AST 101
Introduction to Astronomy: Stars & Galaxies
Measuring the Stars

Last Class

1. Measuring distances
2. Measuring stellar luminosities
3. Measuring temperatures

Next

4. Measuring masses
Masses are much harder than distance, luminosity, or temperature

- Since we are only ever seeing a point source, it is hard to determine how much mass is contained.
  - If we could see another nearby object (another star maybe?) we could use the gravity between the objects as a measure of the mass.
Binary Stars to the Rescue!!

- Types of binary star systems:
  - Visual Binary
  - Eclipsing Binary
  - Spectroscopic Binary

*About half of all stars are in binary systems*
Visual Binary

We can directly observe the orbital motions of these stars
Eclipsing Binary

We can measure periodic eclipses
Spectroscopic Binary

We determine the orbit by measuring Doppler shifts.
Animation from http://www-astronomy.mps.ohio-state.edu/~pogge/Ast162/Movies/spanim.gif
Direct mass measurements are possible only for stars in binary star systems.

Once we know:

\[ p = \text{period} \]
\[ a = \text{average separation} \]

We can solve Newton’s equations for mass (M).
Astronomer’s Toolbox:

• **Measure Distance:**
  – parallax…good to nearby stars but not beyond

• **Measure Luminosity:**
  – measure apparent brightness and distance, infer luminosity

• **Measure Temperature:**
  – Wien’s law, or, better yet, take spectra and use spectral classification.

• **Measure Mass:**
  – For stars in binary orbits, if we can get their orbital parameters, we can figure out their mass
Wide range of luminosities, temperatures and masses

Any *correlation* among these quantities?
The Hertzsprung Russell Diagram

• THIS IS AN IMPORTANT DIAGRAM TO UNDERSTAND.

• Basics:
  – Plots Stellar Luminosity (not apparent brightness) Vs
  – Temperature or Color or Spectral Class
Study this plot!
Clicker Question

Are the variables plotted here related to each other?

A. Yes, they show a relationship
B. You can’t be sure – you don’t know what they are!
C. They are related to each other or else both are related to a third variable
D. Either A or C
E. None of the above
D. They DO show a relationship or relation between them!
Emitted power per unit area = $\sigma T^4$

where

$\sigma = 5.67 \times 10^{-5} \text{ergK}^{-4} \text{cm}^{-2} \text{s}^{-1}$

Total luminosity from a star of radius $R$:

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

For the same temperature, more luminous stars have larger radii.
Main sequence stars

- Burning **hydrogen** in their cores

- Stellar masses decrease downward

- Temperatures are **hotter** for more massive stars (more gravitational pressure $\rightarrow$ higher T, remember Equation of State)

- More **luminous** (higher T $\rightarrow$ much higher emitted power)
Available hydrogen fuel is greater for the most massive stars…

But luminosity (rate at which hydrogen is fused) is MUCH MUCH higher

→ More massive (more luminous) main sequence stars run out of fuel sooner

Example: Most massive O star:

\[
M = 100 \, M_{\text{Sun}} \\
L = 10^6 \, L_{\text{Sun}} \\
M/L = 10^2 / 10^6 = 10^{-4} \text{ of the Sun}
\]

\[
\text{Life}_{\text{O-Star}} = 10^{10} \text{ yrs} \times 10^{-4} = 10^6 \text{ yrs}
\]
Lifetimes on Main Sequence (MS)

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

- For **Sun (G)**, this is about 10 billion years
- For **more massive stars** (OBAF), lifetime is (much) shorter
- For **less massive stars** (KM), lifetime is longer
Main-Sequence Star Summary

**High Mass:**
- High Luminosity
- Short-Lived
- Large Radius
- Hot
- Blue

**Low Mass:**
- Low Luminosity
- Long-Lived
- Small Radius
- Cool
- Red

**Stars:**
- **Spica**: B1 V, $11M_{\text{Sun}}$, Lifetime $10^7$ yrs
- **Sirius**: A1 V, $2M_{\text{Sun}}$, Lifetime $10^9$ yrs
- **Sun**: G2 V, $1M_{\text{Sun}}$, Lifetime $10^{10}$ yrs
- **Proxima Centauri**: M5.5 V, $0.12M_{\text{Sun}}$, Lifetime $10^{12}$ yrs
George and Abe are two main sequence stars; George is an M star and Abe is a B star. Which is more massive? Which is redder in color?

