ASTR 1040: Stars & Galaxies

Etched Hourglass Nebula

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Lecture 12 Thur 23 Feb 2017

zeus.colorado.edu/astr1040-toomre

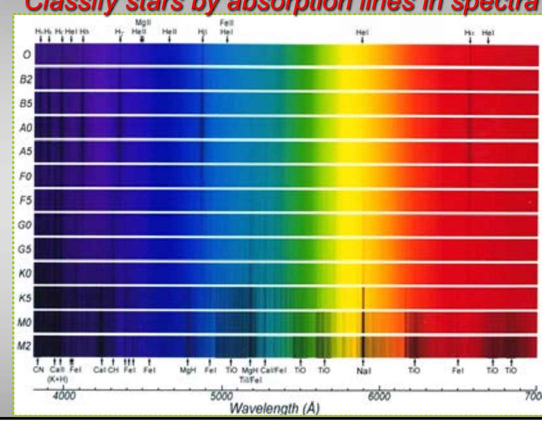
Stuff to do

- Paper shuffle: Homework #5 due, new HW #6 passed out. Graded MT-Exam 1 still available, and so too HW #4, plus answers
- Observatory #3 nominally tonight, but dubious -- Observ #4 next on Tues Feb 28
- Re-read 15.3 Star Clusters with care
- Read 16.1 "Stellar Nurseries" & 16.2 "Stages of Star Birth" for Tues lecture (getting to the Main Sequence)

Topics for Today

- Brief review of roadmap to the stars: Hertzsprung-Russell (H-R) diagram
- Binary stars allow us to measure MASS
- Why O and B stars are so luminous on MS?
- C-N-O cycle dominates fusion burning of H in massive stars, really pours out the energy
- Explains observed MASS-LUMINOSITY relation
- Estimate lifetime on the main sequence (MS)
- What star clusters can tell us

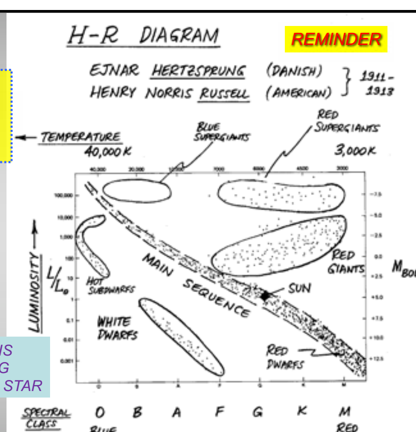
Classify stars by absorption lines in spectra



Hertzsprung-Russell (H-R) Diagram

Luminosity (magnitude) vs Spectral class (temperature)

… BUT TO MAKE THIS REQUIRES KNOWING DISTANCE TO EACH STAR



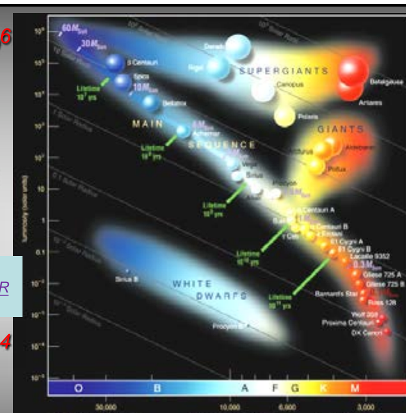
10^6

Luminosity

(solar units)

NOTE DIAGONAL LINES OF STELLAR RADII HERE

10^{-4}



40,000 ← Temperature 3,000

Further refinements:

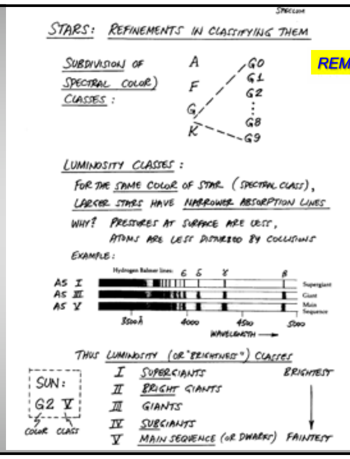
DECIMAL SUBDIVISION

LUMINOSITY CLASSES

Sun is: G2 V

COLOR CLASS

REMINDER



Why do spectra of hottest stars (O and B types) show few absorption lines?

