ASTR 1040: Stars & Galaxies

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Lecture 14 Thur 27 Feb 2020

zeus.colorado.edu/astr1040-toomre

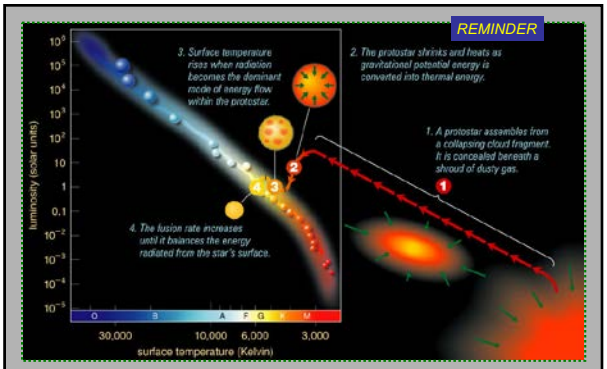
Topics for Today

- 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

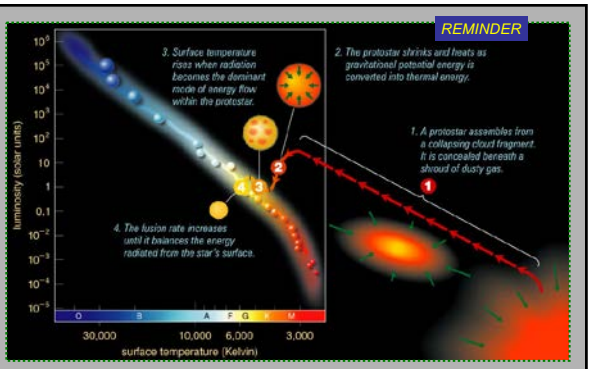
- Read Chap17 'Star Stuff', with 17.2 'Life as Low-Mass Star' covering today's lecture
- Then read 17.3 'Life as High-Mass Star' for next class … look over 18.3 Black Holes
- Homework #6 due today, new HW #7 passed out
- Overview on Stellar Evolution still available
- Next week: Observatory Night #5 on Tues, Fiske Planetarium on Thur

REMINDER



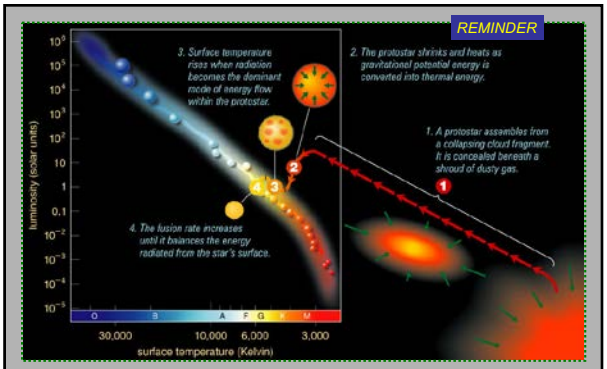
1 → 2: Collapsing protostar is first shrouded by cocoon of dusty gas, but then winds and jet blast through

REMINDER

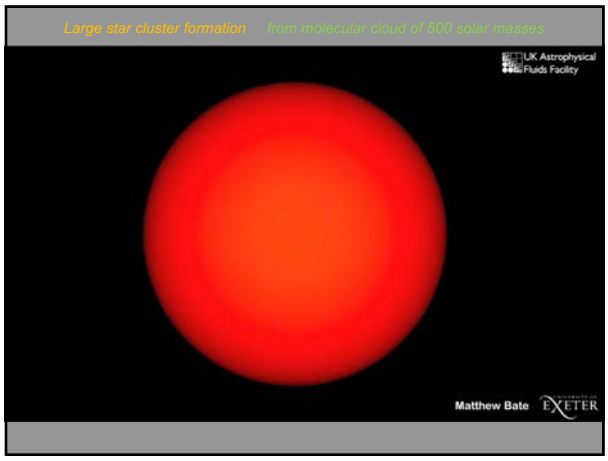


2: Collapse continues, temperature stabilizes as deep convection circulates energy outwards

