Astronomical Distance Measurements

PHYSICS RESEARCH CLASS

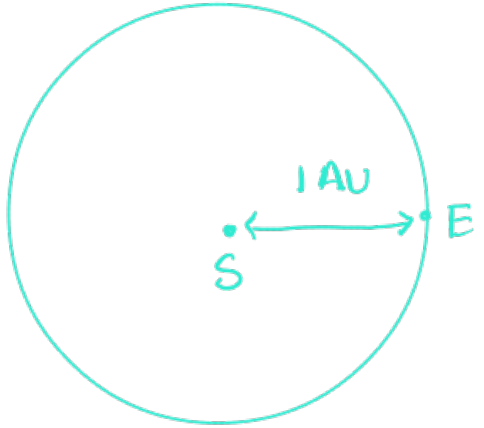
Some Relevant Units

3×10^8 m/s $\times$ 1 yr =

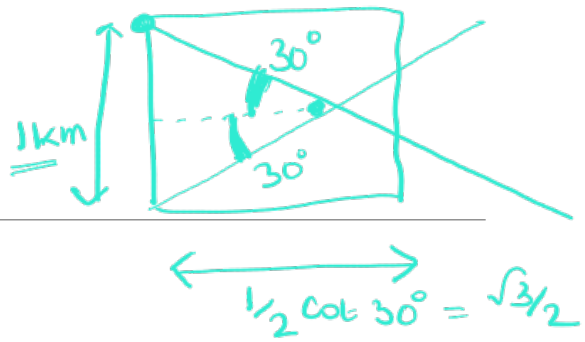
- Lightyear: 1 Ly = 9.461×10^{15} m
- Astronomical Unit: 1 AU = 1.496×10^{11} m
- Parsec: 1 pc = 3.086×10^{16} m

1 AU = (8 min 20 s) $\times$ 3×10^8 m/s

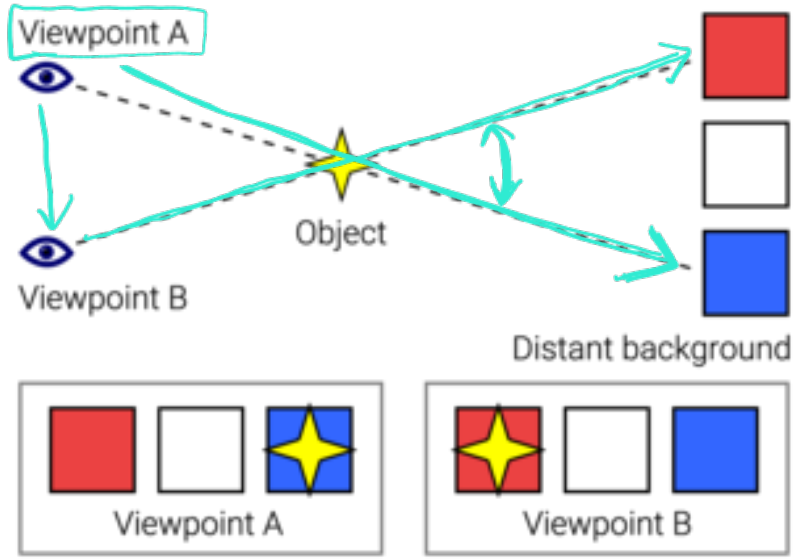
1 pc $\approx$ 3 ly



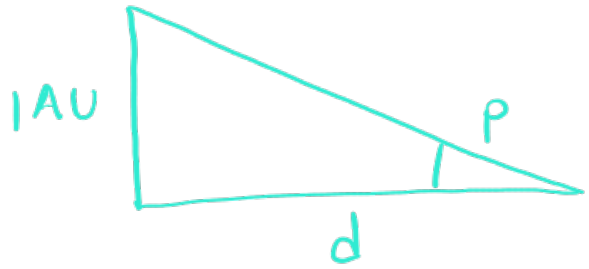
Different methods to measure astronomical distances



