  - generating lots of energy





Helium Burning

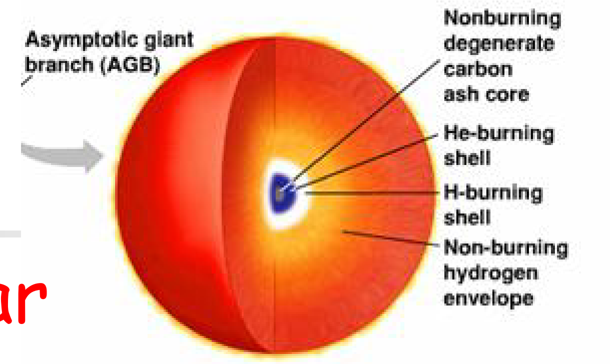


- Helium starts to burn at 100 million K
- Triple alpha process
  - three He atoms combine to form carbon
- Core temperature
  - as helium gets added to star's core
    - gravity increases
    - temperature increases
    - pressure does not increase (degenerate)
- Once degenerate helium begins to burn, it "snowballs" VERY rapidly

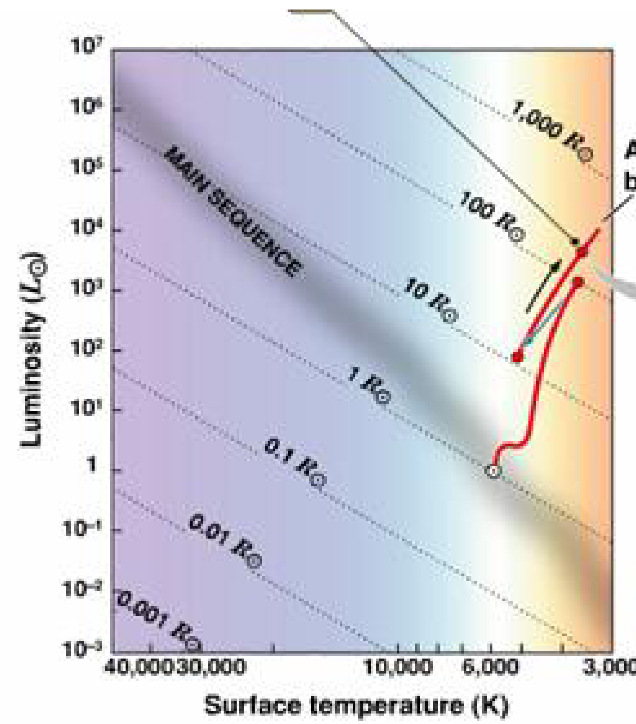
Helium Flash

- The degenerate helium core begins to burn
  - ignites and burns within hours!
- Eventually the temperature rises to the point where the core “explodes”
  - helium/carbon pushed outwards into overlying layers
  - explosion not visible on surface
- Temperature high enough for helium to continue to burn
  - burns for 100,000 years or so

