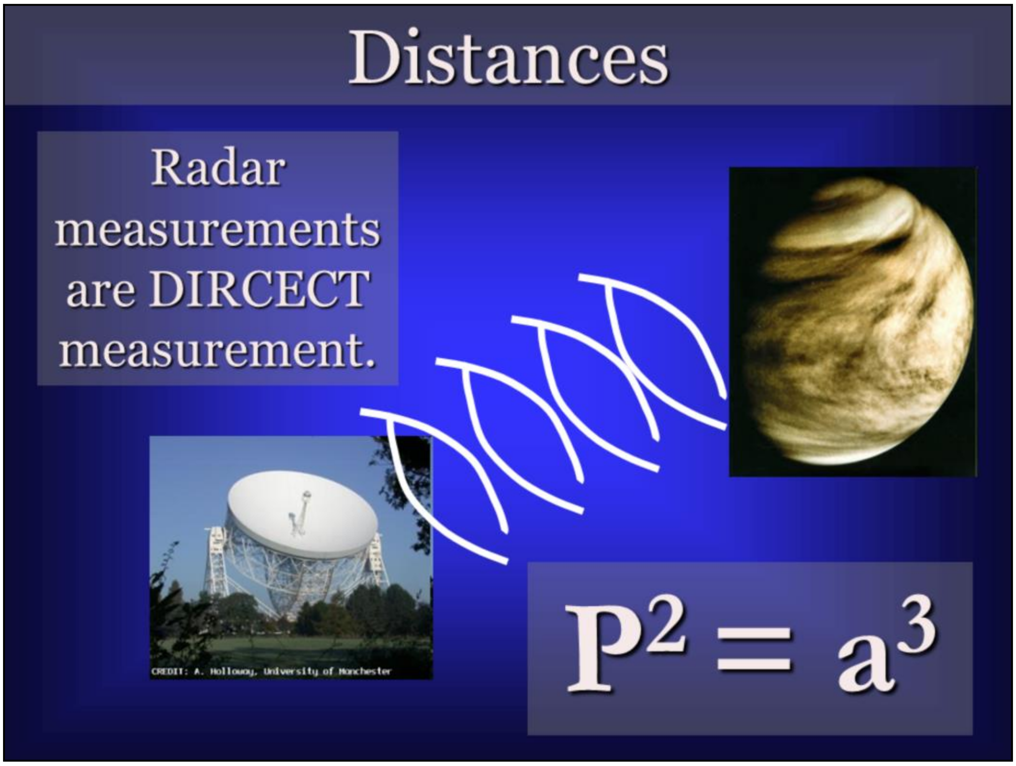
Distances: Pulling it Together

1. What are ways that we know distance?
2. How are the measures related?
3. What is the difference between a direct and an indirect measure?
4. What is a standard candle? What are some examples?
5. For what distance scale does each measurement work best?



We bounce radar signals off of Venus to measure our precise distance from it.

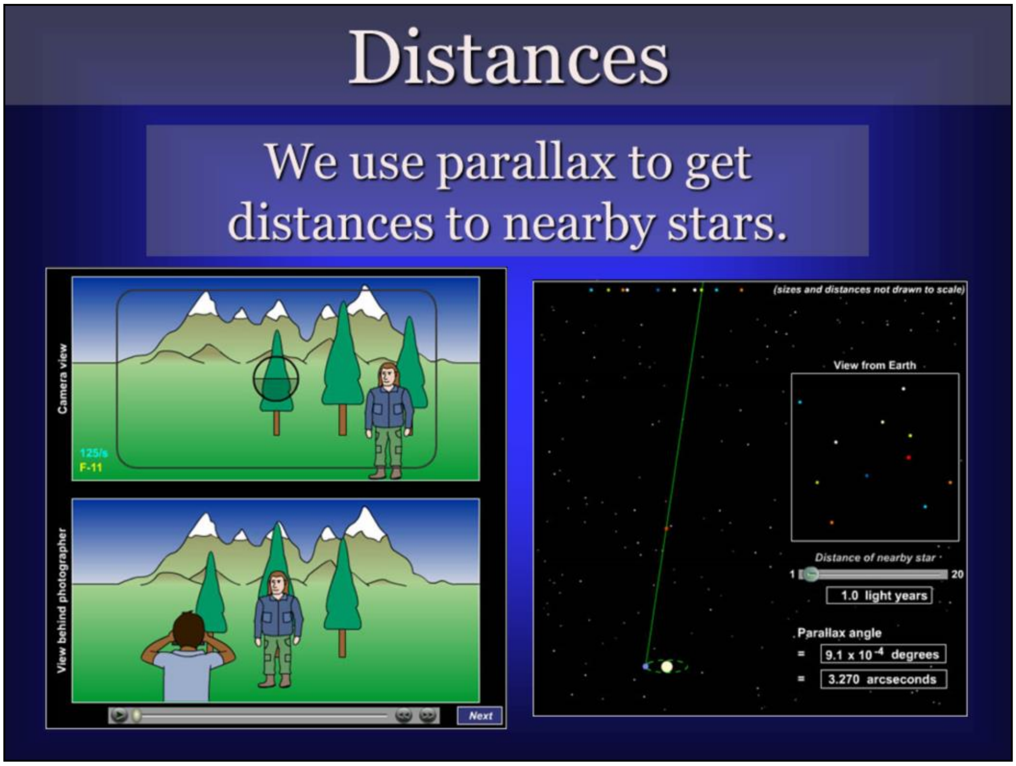
Remember Kepler's Laws?

