

ASTR 1040: Stars & Galaxies in Fiske Planetarium



Blinking Eye Nebula

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Lecture 15 Tues 7 Mar 2017
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Topics for Today & Thur

- Life tracks of massive stars: late stages allow fusion like "layers of an onion"
- Massive stars end life with **supernova explosion**, when iron core exceeds $1.4 M_{\text{sun}}$
- Pulsars – fast spinning neutron stars with fierce magnetic fields; gradually slow down
- We take a tour of our galaxy, then turn to **Black Holes** show

Things to do

- Review 17.3 'Life as High-Mass Star'
- Read **Chap 18: "Bizarre Stellar Graveyard"** and white dwarfs in detail, neutron stars next lecture
- Homework #6 now graded (plus answers), outside for pickup
- Review Set 2 for **Mid-Term Exam 2** next week on Thur (March 16)

Clicker review – red giants

- The **main source of energy** for a star as it grows in size to become a **red giant** is

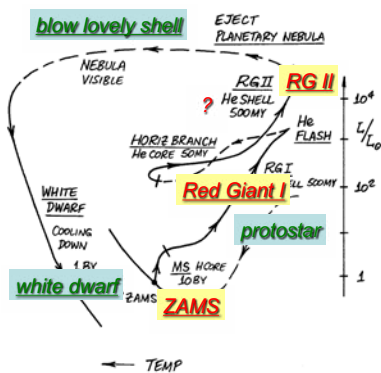
B.

- A. gravitational contraction
- B. hydrogen fusion in a shell around core
- C. helium fusion in the core
- D. hydrogen fusion in the core

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

EVOLUTION TRACK OF $1 M_{\odot}$ STAR



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

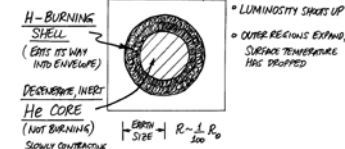
STEP 2. RED GIANT STAR REMINDER

H SHELL BURNING LAYS 500 MY



WHY A RED GIANT?

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



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

STEP 5. RED SUPERGIANT REMINDER

He AND H SHELL BURNING LASTS 500 MY

HUGE CONVECTIVE ENVELOPE (NOT TO SCALE)

$L \sim 1000 - 10^4 L_{\odot}$
 $T \sim 3000 - 4000 K$
 $R \sim 100 - 500 R_{\odot}$

DEGENERATE INERT CARBON CORE

HE BURNING SHELL
 H BURNING SHELL

→ SECOND VISIT TO RED GIANT STAGE ENDS WITH RAPID BLOWING OFF ENVELOPE ⇒ "PLANETARY NEBULA" + "NAKED DWARF"

6. Planetary Nebula

RED SUPERGIANT EJECTS ENVELOPE IN SERIES OF "GENTLE PUFFS"

EJECTION NOT EXPLOSIVE, TAKES YEARS LASTS 0.1 MY

Outer shells of red supergiant "puffed off"

Great pictures!

"Naked" white dwarf emerges

STEP 6. PLANETARY NEBULA

EXPANDING NEBULA SHELL

HOT CENTRAL STAR ILLUMINATES NEBULA

HOT "NAKED" DWARF LEFT BEHIND SLOWLY COOLS DOWN ⇒ WHITE DWARF



Life after brief "planetary nebula" stage

Hot central core emerges as

WHITE DWARF

Ring 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}

STEP 7. WHITE DWARF

FOR 1 M_⊙ STAR, CARBON CORE NEVER HOT ENOUGH TO BURN ⇒ HOT DWARF SITS & COOLS VISIBLE ~ 1 BY

LESS INERTIVE STAGE MAY NOT BURN BEHIND HE

INERT H (SOMETIMES MIXING)
 INERT He
 INERT C

DENSITY ~ MILLION X WATER!
 ~ 10⁴ Km
 ~ EARTH RADIUS

HYDROSTATIC EQUILIBRIUM: ELECTRON DEGENERACY PRESSURE VS. GRAVITY

ENERGY SOURCE: NONE REQUIRED

MAY NOT EXCEED 1.4 M_⊙ "CHANDRASEKHAR LIMIT" ... OR ELSE COLLAPSES FURTHER

Final stage: Cooling white dwarf --- snooze

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

EVOLUTION TRACK OF 1 M_⊙ STAR

NEBULA

EJECT PLANETARY NEBULA

NEBULA VISIBLE

RG II He SHELL SOONY

He FLASH

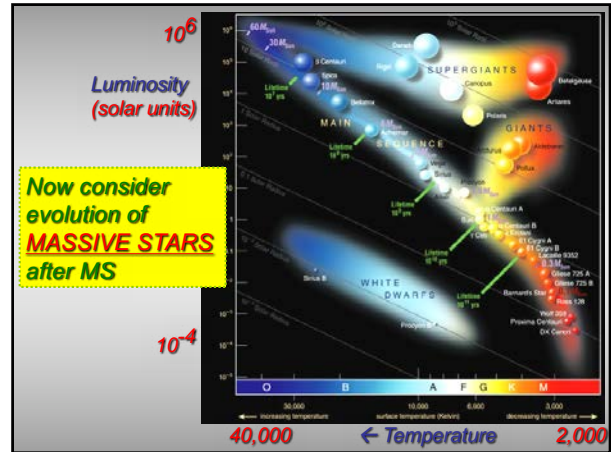
RG I SHELL SOONY

MS HORSE SHOBY

COOLING DOWN 1 BY

WHITE DWARF

TEMP



Evolution of massive stars

Clock runs faster, can burn heavier elements

First 4 steps pretty familiar, but no helium flash

EVOLUTION OF MASSIVE STARS $M > 2M_{\odot}$

SO WHAT IS DIFFERENT?