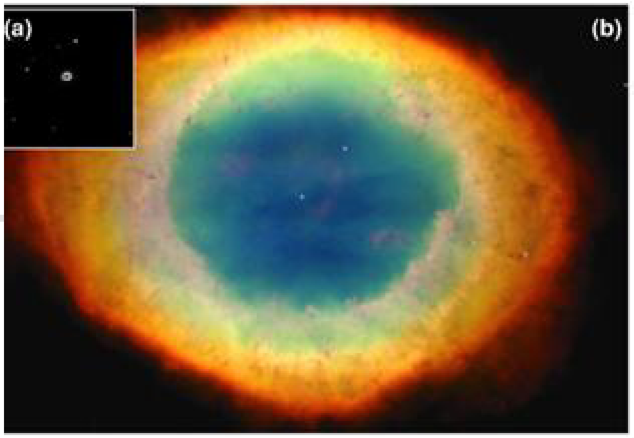
AGB Star



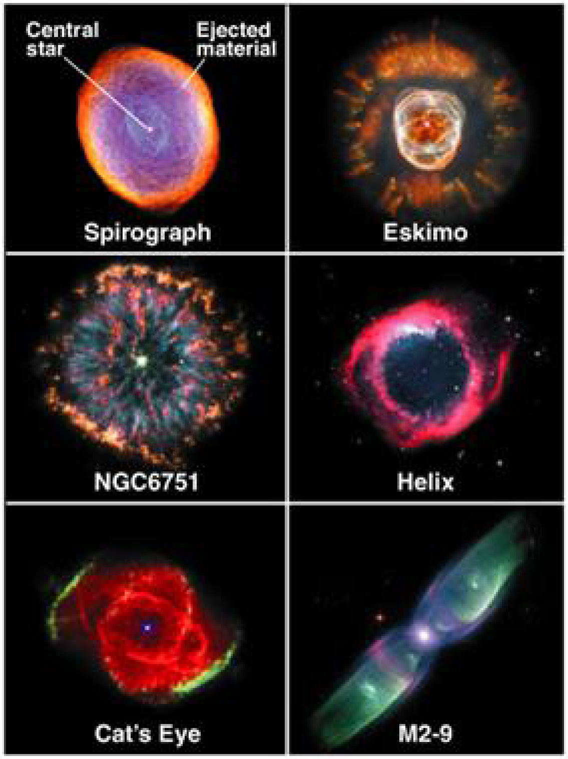
- Asymptotic Giant Branch (AGB) star
- Burns helium in core, hydrogen in shell
- Eventually,
  - Helium becomes depleted
  - Carbon core forms
- Giants lose mass
  - outer surface of giant stars feel less gravity
    - farther away than before
  - gases can escape the star's surface