The third law relates orbital period to distance.

So, we have distances in terms of the AU, or the average Earth/Sun distance.

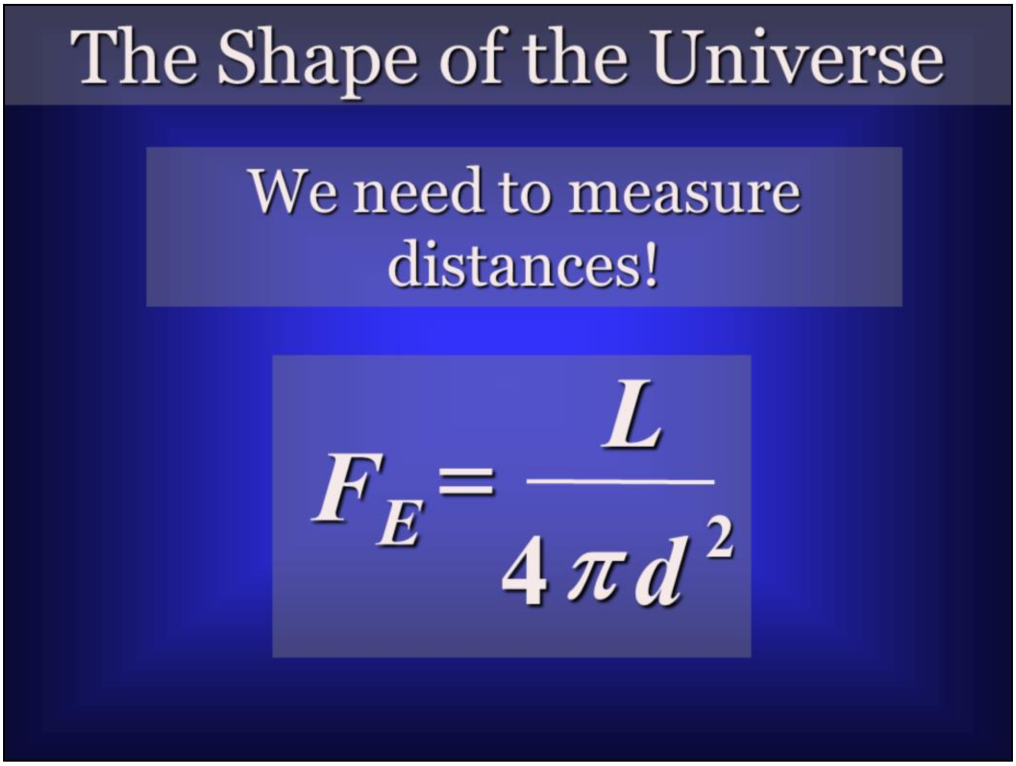
Once we know the distance between us and one other planet, we can calculate

the exact value of the AU and get the distance to the Sun



Parallax is purely a geometric measurement! Accurate to within detection limits (how well we can resolve the motion). In the late 90's Hipparcos satellite recalibrated all our distance measurements.

Note: This depends on having an accurate measurement of the A.U. – which we got from radar measurements!



We will get the distances to objects by “knowing” their Luminosity and solving this equation

Distances: Standard Candles

Objects of known luminosity

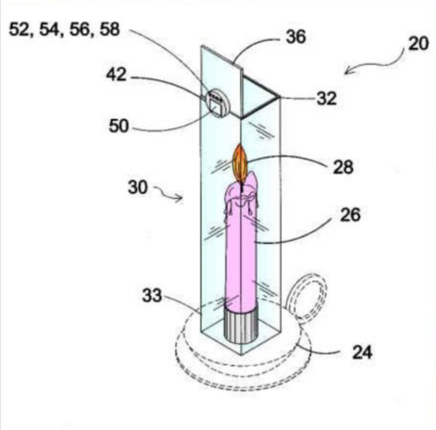
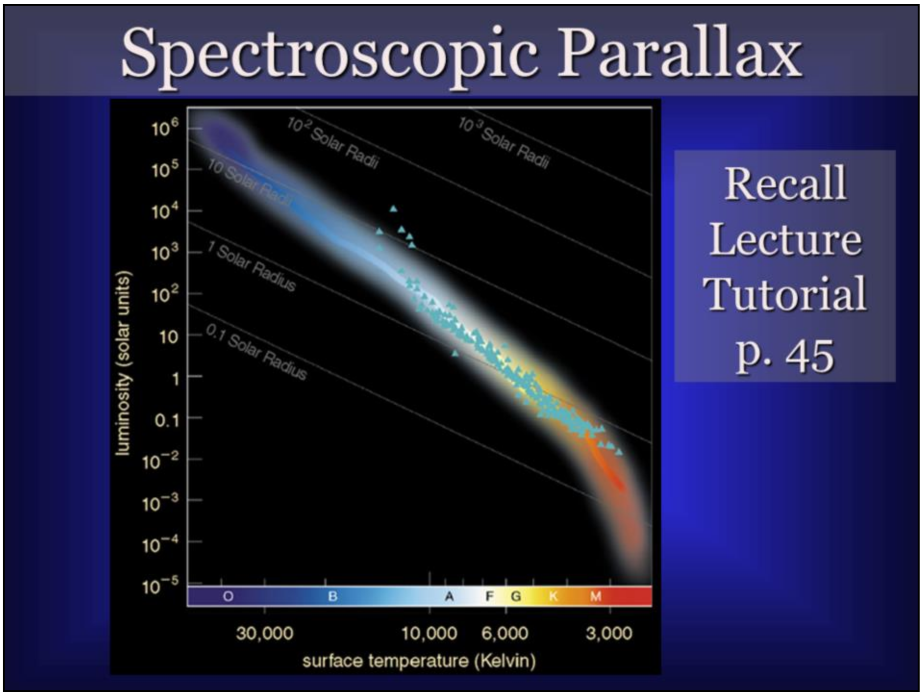


