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 Bluges	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

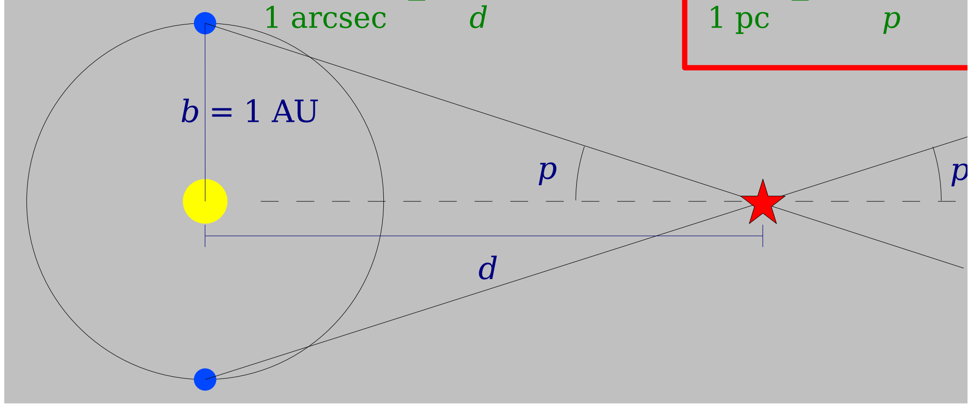
From the small angle formula to the parallax formula....

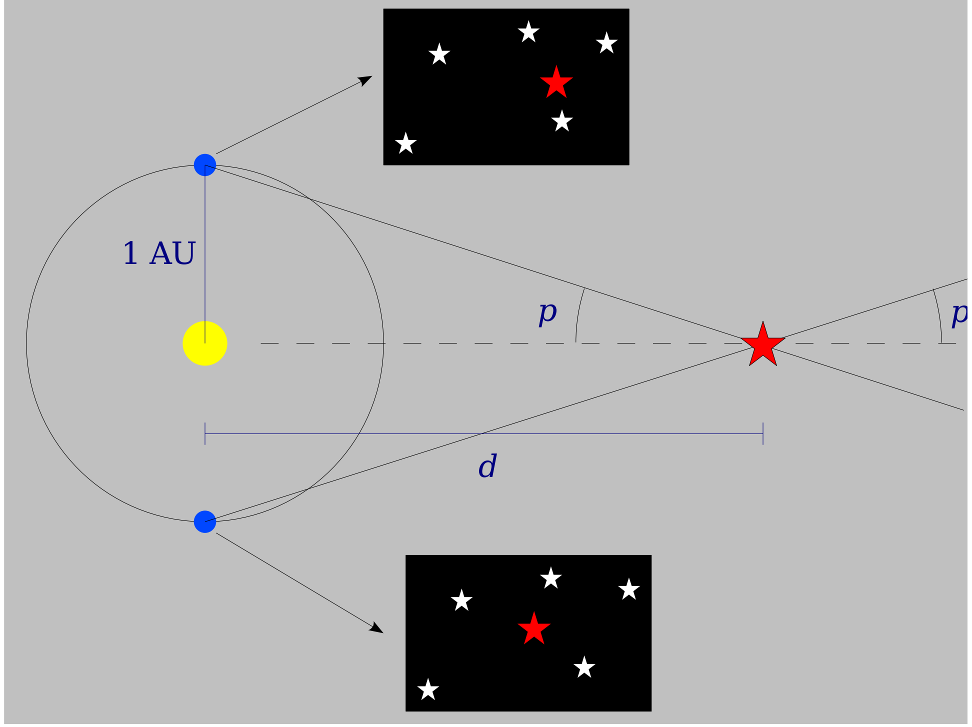
$$\frac{p}{1\text{ rad}} = \frac{b}{d} = \frac{1\text{ AU}}{d}$$

