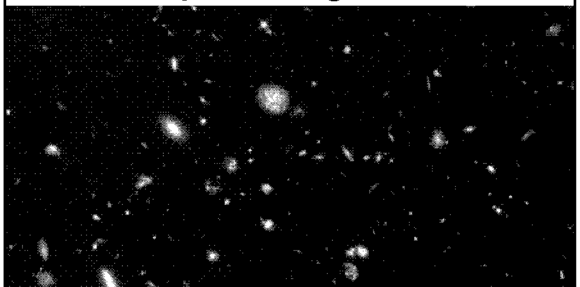
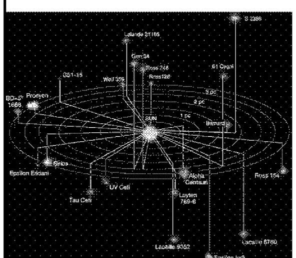
The Expanding Universe



Wednesday, October 14

Put P.S. #3 into “in box”, pick up P.S. #4

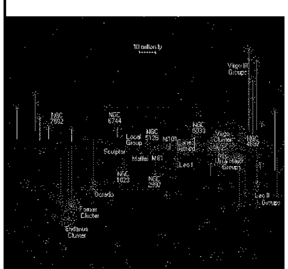
Thinking locally: stars within **3 parsecs** of the Sun.



Equal numbers of redshifts and blueshifts.

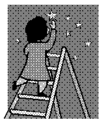
Typical radial velocity v = 20 km/second

Thinking more globally: galaxies within **30 million parsecs** of the Milky Way.



Almost all **redshifts** rather than blueshifts.

Typical radial velocity v = 1000 km/second

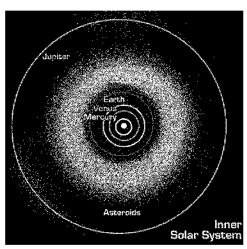


Climbing the
"cosmic distance ladder".

We can't use the same technique to find the distance to **every** astronomical object.

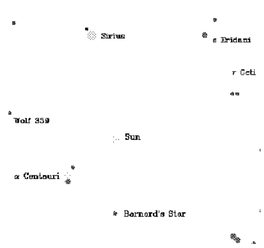
Use one technique within Solar System (1st "rung" of ladder); another for nearby stars (2nd "rung"), etc...

1st rung of the distance ladder: distances within the Solar System.



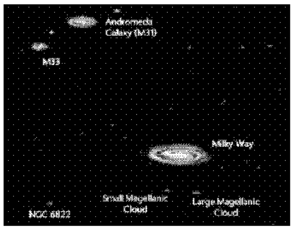
Distances from Earth to nearby planets are found by **radar**.

2nd rung: distances to nearby stars within the Milky Way Galaxy.



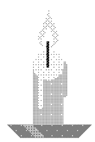
Distances from Solar System to nearby stars are found by **parallax**.

3rd rung: distances to galaxies beyond our own.



Distances from the Milky Way to nearby galaxies are found with **standard candles**.

"Standard candle" = a light source of known luminosity.

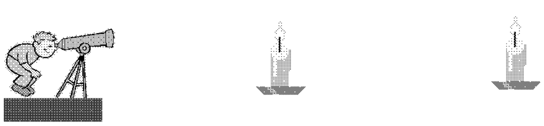


Know luminosity (L): measure flux (f): compute distance (r).

$$f = \frac{L}{4\pi r^2} \Rightarrow r = \sqrt{\frac{L}{4\pi f}}$$

Climbing the distance ladder.

1) Measure flux of two standard candles: one near, one far.



2) Find distance to near standard candle from its parallax.

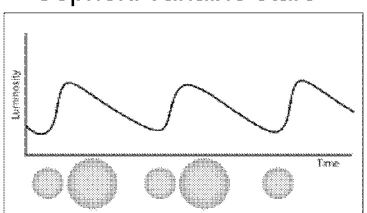
3) Compute luminosity of near standard candle: $L = 4 \pi r^2 f$.

4) Assume far standard candle has same luminosity as the near.

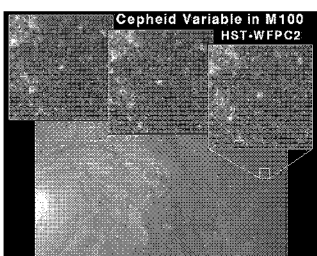
5) Compute the distance to the far standard candle:

$$r = \sqrt{\frac{L}{4\pi f}}$$

A good standard candle: Cepheid variable stars



Cepheid stars vary in brightness with a period that depends on their average luminosity.



Observe Cepheid.

Measure period.

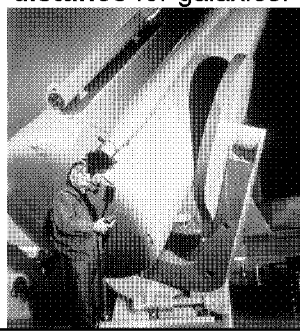
Look up luminosity.

Measure flux.

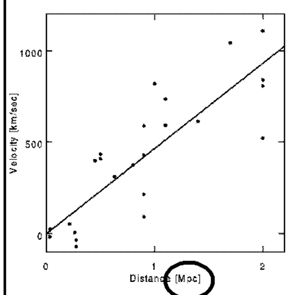
Compute its distance!

$$r = \sqrt{\frac{L}{4\pi f}}$$

In 1929, **Edwin Hubble** looked at the relation between **radial velocity** and **distance** for galaxies.