FIG 3

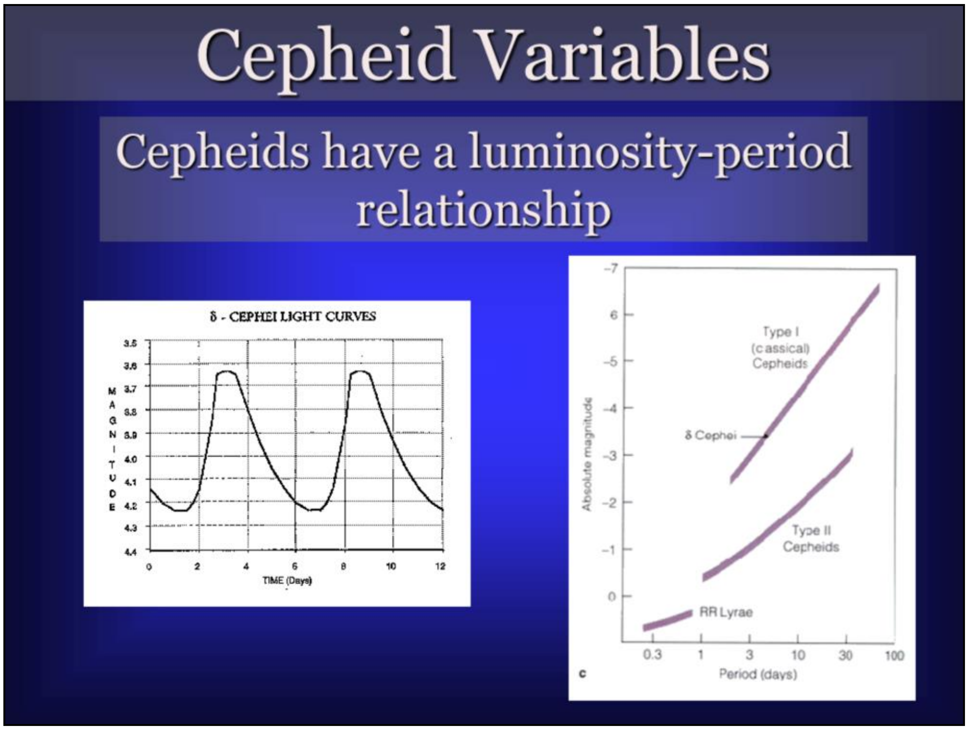
- Main Sequence Stars
- Cepheid Variables
- Novae
- Supernovae
- Spiral Galaxies



Lecture Tutorial: Spectroscopic Parallax, p 45

The technique of using spectroscopic sequence to determine actual luminosity is based on understanding the HR diagram. You get the spectral type of the star in question (take its temperature) and look up what its luminosity should be. Note that the main sequence on the HR diagram has some thickness. (recall that main sequence stars get more luminous as they age)

This causes the distance measurement using a single star to be somewhat inaccurate. *This has nothing to do with geometric parallax.* It's just another stupid name astronomers use.

