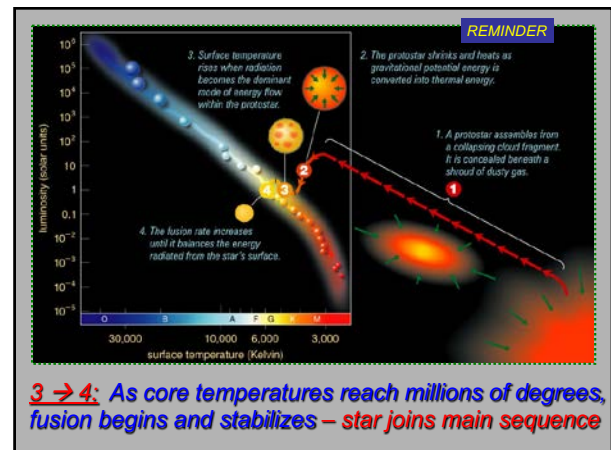
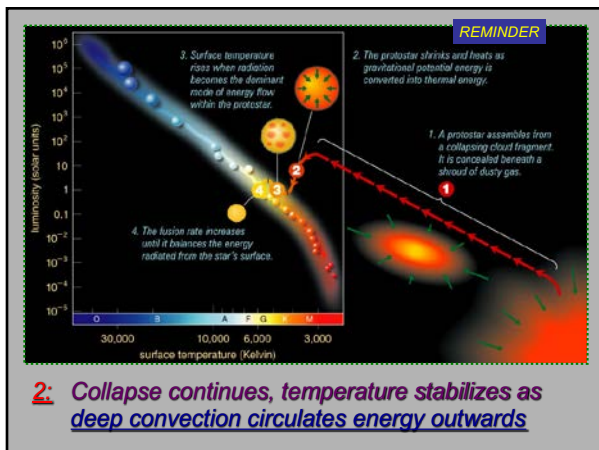
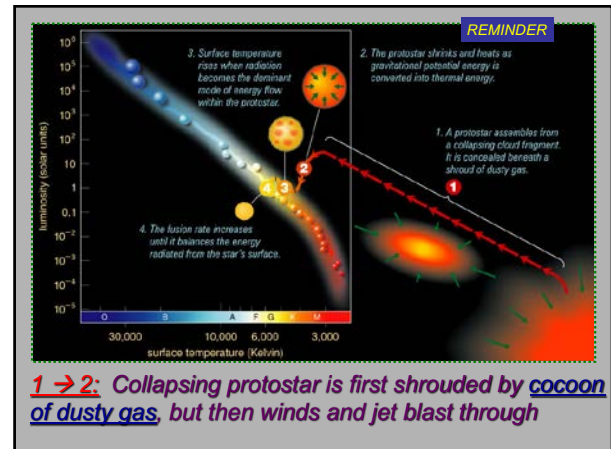