Planetary Nebula

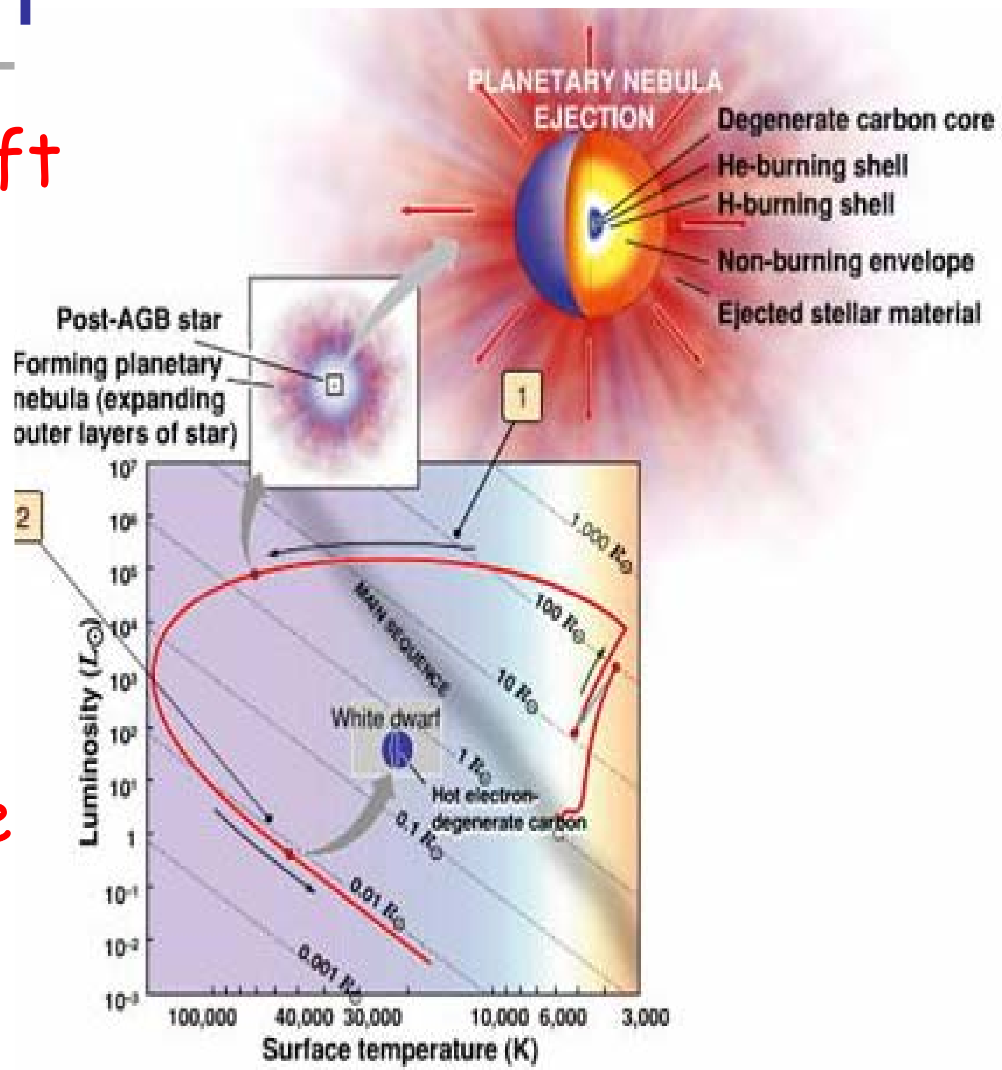


- Ejection of material "snowballs"
  - less pressure from above to hold onto lower layers
- Gases form cloud around star
  - Planetary Nebula
- Surface starts to disappear
  - 50,000 years
- Core is left behind