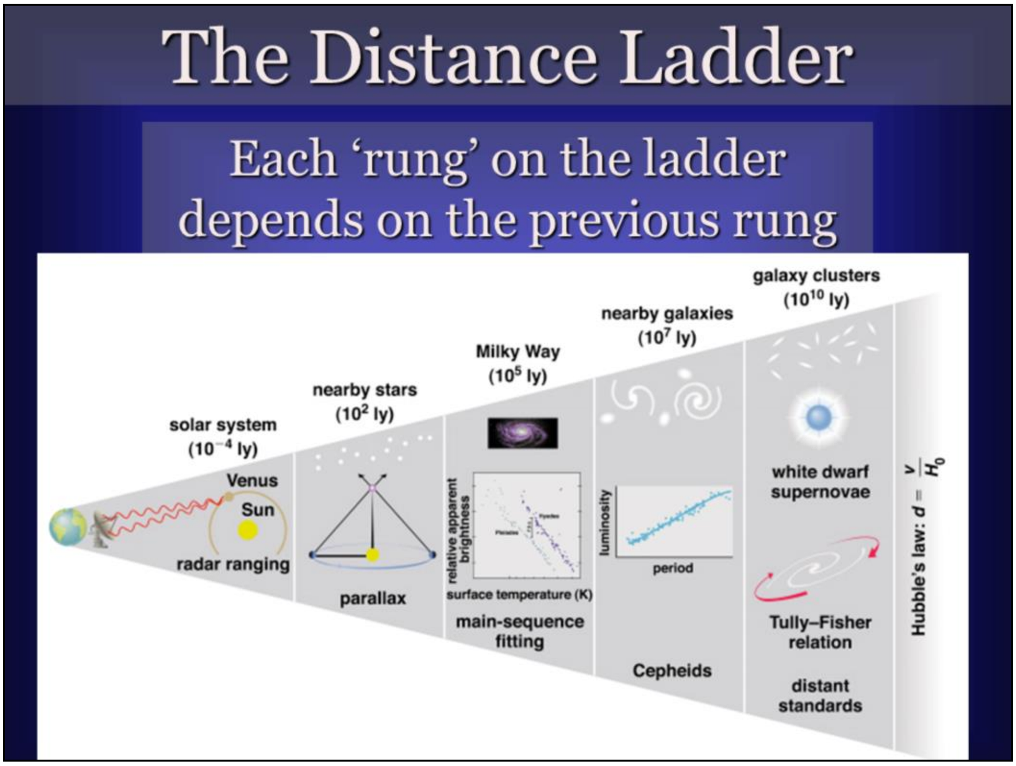


Cepheids have a period luminosity relationship. We measure the period and derive the luminosity.

We them measure the flux and calculate the distance.

Measure the period, look up the luminosity, calculate the distance.

Cepheids are bright enough to see in other galaxies.



Our first distances were ratios: the ratio of the different planets distance from the Sun.

When we developed radar we could bounce signals off Venus. Since we know the speed of light, we could figure out far away Venus is. With that, and the ratios of all the planets, we could figure out those distances.

Parallax is using geometry to find distances to the nearest stars. It still depends on the distance from the Earth to the Sun (that we determined with ratios & radar)

With enough near stars we can *calibrate* our distances to clusters using main-sequence fitting and then us that to find distances to clusters throughout our Galaxy.

Some of those clusters have special stars called Cepheid variable stars. These have a relationship between their luminosity (brightness) and the period of their pulsations. We use the calibration from the clusters to figure out how far Cepheids in other galaxies are.

But even Cepheids are not bright enough to see in far away galaxies. For that, we need to use white dwarf supernovae (Type Ia) and a few other methods. We calibrate those with Cepheid variable stars.

Lastly, we use Hubble's Law: distance = v / Ho   where v = speed a galaxy is going away from us (as measured by Doppler shift) and Ho is Hubble's constant.

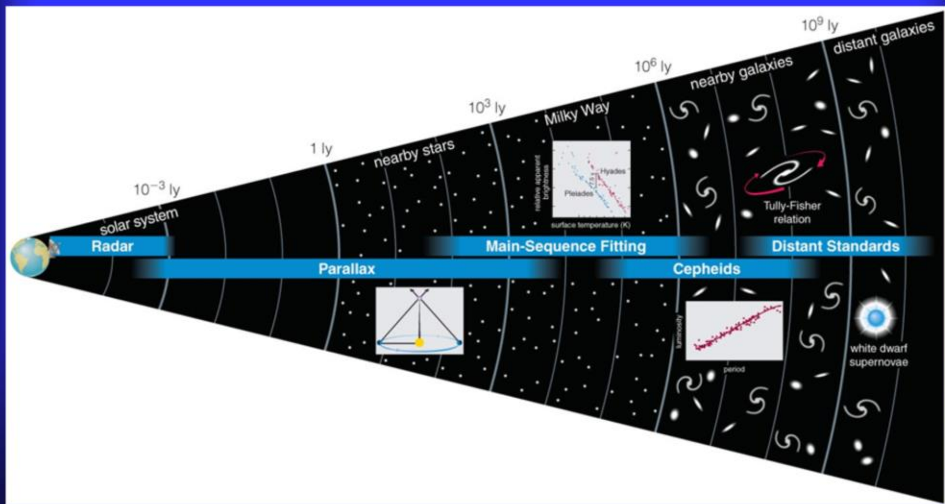
Since each level depends on the calibration from the closer method, uncertainties get bigger the farther we are out. And if we mess up one calibration (due to dust or whatever) it affects everything else.

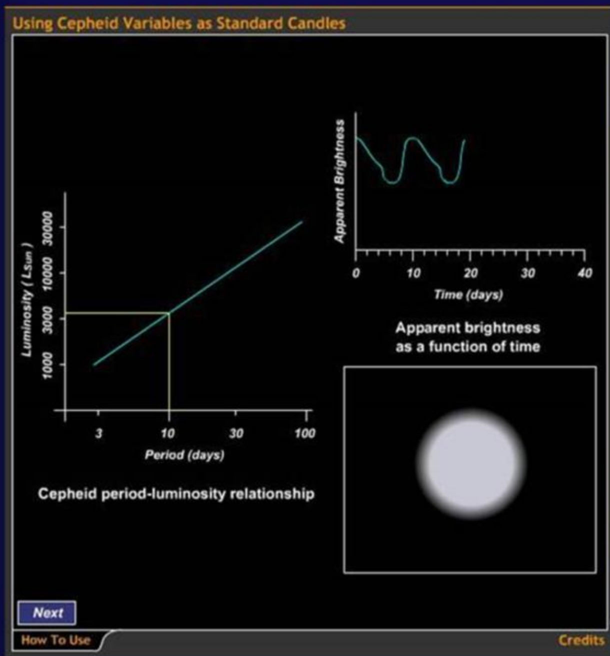
The Distance Ladder

If the real speed of light was slightly faster than we think

A) our distances derived from Cepheids would be too small.
B) our distances derived from Cepheids would be too large.
C) only our Earth-Venus distance would be affected.
D) No distances would be affected.