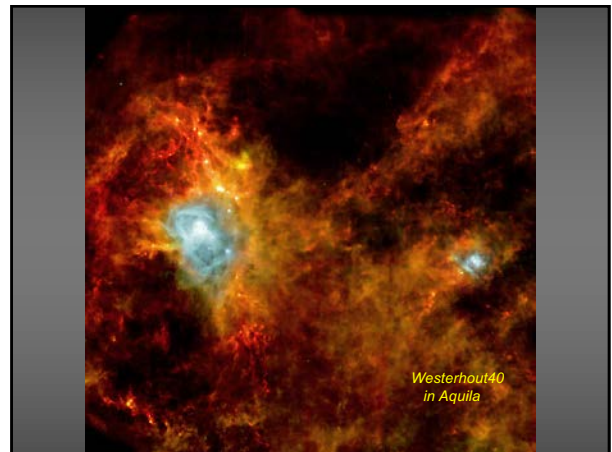
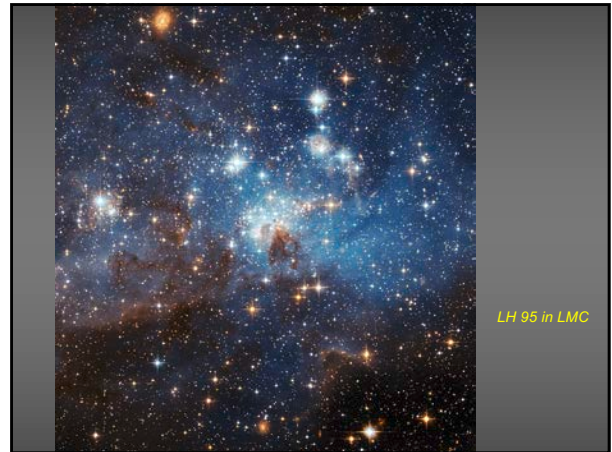
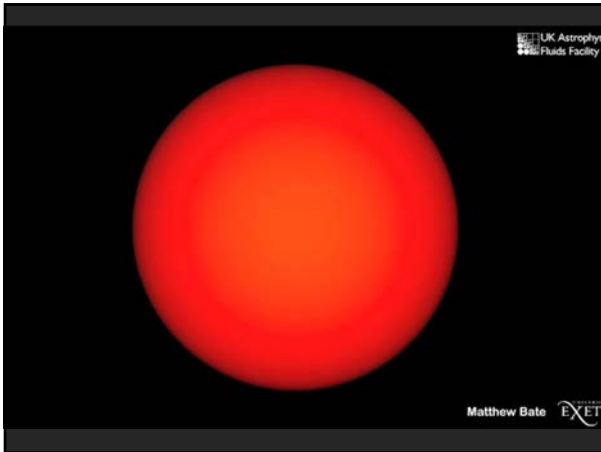
Topics for Today

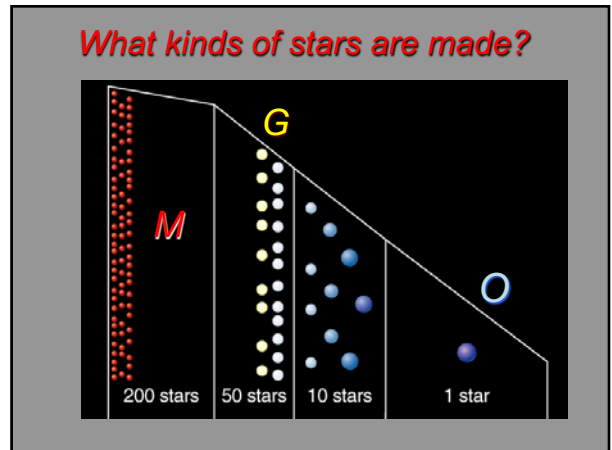
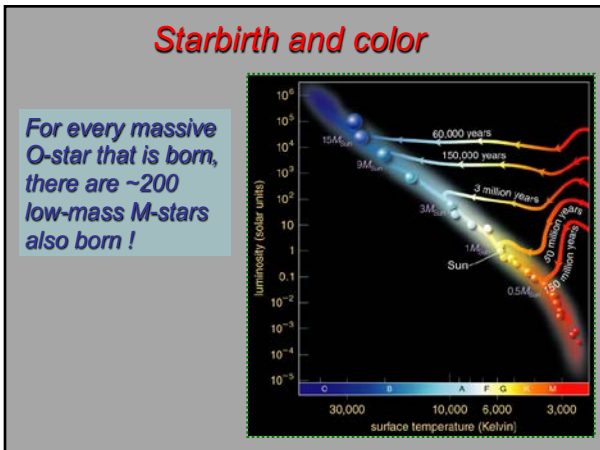
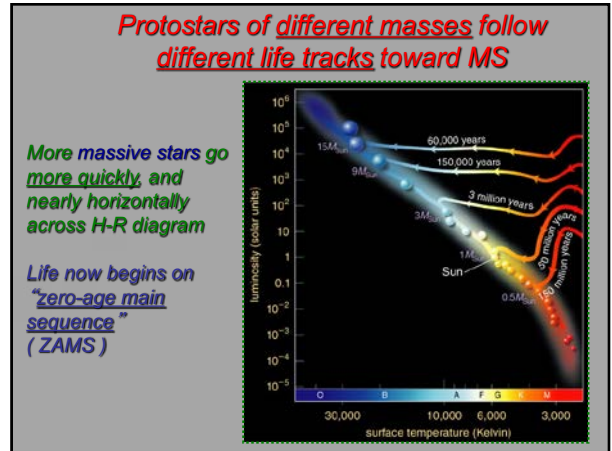
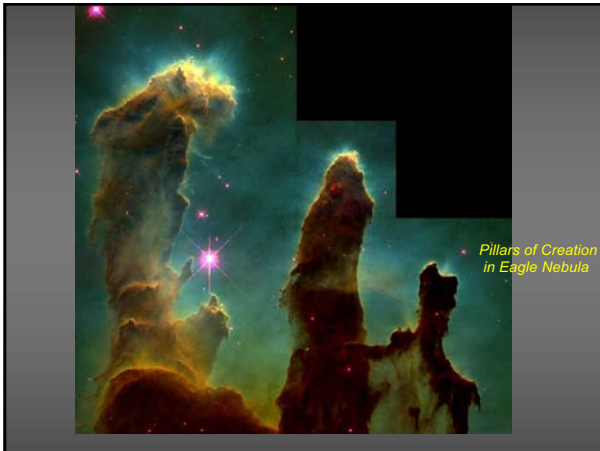
- Revisit **birth of stars** in dark molecular clouds
- Many more **M and G** stars are made than massive **O** stars
- Next turn to **"life after the MS"**
- What happens to **solar-mass star** after it exhaust its central H fuel and **leaves the MS**
- Shell burning of H builds **red giants**
- And then **He flash, supergiants, big winds ...**
- Finally **white dwarf** emerges in the embers