Hubble's result:
The radial velocity of a galaxy is linearly proportional to its distance.



Hubble's original data

1 Mpc = 1 million parsecs
= 3.26 million light-years
= 670 billion A.U.

Hubble's law
in mathematical form:

$$v = H_0\, d$$

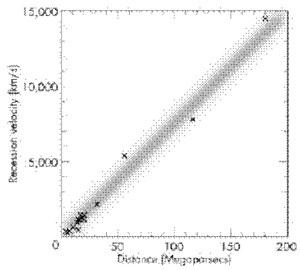
v = radial velocity of galaxy

d = distance to galaxy

H_0 = the "Hubble constant"
(same for all galaxies in all directions)

What's the numerical value of H_0?

What's the slope of this line? →



H_0 = 71 kilometers per second per megaparsec (million parsecs)

Or, more concisely…

H_0 = 71 km / sec / Mpc

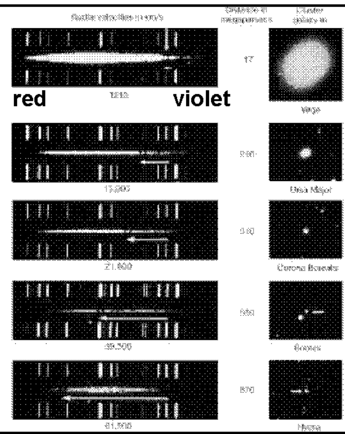
Why it's **useful** to know the Hubble constant, H_0:

Measure redshift of galaxy: $z = (\lambda - \lambda_0)/\lambda_0$

Compute radial velocity: $v = c\, z$

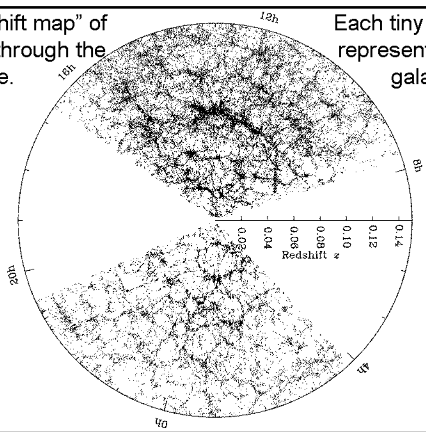
Compute distance: $d = v / H_0$

Cheap, fast way to find distance!



A "redshift map" of a slice through the universe.

Each tiny dot represents a galaxy.



Kilometers per second per megaparsec??

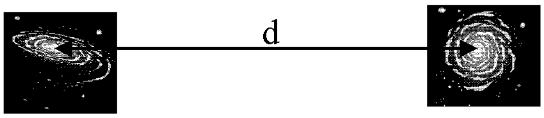
What **BIZARRE** units!

1 megaparsec = 3.1×10^{19} kilometers

$$H_0 = \frac{71 \text{ km/sec/Mpc}}{3.1 \times 10^{19} \text{ km/Mpc}} = 2.3 \times 10^{-18} \text{ / sec}$$

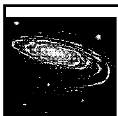
$$H_0 = \frac{1}{4.4 \times 10^{17} \text{ sec}}$$

Why it's **intriguing** to know H_0:

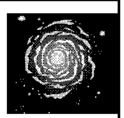


Two galaxies are separated by a distance d.

They are moving apart from each other with a speed $v = H_0\, d$.



How long has it been since the galaxies were touching?



$$\text{travel time} = \frac{\text{distance}}{\text{speed}}$$

$$t = \frac{d}{H_0 d} = \frac{1}{H_0} = 4.4 \times 10^{17}\,\text{sec}$$

PLEASE NOTE: This length of time ($t = 1/H_0$) is **independent of** the distance between galaxies!!

If galaxies' speed has been constant, then at a time $1/H_0$ in the past, they were **all** scrunched together.

Hubble's law (radial velocity is proportional to distance) led to acceptance of the **Big Bang** model.

Big Bang model: universe started in an extremely dense state, but became less dense as it expanded.

Heart of the "Big Bang" concept:

At a finite time in the past ($t \approx 1/H_0$), the universe began in a very dense state.

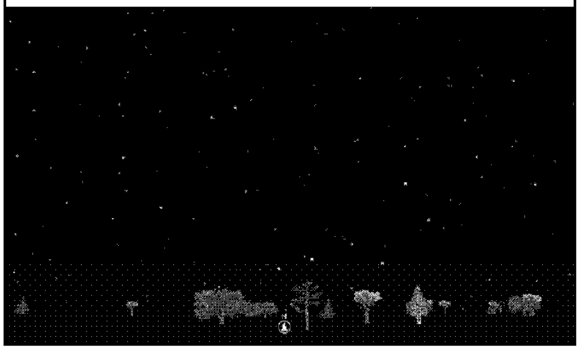
$1/H_0$, called the "**Hubble time**", is the approximate age of the universe in the Big Bang Model.

$$t = \frac{1}{H_0} = 4.4 \times 10^{17} \sec$$

Since there are 3.2×10^7 seconds per year, the Hubble time is

$$1/H_0 = 14 \text{ billion years}$$

The Big Bang model "de-paradoxes" Olbers' paradox.



Hubble time:

$1/H_0$ = 14 billion years.

Hubble distance:

c/H_0 = 14 billion light-years
= 4300 megaparsecs.

Friday's Lecture:

Newton vs. Einstein

Reminders:

Have you read chapters 1 – 6 ?
Planetarium shows **Oct 27 & 28.**
Midterm exam **Friday, October 30**.