Lecture 19
The Properties of Stars

What is the range stellar properties:

- Luminosity
- Mass
- Temperature
- Radius

And how can we measure it?
**Luminosity:**
The total energy a star radiates per second.
(energy/second, Watts)
Luminosity passing through each sphere is the same: conservation of energy

**Apparent brightness:**
Measures energy density of star at the Earth.
[energy/second/square meter]

Area of sphere = $4\pi (\text{radius})^2$
Divide luminosity by area to get brightness
The relationship between apparent brightness and luminosity depends on distance:

\[
\text{Brightness} = \frac{\text{Luminosity}}{4\pi (\text{distance})^2}
\]

We can determine a star’s luminosity if we can measure its distance and apparent brightness:

\[
\text{Luminosity} = 4\pi (\text{distance})^2 \times (\text{Brightness})
\]
Thought Question

How would the apparent brightness of Alpha Centauri change if it were three times farther away?

A. It would be only 1/3 as bright
B. It would be only 1/6 as bright
C. It would be only 1/9 as bright
D. It would be three times brighter
Thought Question

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To understand how bright stars are we need to know how far away they are.
Parallax is the apparent shift in position of a nearby object against a background of more distant objects.
Apparent positions of the nearest stars shift by about an arc second as Earth orbits Sun
This shift, the **Parallax angle**, depends on distance
We measure **Parallax** by comparing snapshots taken at different times and measuring the shift in angle to star.
Every January, we see this:

Every July, we see this:

nearby star

1 AU

Not to scale
Most luminous stars:

\[ 10^6 \, L_{\text{Sun}} \]

Least luminous stars:

\[ 10^{-4} \, L_{\text{Sun}} \]

\( L_{\text{Sun}} \) is luminosity of Sun
Every object emits *thermal radiation* with a spectrum that depends on its temperature.
Hottest stars: 
50,000 K

Coolest stars: 
3,000 K

(Sun’s surface is 5,800 K)
BB Radiation:
Energy per area $\propto T^4$
so:
An object grows more luminous as its temperature rises, or as its area increases.

Luminosity $\propto$ Area $\times T^4$
Or:
$$\left( \frac{L}{L_\odot} \right) = \left( \frac{R}{R_\odot} \right)^2 \left( \frac{T}{T_\odot} \right)^4$$
Measuring Stellar Parameters

- Apparent Brightness: Photometry
- Distance: Astrometry
- Temperature: Spectroscopy
- Luminosity: Distance + Apparent Brightness
- Radius: Luminosity + Temperature
Largest *Normal* Stars:

\[15 \times \text{Radius}_{\text{Sun}}\]

Smallest *Normal* Stars

\[0.1 \times \text{Radius}_{\text{Sun}}\]

What is *Normal*?
Level of ionization also reveals a star’s temperature

- Ionized Gas (Plasma)
- Neutral Gas
- Molecules
- Solid
Absorption lines in star’s spectrum tell us ionization level
Stars are classified according to *spectral type*. Defined by which spectral lines are present.
Remembering Spectral Types

(Hottest) O B A F G K M (Coolest)

• Oh, Be A Fine Girl, Kiss Me

• Only Boys Accepting Feminism Get Kissed Meaningfully
Thought Question

Which kind of star is hottest?

A. M star
B. F star
C. A star
D. K star
Thought Question

Which kind of star is hottest?

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C. A star
D. K star
About half of all stars are binary. The orbit of a binary star system depends on the masses of the stars.
Types of Binary Star Systems

• Visual Binary: usually closer, wider, slower
• Eclipsing Binary: edge on, more distant
• Spectroscopic Binary: more distant, rapid
Visual Binary

We can directly observe the orbital motion of the stars.
Eclipsing Binary

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.

We can measure periodic eclipses
Spectroscopic Binary

Star B spectrum at time 1: approaching, therefore blueshifted

1 approaching us

to Earth

Star B spectrum at time 2: receding, therefore redshifted

2 receding from us

We determine the orbit by measuring Doppler shifts
We measure mass from a more general form of Kepler’s 3rd Law derived from Newton’s Laws:

Direct mass measurements are possible only for stars in binary star systems:

\[ p^2 = \frac{4\pi^2}{G (M_1 + M_2)} a^3 \]

\( p = \) period

\( a = \) average separation

Isaac Newton
Need 2 out of 3 observables to measure mass:

1) Orbital Period (p)
2) Orbital Separation (a or r=radius)
3) Orbital Velocity (v)

For circular orbits, $v = \frac{2\pi r}{p}$
Most massive stars:

$100 \, M_\odot$

Least massive stars:

$0.08 \, M_\odot$

($M_\odot$ is the mass of the Sun)
Summary: Stellar Properties

For a few hundred stars we have measured:

Luminosity: \[ 10^{-4} < \left( \frac{L}{L_\odot} \right) < 10^6 \]

Temperature: \[ 0.5 < \left( \frac{T}{T_\odot} \right) < 10 \]

Radius: \[ 0.1 < \left( \frac{R}{R_\odot} \right) < 15 \]

Mass: \[ 0.08 < \left( \frac{M}{M_\odot} \right) < 100 \]