


**ASTR 1040: Stars & Galaxies**



Etched Hourglass Nebula

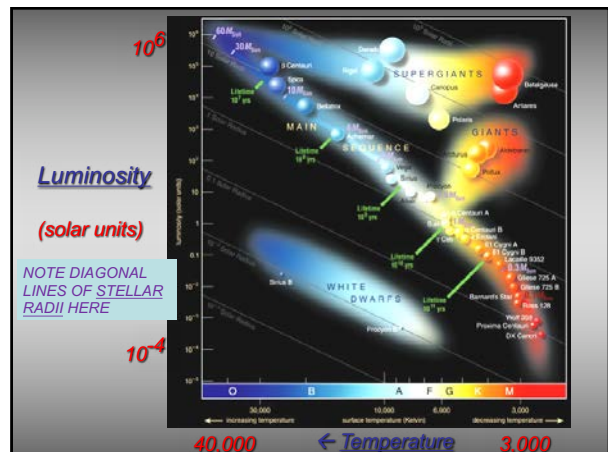
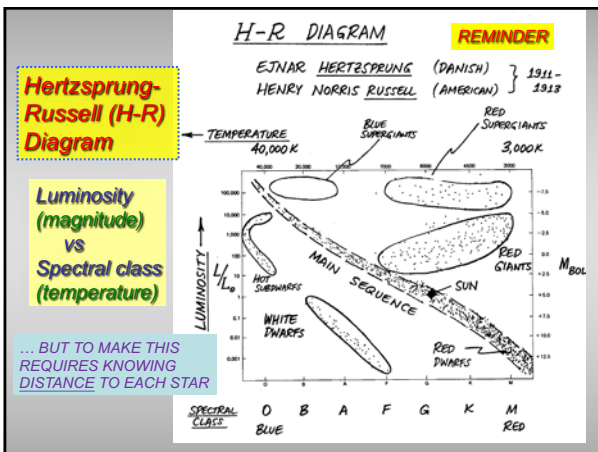
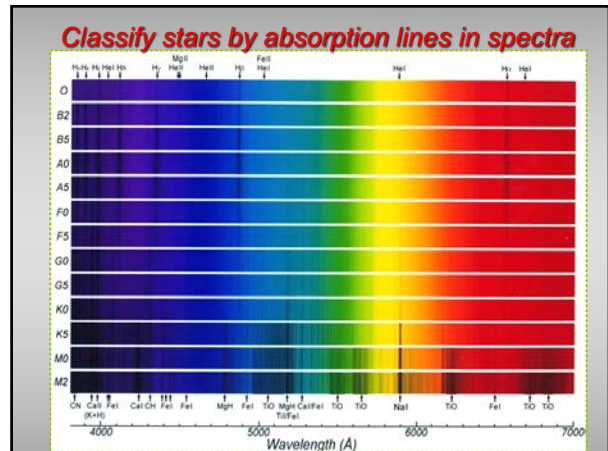
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Lecture 12 Thur 23 Feb 2017  
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**Stuff to do**

- **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



**Further refinements:**

**DECIMAL SUBDIVISION**

**LUMINOSITY CLASSES**

**Sun is: G2 V**

**COLOR CLASS**

**STARS: REFINEMENTS IN CLASSIFYING THEM**

**REMINDER**

SUBDIVISION OF SPECTRAL COLOR CLASSES:

```

    A --- G0
    |   |
    F   G1
    |   |
    G   G2
    |   |
    K   G3
    |   |
    --- G4
    
```

LUMINOSITY CLASSES:

FOR THE SAME COLOR OF STAR (SPECTRAL CLASS), LARGER STARS HAVE NARROWER ABSORPTION LINES

WHY? PRESSURES AT SURFACE ARE GREATER, ATOMS ARE LESS DISTURBED BY COLLISIONS

EXAMPLE:

AS X: [Spectral lines diagram]

AS Y: [Spectral lines diagram]

3000Å 4000Å 6000Å 8000Å

THIS LUMINOSITY (OR "TECHNICAL") CLASSIFICATION:

SUN: G2 V

COLOR CLASS

I: SUPERGIANTS

II: BRIGHT GIANTS

III: GIANTS

IV: SUBGIANTS

V: MAIN SEQUENCE (OR DWARF) FAINTLY

**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**

**MEASUREMENTS OF STARS:**

TEMPERATURE (from spectral lines)

BRIGHTNESS } ⇒ LUMINOSITY

DISTANCE } (NEARBY STARS < 100 PC)

RECALL STEFAN-BOLTZMANN LAW:

$$L = 4\pi R^2 \times \sigma \times T^4$$

LUMINOSITY (MEASURED) = STAR'S RADIUS (UNKNOWN) × CONSTANT × TEMPERATURE (MEASURED)

⇒ LUMINOSITY & TEMP ⇒ RADIUS

BUT HOW TO GET THE MASS?