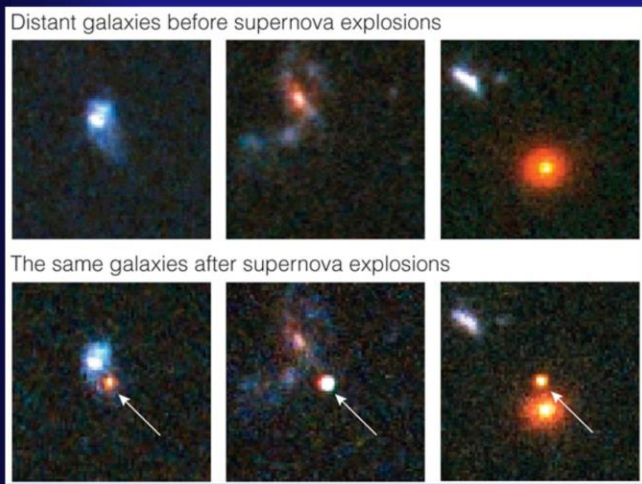
How do we measure the distances to galaxies?





Cepheids

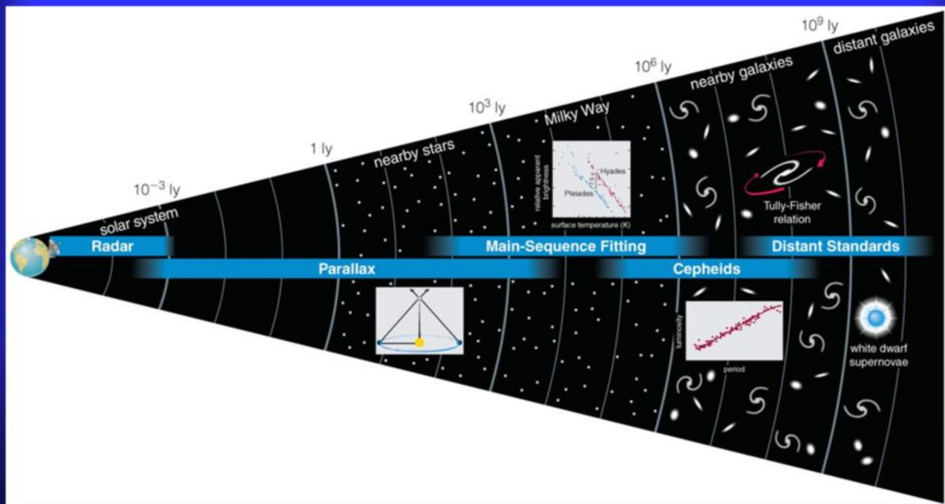
Because the period of Cepheid variable stars tells us their luminosities, we can use them as standard candles.



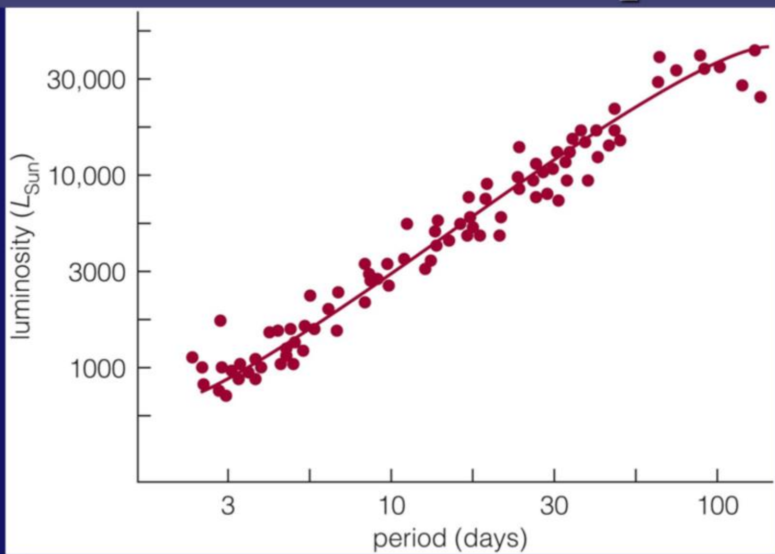
Type I SN

The apparent brightness of a white dwarf supernova tells us the distance to its galaxy (up to 10 billion light-years).