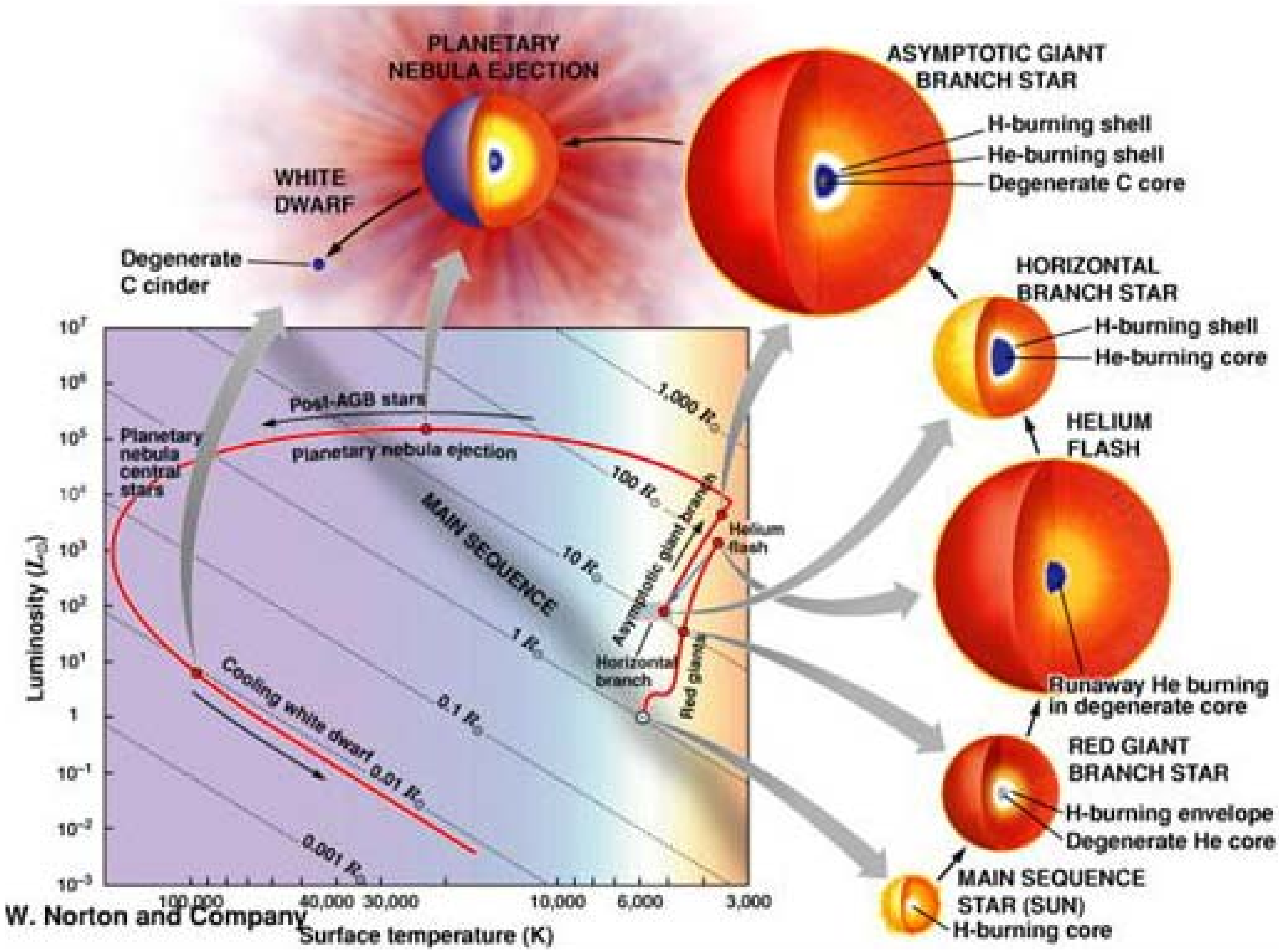


A White Dwarf

- Eventually all that is left is a core of spent gas
- All low mass stars become white dwarfs
  - helium based
    - too light to ignite helium
  - carbon based
- Glow from temperature
  - blackbody radiation
- Shrinks to size of the Earth

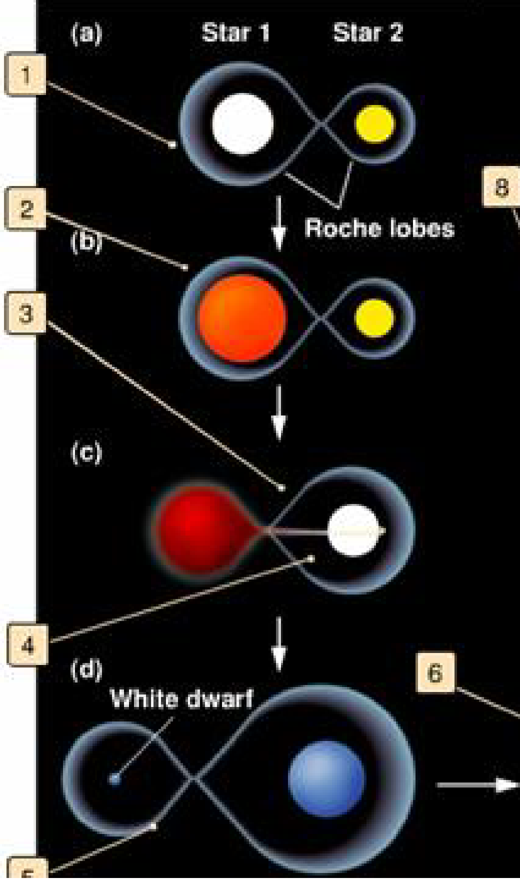


Main Sequence → White Dwarf

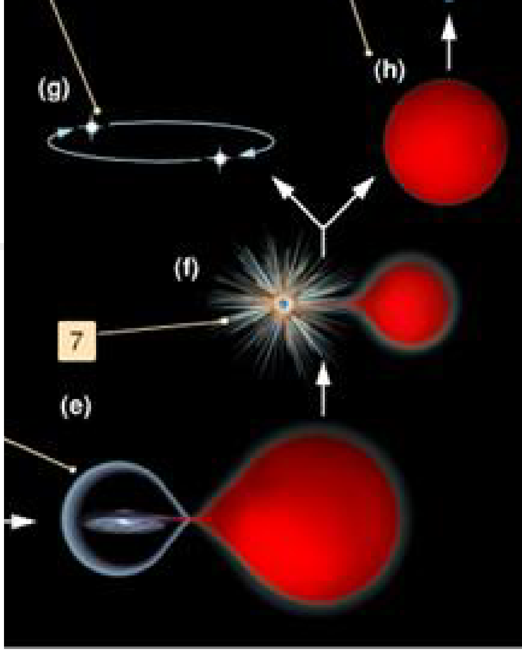


Binary Star Systems

- Interesting things happen in binary star systems
  - larger star becomes a giant first
- Roche limit
  - each star has an area in which any particle is within its gravitation pull
- Once the larger star grows into the second star's Roche limit, it transfers mass
  - the second star begins to get more massive

