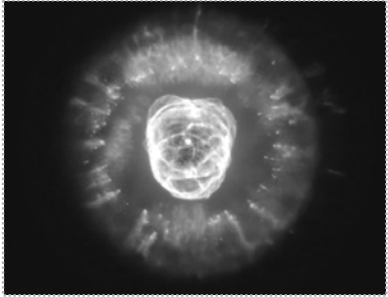


# ASTR 1120: Stars & Galaxies



Eskimo planetary nebula

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Lecture 17 Fri 18 Feb 05

zeus.colorado.edu/astr1120-toomre

## Topics for Today

- Look further at **BINARY STARS** to measure **STELLAR MASS**
- We shall estimate **LIFETIMES** of stars on main sequence (MS)
- Observed **MASS-LUMINOSITY** relation reveals that *massive stars* have very short lives!
- **HW 4** due today, new **HW # 5** passed out
- Start overview reading **Chap 17 Star Stuff**

### REMINDER

### BINARY STARS

4 varieties:

- Visual
- Astrometric
- Spectroscopic
- Eclipsing

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

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

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

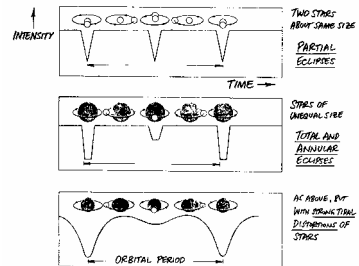
### Eclipsing binaries

one star gets in front or behind other

#### ECLIPSING BINARY STAR SYSTEMS

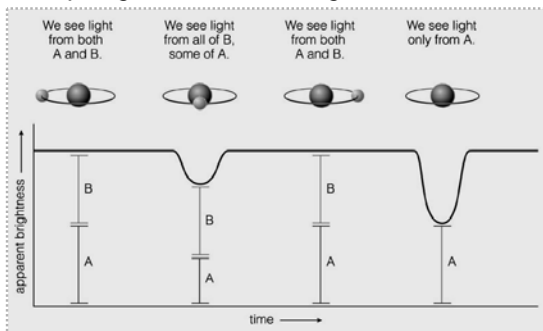
STARS IN CLOSE ORBITS CAN BLOCK OR ENHANCE LIGHT

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



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

### 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

Don't see stars individually -- but see shifting absorption lines

Sometimes TWO sets

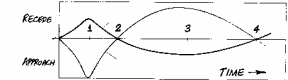
#### SPECTROSCOPIC BINARY SYSTEM

DETECT AS PERIODIC DOPPLER SHIFTS IN SPECTRA

ORBITS (TOP VIEW) SUCCESSIVE INSTANCES



DOPPLER VELOCITY (POSSIBLY DETERMINED FROM LINE SHIFTS IN SPECTRA)



TWO SPECTRA FROM K. ADIERS "DOUBLE LINE BINARY"

DOUBLE-LINE SPECTRA


TWO SPECTRA FROM G. GEMONDINI "SINGLE LINE BINARY"

SINGLE-LINE SPECTRA

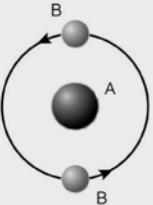
SPECTRA 1 SPECTRA 2

### Spectroscopic Binary

Star B spectrum at time 1:  
approaching, therefore blueshifted

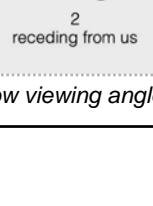


1  
approaching us

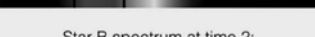


to Earth  
←

2  
receding from us


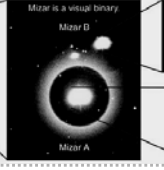
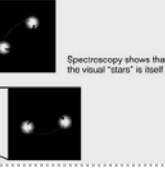


Star B spectrum at time 2:  
receding, therefore redshifted



Harder to interpret, since don't know viewing angle

### Mizar the "daemon" – four stars, actually

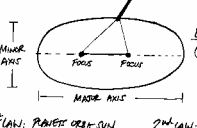




Spectroscopy shows that each of the visual "stars" is itself a binary.

