Problem Set 7 due today
Third Exam will be given on April 24
Last observatory opportunity April 24 8:30pm

Website
http://casa.colorado.edu/~wcash/APS1120/APS1120.html
The Distance Scale

All the things astronomers have done to gain a handle on distance
Solar System Distances to 3AU

• Radar
  – Measure time of flight of signal bouncing off planets

• Transit of Venus
  – Captain Cook in Hawaii
  – Time that Venus hits limb of Sun
Parallax to 100pc

I year cycle
Main Sequence Fitting
to 55,000pc

Plot enough stars and the Main Sequence becomes clear.

This works out to Magellanic Clouds.

Beyond that, MS stars too faint
Cepheid Variables to 100Mpc
Period-Luminosity Relationship

Cepheids are bright and can be seen at very large distances.
Type I Supernovae

All Type Ia supernovae are the same brightness. That white dwarf that implodes and then explodes is always about the same. And they’re bright. You can see them at billions of parsecs!

Apparent magnitude can be converted to distance.
Tully-Fisher Relation

The brighter the galaxy is, the faster it rotates.

Use radio spectrum to measure Doppler width.

Not super accurate, but it works.
The Distance Scale
Redshift of Galaxies

Hubble found that galaxies are redshifted.

The absorption lines are those of the stars that make up the galaxy.
Hubble's Law

The more distant the galaxy, the greater the redshift.

The more distant is the galaxy, the faster it is flying away from us.

\[ v = H_0 d \]

\( H_0 = 70 \text{ km/s/Mps} \)
Example

Galaxy in Virgo Cluster is at 15Mpc

will recede at $v = 70 \text{ km/s/Mpc} \times 15\text{Mpc} = 1050\text{km/s}$

$$\delta \lambda = \lambda \times \frac{v}{c} = 4000\text{Å} \times \frac{1050}{300,000} = 14\text{Å}$$

a 4000Å line will appear at 4014Å
Example 2

\[ \lambda_0 = 1216 \text{Å} \]  but is observed at \[ \lambda = 1228 \text{Å} \]

\[ \delta \lambda = 12 \]

\[ \frac{v}{c} = \frac{\delta \lambda}{\lambda_0} = \frac{12}{1216} = .01 \]

\[ D = \frac{v}{H_0} = \frac{3000}{70} = 43 \text{Mpc} \]
A Modern Hubble Diagram
Galaxies are Flying Apart

Galaxies remain same size. They just get farther apart.

Effect is the same no matter which position you occupy
Expanding Universe

The volume of the universe is increasing.
The Age of the Universe

\[
v = Hd
\]

\[
d = \left(\frac{1}{H}\right)v
\]

\[
d = vt
\]

Notice: At time zero, \( d = 0 \)

All galaxies are at zero distance!

The universe has zero volume!

when \( t=1/H \)
The Begining

\[ t = \frac{1}{H_0} \]

\[ H = 70 \text{km/s/Mpc} = \frac{70 \times 10^3 \text{m/s}}{\frac{10^6 \text{m}}{3 \times 10^{18} \text{s}}} = 2.3 \times 10^{-18} \text{s}^{-1} \]

\[ H = \frac{1}{2.3 \times 10^{-18}} = 4 \times 10^{17} \text{s} = 13 \text{Billion years} \]

Before 13 billion years ago, there was no before.

Time and space started with the Big Bang

We will return to this in a few more lectures
Galaxies are Moving

Gravity attracts them to mass centers.
Redshift Survey

Galaxies across the sky. Distance from redshift.

“The Great Wall”
More Galaxies
The Texture of the Universe

2dF Galaxy Redshift Survey

106688 Galaxies
Theory of Structure

Structure grew out of minor fluctuations.

Gravity causes density regions to enhance.

The very origin of structure.
The Cosmic Web