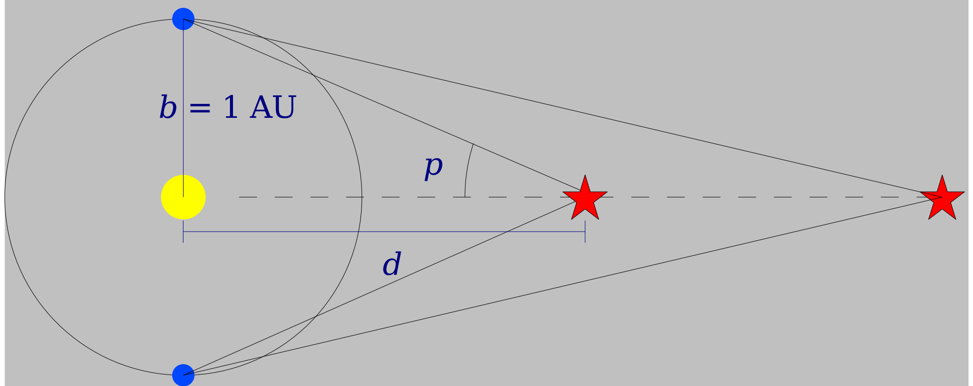
$$\left(\frac{1\text{ rad}}{206265\text{ arcsec}}\right)\left(\frac{p}{1\text{ rad}}\right) = \left(\frac{1\text{ AU}}{d}\right)\left(\frac{1\text{ pc}}{206265\text{ AU}}\right)$$

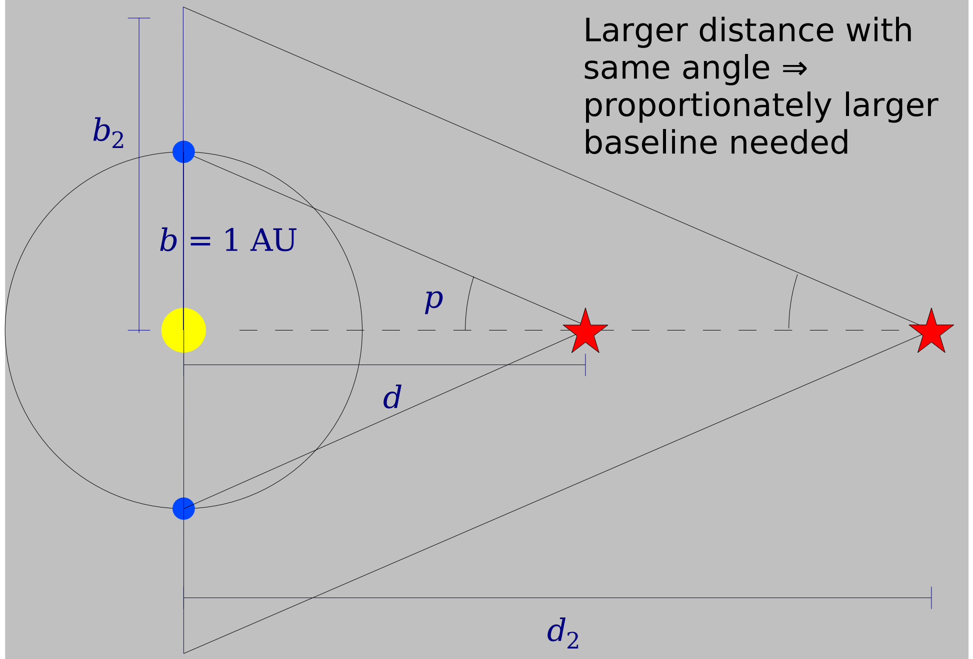
$$\frac{p}{1\text{ arcsec}} = \frac{1\text{ pc}}{d}$$

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









Larger distance with same angle ⇒ proportionately larger baseline needed

From Earth (baseline 1 AU), the greatest distance that can be measured with a minimum parallax angle of 0.001" is:

$$d = \frac{1}{p} = \frac{1}{0.001}\ \mathrm{pc} = 1000\ \mathrm{pc}$$

To measure 800,000 pc, you need a baseline that is 800 times longer, or 800 AU.

800 AU is well beyond the orbit of Pluto, but isn't really that much of the way towards the closest star (distance : 1.3pc = 270,000 AU).