REMINDER

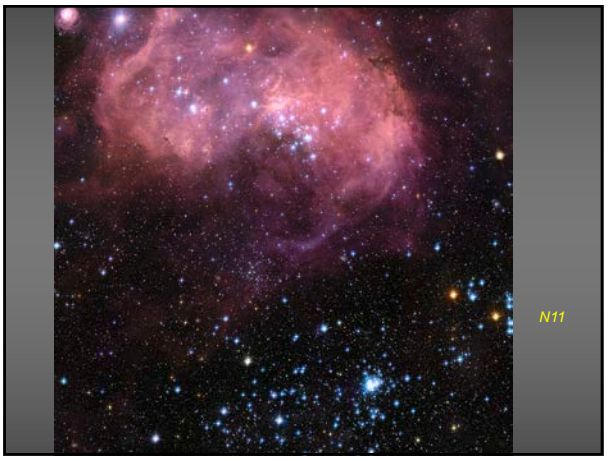


3 → 4: As core temperatures reach millions of degrees, fusion begins and stabilizes – star joins main sequence


Large star cluster formation
from molecular cloud of 500 solar masses
UK Astrophysical Fluids Facility
Matthew Bate
EXETER

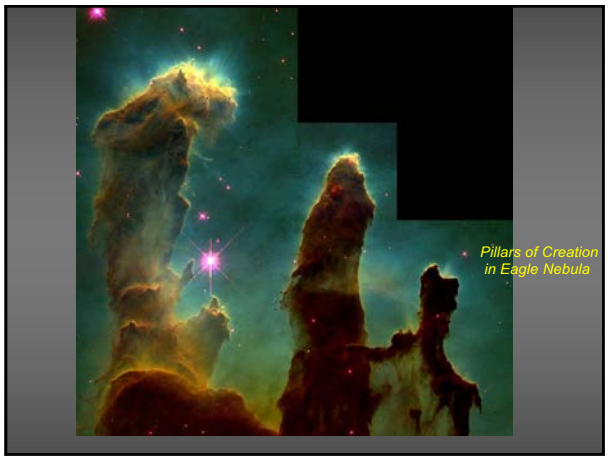

LH 95 in LMC


Lupus 3


N11


NGC2024
Flame
Nebula

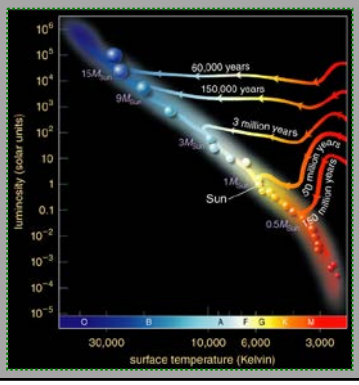

Westerhout40
in Aquila



Protostars of different masses follow different life tracks toward MS

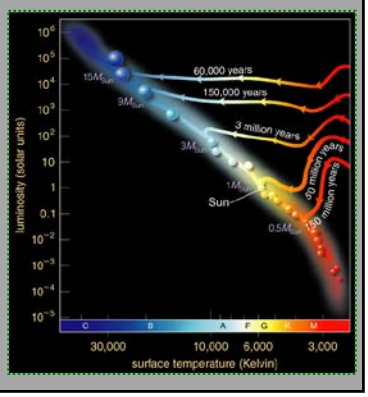
More massive stars go more quickly, and nearly horizontally across H-R diagram

Life now begins on "zero-age main sequence" (ZAMS)

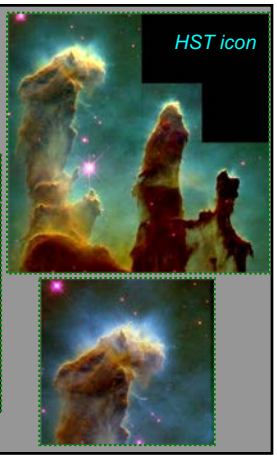


Starbirth and color

For every massive O-star that is born, there are ~200 low-mass M-stars also born !



