ASTR 1120: Stars & Galaxies

30 Doradus: star forming region

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Lecture 18 Mon 21 Feb 05
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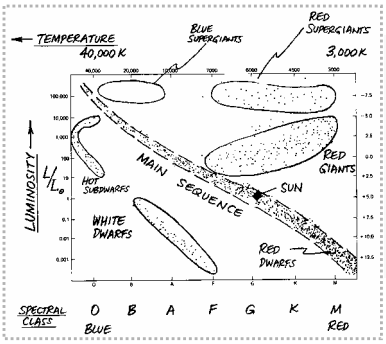
Topics Today

- See how *C-N-O fusion cycle* makes the vast energy released by massive stars
- *Clusters of stars* can be used to test our ideas about lifetimes on MS
- Then begin to look at what happens to star like the Sun *after exhausting H in core* -- post MS
- *Observatory Night #4* tomorrow, Tues, by signup
- *Planetarium #2 this Friday* – <u>class meets in Fiske</u>: Ben Brown, *"Birth of Stars"*

Main sequence (MS) stars



Burning <u>hydrogen in their cores</u>

<u>Temperatures are hotter</u> for more massive stars (crush of gravity)

<u>More luminous</u> (higher fusion rates)

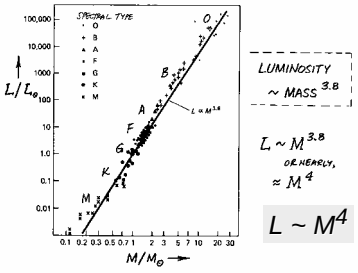
REMINDER

"Observed" MASS -- LUMINOSITY relation for main sequence

Why such a <u>steep increase of L with M</u> ?

Need higher central P (and T) to support star -- and fusion burning goes much faster !

MASS-LUMINOSITY RELATION
MAIN SEQUENCE STARS



LUMINOSITY ~ MASS$^{3.8}$

$L \sim M^{3.8}$ OR NEARLY, $\approx M^4$

$L \sim M^4$

MASSES DETERMINED MOSTLY FROM BINARY PAIRS

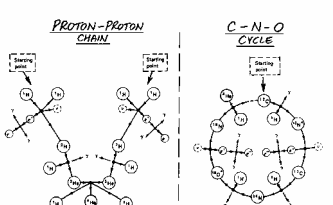
⇒ MAIN SEQUENCE IS REALLY A SEQUENCE IN STELLAR MASS (NOT EVOLUTION!)

P-P Chain & C-N-O Cycle

Both fusion processes occur in parallel, but C-N-O makes <u>far more energy</u> at higher temperatures

Stars hotter than F1, C-N-O wins

THERMONUCLEAR FUSION : HYDROGEN BURNING

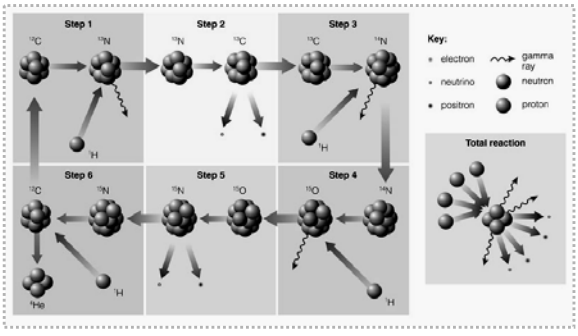


C-N-O CYCLE DOMINATES ENERGY PRODUCTION AT HIGHER TEMPERATURES :

$^{12}C_6 + {}^1H_1 \rightarrow {}^{13}N_7^* + \gamma$
$^{13}N_7^* \rightarrow {}^{13}C_6 + e^+ + \nu$
$^{13}C_6 + {}^1H_1 \rightarrow {}^{14}N_7 + \gamma$
$^{14}N_7 + {}^1H_1 \rightarrow {}^{15}O_8^* + \gamma$
$^{15}O_8^* \rightarrow {}^{15}N_7 + e^+ + \nu$
$^{15}N_7 + {}^1H_1 \rightarrow {}^{12}C_6 + {}^4He_2$

⇒ 4 HYDROGEN + CARBON → HELIUM + ENERGY + CARBON TO RECYCLE !

