Today

- Look at BINARY STARS to measure STELLAR MASS
- C-N-O cycle dominates fusion burning of H in massive stars, really pours out the energy
- Explains observed MASS-LUMINOSITY relation
- Estimate LIFETIMES of stars on main sequence (MS), reveals massive stars have short lives!
- Test ideas of peel-off from main sequence as seen in star clusters
- Observatory #3 tonight, 22 Feb 7+pm
- Respond to new discussion topic on clusters
- Overview reading of Chap 16: Star Birth

Clicker: Stellar puzzle

- Two stars, Antony and Cleopatra, are both of spectral class M3, and of the same apparent brightness (magnitude) in the sky. Cleopatra shows narrow absorption lines in her spectrum, Anthony broad ones. Which star must be far more distant?

  - A. Antony
  - B. Cleopatra

Estimating the size of a star – its RADIUS

MEASUREMENTS OF STARS:

- Temperature (Mean Thermal Energy) → Luminosity
- Distance (parallax) → Luminosity

Stefan-Boltzmann Law:

\[ L = 4\pi R^2 \cdot \sigma \cdot T^4 \]

\( \sigma \) = Stefan-Boltzmann Constant

Luminosity \( \propto \) Temperature \( \propto \) Radius

But how to get the mass? ε (Treasure 2: Use Binaries)

Proper motions (parallax) and binaries...

STELLAR MOTIONS IN SKY...

Proper motion caused by:
1. Stellar motion in space: Relative to the Sun
2. Motion of the Sun relative to the Galaxy

Much loops in plane of celestial equator – proper motion
1. Due to nearby motion
2. Due to orbit pre-2000
3. Due to 360°
4. Due to 60°

Å

Temperature

Cleopatra has narrow absorption lines → giant or supergiant

Much more luminous

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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
Don’t see stars individually -- but see shifting absorption lines
Sometimes TWO sets

Spectroscopic Binary

Harder to interpret, since don’t 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.

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).

Luminosity (solar units)

Temperature

10^6

10^4

40,000 ◀ Temperature 3,000

Main sequence (MS) stars

- Burning hydrogen in their cores
- Temperatures are hotter for more massive stars (crush of gravity)
- More luminous (higher fusion rates)

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
- Life time 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?

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

C-N-O Fusion Cycle

Can provide vast luminosity for massive stars on MS

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!

"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)

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!

Estimating LIFE on MS

Four steps in our estimate
Simple play with numbers -- just be bold!

Thus we get this huge range of LIFETIMES on MS
Higher on MS, higher MASS, shorter LIFE