Doing it with the small angle formula:

$$A = 0.001'' \left(\frac{1\ \mathrm{rad}}{206265''}\right) = 4.85\times10^{-9}\ \mathrm{rad}$$

$$A = \frac{b}{d}$$

$$b = d\,A = (800{,}000\ \mathrm{pc})\,(4.85\times10^{-9}) = 0.004\ \mathrm{pc}$$

$$b = 0.004\ \mathrm{pc}\left(\frac{206265\ \mathrm{AU}}{1\ \mathrm{pc}}\right) = 800\ \mathrm{AU}$$

Remember this question?

(Online assignment, due Mon, Aug 28)

Later in the course, we will be discussing the "parallax" method of measuring star distances. Right now, most of you probably don't know anything about this method.

I will sometimes ask the question: why would it be easier to measure parallax from Pluto than it is from the Earth? In the past, I have seen many students give the answer, "because Pluto is closer to the stars."

Given what you know about the Solar System, the stars, and the Galaxy from the first two lectures of class, is this likely to be a good answer? Why or why not?

robert.a.knop's Answer

Pluto is not appreciably closer to the stars. The closest star is so, so much farther away than Pluto that you don't really gain much benefit.

What's more, Pluto is (by the same tiny fraction) farther from some of the stars...!

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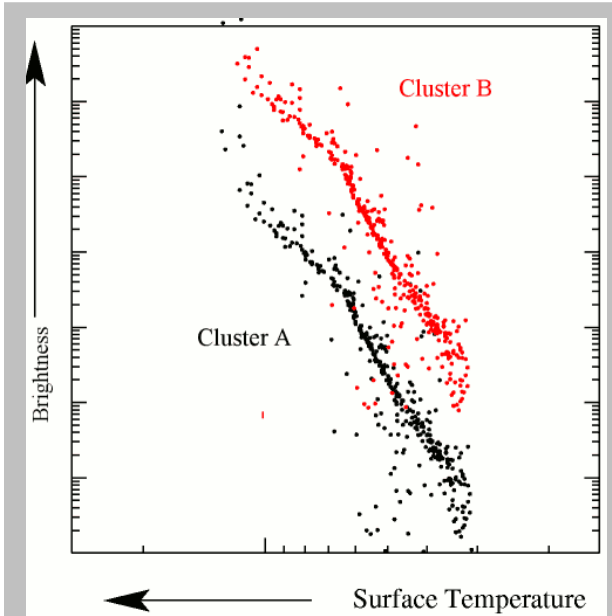
"The Equation" for main-sequence fitting and for the method of standard candles...

...drumroll please...

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

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

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

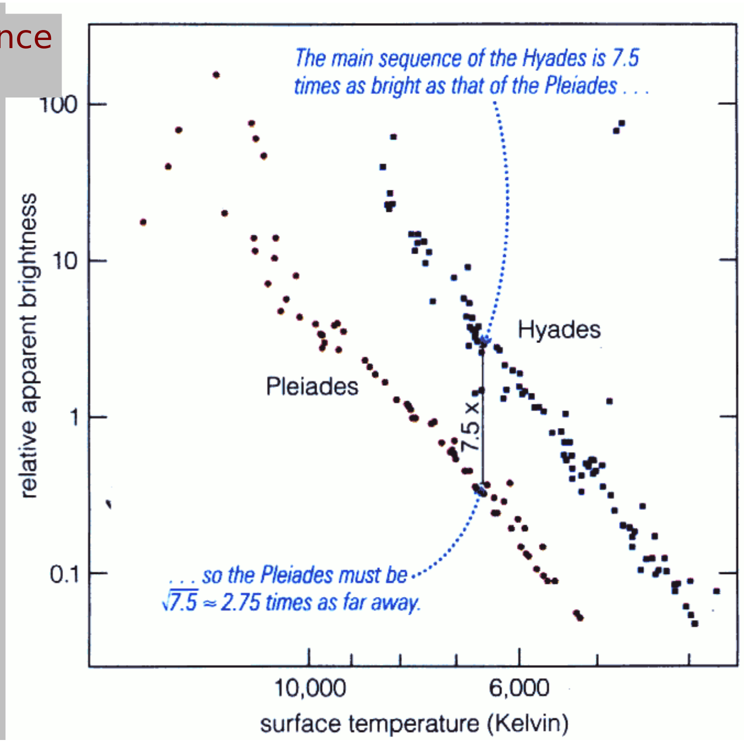


Shown to the left is a temperature/brightness diagram for two star clusters. The size of each cluster is small compared to its distance from us.