- Parallax
- Brightness Measurement



Parallax

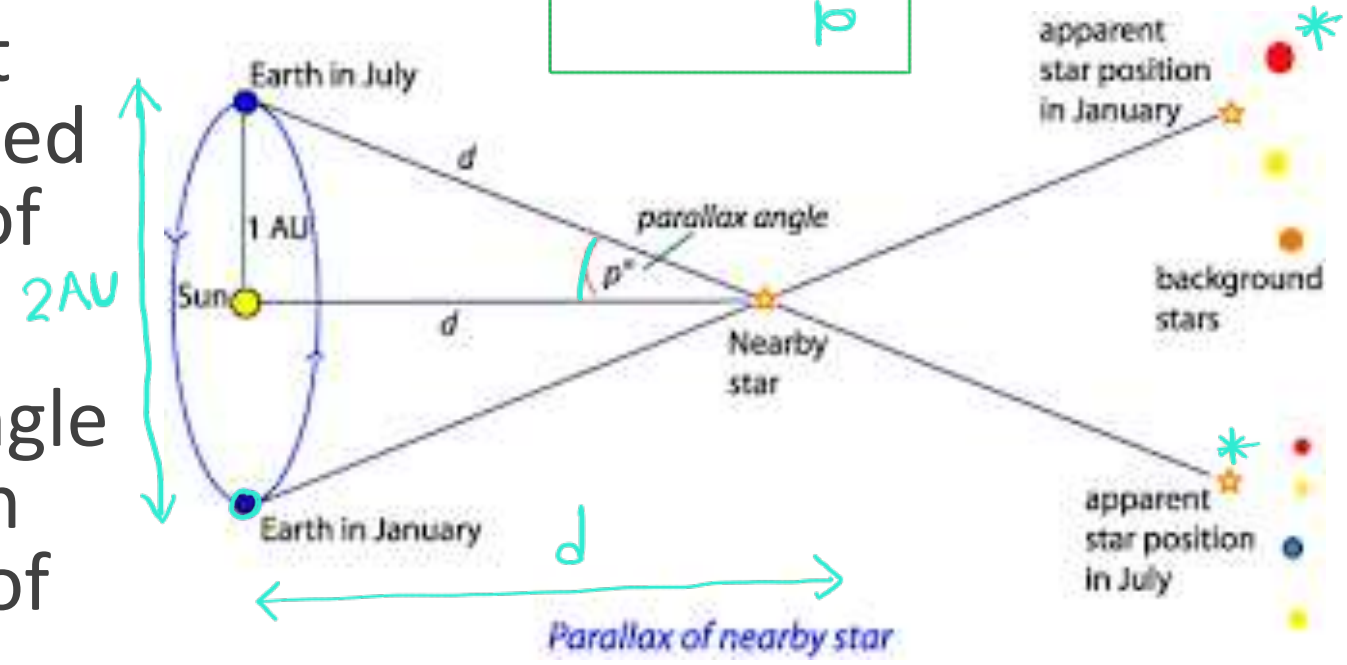


$$\tan p = \frac{1\,AU}{d}$$

$$\tan p \approx p \approx \frac{1AU}{d}$$

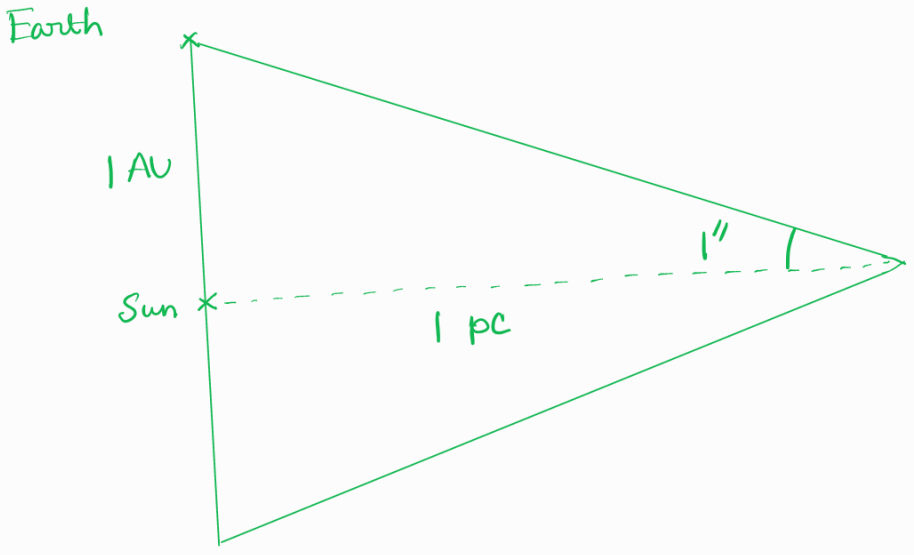
- Parallax is a displacement or difference in the apparent position of an object viewed along two different lines of sight.
- It is measured by the angle or half-angle of inclination between those two lines of sight.