(TRICKIER: USE BINARIES)

**"Proper motions" wiggly motions (parallax) and binaries ...**

**STELLAR MOTIONS IN SKY... WITH RESPECT TO "FIXED STARS"**

PROPER MOTION CAUSED BY:

- ACTUAL MOTION OF STARS RELATIVE TO SUN
- MOTION OF SUN AROUND OUR GALAXY

BIG DIPPER IS CHANGING

10<sup>6</sup> YEARS AGO

WIGGLY LOOPS IN PATHS OF NEARBY STARS = PARALLAX:

- DUE TO EARTH MOTION AROUND SUN
- ONE LOOP PER YEAR
- SIZE OF LOOP ~ 1/DISTANCE

10<sup>6</sup> YEARS IN FUTURE

**BINARY STARS**

**4 varieties:**

**Visual Astrometric Spectroscopic Eclipsing**

**Use to measure stellar masses**

**BINARY STARS MORE THAN 1/2 OF ALL STARS!**

EVIDENCE OF ORBITAL MOTION (... HOW WE DETECT THEM):

- VISUAL BINARY** TRACK PROPER MOTIONS OF BOTH STARS
- ASTROMETRIC BINARY** WIGGLY MOTION OF ONE STAR REVEALS UNSEEN COMPANION
- SPECTROSCOPIC BINARY** ABSORPTION LINES OF ONE OR BOTH STARS SHOW PERIODIC DOPPLER SHIFTS
- ECLIPSING BINARY**
  - ONE STAR BLOCKS OR ENHANCES LIGHT FROM OTHER
  - REDUCE PROPERTIES FROM PERIODIC LIGHT CURVE

**Eclipsing binaries**

**one star gets in front or behind other**

**ECLIPSING BINARY STAR SYSTEMS**

STARS IN CLOSE ORBITS CAN BLOCK OR ENHANCE LIGHT

SHAPE OF PERIODIC LIGHT CURVE CAN BE USED TO DEDUCE ORBITS AND NATURE OF COMPANIONS

INTENSITY vs TIME

TWO STARS ABOUT SAME SIZE

PARTIAL ECLIPSES

SIZE OF UNOCCULTED STAR

TOTAL AND ANNULAR ECLIPSES

AS ABOVE, BUT WITH DIFFERENTIAL DIAMETERS OF STARS

ORBITAL PERIOD

WHAT YOU SEE AS OBSERVER IS SENSITIVE TO TILT OF ORBIT PLANE RELATIVE TO YOU!

### Eclipsing: Variations in brightness with time

We see light from both A and B. We see light from all of B, some of A. We see light from both A and B. We see light only from A.

apparent brightness

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 SYSTEM**  
 DETECT AS PERIODIC DOPPLER SHIFTS IN SPECTRA

ORBITS (TOP VIEW) SUCCESSIVE INSTANTS

DOPPLER VELOCITY (POSSIBLY DETECTABLE FROM LINE SHIFTS IN SPECTRA)

TWO SPECTRA FROM IC ARCTICUS "DOUBLE LINE BINARY"

TWO SPECTRA FROM 61 CYGNUS "SINGLE LINE BINARY"

### Spectroscopic Binary

Star B spectrum at time 1: approaching, therefore blueshifted

to Earth

Star B spectrum at time 2: receding, therefore redshifted

1 approaching us

2 receding from us

**Harder to interpret, since do not know viewing angle**

### MIZAR the "DEAMON" – four stars, actually

Mizar is a visual binary ...

... and spectroscopy shows that each of the visual "stars" is itself binary.

**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

**GRAVITY (INVERSE SQ LAW), ELLIPTICAL ORBITS AND ANGULAR MOMENTUM** (INVERSE)

- ARISTOTLE, COPERNICUS (1543), TYCHO BRAHE (~160)
- KEPLER (1609, 1618): LAWS OF PLANETARY MOTION

1<sup>st</sup> LAW: PLANETS ORBIT SUN ON ELLIPSES, SUN AT ONE FOCUS (COMBINED MASS)

2<sup>nd</sup> LAW: ALL PLANETS MOVE ABOUT SUN AT CONSTANT SPEEDS, SWEEPING EQUAL AREA IN EQUAL TIME

3<sup>rd</sup> LAW:  $(\text{ORBITAL PERIOD})^2 = (\text{AVERAGE DISTANCE})^3$

NEWTON (1687):