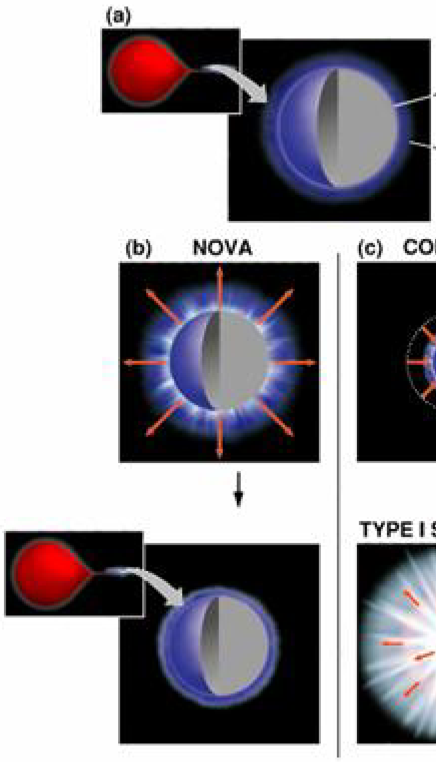


Binary Star Systems



- Bigger star becomes a white dwarf
- Smaller star eventually becomes a red giant
- Once smaller star fills its Roche limit, it transfers mass to the white dwarf
  - if both are low mass, two white dwarfs are formed
  - if more mass is present, more interesting stuff happens…

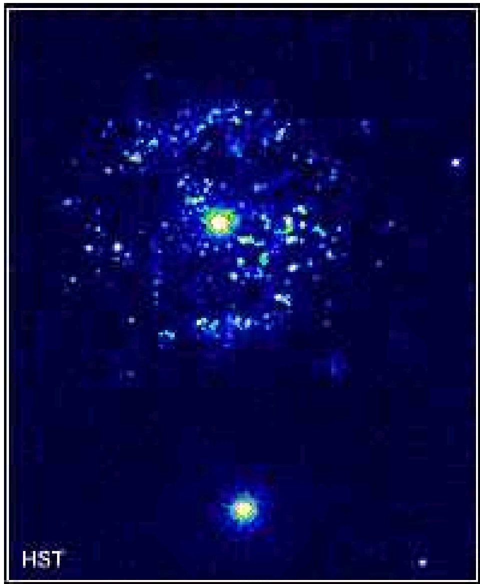
Novae



- Hydrogen is added to the surface of a white dwarf
  - gains a lot of energy "falling into" small, dense white dwarf
  - heats up
  - collects in shell on outside of white dwarf
- Once 10 million K is reached, hydrogen ignites
- Uncontrolled burn/explosion
- Huge amounts of light/energy/particles are released