Things to do

- Read **Chap17 'Star Stuff'**, with **17.2 'Life as Low-Mass Star'** covering today's lecture
- Then read **17.3 'Life as High-Mass Star'** for next class ... look over **18.3 Black Holes**
- **Homework #6** due today, new **HW #7** passed out ... plus **Overview on Evolution**
- Next class on **Tues Oct 16** meets in **Fiske Planetarium** – go there **directly**. Tour stellar evolution... and **"Black Holes"** program
- **Observatory Night # 7** next **Tues**, sign up









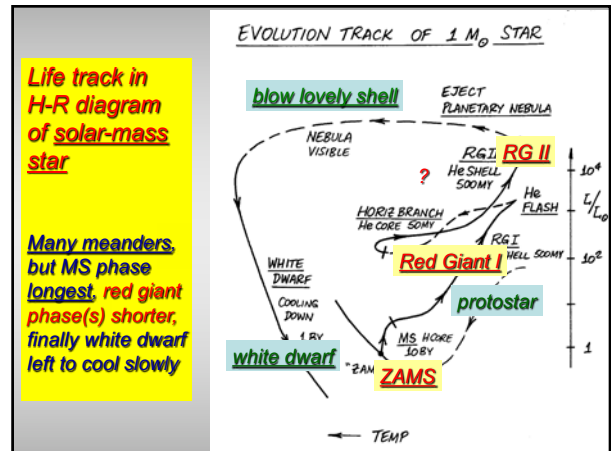
Reading Clicker -- life tracks

- What can we find out about a star from its life track on the H-R diagram?
 - B.
 - A. When the star was born
 - B. The surface temperature and luminosity of the star at each stage of its life
 - C. The star's current stage of life
 - D. Where the star is located

Let us make some plasma!
Demo of TESLA COIL

(Nikola Tesla, not just Musk's all-electric car!)

