The Cosmic Distance Ladder *(Incomplete)*

Distance Method	Used For	Good To
Thermonuclear Supernovae	Nearby and Distant Galaxies	10 Gpc
(Tully Fisher)	Spiral Galaxies	<100 Mpc
(Surface Brightness Fluctuations)	Elliptical Galaxies Spiral Bulges	10^1 Mpc
Cepheid Variables	Close Spiral Galaxies	10-20 Mpc
RR Lyrae Variables	Globbies, Very Near Galaxies	100 kpc, few Mpc
Main-Sequence Fitting	Clusters in the Milky Way	10^1 kpc
Parallax	Close Stars in the Milky Way	10^0 kpc

From the small angle formula to the parallax formula....

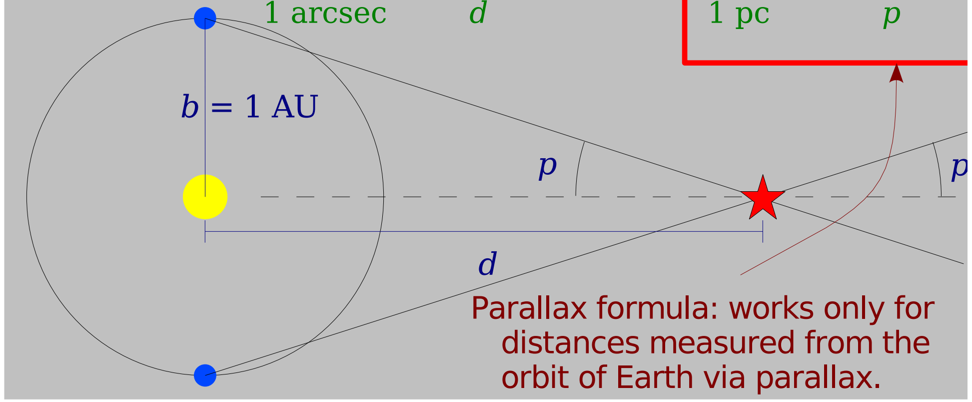
Works for any old small angle in a triangle, astronomical or otherwise.

$$\frac{p}{1\ \text{rad}} = \frac{b}{d} = \frac{1\ \text{AU}}{d}$$

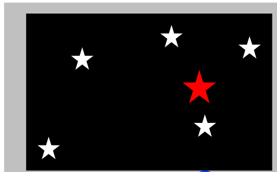
$$\left(\frac{1\ \text{rad}}{206265\ \text{arcsec}}\right)\left(\frac{p}{1\ \text{rad}}\right) = \left(\frac{1\ \text{AU}}{d}\right)\left(\frac{1\ \text{pc}}{206265\ \text{AU}}\right)$$

$$\frac{p}{1\ \text{arcsec}} = \frac{1\ \text{pc}}{d}$$

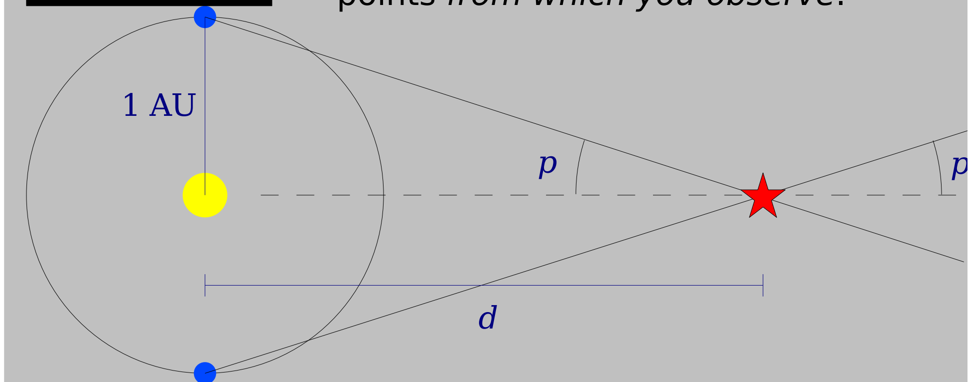
$$\frac{d}{1\ \text{pc}} = \frac{1\ \text{arcsec}}{p}$$

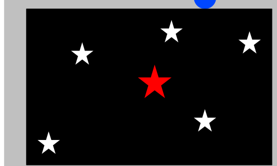


Parallax formula: works only for distances measured from the orbit of Earth via parallax.



Parallax (or “trigonometric parallax”): the triangle is formed by the object observed and *two* different vantage points *from which you observe*.





If (say) a Cepheid variable is close enough, we can measure its distance with parallax, and thus figure out its luminosity.

What parallax would you measure for Pluto?

Since you are measuring from Earth, which has a baseline of 1 AU, then you can use the formula p = 1/d. Therefore,

p = 1/40 AU p = .025 arcseconds

What is wrong with this answer?

in parsecs → $d = \frac{1}{p}$ ← in arcseconds

$$d = 40\ \text{AU}\left(\frac{1\ \text{pc}}{206265\ \text{AU}}\right) = 0.00019\ \text{pc}$$

$$p = \frac{1}{d} = \frac{1}{0.00019}'' = 5160'' = 1.4^\circ$$

The method of standard candles : measure the brightness B of something whose luminosity L you already know. From that, you can figure out the distance.