"CLOCK" CAN RUN MUCH FASTER
CAN BURN MORE ELEMENTS (C, O, Ne, Si...)
FINAL FATE CONTROLLED BY HOW MUCH MASS LOST BY STRONG WINDS

- 1. MAIN SEQUENCE** H CORE BURNING, C-N-O CYCLE
STELLAR WINDS $M \downarrow$ ($4H \rightarrow He$)
- 2. RED GIANT I** H SHELL BURNING
INSERT HE CORE SLOWLY CONTRACTING
- 3. HORIZONTAL BRANCH** LEFT BRANCH, NO DEGENERACY IN He CORE (IF $M > 1.5M_{\odot}$)
 \rightarrow NO HELIUM FLASH
SMOOTH TRANSITION TO HE CORE BURNING: TRIPLE- α ($3He \rightarrow C$)
- 4. RED GIANT II (SUPERGIANT)** HE SHELL BURNING STARTED, H CONTINUES TO BURN IN SHELL
INSERT C CORE SLOWLY CONTRACTING, MAY BECOME DEGENERATE MATTER!

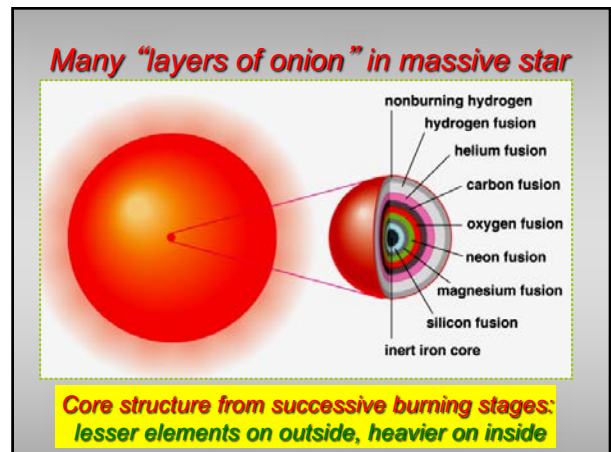
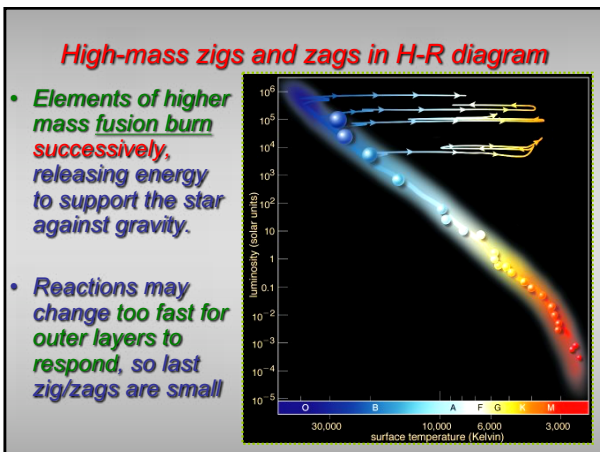
Successive core & shell fusion of C, O, Ne, Si ..

all with "alpha capture" (or He)

stars make many shallow H-R loops

MASSIVE STARS ...

- 5. CARBON FLASH** INITIATE CARBON BURNING IN DEGENERATE CORE WITH EXPLODIVE FLASH
"ALPHA CAPTURE"
 $C + He \rightarrow O + ENERGY$
A. EXPLODE AS SUPERNOVA TYPE I OR
B. REMOVE DEGENERACY, BURN QUIETLY IN STAGES TO PRODUCE IRON IN CORE
- 6. HORIZ. BRANCHES, RED SUPERGIANTS** (MANY LOOPS IN H-R DIAGRAM!)
AT CENTER OF SUPERGIANT
IF $M > 8M_{\odot}$:
SUCCESSIVE STAGES OF CORE AND SHELL IGNITION
"ONION RING" STRUCTURE OF BURNING SHELLS
H SHELL
He SHELL
O...
Ne...
C BURNING SHELL
Si BURNING SHELL
INERT Fe CORE



Fusion by "helium-capture" (alpha-particles) burns C, O, Ne, Mg, Si .. "layers of onion"

- Helium nucleus (2 protons) is absorbed, energy is released
- Elements are created going up periodic table in steps of 2

Creation of elements from He-capture: evidence

Even numbers favored!

- Mixture of elements in our near universe follows the pattern of He-capture fusion reactions, up to iron
- Even heavier elements are made by nucleosynthesis during supernova explosion

A few of many other fusion reactions also feasible in high-mass stars

"Onion-shell fusion burning" stops with IRON (Fe, 26 protons)

CARTOON

Iron does NOT release energy when it fuses!

Several fates for massive star

1. Strong winds shrink star, may end as WHITE DWARF

2. Or core burns to Fe, eventually sudden CORE COLLAPSE! → SUPERNOVA

FINAL FATE OF MASSIVE STAR

TWO POSSIBILITIES

1. LOSES ENOUGH MASS IN WIND / PLANETARY NEBULA
 $< 1.4 M_{\odot}$ LEFT → WHITE DWARF
 (W.D. COMPOSED OF HEAVIEST ELEMENTS PRODUCED)
2. ENTIRE CORE BURNS TO IRON
 NO MORE NUCLEAR ENERGY CAN BE RELEASED!
AND $> 1.4 M_{\odot}$ LEFT
 COLLAPSE CANNOT BE STOPPED BY ELECTRON DEGENERACY PRESSURE
 ⇒ NEUTRON STAR
 OR
BLACK HOLE

Now on to travels within our galaxy with the big-sky of the planetarium

... and then the black-holes program