Powerful electric fields reach out



1: Low-Mass Star on MS

H burning in core

Longest phase: 10,000 MY = 10 BY if solar mass

EVOLUTION OF LOW MASS STARS $M < 2M_{\odot}$
 ... CONSIDER SUN AS AN EXAMPLE

STEP 1. MAIN SEQUENCE PHASE
 HYDROGEN BURNING IN CORE

LONGEST PHASE:
 LASTS 10,000 MY = 10 BY

- CORE CONTRACTS VERY SLOWLY
 RAISING CORE TEMPERATURE & ENERGY OUTPUT (L)
- WITH INCREASING L , RADIUS R INCREASES
 ALMOST DOUBLING BY TIME H EXHAUSTED IN CORE
- MAIN SEQUENCE PHASE ENDS WITH INERT He CORE
 CONTINUED CONTRACTION \rightarrow HIGHER TEMP
 (LIBERATING POTENTIAL ENERGY)
 ... SOON H SHELL BURNING STARTS

2: Subgiant to Red Giant (first visit)

H burning in shell, makes much more energy

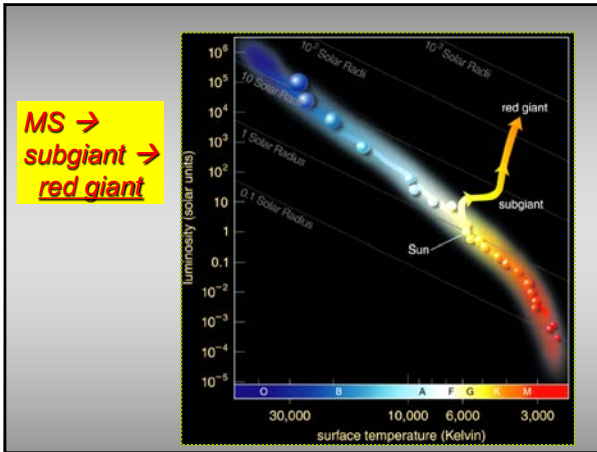
Vast expansion, RG phase lasts ~ 500 MY

Huge convective envelope

STEP 2. RED GIANT STAR (FIRST VISIT)
 H SHELL BURNING LASTS 500 MY

WHY A RED GIANT?

- SHELL BURNING SURFACES MUCH MORE ENERGY
- LUMINOSITY SPURTS UP
- OUTER REGIONS EXPAND, SURFACE TEMPERATURE HAS DROPPED



Without Fusion, the Core Starts to Contract

- Helium has built up in the core
 - Temperatures not hot enough to fuse helium (100 million K needed).
- With fusion no longer occurring in the core, gravity causes core contraction (collapse)
 - Core temperature starts to heat up
- Layer just above the core must contract also (and heat up)
 - Now hot enough for hydrogen fusion in that layer
 - Hydrogen "shell fusing" pushes outer layers of the star out

RED GIANT

Red Giants

- Thermostat is broken
 - No more fusion in the core!
- As core contracts, hydrogen SHELL fuses faster and faster – more energy created
- Star becomes larger, cooler, but **brighter!**
- All the while, the core is continuing to shrink and is heating up

MS → subgiant → red giant

Contracting core in red giant gradually becomes "electron degenerate" -- what does that mean?

Oops!

Thermostat is missing in degenerate gas

Could get exciting!

EM 6

DEGENERACY AND STELLAR EVOLUTION

HEAT NORMAL GAS (TEMP ↑)

- ⇒ PRESSURE ↑ ⇒ GAS EXPANDS
- ⇒ COOLS DOWN "THERMOSTAT WORKS"

HEAT DEGENERATE GAS (TEMP ↑)

- ⇒ PRESSURE UNCHANGED
- ⇒ NO THERMOSTAT

IF NUCLEAR FUSION STARTS IN CORE ...