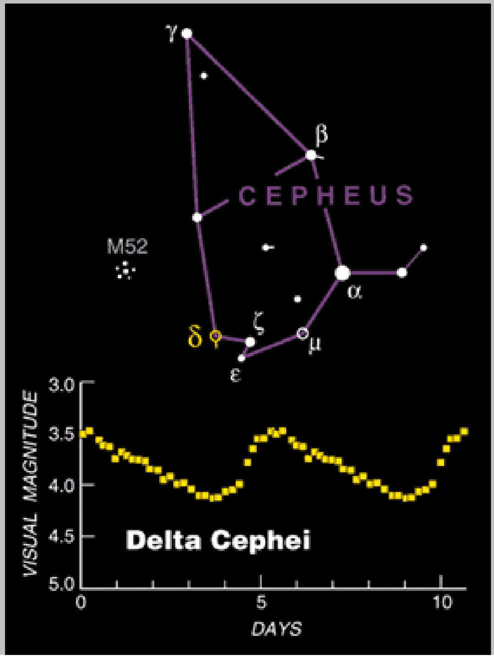
If cluster A is 1000 pc away, what can you say about the distance of cluster B?

- A d_B = 1000 pc
- B d_B > 1000 pc
- C d_B < 1000 pc
- D Not enough information.

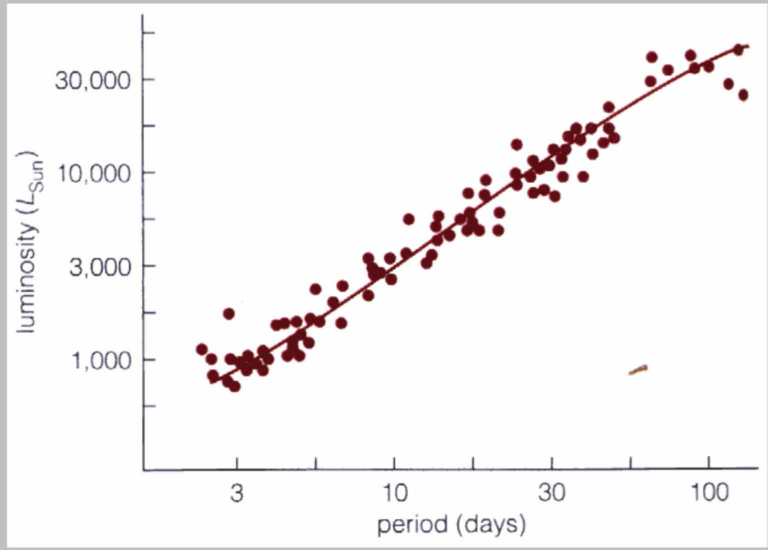
Main-Sequence Fitting



Calibratable standard candle : Cepheid Variables

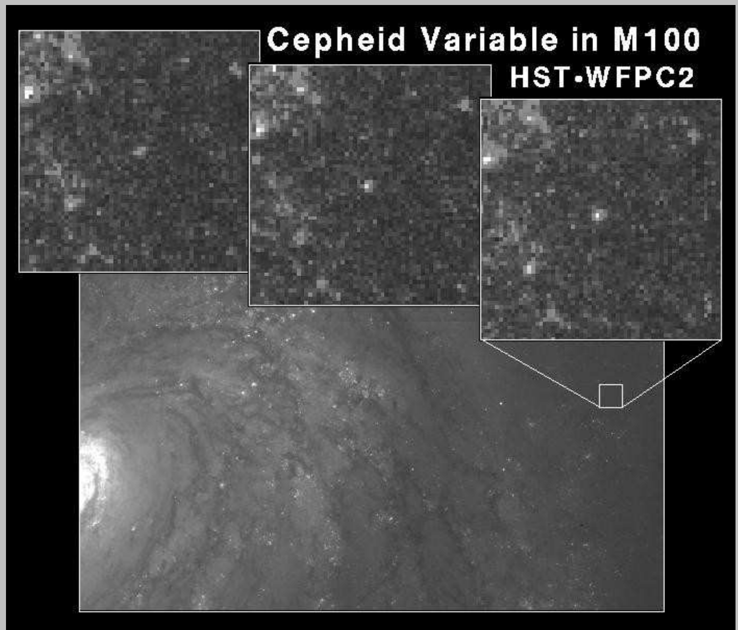


Calibratable standard candle : Cepheid Variables



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

Cepheid Variable in galaxy M100 (distance : 17 Mpc)



Cepheid Variables are evolved (i.e. giant-stage) stars that started life as main-sequence stars 2–8 times as massive as the Sun.