C-N-O Fusion Cycle



Can provide <u>vast luminosity</u> for massive stars on MS

REMINDER

How long can MS stars burn H in their cores?

More massive star have (very) short lives !

TIME TO BURN UP HYDROGEN IN CORE
... OR "LIFE ON MAIN SEQUENCE"

OTHER STARS COMPARED TO SUN:

ENERGY: $E_{TOTAL} \propto$ MASS $(\propto M)$ — L PROPORTIONAL TO

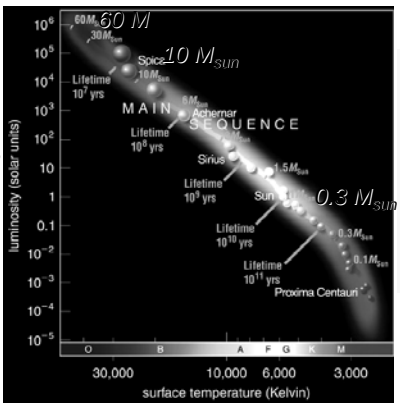
LUMINOSITY: $L \propto (\text{MASS})^{3.8}$ $(\simeq M^4)$ ← MASS-LUMINOSITY RELATION

LIFETIME: $t_{LIFE} \sim \frac{E_{TOTAL}}{L} \propto M^{-3}$ (ROUGHLY)

⇒ MASSIVE STARS HAVE SHORT LIVES !

MASS $(M_\odot)$	LIFETIME (MILLION YEARS)
1	10,000 MY = 10 BY
2	700
3	250
5	70
10	20
15	10
30	5

(LEVELS OFF AT A FEW MY)



Thus we get this huge range of LIFETIMES on MS

Higher on MS, higher MASS, shorter LIFE

Clicker: Main Sequence

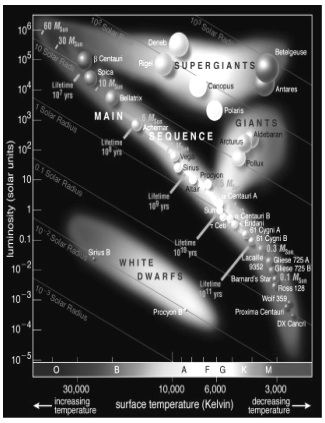
- *Jen and Ben are two main sequence stars: Jen is an M star and Ben is a B star. Which is more massive ? Which is redder in color ?*

D.

- A. Jen is more massive and redder
- B. Ben is more massive and redder
- C. Jen is more massive; Ben is redder
- D. Ben is more massive; Jen is redder

Who is who ?

- *Jen is an M star -- far to the right (red) on the HR diagram*
- *Ben is a B star, bluer and (for main sequence stars) more massive*
- *D. Ben is more massive, Jen is redder*



Main Sequence:

range of stellar properties

L range is biggest !

THE MAIN SEQUENCE:

MSPROP

STARS BURNING HYDROGEN IN CORE

RANGE OF PROPERTIES

(RED GIANTS, WHITE DWARFS NOT MAIN SEQUENCE STARS: SHOW DIFFERENT EXTREMES OF R, L ...)

SUN IS "INTERMEDIATE" MAIN SEQ STAR

MASS: 0.01 → 100 $M_\odot$

TEMPERATURE: (SURFACE) ~ 2000 → 100,000 °K

RADIUS: 0.01 → 100 $R_\odot$

LUMINOSITY: 0.0001 → 100,000 $L_\odot$

LUMINOSITY ~ $(\text{MASS})^{3.8}$

RADIUS ~ $(\text{MASS})^{0.75}$ (ROUGHLY)

How MS stars do it

THEORY OF MAIN SEQUENCE STARS

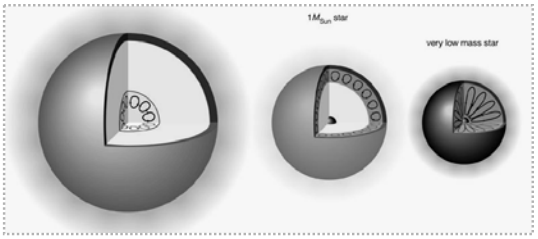
SAME 3 PRINCIPLES AS SUN !