$$d = \frac{1\,AU}{p}$$

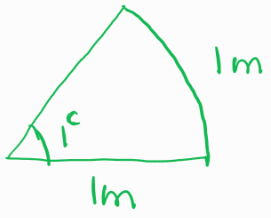


$$\text{Arcsecond}\,(") = \frac{1}{3600}\,^{\circ}$$

$$1\,pc = \frac{1\,AU}{1"}$$



$$\frac{1\,AU}{1\,pc} = \tan 1'' \approx 1''$$



$$1\ rad = \frac{1m}{1m}$$

pc to m

$$\pi\ rad = 180^\circ$$

$$1pc = \frac{1\,AU}{1''}$$

$$1'' = \frac{1}{60}' = \frac{1}{3600}^\circ = \frac{1}{3600} \times \frac{\pi}{180}\ c$$

$$1\,pc = \frac{1\,AU}{\frac{1}{3600} \times \frac{\pi}{180}\ c} = \frac{180 \times 3600}{\pi}\ AU$$

$$\approx 2.16 \times 10^5\ AU$$

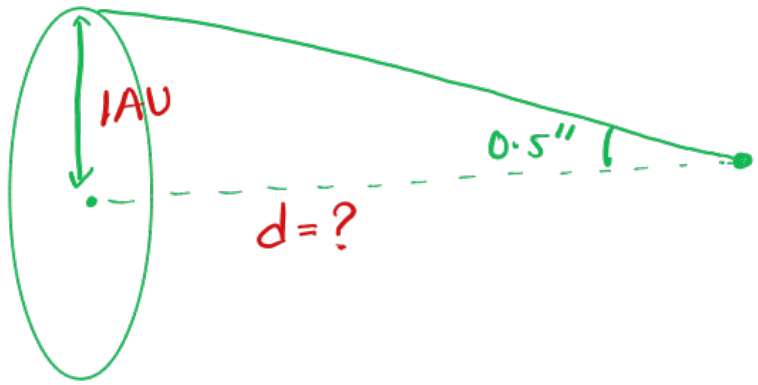
$$1.5 \times 10^{11}\ m \times 2.16 \times 10^5$$

Problem

What is the distance of a star that has a parallax of 0.5 arcseconds?

$$\frac{1\,AU}{d} = 0.5''$$

$$d = \frac{1\,AU}{0.5''} = 2\,\frac{AU}{''} = 2\,pc$$



If parallax angle ↓ distance to star ↑

Measuring Distance to Proxima Centauri by Parallax

Parallax = ?

$768.5 \text{ mas} = 0.7685''$

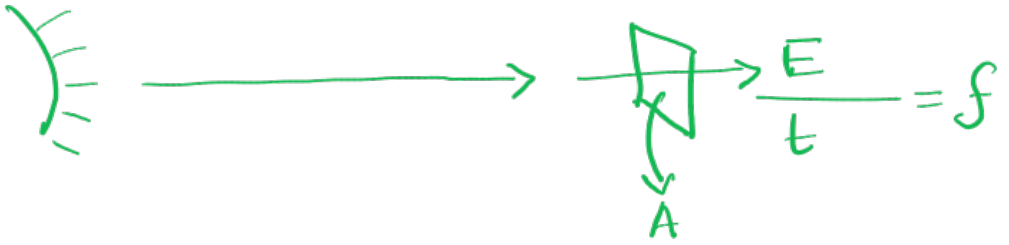
Distance = ?