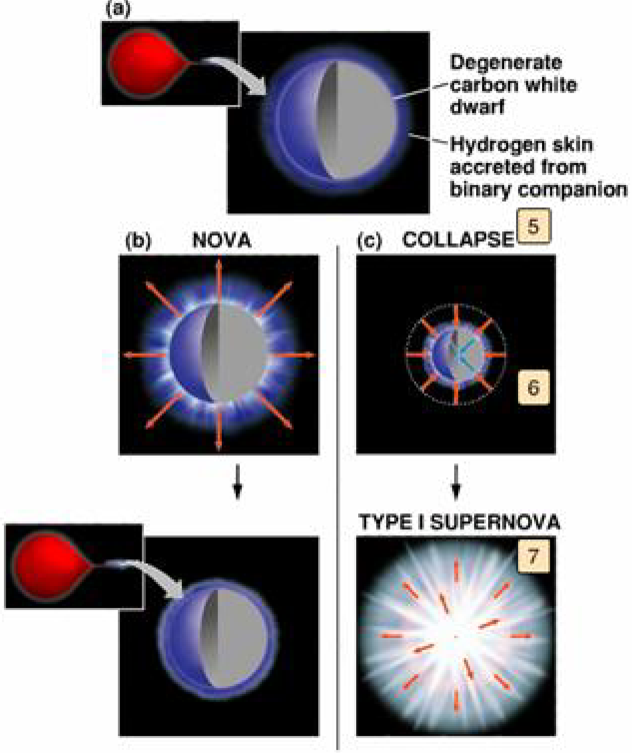
Novae

- After explosion, hydrogen can still be added to white dwarf from red giant
- Process can repeat itself
  - a given nova may explode every 10-10,000 years
  - there are some observed recurring novae
- There are about 50 novae each year in the Milky Way
  - we see only a few
    - due to interstellar dust



Type Ia Supernova

- Chandrasekhar limit
  - a white dwarf must be less than 1.4 solar masses
- If a white dwarf reaches the Chandrasekhar limit, it starts burning carbon
- The whole dwarf burns in seconds!
- More energy released than the whole 10 billion years on main sequence!
- Glows very brightly for weeks/months and fades away



Type Ia supernovae occur about once a century in the Milky Way

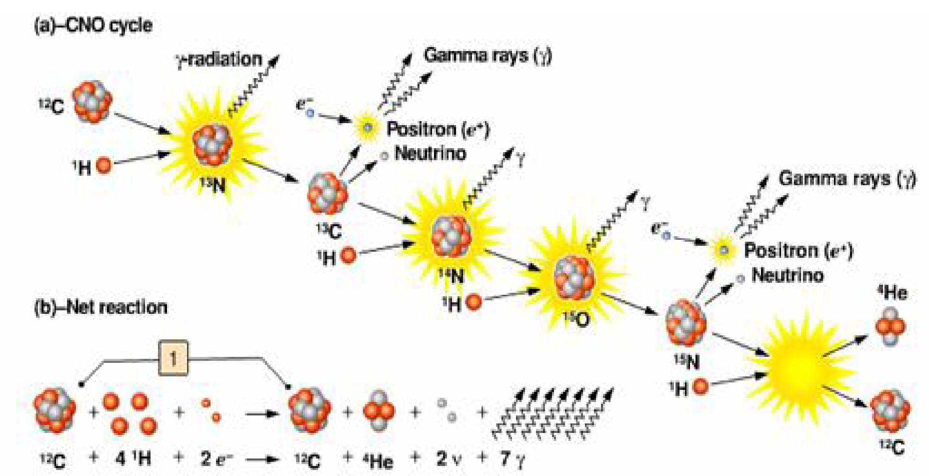
Have a luminosity 10 billion times our Sun

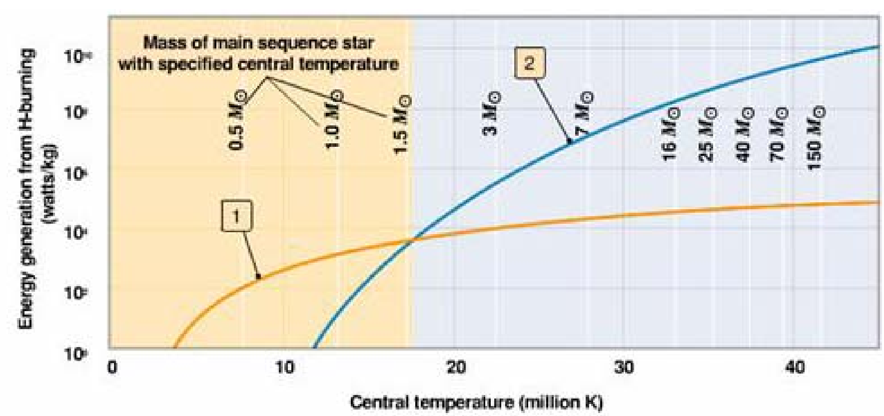
Hotter Stars

- More massive stars are hotter
- Hotter stars burn faster
- Gravity is stronger
- More interesting stuff happens…
  - more supernovae
  - neutron stars
  - black holes
  - variable stars