NORMAL GAS : STABLE , LIKE M.S. STAR

DEGENERATE GAS : "THERMAL RUNAWAY"

... BURNING ⇒ HIGHER ⇒ FASTER ⇒ EVEN FASTER ⇒

TEMP BURNING ⇒ TEMP ⇒

⇒ **EXPLOSIVE !**

3: Helium Flash

He core burning -- removes electron degeneracy

- He core burning now with thermostat !
- "horizontal branch star"

EM 7

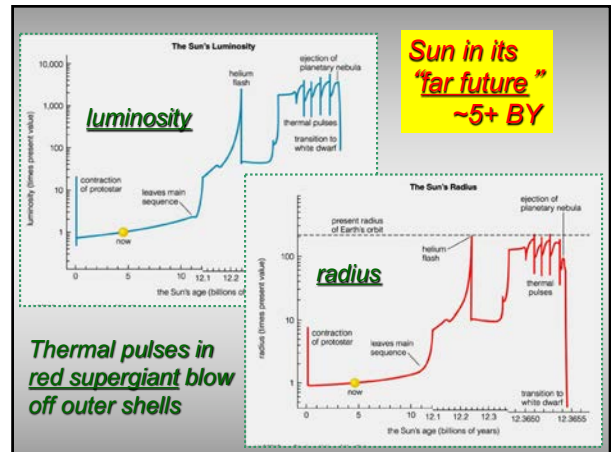
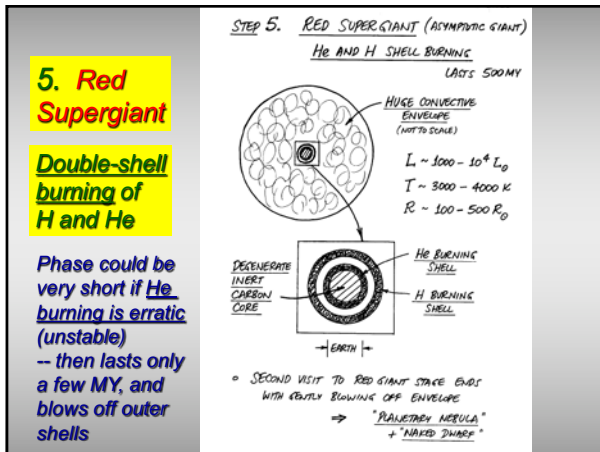
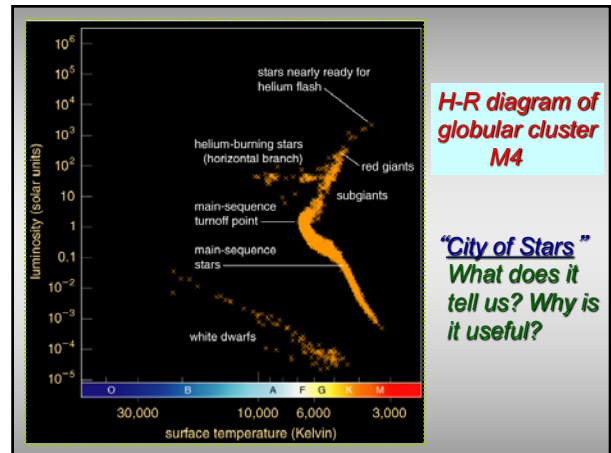
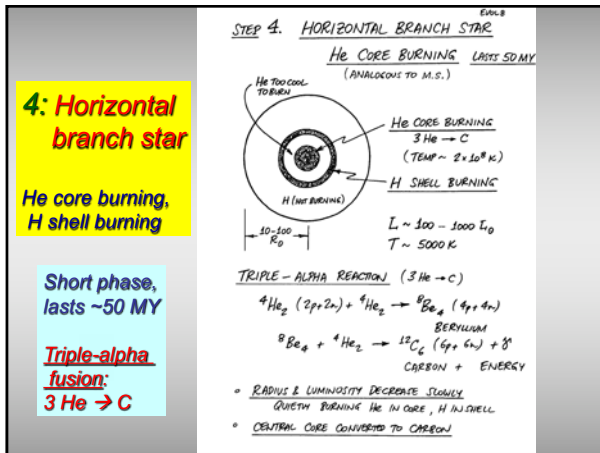
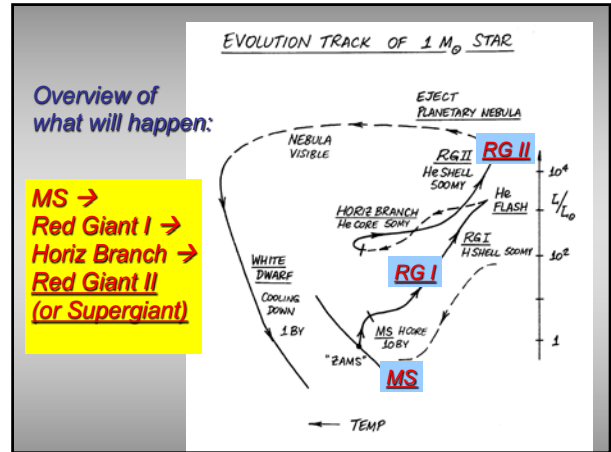
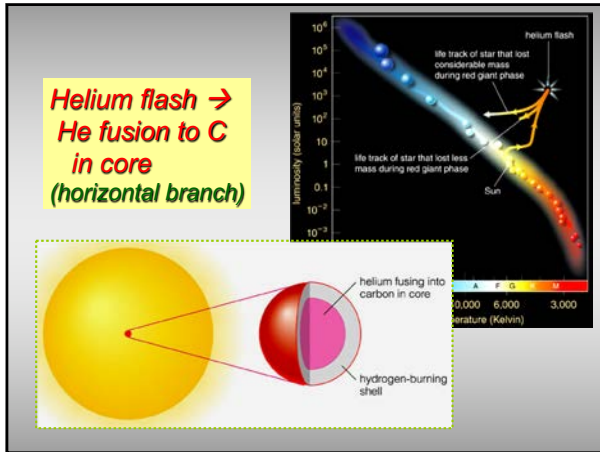
STEP 3. HELIUM FLASH