Eagle Nebula: cold dark clouds are eroded by intense starlight



Reading Clicker -- life tracks

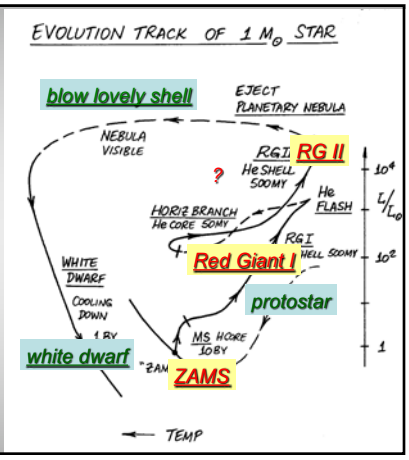
- *What can we find out about a star from its life track on the H-R diagram?*

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

Life track in H-R diagram of solar-mass star

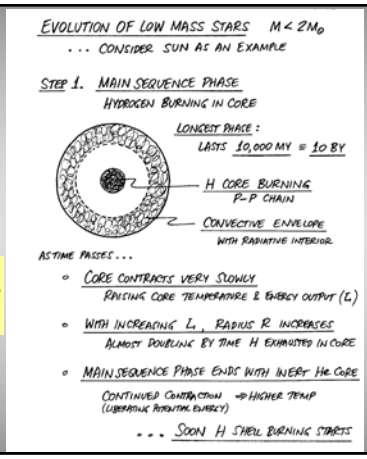
Many meanders, but MS phase longest, red giant phase(s) shorter, finally white dwarf left to cool slowly



1: Low-Mass Star on MS

H burning in core

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

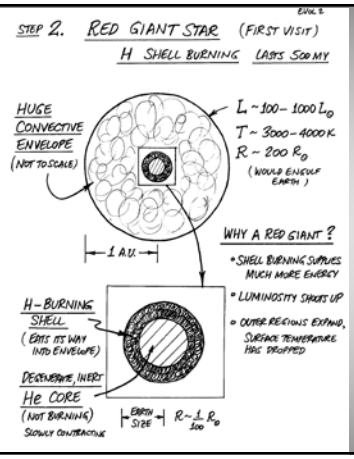


2: Subgiant to Red Giant (first visit)

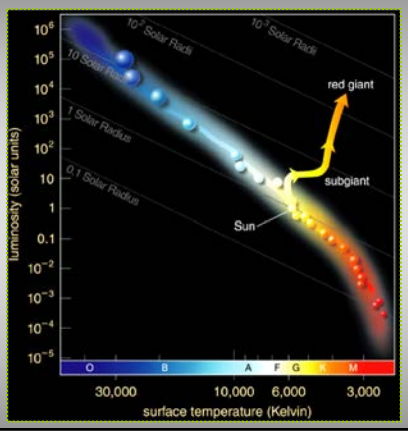
H burning in shell, makes much more energy

Vast expansion, RG phase lasts ~ 500 MY

Huge convective envelope

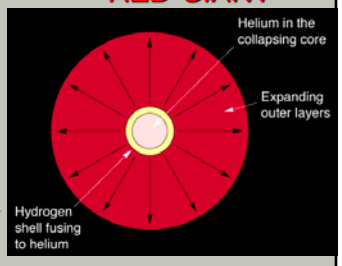


MS → subgiant → red giant



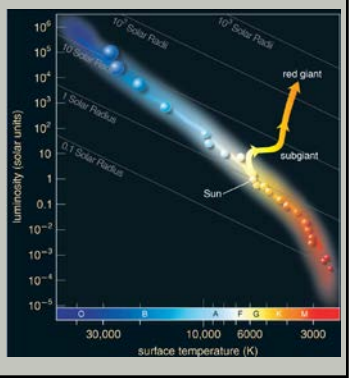
Without Fusion, the Core Starts to Contract

