SECTION II: Nature of Stars

• Astronomers measure properties of Stars
  
  Distance
  Mass
  Apparent Brightness
  Surface Temperature
  Radius

• Find that some are related

  Large Mass \rightarrow \text{Large Absolute Brightness}

• We will end up with a model of stellar formation and life cycle from “birth” to “death” and their final states: white dwarf, neutron star, black hole
Distances to Stars

• Important as determines actual brightness but hard to measure as stars are so far away

  Closest star system (3 stars)      Alpha Centauri

  4.3 light years    =   4 x 10^{13} km

  (1 AU = distance Earth to Sun = 8 light minutes)

• Close stars use stellar parallax (heliocentric parallax or triangulation \(\rightarrow\) same meaning)

• Can “easily” measure distance using parallax to about 500 LY. Need telescope: first observed in 1838. Study close stars in detail. Other techniques are used (later) for more distant stars
Distances to Stars - Parallax

In January, the nearby star appears to be here.

In July, the nearby star appears to be here.

The closer the star, the more its apparent position shifts as seen from Earth.

1 AU

Earth (July)

Sun

Earth (January)

Nearby star

d

p

a Parallax of a nearby star

b Parallax of an even closer star

Compare position in sky of nearby star to those much further away
Shifting Star Positions

• The orbit of the earth is used as the base.
• Near stars appear to move more than far stars as Earth orbits Sun
• distance = (base length)/angle
• define: 1 parsec = 1/(angle of 1 second of arc) = 3.3 LY
Stellar Parallax

- A photo of the stars will show the shift between January and June with green having bigger shift and so closer than blue and both green and blue closer than black stars. (in reality somewhat more complicated as stars also have a proper motion in a given direction and need to make measurements over many years to separate the two effects)
Nearest Stars

61 Cygni first observed parallax in 1838

Alpha Centauri  
Sirius  
Procyon  
61 Cygni  
Epsilon Indi  
All binaries (2-3 stars)

Tau Ceti 12 LY closest single (not binary)  
“Sun-like” star

Epsilon Eridani single star - youngish

Color of stars indicates surface temp with white hottest, then yellow, orange, red. Most close by stars are small red stars.
### Nearest Stars

- The larger the angle (T.Par. = trigonometric parallax) the closer the star. \( pc = \text{parsecs ly} = \text{light year with 3.3 factor between} \)

- Many stars come in groups like the 2 stars A and B in the Sirius “binary cluster” → close together, within same “solar system” A is a little bit bigger than the Sun while B is a white dwarf

- Alpha Centauri A and B are a close binary systems. Proxima Centauri is a red dwarf which probably orbits Alpha Centauri every 500,000 years

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Parallax Data – new digital camera on satellites vastly improve number of stars well-measured

- In 1900 only 60 stars had parallax measurements
- 1997-2000 a European satellite Hipparcos released parallax measurements for more than 2,300,000 stars up to 500 LY distance
- 118,000 stars measured with .001 arc-second resolution and 0.2% error on light intensity
- OLD(1990): 100 stars with distance known to 5%. “NEW” (2005): 7000 such stars. “NEWest” (2018) about 50,000,000 stars
- European Space Agency Gaia satellite: launched 2013 0.00001 arc-second. Goal: measure >1 billion objects ~70 times each over 5 years. Measure star distances to 30,000 LY, with over 20 million with 1% accuracy. Also measure exoplanets, asteroids, galaxies, etc. April 2018 releases position and brightness data on 1.7 billion stars (of which parallax on 1.3 billion), 500,000 quasars (active blackholes), and 14,000 asteroids
April 2018 Gaia Data Release (European Space Agency)
Luminosity of Stars

• Luminosity = Absolute Brightness = how much light/energy a star produces

• Scale relative to Sun. So

\[ L_{\text{Sirius}} = 23L_S \] means Sirius A radiates 23 times more energy than the Sun

• Stars range from \(0.0001xL_S\) to \(1,000,000xL_S\)

Another scale: “magnitude” often used. A log scale to the power of \(\sim 2.5\). **YOU DON’T NEED TO KNOW.** The lower the Mag the brighter the object.
Absolute vs Apparent Brightness

Absolute Brightness/Luminosity means total energy output

Apparent Brightness is what is seen by eye or in a telescope and so depends on distance \((1/\text{Distance}^2)\)

With greater distance from the star, its light is spread over a larger area and its apparent brightness is less.
Absolute vs Apparent Brightness

Example: 2 stars with the same absolute brightness

Star(A) is 3 times further away from us then Star(B) therefore the apparent brightness of Star(A) is 1/9 that of Star(B)
Magnitude Scale

• **YOU DON’T NEED TO KNOW**

• Historically, first magnitude stars are the brightest as seen by the eye and sixth magnitude stars are just barely visible to the eye. The lower the magnitude the brighter the star

• About a factor of 2.5, so a second magnitude star is about 2.5 times brighter than a third magnitude star

• Need to convert magnitude (which is really apparent magnitude) to absolute magnitude and they do buy asking what magnitude each star would have if it was at a distance of 10 parsecs. This is compared to the Sun’s absolute magnitude to give the absolute luminosity relative to the Sun.
Absolute vs Apparent Brightness

A star’s apparent brightness is a combination of its absolute brightness and its distance from us.