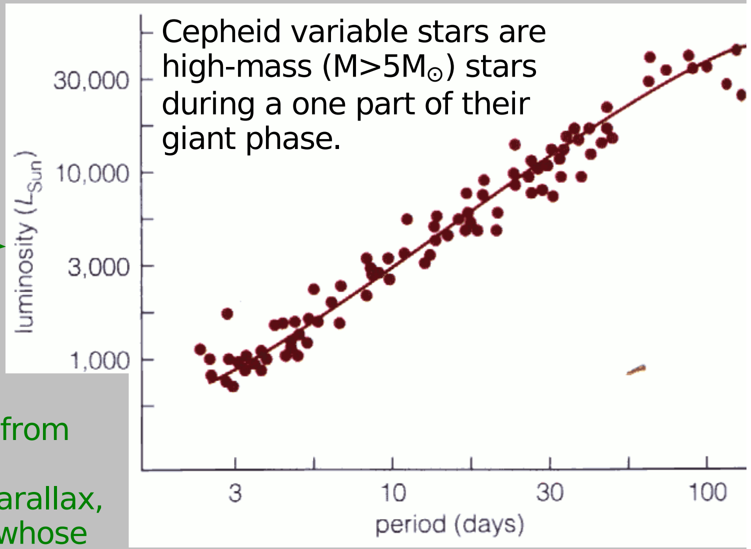
$$B = \frac{L}{4\pi d^2} \qquad \text{so} \quad d = \sqrt{\frac{L}{4\pi B}}$$

Standard candle : some object where L is known, or at least is known to always be the same

If you know L is always the same, but don't know the absolute value of L, you can still measure relative distances:

$$\frac{d_2}{d_1} = \sqrt{\frac{B_1}{B_2}}$$

Calibratable standard candle : Cepheid Variables



These were bootstrapped from Cepheids with measurable parallax, or in clusters whose distance was known ("main-sequence fitting").

Good for relatively nearby galaxies (within a few × 10 million pc)

It turns out that Cepheid Variable stars are sometimes in regions of galaxies that have a fair amount of dust. If you use a Cepheid to measure the distance to a galaxy without taking this dust into account, you will:

A overestimate the distance to the galaxy.

B under-estimate the distance to the galaxy.

Why is it useful in constructing the cosmic distance ladder to find Cepheid variables in open clusters?

A Open clusters are all less than 1Gyr in age, and Cepheids, which are stars of mass 5M$_\odot$ to 20M$_\odot$, live less than 1Gyr, so Cepheids will be found in open clusters.

B If we can measure the distance to an open cluster, we can then use the baseline from the Sun to the open cluster to measure much more distant parallaxes than we can measure from Earth.

C Because Cepheids are very massive stars, we can see them all the way out to the edge of the galaxy, and that lets us find those open clusters.

D This distance to the open cluster can be found from main-sequence fitting, allowing us to calibrate the luminosity of the Cepheid.

E Because Cepheids are stars of mass 5M$_\odot$ to 20M$_\odot$, they live less than 1 Gyr; this lets us calibrate the age of the open cluster.

An open cluster is found that has a Cepheid variable star in it. From main-sequence fitting, we measure the distance to the open-cluster to be 2,000 pc (2kpc).

A Cepheid variable of the same period of variation is found in a galaxy.

The Cepheid in the open cluster is 250,000 times brighter than the Cepheid in the galaxy.

How far away is the galaxy? (Hint : $\sqrt{250{,}000}=500$.) (Hint : $250{,}000^2=6.25\times10^{10}$)

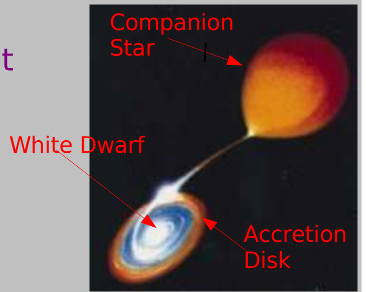
- A 4 pc
- B 1,000 pc = 1kpc
- C 1,000 kpc = 1 Mpc
- D 10,000 kpc = 10 Mpc
- E 6.25×10^{10} pc = 6,250 Mpc = 6.25 Gpc

Core-Collapse Supernova

- End of life of $M>8M_\odot$ star
- Inert iron core gets too big ($>1.4M_\odot$) to hold itself up against gravity
- Collapse of core releases huge amount of gravitational energy
- 1 per ~100 years in a galaxy

Thermonuclear Supernova

- White dwarf draws mass from a companion
- Mass of white dwarf exceeds $1.4M_\odot$, it *starts* to collapse
- Runaway fusion releases a huge amount of $E=mc^2$ fusion energy
- 1 per ~500 years in a galaxy
- Is a standard candle



What kinds of supernovae should you see in what types of galaxies? Recall what we've talked about (and have mentioned in test and homework problems) about the differences between spiral and elliptical galaxies. (Assume nearby galaxies, within a couple of billion light-years.)

- A Thermonuclear supernovae happen in spirals; core-collapse supernovae happen in ellipticals.
- B Core-collapse supernovae happen in spirals; core-collapse supernovae happen in ellipticals.
- C Both types of supernove happen in both types of galaxies.
- D Both types of supernovae happen in spirals; only thermonuclear supernovae happen in ellipticals.
- E Both types of supernovae happen in ellipticals; only core-collapse supernovae happen in spirals.