1. HYDROSTATIC EQUILIBRIUM:
   INTERIOR HOT AND DENSE
   ⇒ HIGH PRESSURE TO BALANCE GRAVITY
2. ENERGY TRANSPORT: FROM CORE TO SURFACE
   BY RADIATION — PHOTONS "RANDOM WALK" OUTWARD
   BY CONVECTION — ENERGY CARRIED BY TURBULENT MOTIONS
   $M \leq 1 M_\odot$: RADIATIVE CORE & CONVECTIVE ENVELOPE
   $M \geq 1 M_\odot$: CONVECTIVE CORE & RADIATIVE ENVELOPE
3. NUCLEAR ENERGY GENERATION:
   $M \leq 2 M_\odot$ "P-P CHAIN"
   $M \geq 2 M_\odot$ "C-N-O CYCLE"
   (F1 CHANGEOVER)

ALL BURN $4\,H \Rightarrow {}^4He$ IN CORE

"DEFINITION" OF MAIN SEQUENCE STAR !

Differing convection and radiation zones on MS



High mass:	*Solar mass:*	*Low mass:*
convective core, deep radiative envelope	*radiative interior, convective envelope*	*very deep convective envelope*

Deeper convection may yield fiercer magnetic dynamos

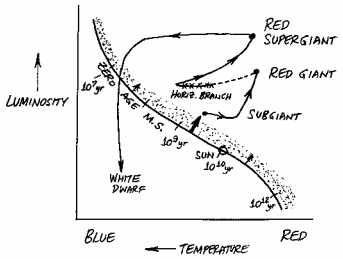
IS THERE LIFE AFTER THE MAIN SEQUENCE?

YES .... READ ABOUT IT IN H-R DIAGRAM!

STELLAR EVOLUTION STORY TO FOLLOW WITH SOME DETAIL ....

Life AFTER main sequence

Stars evolve off MS, not along it !



Now let us test such ideas with star clusters

STAR CLUSTERS – two varieties

both are groups of star that have evolved together -- great for testing ideas about evolution of stars

Globular cluster — *old, millions of stars*

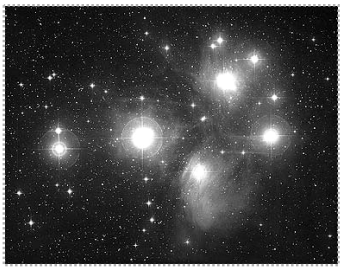
Open cluster — *young, thousands of stars*

Globular clusters -- *much older, bigger*

- generally *much older* -- up to 13 BILLION years
- made up of *millions of stars*, very densely packed

Open star cluster: Pleiades

- "Open cluster" only about 100 MY old – involves *several thousand stars*
- Unlike Sun's age of 4.6 BY



Bright B-type stars, O stars now missing

Clusters can test lifetimes on main sequence

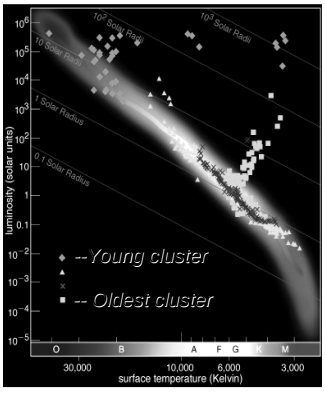
Great advantages:

All stars at about same distance (apparent brightness tracks luminosity)

All formed at about same time

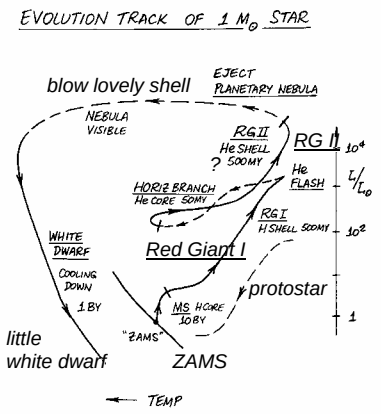
Range of different mass stars !

Stars "peel off" MS as core H exhausted → red giants



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



Next Events

- *Continue reading 17.3 Life as Low-Mass Star, looking at shell burning red giant phase*