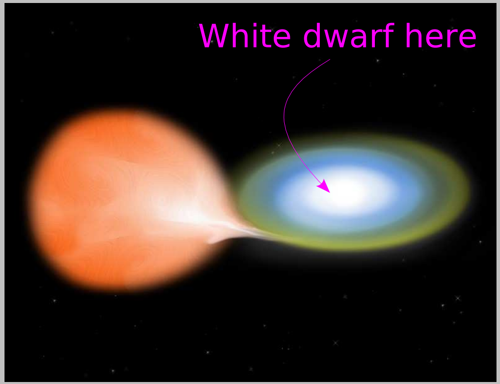
Are Cepheid Variables good standard candles for measuring the distance to a globular cluster?

A Yes

B No

Standard Candle : Type Ia Supernova

$L_{peak} = 7 \times 10^9 \, L_{\odot}$



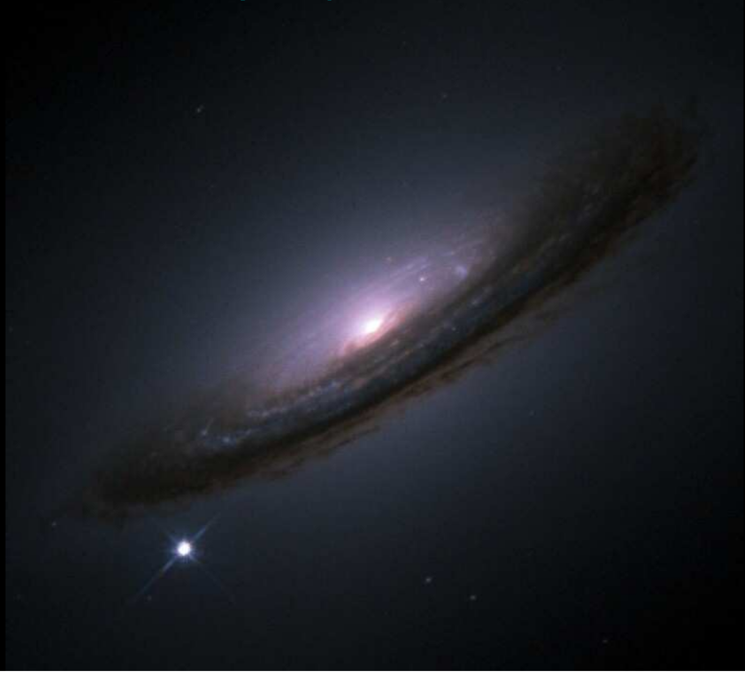
White dwarf : inert carbon stellar remant, held up vs. gravity by electron degeneracy.

- White dwarf accretes matter from a companion.
- Reaches 1.4 $M_{\odot}$, where e^- degeneracy can't hold it up
- Begins collapse, gets dense enough for Carbon fusion
- Foom

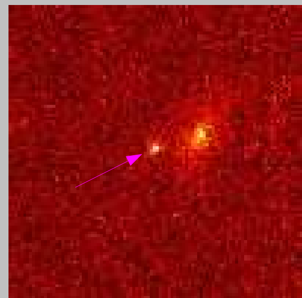
Which happened first in the Universe : a Type Ia (thermonuclear) supernova, or a Type II (core-collapse) supernova?

A Type Ia (thermonuclear)
B Type II (core collapse)
C It could have been either one

Nearby Supernova 1994D



Supernova 1997ek (z=0.86)



It exploded 7 billion years ago, when the Universe was 54% its present size....

...we saw it in December 1997.