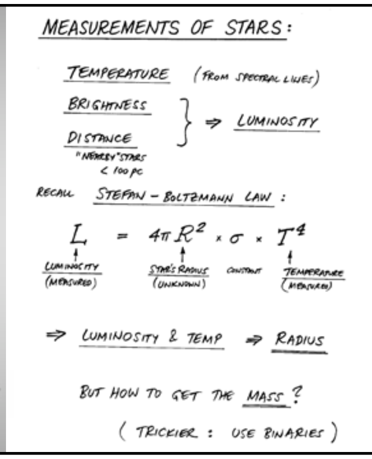
E.

- A. Many elements have been used up in these stars
- B. These stars are old and were formed before there were many elements in the galaxy
- C. Many atoms in these stars are ionized – have lost electrons – so can't absorb
- D. Much of their absorption is in the ultraviolet
- E. C and D

Estimating the size of a star – its RADIUS

Stefan-Boltzmann

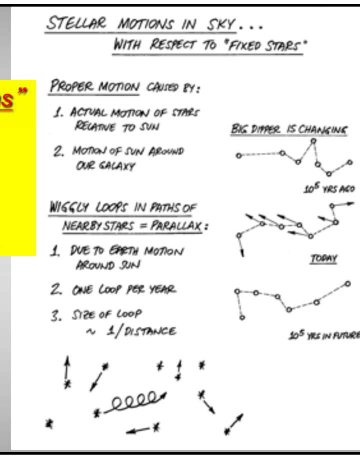
But how to measure MASS: … binary stars



"Proper motions"

wiggly motions (parallax)

and binaries …

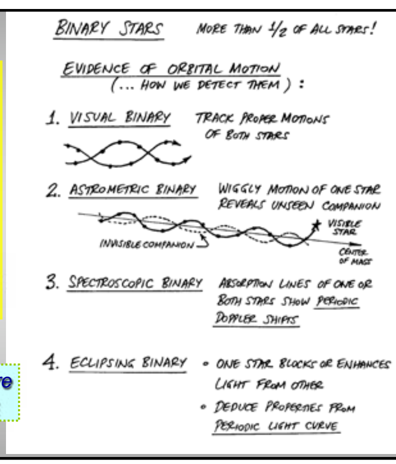


BINARY STARS

4 varieties:

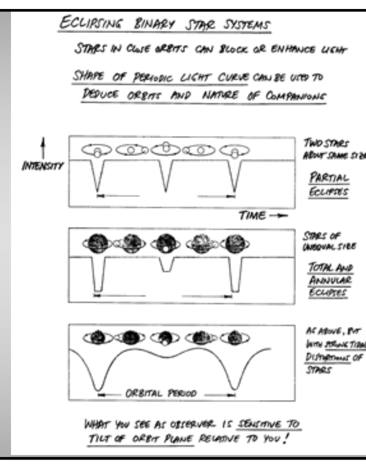
Visual
Astrometric
Spectroscopic
Eclipsing

Use to measure stellar masses

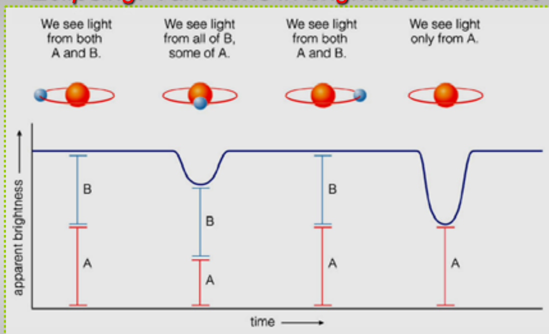


Eclipsing binaries

one star gets in front or behind other



Eclipsing: Variations in brightness with time



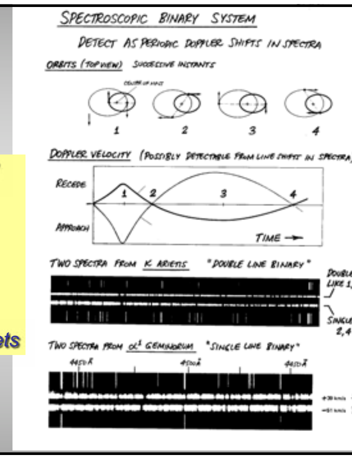
Very useful (can even infer stellar radii), but RARE … viewing angle has to be right on edge!