A. George is more massive and redder
B. Abe is more massive and redder
C. George is more massive; Abe is redder
D. Abe is more massive; George is redder
E. They are both main sequence, they’re the same mass and same color.
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What about the other objects on the H-R diagram?

As stars run out of hydrogen fuel their properties change (generally they turn into red giants—more on why later).
• Top end of main sequence starts to “peel off”

• Pleiades star cluster shown → no more O and B stars
Main-sequence turnoff point of a cluster tells us its age.
How do we measure the age of a stellar cluster?

A. Use binary stars to measure the age of stars in the cluster.
B. Use the spectral types of the most numerous stars in the cluster to infer their temperatures, and thus, the age of the cluster.
C. Find stars in the instability strip and use their variability period to measure their age.
D. Look for the age of stars at the main-sequence turnoff point.
E. Determine if the cluster is an open cluster or globular cluster and use the average age of those types of clusters.
Clicker Question

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Main sequence A-stars have masses about 3 times that of the Sun, and luminosities about 30 times that of the Sun. What is the age of a cluster which has a “turnoff” at A-stars? (Remember: The Sun’s lifetime ~ 10 billion years)

A) 100 thousand years
B) 100 million years
C) 1 billion years
D) 10 billion years
E) 100 billion years
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Where we see this best: Star Clusters

- Groups of 100’s to millions of stars
- All about the same distance (apparent brightness tracks luminosity well)
- All formed about the same time (i.e. all are same age)
- Range of different mass stars!
1.) Open Clusters

- Loose groups of 1000’s of stars
- This is where most stars in the Galaxy are born
• **Pleiades**: an “open cluster” of stars about 100 million years old.

• Compare with Sun’s age of about 4.6 BILLION years old.

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2.) Globular Clusters

- Generally much older - up to 13 BILLION years
- ~millions of stars, densely packed
- Intense gravitational interactions
Cepheid Variable Stars

- Some stars vary in brightness because they cannot achieve proper balance between power welling up from the core and power radiated from the surface.
- Most pulsating variable stars inhabit an instability strip on the H-R diagram.
- The most luminous ones are known as Cepheid variables: important for distance measurements.
Which star is most like our Sun?

Clicker question
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Clicker question
Which of these stars will have changed the least 10 billion years from now?

A  
B  
C  
D  

Clicker question
Which of these stars will have changed the least 10 billion years from now?
Which of these stars can be no more than 10 million years old?

A

B

C

D

Clicker question
Which of these stars can be no more than 10 million years old?

- A
- B
- C
- D

Clicker question
Stellar Properties Review

*Luminosity:* from brightness and distance

\[
(0.08 \, M_{\text{Sun}}) \quad 10^{-4} \, L_{\text{Sun}} - 10^{6} \, L_{\text{Sun}} \quad (100 \, M_{\text{Sun}})
\]

*Temperature:* from color and spectral type

\[
(0.08 \, M_{\text{Sun}}) \quad 3,000 \, K - 50,000 \, K \quad (100 \, M_{\text{Sun}})
\]

*Mass:* from period (p) and average separation (a) of binary-star orbit

\[
0.08 \, M_{\text{Sun}} - 100 \, M_{\text{Sun}}
\]
The H-R Diagram review

So far:
Stars on Main Sequence (MS)

Next:
- Pre MS (Star Birth)
- Post MS: Giants, Super Giants, White dwarfs