GRAVITY FORCE:  $F = G \frac{M_1 M_2}{d^2}$

**DOUBLE STARS: WEIGHING THEM**

BINARIES HELP DETERMINE STELLAR MASS & RADIUS

MEASURE: PERIOD (ONLY)

ORBITAL SPEED (SPECTROSCOPIC BINARIES)

SEPARATION (VISUAL BINARIES)

RECALL KEPLER'S THIRD LAW:

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

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

$\Rightarrow$  PERIOD & SEPARATION  $\Rightarrow$  MASS

ECLIPSING BINARIES:

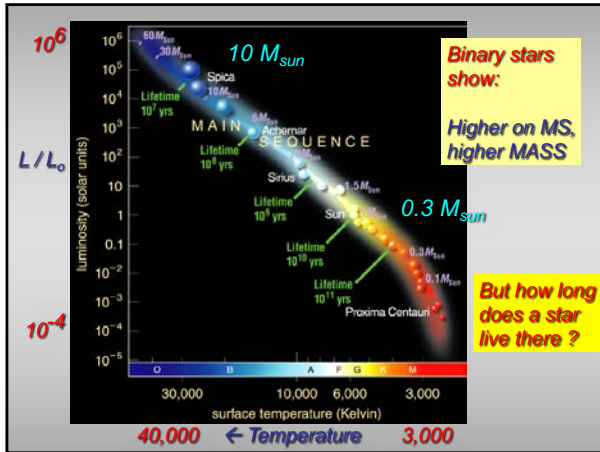
ORBITAL SPEED & ECLIPSE DURATION  $\Rightarrow$  RADIUS (INDEPENDENT MEASURE)

**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)



### Brightness / Distance **B.**

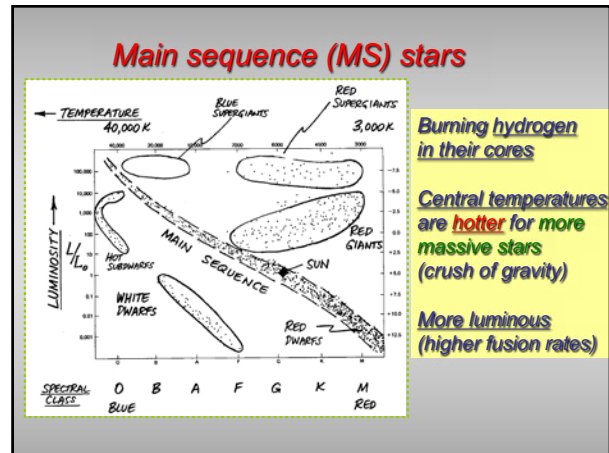
#### Clicker Q

- 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



### 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:

$$\begin{aligned}
 &^{12}\text{C}_6 + ^1\text{H}_1 \rightarrow ^{13}\text{N}_7 + \gamma \\
 &^{13}\text{N}_7 \rightarrow ^{13}\text{C}_6 + e^+ + \nu \\
 &^{13}\text{C}_6 + ^1\text{H}_1 \rightarrow ^{14}\text{N}_7 + \gamma \\
 &^{14}\text{N}_7 + ^1\text{H}_1 \rightarrow ^{15}\text{O}_8 + \gamma \\
 &^{15}\text{O}_8 \rightarrow ^{15}\text{N}_7 + e^+ + \nu \\
 &^{15}\text{N}_7 + ^1\text{H}_1 \rightarrow ^{12}\text{C}_6 + ^4\text{He}_2
 \end{aligned}$$

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<sub>⊙</sub>

TEMPERATURE: ~ 2,000 → 100,000 K (SURFACE)

RADIUS: 0.01 → 100 R<sub>⊙</sub>

LUMINOSITY: 0.001 → 100,000 L<sub>⊙</sub>

LUMINOSITY ~ (MASS)<sup>3.8</sup>

RADIUS ~ (MASS)<sup>0.75</sup> (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<sup>3.8</sup>

L ~ M<sup>3.8</sup> OR NEARLY, ≈ M<sup>4</sup>

**L ~ M<sup>4</sup>**

MASSSES 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<sub>TOTAL</sub> ∝ MASS (∝ M)

LUMINOSITY L ∝ (MASS)<sup>3.8</sup> (∝ M<sup>4</sup>) ← MASS-LUMINOSITY RELATION

LIFETIME t<sub>LIFE</sub> ∝ E<sub>TOTAL</sub> / L ∝ M<sup>-3</sup> (ROUGHLY)

⇒ MASSIVE STARS HAVE SHORT LIVES!

MASS (M <sub>⊙</sub> )	LIFETIME (MILLION YEARS)
1	10,000 MY ≈ 100EY
2	700
3	250
5	70
10	20
15	10
30	5 (LEVEL OFF AT A FEW MY)