Spectroscopic binaries

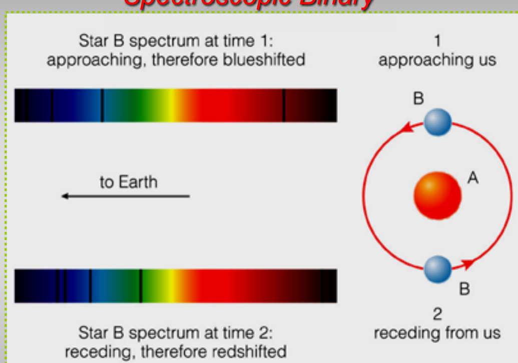
Most common of all

Do not see stars individually -- but see shifting absorption lines

Sometimes TWO sets

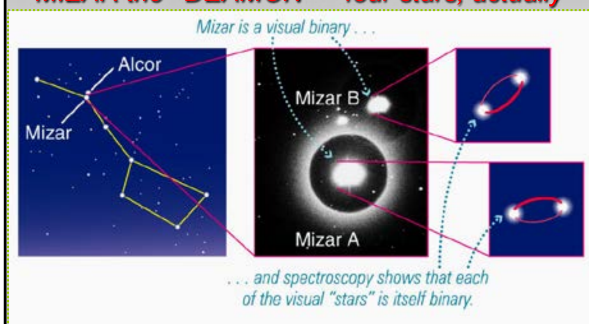


Spectroscopic Binary



Harder to interpret, since do not know viewing angle

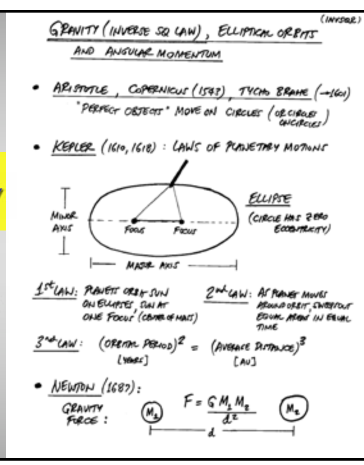
MIZAR the "DEAMON" – four stars, actually



Recall from Chap 3 :

KEPLER devised 3 laws for planetary (or stellar) motions

In 1687, NEWTON explained them as balance of gravity and centrifugal force



So why all the fuss with BINARIES?

Can really "weigh" a star !

STELLAR MASSES can be inferred from watching orbits

(via law of gravity – Kepler and Newton)

DOUBLE STARS: WEIGHING THEM

BINARIES HELP DETERMINE STELLAR MASS & RADIUS

MEASURE : PERIOD (EASY)
ORBITAL SPEED (SPECTROSCOPIC BINARIES)
SEPARATION (VISUAL BINARIES)

RECALL KEPLER'S THIRD LAW :

$$(M_1 + M_2) \times P^2 = a^3$$

MASSES, SOLAR UNITS (UNKNOWN) — PERIOD, YEARS (MEASURED) — SEPARATION, A.U. (EARTH-SUN DIST) (MEASURED)

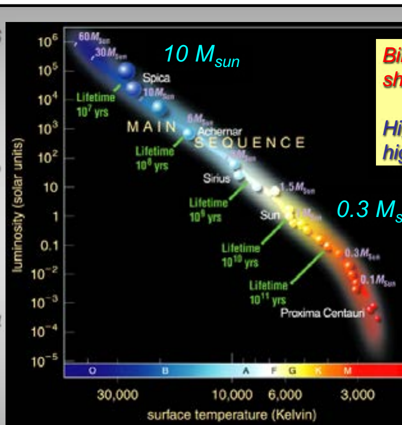
⇒ PERIOD & SEPARATION ⇒ MASS

ECLIPSING BINARIES :
ORBITAL SPEED & ECLIPSE DURATION
⇒ RADIUS
(INDEPENDENT MEASURE)

10^6

L / L_o

10^{-4}



40,000 ← Temperature 3,000

Binary stars show:

Higher on MS, higher MASS

But how long does a star live there ?

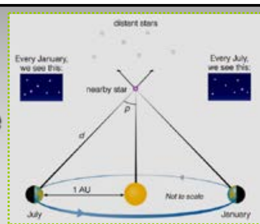
Brightness / Distance Clicker Q

B.

- Leonardo and Guinevere are two stars that have the same apparent brightness. Leonardo has a larger parallax angle than Guinevere. Which star is more luminous?