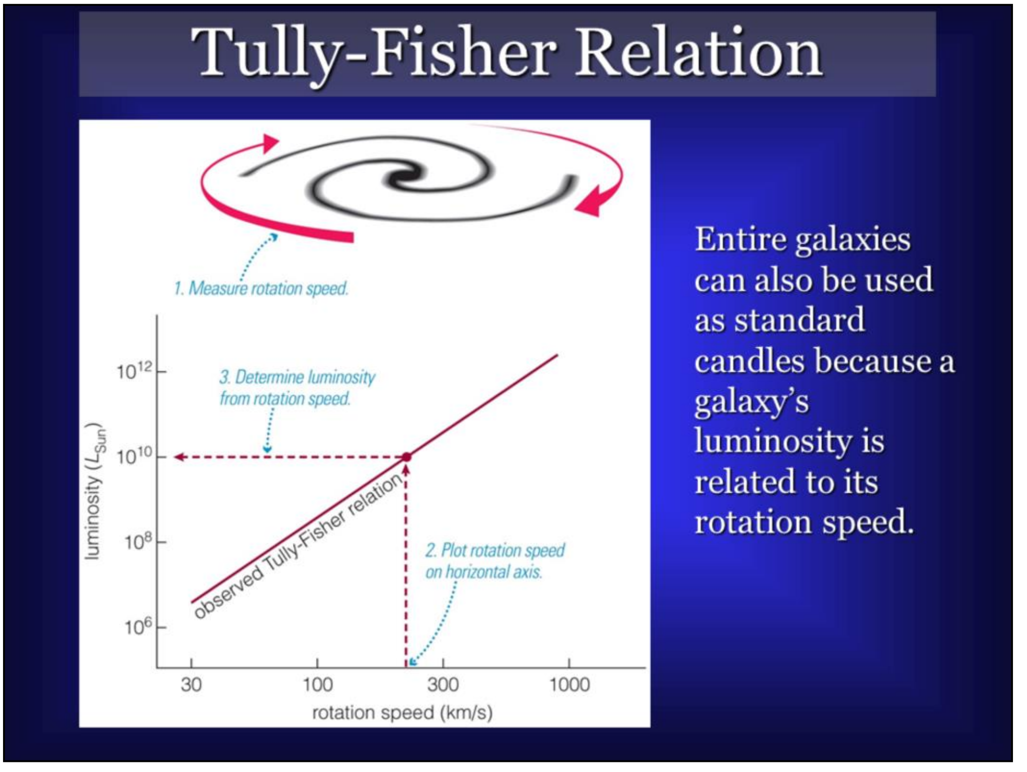
How do we measure the distances to galaxies?



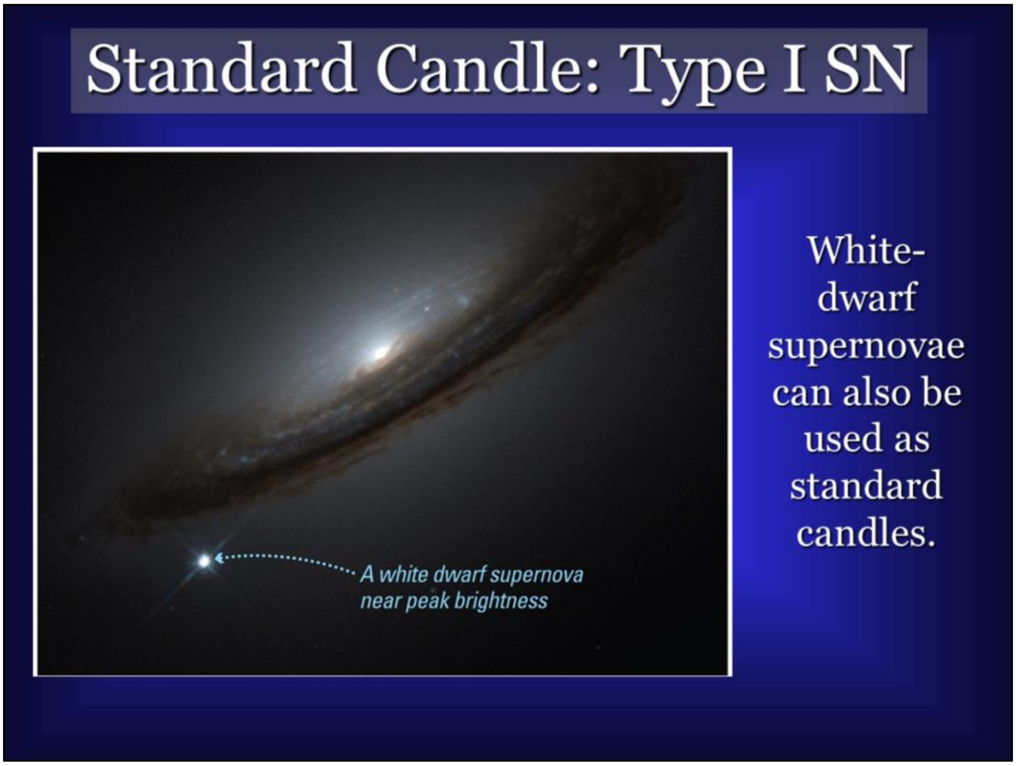
Standard Candle: Cepheid



Cepheid variable stars with longer periods have greater luminosities.



This is an *empirical* relationship!



Type Ia supernova are the result of a white dwarf collapse and detonation.

A white dwarf in a binary system goes nova nova nova nova

Each time a little more material is left behind until the Chandrasekhar limit is reached.

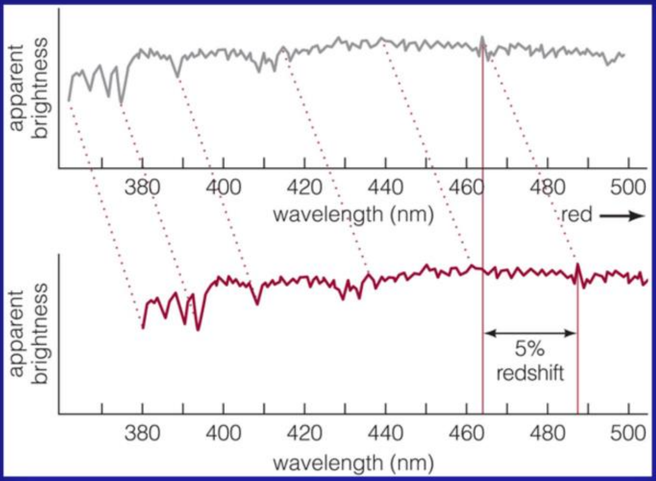
And then KABOOM!