$$\frac{1 \text{ AU}}{0.7685''} = \frac{1}{0.7685} \text{ pc} = 1.3 \text{ pc}$$

$$= 1.3 \text{ pc} \times \frac{3.26 \text{ ly}}{1 \text{ pc}}$$

$$= 4.2 \text{ ly}$$

$$\text{Intensity} = \frac{\text{Energy}}{\text{area} \times \text{time}}$$

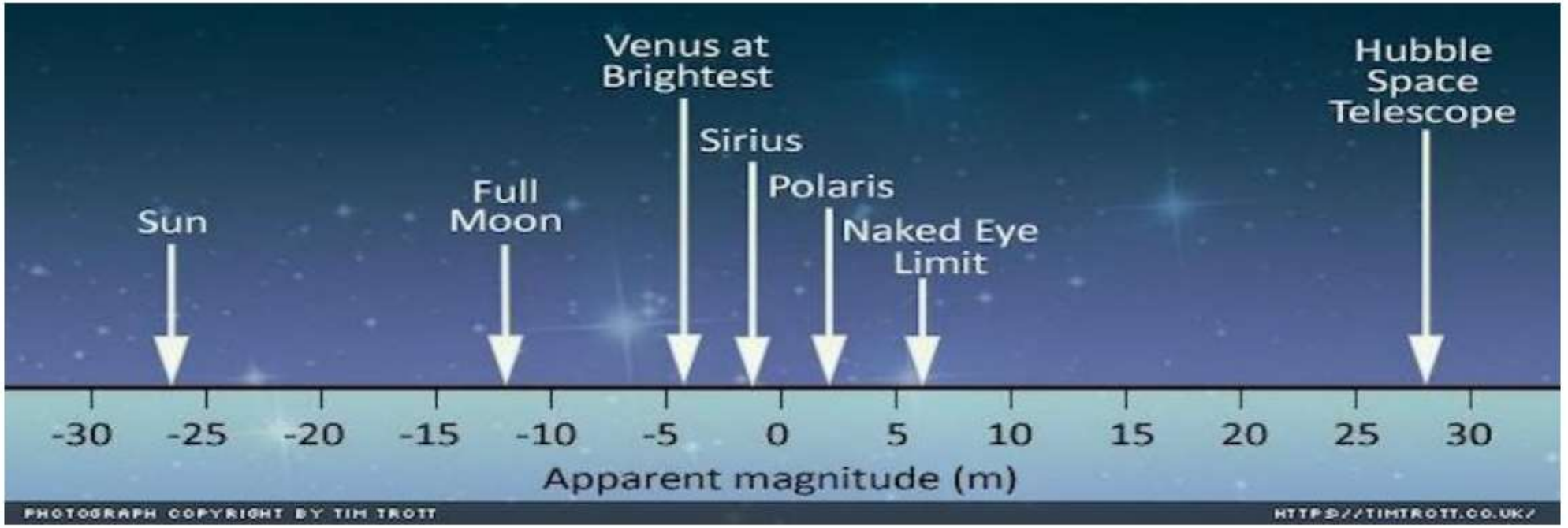


Brightness Measurement

- Far away stars are dimmer because the intensity of a source drops with distance
- In astronomy, brightness is measured in mag (magnitude) scale.
- More magnitude means less bright and vice-versa.

$$\text{SI unit of Intensity} = J\,m^{-2}s^{-1} = W m^{-2} \qquad I = \frac{P}{4\pi r^2}$$

Magnitude Scale



brighter

dimmer

Credit: Tim Trott

Apparent Brightness

$$\begin{cases} m_1 = -2.5 \log_{10} f_1 + \text{Constant} \\ m_2 = -2.5 \log_{10} f_2 + \text{Constant} \end{cases}$$

$$\rightarrow m_1 - m_2 = -2.5 \log_{10}(f_1/f_2)$$

- Measures the amount of starlight reaching us, this is also called flux
- Magnitude corresponding to apparent brightness is called apparent magnitude
- Apparent magnitude of two stars of flux f_1 and f_2 are related as:

$$m_1 - m_2 = -2.5 \log_{10}\left(\frac{f_1}{f_2}\right)$$

$f \uparrow \quad m \downarrow$

$f_1 > f_2 \rightarrow f_1/f_2 > 1$

$\rightarrow \log(f_1/f_2) > 0$

$\rightarrow m_1 - m_2 < 0 \rightarrow m_1 < m_2$

Absolute Magnitude

- In this case, we keep every stellar object at a distance of 10 pc from us, and find the amount of light reaching us (absolute flux)
- Absolute magnitude of two stars of absolute flux F_1 and F_2 are related as:

$$M_1 - M_2 = -2.5 \log_{10}\left(\frac{F_1}{F_2}\right)$$

Distance from Absolute and Apparent Magnitude

- Flux of a star is related to its distance(d):

$$f \propto \frac{1}{d^2}$$

- So, apparent flux (f), absolute flux (F) and distance (d) of the star are related as:

$$\frac{f}{F} = \left(\frac{10\ pc}{d}\right)^2$$

Distance from Absolute and Apparent Magnitude

- Taking logarithms, we have the relation between absolute and apparent magnitude as:

$$M - m = -5 \log_{10} \left(\frac{d}{10pc} \right)$$

Problem

The Black-Eye galaxy has an apparent magnitude of +9.36 and an absolute magnitude of -21.7. Calculate its distance from Earth.

Measuring Distance to Proxima Centauri by Flux

Absolute Magnitude = ?

Apparent Magnitude = ?

Questions?