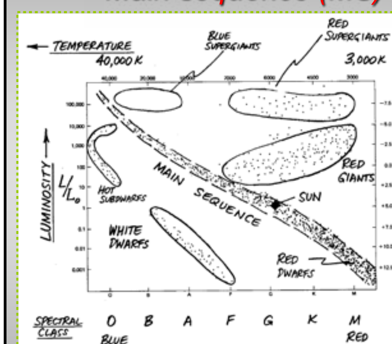
- A. Leonardo
- B. Guinevere
- C. Cannot determine from data given

Brightness vs Distance



- Leonardo has a larger parallax angle -- thus he is closer to us
- They both have the same APPARENT brightness, but Leo is closer
- B. Guinevere must be more luminous

Main sequence (MS) stars



Burning hydrogen in their cores

Central temperatures are hotter for more massive stars (crush of gravity)

More luminous (higher fusion rates)

Lifetimes on Main Sequence (MS)

- Stars spend 90% of their lives on MS
- Lifetime on MS = amount of time star burns hydrogen (gradually) in its core

- For Sun, this is about 10 billion years
- For more massive stars (OBAF), lifetime is (much) shorter
- For less massive stars (KM), lifetime is longer
- But how do we get these numbers?

Look at broad sample, to figure out any lifespan

- Stars take millions to billions of years to go through their life stages - we rarely see a single star change

- Observing many different stars lets us figure out the sequence of a single star's life

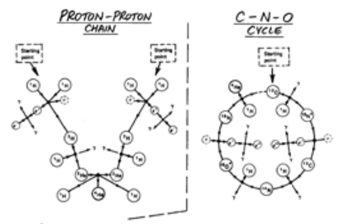
P-P Chain & C-N-O Cycle

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

Stars hotter than F1, C-N-O wins

THERMONUCLEAR FUSION : HYDROGEN BURNING

PROTON-PROTON CHAIN | C-N-O CYCLE



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

$^{12}C_6 + {}^1H_1 \rightarrow {}^{13}N_7^* + \gamma$

$^{13}N_7^* \rightarrow {}^{13}C_6 + e^+ + \nu$

$^{13}C_6 + {}^1H_1 \rightarrow {}^{14}N_7 + \gamma$

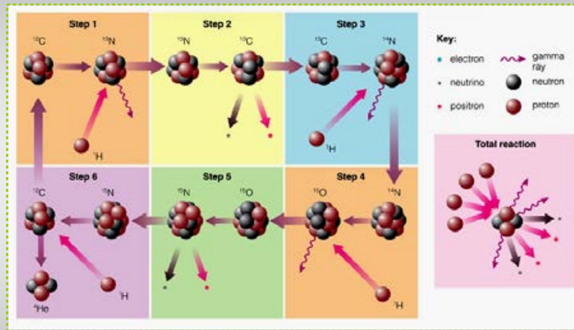
$^{14}N_7 + {}^1H_1 \rightarrow {}^{15}O_8^* + \gamma$

$^{15}O_8^* \rightarrow {}^{15}N_7 + e^+ + \nu$

$^{15}N_7 + {}^1H_1 \rightarrow {}^{12}C_6 + {}^4He_2$

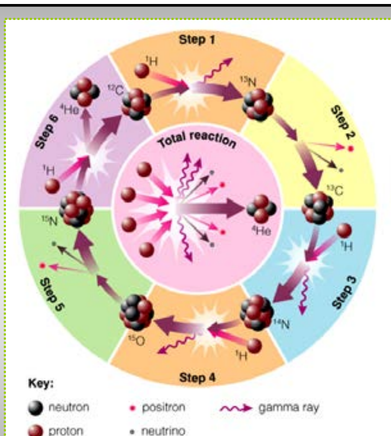
4 HYDROGEN + CARBON ⇒ HELIUM + ENERGY + CARBON TO RECYCLE !

C-N-O Fusion Cycle



Can provide vast luminosity for massive stars on MS

C-N-O Cycle (another view)



Main Sequence: range of stellar properties

L range is biggest !

THE MAIN SEQUENCE :
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) : ~ 2,000 → 100,000 °K

RADIUS : 0.01 → 100 $R_\odot$

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

LUMINOSITY ~ $(MASS)^{3.8}$

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

"Observed" MASS -- LUMINOSITY relation for main sequence

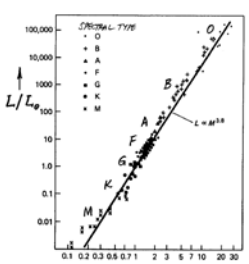
But why such a steep variation with mass ?

BIGGER CRUSH OF GRAVITY needs…

→ HIGHER central PRESSURE (or temperature)

→ FASTER BURNING (CNO-fusion-cycle comes into play)

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!)

How long can 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: $E_{TOTAL} \propto MASS \ (\propto M)$ (PROPORTIONAL TO)

LUMINOSITY: $L \propto (MASS)^{3.8} \ (\approx M^4)$ ← 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)