The peak luminosity is the same for all Type Ia SN.

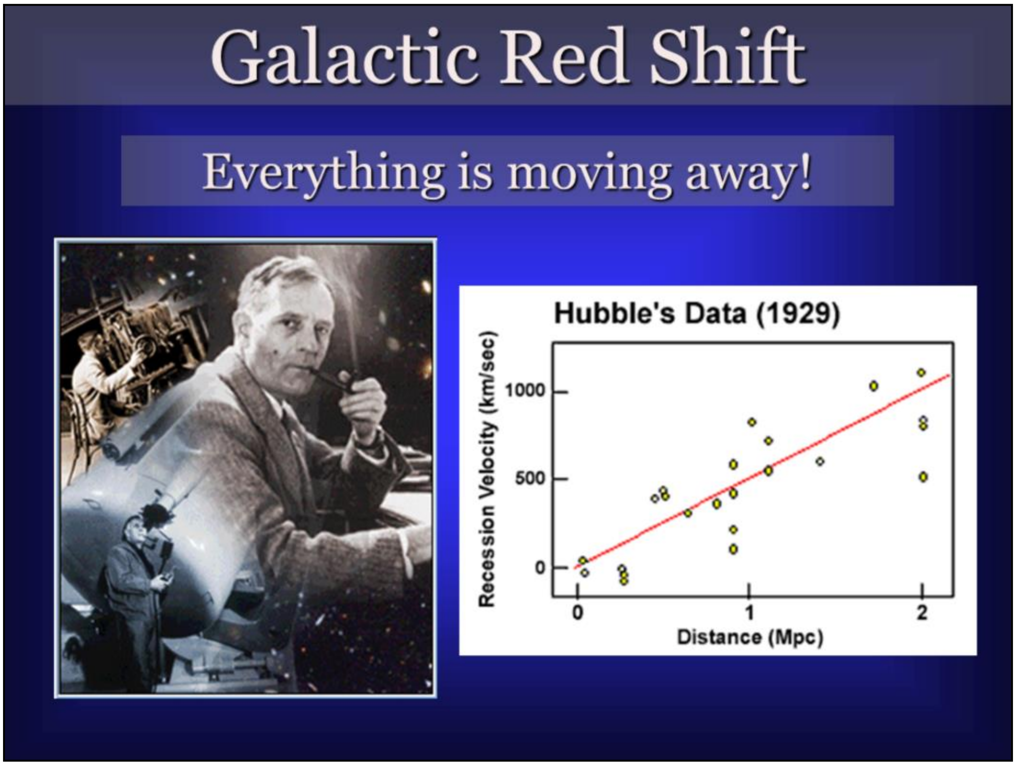
They are 500 times brighter than Cepheids

Have to catch one as it’s happening.

Redshifted Galaxy Spectra



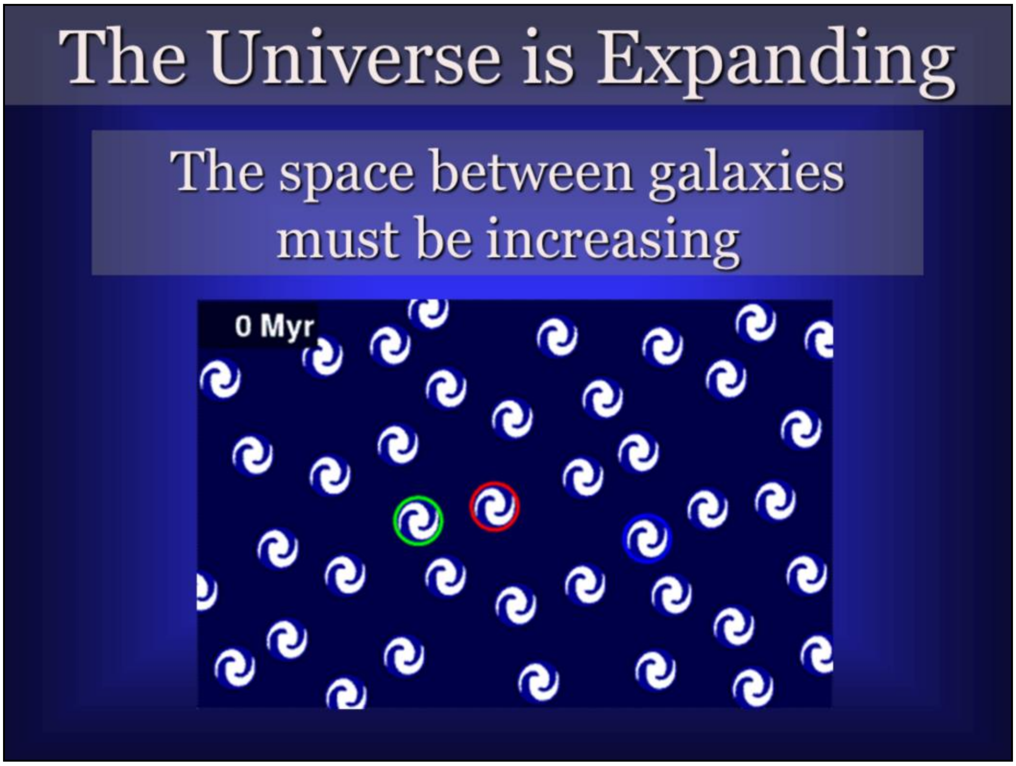
Spectral features of virtually all galaxies are redshifted



After determining that the distance to M31 (Andromeda) is about 3 million light years, Edwin Hubble went on to survey many other galaxies.