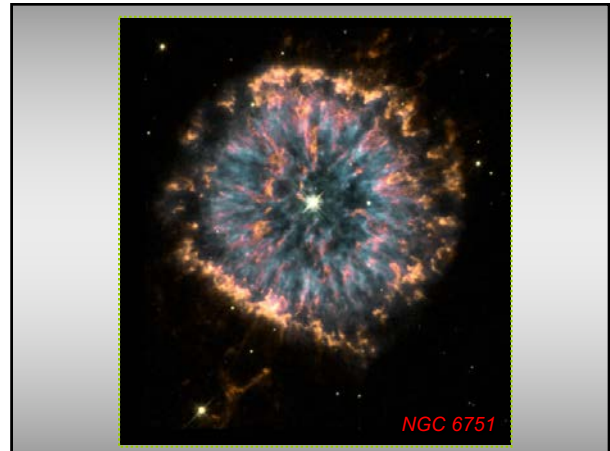
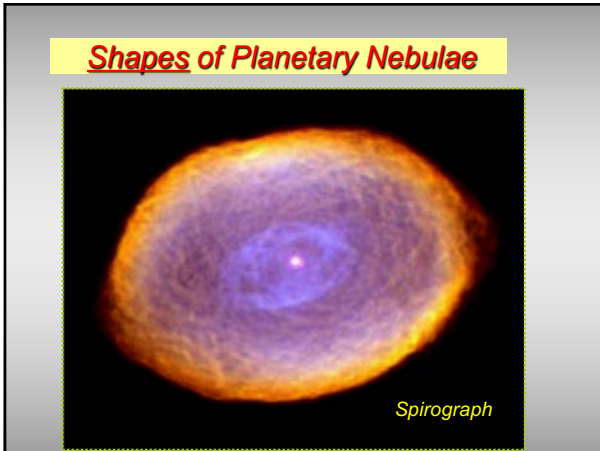
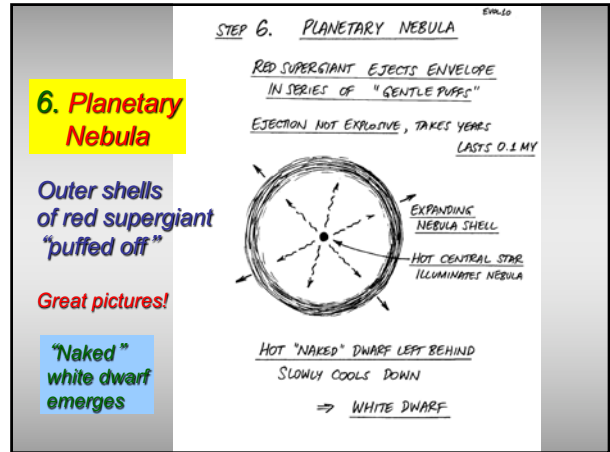
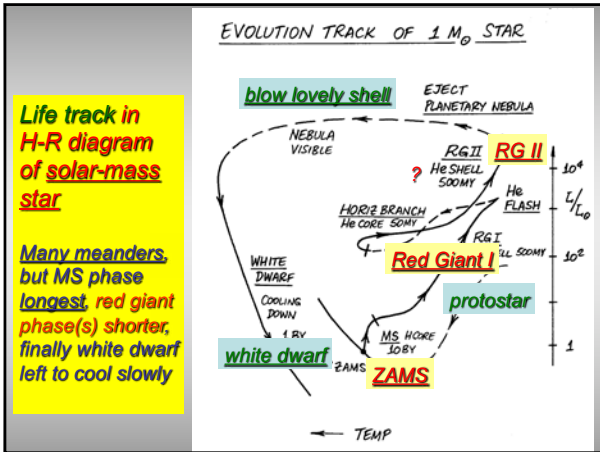
AS INERT, DEGENERATE HE CORE OF RED GIANT CONTRACTS, CORE GETS HOTTER & DENSER UNTIL AT ~120 MILLION K