CNO Cycle – More Burning

- Carbon-Nitrogen-Oxygen (CNO)
  - $^{12}C + 4\ ^{1}H \rightarrow\ ^{12}C + ^{4}He$
  - occurs if carbon and hydrogen are together and hot enough
  - needs 1.5 solar masses





Nucleosynthesis

- If temperatures get high enough, additional fusion reactions are available

  $$H \rightarrow He \rightarrow C \rightarrow Ne \rightarrow O \rightarrow Si \rightarrow Fe$$

- Hotter stars produce heavier elements
- Each fusion stage produces energy
  - each stage goes faster than previous
- Iron does not burn
  - needs energy into reaction rather than giving up energy

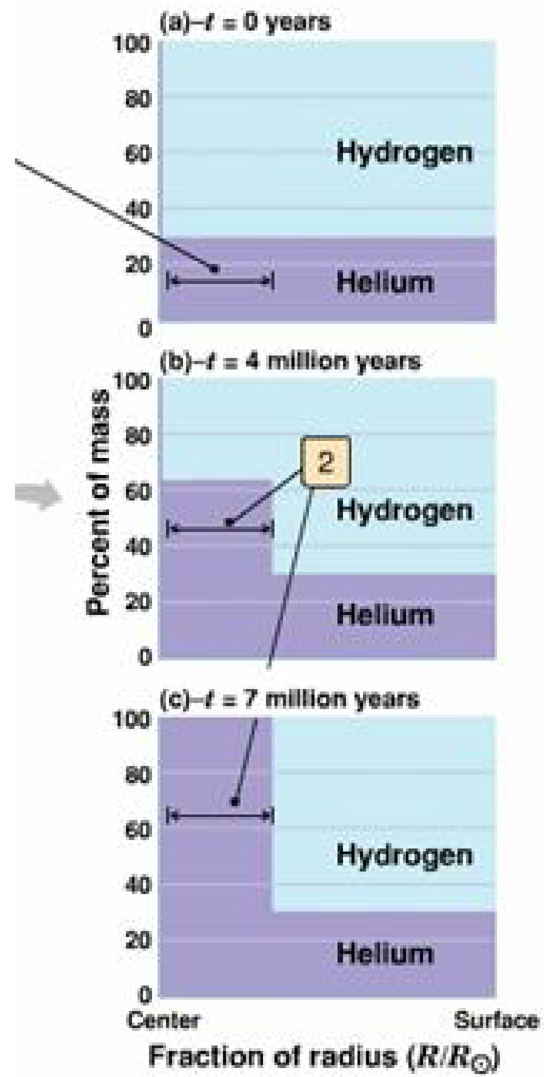
Nucleosynthesis

- Some typical times and temperatures of reactions

Stage	9 solar masses	Temperature (K)
H burning	20 million years	$(3\text{-}10)\times10^{7}$
He burning	2 million years	$(1\text{-}7.5)\times10^{8}$
C burning	380 years	$(0.8\text{-}1.4)\times10^{9}$
Ne burning	1.1 years	$(1.4\text{-}1.7)\times10^{9}$
O burning	8 months	$(1.8\text{-}2.8)\times10^{9}$
Si burning	4 days	$(2.8\text{-}4)\times10^{9}$

Massive Core Burning

- Core burns differently
- Convection stirs core
  - mixes elements
- Converts all of core to helium
  - not degenerate core
- Then starts burning helium
- Hydrogen burning shell appears



A Giant Onion

- During its life, a massive star burns each step progressively outward
- Shells form
- Innermost shells burning heavier elements
  - Fe
  - Si
  - O
  - Ne
  - C
  - He
  - H