- *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 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



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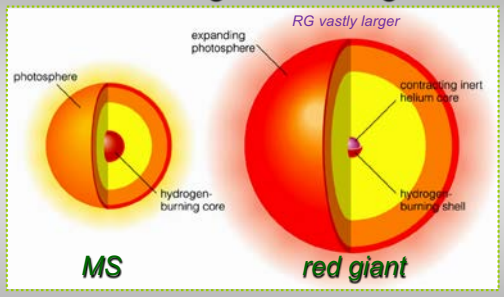
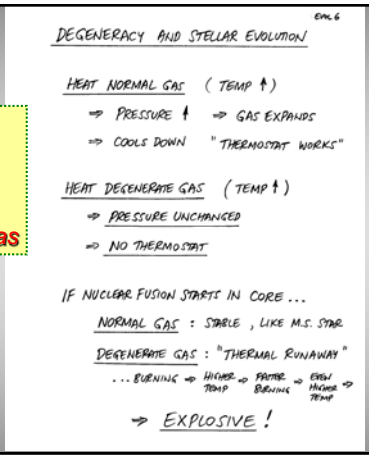


Contracting core in red giant gradually becomes "electron degenerate" -- what does that mean?

Oops!

Thermostat is missing in degenerate gas

Could get exciting!



DEGENERACY AND STELLAR EVOLUTION

HEAT NORMAL GAS (TEMP ↑)
⇒ PRESSURE ↑ ⇒ GAS EXPANDS
⇒ COOLS DOWN "THERMOSTAT WORKS"

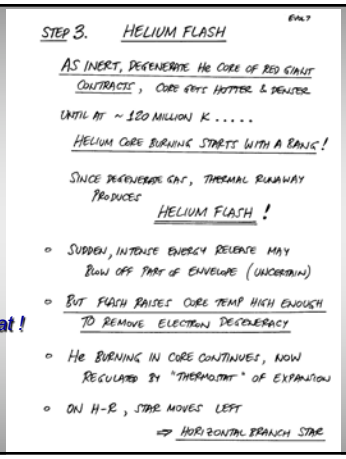
HEAT DEGENERATE GAS (TEMP ↑)
⇒ PRESSURE UNCHANGED
⇒ NO THERMOSTAT

IF NUCLEAR FUSION STARTS IN CORE ...
NORMAL GAS : STABLE , LIKE M.S. STAR
DEGENERATE GAS : "THERMAL RUNAWAY"
... BURNING ⇒ HIGHER TEMP ⇒ FASTER BURNING ⇒ EVEN HIGHER TEMP ⇒
⇒ EXPLOSIVE !

3: Helium Flash

He core burning -- removes electron degeneracy

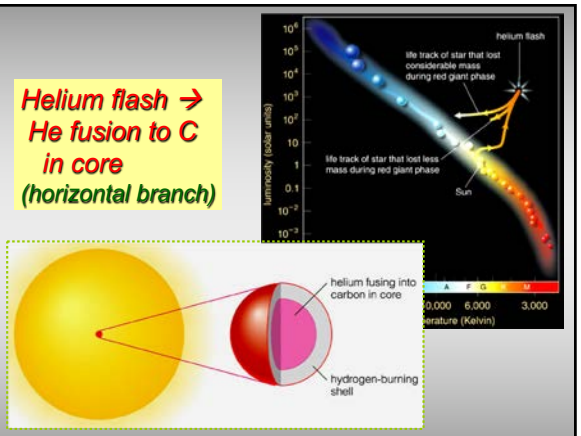
- He core burning now with thermostat !
- "horizontal branch star"