### Recall from Chap 3:

GRAVITY (INVERSE SQ LAW), ELLIPTIC ORBITS AND ANGULAR MOMENTUM (INVERSE)

- ARISTOTLE, COPERNICUS (1543), TYCHO BRAHE (~1600)  
"PERFECT OBJECTS" MOVE ON CIRCLES (OR CIRCLES OF SPHERES)
- KEPLER (1609, 1618): LAWS OF PLANETARY MOTION



ELLIPSE (CIRCLE HAS 2 FOCI EQUIDISTANT)

1<sup>st</sup> LAW: PLANETS ORBIT SUN ON ELLIPSE, SUN AT ONE FOCUS (COMBINATION)  
 2<sup>nd</sup> LAW: AS PLANET MOVES AROUND ORBIT, ANGULAR SPEED INCREASES OR DECREASES IN EQUAL TIME  
 3<sup>rd</sup> LAW:  $(\text{ORBITAL PERIOD})^2 = (\text{AVERAGE DISTANCE})^3$  (YEARS) (AU)

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

NEWTON (1687):  
GRAVITY FORCE:  $F = G \frac{M_1 M_2}{d^2}$

### DOUBLE STARS: WEIGHING THEM

BINARIES HELP DETERMINE STELLAR MASS & RADIUS

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)

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))


⇒ PERIOD & SEPARATION ⇒ MASS

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

### From mid-term answers

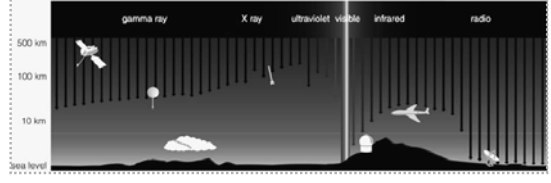
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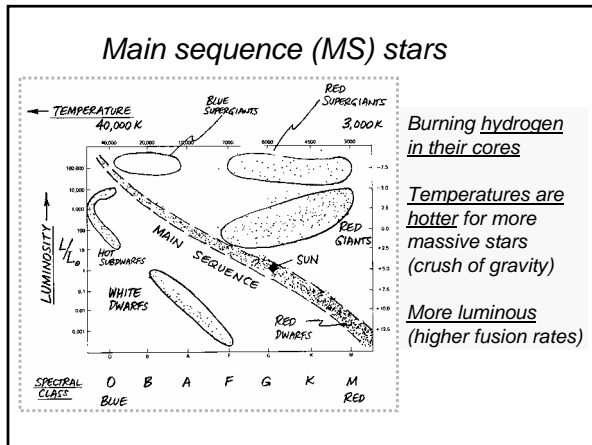
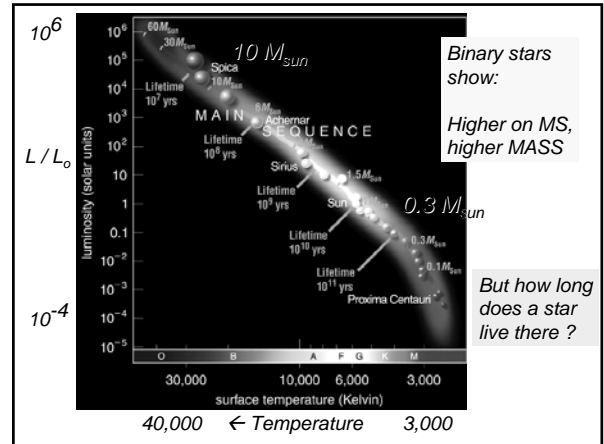
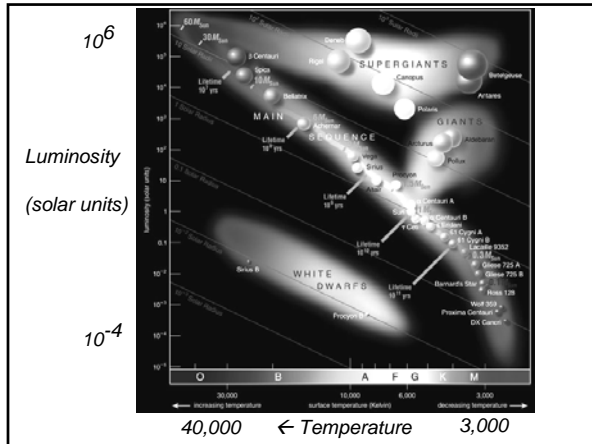
- Chandra X-Ray Observatory is located:
  - A. in a deep gold mine in South Dakota
  - B. on Mauna Kea, Hawaii
  - C. on the high altitude desert in Chile
  - D. in Earth orbit
  - E. flying in a 747 with telescope cutout