Some stars have a very large apparent brightness as they are close to us – Table on next slide

Some stars have a very large apparent brightness as they have a very large absolute brightness – Table on next slide
Order of apparent brightest stars

apparent brightness = what we see

magnitude scale

Absolute brightness

Stars close to us

Stars far away

but very large

Absolute brightness

Sun is brightest (0), Sirius is next (1)
Brightness: Sirius vs Rigel

• Sirius is 23 times as bright as our Sun
  Rigel is 30,000 times as bright as our Sun

• Sirius is 8.6 light years from us
  Rigel is 680 light years from us

• Which star looks brighter in the sky? Which has the larger apparent luminosity? \(\rightarrow\) Sirius

\[
\text{Sirius : } \frac{23}{8.6^2} = \frac{23}{74} = 0.3 \\
\text{Rigel : } \frac{30000}{680^2} = \frac{30000}{460000} = 0.07
\]

Arbitrary unit for ratio
Measuring Apparent Brightness

• With today’s digital cameras, with millions of pixels, and the ability to store the data for later computer analysis it is very important to see if the brightness of a star varies with time. Very hard with photographic film, “easy” today

• Need to calibrate to get very good accuracy.

• Stars whose brightness varies in time are called “variable stars” and can be due to many reasons including
  - binary star system where the stars eclipse each other
  - exoplanet eclipsing its parent star
  - Cepheid variables which are stars in the giant phase (will be used to measure distances)
  - novas
  - supernovas
  - neutron-neutron star collisions gives kilonovas
Binary Star Systems

- Many stars come in groups of 2 or 3 that are close (few AU) to each other: BINARY Star Systems
- Gravitationally bound and probably formed at the same time
- SiriusA is 23 times as bright as our Sun
  SiriusB is 0.005 times as bright as the Sun
- Their separation varies from 8 to 31 AU. Can see both stars using telescope
See link on web page to Algol, the star system that forms one eye of Medusa in the constellation Perseus. Due to the two stars eclipsing each other, the brightness varies and can be seen by unaided eye. Called “demon” or “ghoul” star and its period was probably measured by the Egyptians and used to determine Lucky and Unlucky days.
Binary Stars $\rightarrow$ Stellar Masses

- visually observe both stars $\rightarrow$ Visual Binary. If only separate into 2 stars by looking at the spectrum $\rightarrow$ Spectroscopic Binary (eclipse each other plus have different Doppler shifts)
- Measure orbital information $\rightarrow$ period and separation distance. Get Mass though Kepler/Newtonian-like methods. See link on web page to “Center of mass examples”
Binary Star Orbits – In eclipses sum of light from 2 stars decreases as one passes in front of the other. Also used to measure relative sizes of stars.
Mass vs Luminosity

always on these plots it is the Absolute Luminosity of the star relative to our Sun

High mass $\rightarrow$ High brightness

Log-log plot. Slope gives $L = M^4$

don’t need to know
Stellar Sizes

• For a few close, big stars, they can be seen in a telescope as non-point objects
• Measure angular size; if know distance then get size of star
  Example: Betelgeuse 300 times larger radius than the Sun
• If further away but a binary star, get size of stars when they eclipse each other → length of time one star passes in front or behind each other
Stellar Sizes compared to size of our Sun. So $60R_{\text{sun}}$ means 60 times larger radius than our Sun. Largest stars extend beyond Earth’s distance to Sun.
Extra Slides
Binary Star Orbits — Doppler Shifts – can observe red/blue shifts as stars move to/from us

![Diagram showing stages of binary star orbits and Doppler shifts](image)

- Stage 1: Stars approach Earth, causing redshift.
- Stage 2: Stars move away from Earth, causing blueshift.
- Stage 3: Stars approach Earth again, reversing the blueshift.
- Stage 4: Stars move away from Earth again, reversing the redshift.

![Graph showing radial velocity over time](image)

- Graph illustrates the variation in radial velocity (approaching and receding) over time (days).
- The orbital period is indicated by the cycles of approaching and receding.