STEP 3. HELIUM FLASH

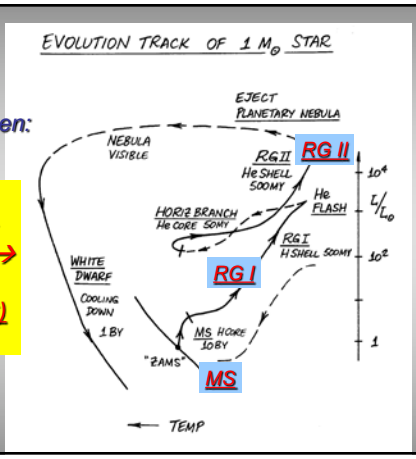
AS INERT, DEGENERATE He CORE OF RED GIANT CONTRACTS, CORE GETS HOTTER & DENSER
UNTIL AT ~ 120 MILLION K .....
HELIUM CORE BURNING STARTS WITH A BANG !
SINCE DEGENERATE GAS, THERMAL RUNAWAY PRODUCES HELIUM FLASH !
- SUDDEN, INTENSE ENERGY RELEASE MAY BLOW OFF PART OF ENVELOPE (UNCERTAIN)
- BUT FLASH RAISES 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

Helium flash → He fusion to C in core (horizontal branch)



Overview of what will happen:

MS → Red Giant I → Horiz Branch → Red Giant II (or Supergiant)

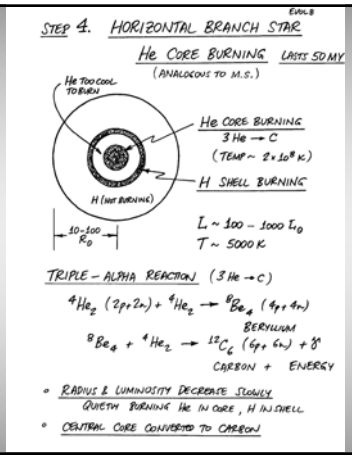


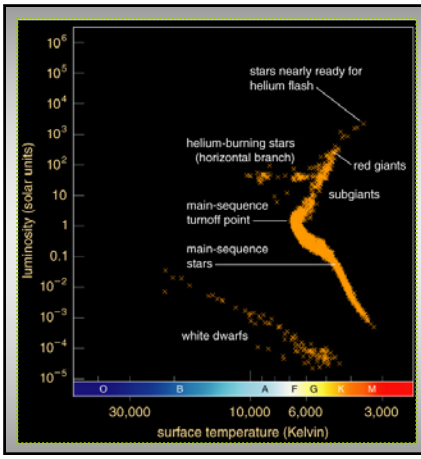
4: Horizontal branch star

He core burning, H shell burning

Short phase, lasts ~50 MY

Triple-alpha fusion: 3 He → C





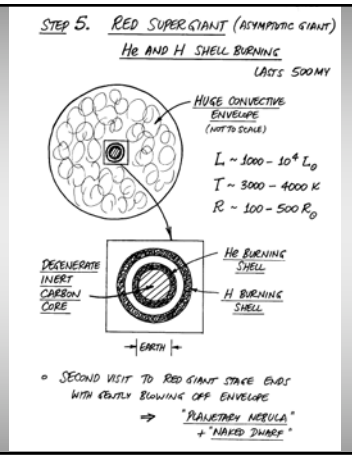
H-R diagram of globular cluster M4

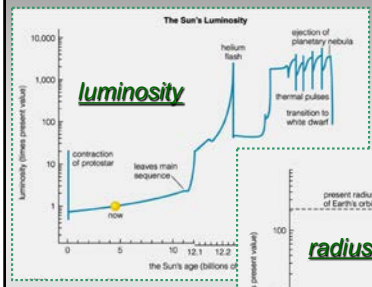
"City of Stars" What does it tell us? Why is it useful?