HELIUM CORE BURNING STARTS WITH A BANG!

SINCE DEGENERATE GAS, THERMAL RUNAWAY PRODUCES **HELIUM FLASH !**

- SUPERN, INTENSE ENERGY RELEASE MAY BLOW OFF PART OF ENVELOPE (UNCOMMON)
- BUT FLASH RAISES CORE TEMP HIGH ENOUGH TO REMOVE ELECTRON DEGENERACY
- HE BURNING IN CORE CONTINUES, NOW REGULATED BY "THERMOSTAT" OF EXPANSION
- ON H-R, STAR MOVES LEFT ⇒ **HORIZONTAL BRANCH STAR**





7. White Dwarf

Inert C core,
He & H shells

electron degeneracy pressure holds it up

Very dense,
size of Earth

max mass of
 $1.4 M_{\text{sun}}$

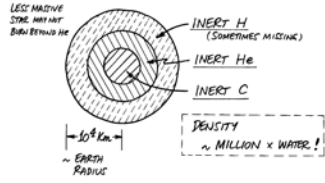
STEP 7. WHITE DWARF

FOR $1 M_{\odot}$ STAR, CARBON CORE

NEVER HOT ENOUGH TO BURN

⇒ HOT DWARF SITS & COOLS

VISIBLE ~
BY



HYDROSTATIC EQUILIBRIUM :

ELECTRON DEGENERACY PRESSURE VS. GRAVITY

ENERGY SOURCE :

NONE REQUIRED

MAY NOT EXCEED $1.4 M_{\odot}$ "CHANDRASEKHAR LIMIT"

... OR ELSE COLLAPSES FURTHER