Hubble noticed that all of the galaxies he was measuring were red shifted…
In fact there was a correlation between distance and recessional velocity.
More distant galaxies were moving away FASTER than nearby galaxies.

This relationship is called Hubble's Law.
The slope of the line (H_0) is Hubble's Constant.



ANIMATED GIF WAIT FOR IT TO PLAY

Hubble observed that all galaxies have red shift.

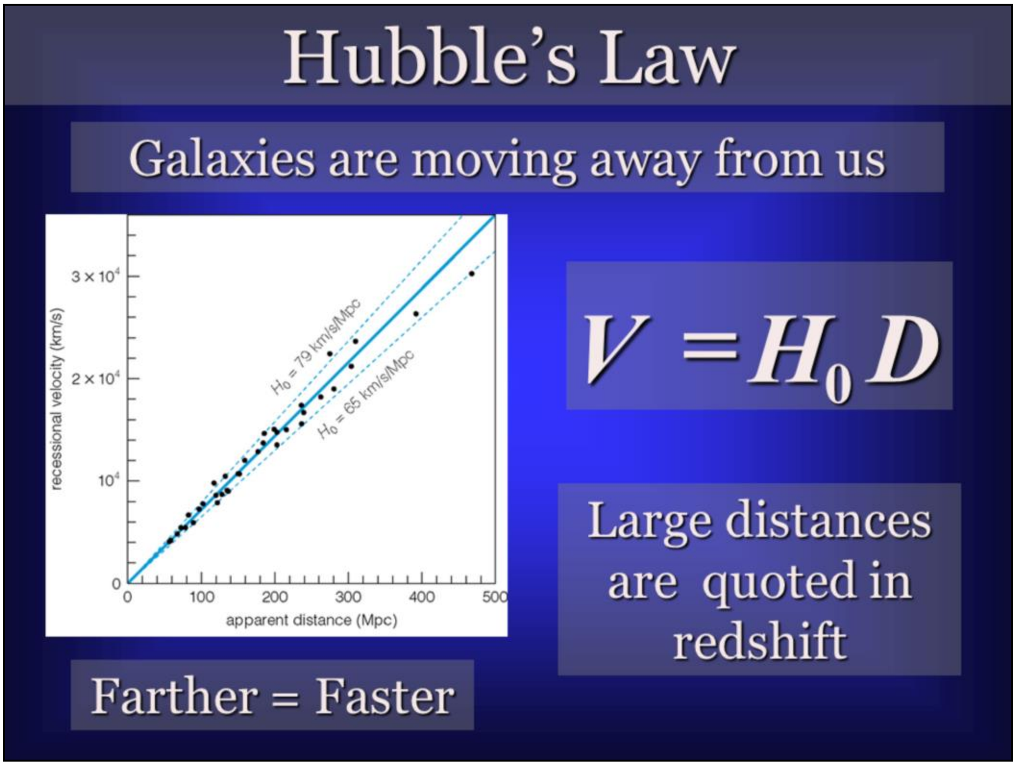
More distant galaxies have larger red shifts.

Like raisins in a cake, the cake stuff expands and the space between raisins gets larger.

Hubble's Law arises naturally from a uniformly expanding universe. (uniform means that the expansion appears to be the *same* everywhere!)

Einstein was very embarrassed when Hubble demonstrated that the universe is expanding.

He called the cosmological constant his greatest folly.



Hubble, after his success with M31, was measuring distances to a whole bunch of galaxies.

He noticed something peculiar. The more distant a galaxy is, the more it is red shifted.

In fact, there is a linear relationship between velocity and distance.

The slope of the line is H_0. H_0

We measure velocity by measuring doppler shift.

Since all distant galaxies appear to be moving away from us, all distant galaxies are red shifted.

More distant objects have a greater redshift, so you will often hear distances quoted as redshifts.

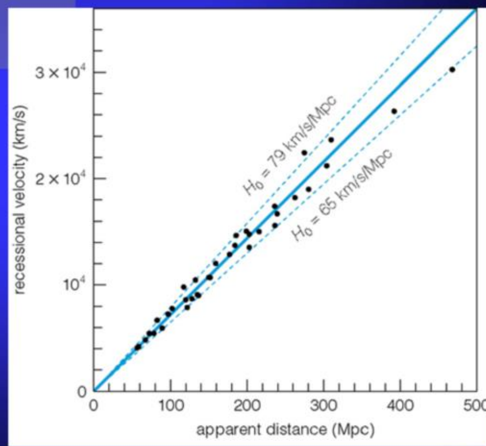
H0 (pronounced H naught) is measured in km per second per Mpc. (kilometers per second per mega parsec) mega = million

Q: How could you find the age of the universe from Hubble's Law?

velocity = $\frac{\text{distance}}{\text{time}}$

velocity = H_o D

H_o = 1/time



Although everything appears to be moving away from us, and the farther away it is, the faster its moving…

We are NOT at the center.

Everything is moving away from everything else. The space between all galaxies is getting larger.

For nearby galaxies, like those in the local group such as M31, the peculiar velocity dominates.

Hubble flow dominates at large distances. Like halfway across the observable universe.