Chandra X-Ray Observatory was launched into orbit in 1999 – X-rays cannot penetrate atmosphere

Latest (2003) "Great Observatory" is Spitzer Space Observatory, in IR range of wavelengths





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

### 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?

### “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,  $\approx M^4$

MASSSES DETERMINED MOSTLY FROM BINARY PAIRS

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

**Estimating LIFE on MS**

*Four steps in our estimate*

*Simple play with numbers – just be bold!*

**"LIFE EXPECTANCY" ON MAIN SEQUENCE**

1. CONSIDER SUN ( $1 M_{\odot}$ ) AS EXAMPLE:  
 $\sim 10\%$  BY TOTAL MASS CAN CORE BURN 0.1  
 $0.7\%$  MASS  $\Rightarrow$  ENERGY 0.007
2. TOTAL ENERGY SUPPLY: ( $E = mc^2$ )  
 $E_{TOTAL} = 0.1 \times 0.007 \times M_{\odot} c^2$   
 $= 1.3 \times 10^{47}$  ergs
3. ENERGY LOST AT RATE: (LUMINOSITY)  
 $L_{\odot} = 3.9 \times 10^{33}$  ergs/sec
4. LIFETIME ON MAIN SEQUENCE:  
 LUMINOSITY  $\times$  LIFETIME = TOTAL ENERGY OUTPUT  
 $L_{\odot} \times t_{LIFE} = E_{TOTAL}$   
 OR  $t_{LIFE} \sim \frac{E_{TOTAL}}{L_{\odot}} = 3 \times 10^{17}$  sec  
 $= 10$  BILLION YEARS (BY)!

SUN IS MIDDLE AGED, OR ABOUT 5 BY OLD

**How long can other 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:  $E_{TOTAL} \propto \text{MASS} (\propto M)$

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

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

$\Rightarrow$  MASSIVE STARS HAVE SHORT LIVES!

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


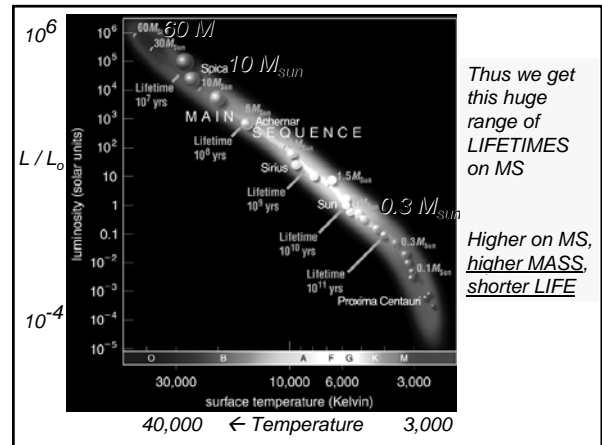
(LEAVE OFF A FEW MY)

**Short lives of massive stars on MS**

- Rock-star analogy:

*More massive, hotter, more luminous stars burn through the available fuel faster -- leading to early burnout*

*C-N-O fusion cycle is the way massive stars do it!*

**How to hold up all stars:**

**PRESSURE**

- What is difference between FORCE and PRESSURE?
- Can a BED OF NAILS support an astronomer? Or YOU? ... time for truth
- Maybe it is all about PRESSURE ..... which is FORCE divided by AREA