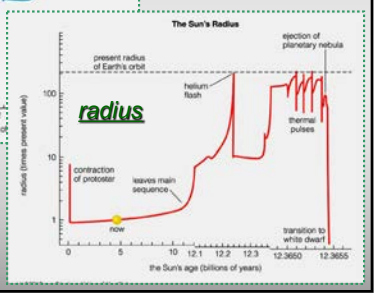
5. Red Supergiant

Double-shell burning of H and He

Phase could be very short if He burning is erratic (unstable) -- then lasts only a few MY, and blows off outer shells





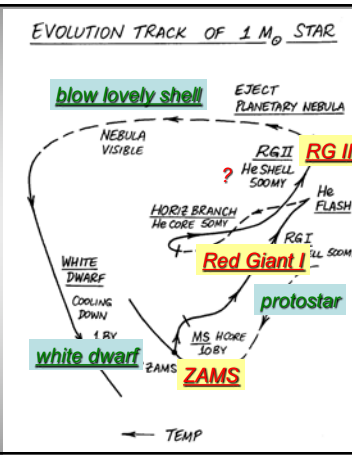


Sun in its "far future" ~5+ BY

Thermal pulses in red supergiant blow off outer shells

Life track in H-R diagram of solar-mass star

Many meanders, but MS phase longest, red giant phase(s) shorter, finally white dwarf left to cool slowly

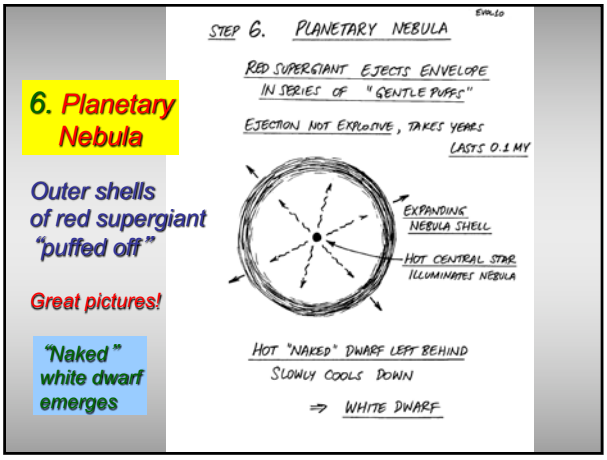


6. Planetary Nebula

Outer shells of red supergiant "puffed off"

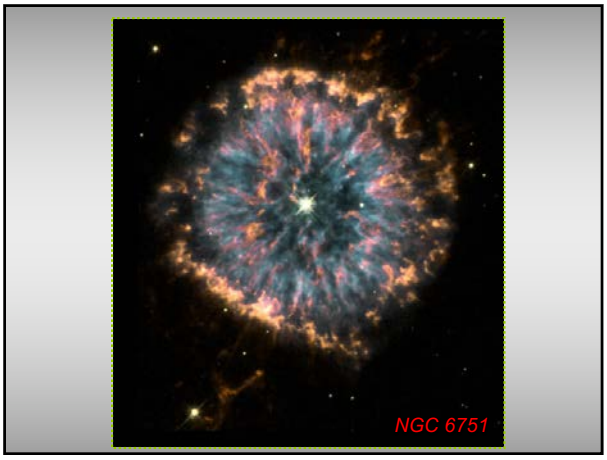
Great pictures!

"Naked" white dwarf emerges



Shapes of Planetary Nebulae

Spirograph



NGC 6751

Cat's Eye

NGC 7293: The Helix Nebula

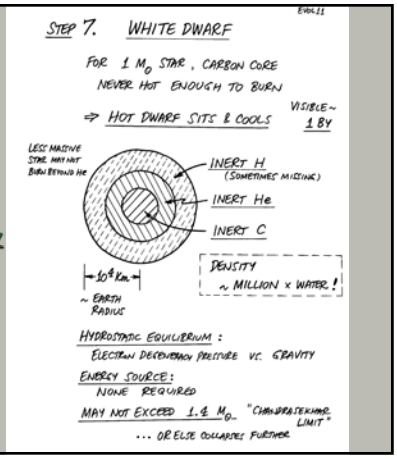
7. White Dwarf

Inert C core,
He & H shells

electron degeneracy pressure holds it up

Very dense, size of Earth

max mass of 1.4 M_{SUN}



Final stage:

Cooling white dwarf --- snooze ....

But if WD has binary companion, much fun can begin !