Observational Astronomy - Lecture 11
Cosmology - I

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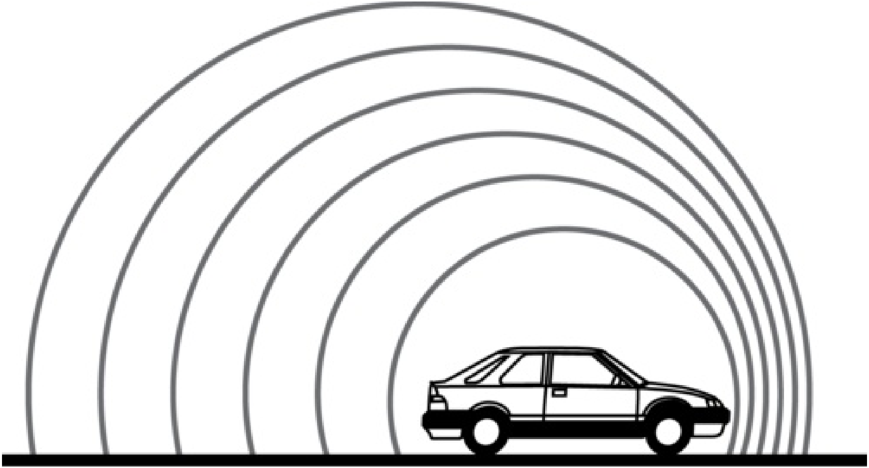
What is Cosmology?

- Cosmology is the study of the origin, evolution, and eventual fate of the universe.
- The Universe is commonly defined as the totality of existence, including planets, stars, galaxies, the contents of intergalactic space, the smallest subatomic particles, and all matter and energy.

Key Ideas Needed to Understand Cosmology

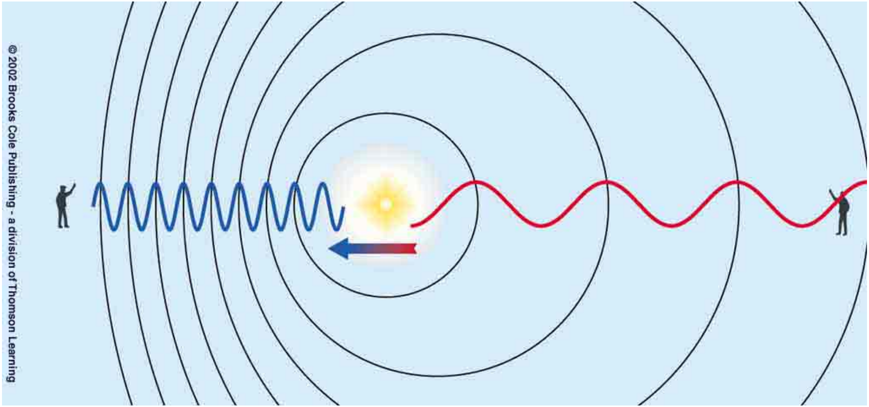
1. Doppler Shift
2. Distance Measures
   - Parallax
   - Standard Candles
   - Cepheid Variables
   - Type 1A Supernovae
   - Cosmic Distance Ladder
3. Hubble's Law and the Expansion of the Universe
4. Gravitational Lensing
5. Dark Matter

Sound and the Doppler Shift



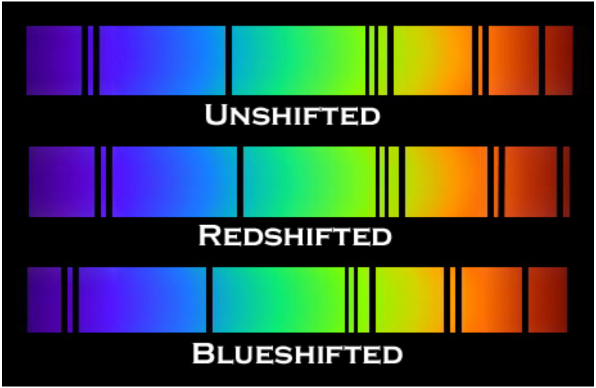
- When moving toward you, you hear a higher frequency.
- When moving away from you, you hear a lower frequency.

Light and the Doppler Shift



- When moving toward you, light is shifted toward the blue (higher frequency, shorter wavelength).
- When moving away from you, light is shifted toward the red (lower frequency, longer wavelength).

Doppler Shift of Spectra



- When moving toward you, light is shifted toward the blue (higher frequency, shorter wavelength).
- When moving away from you, light is shifted toward the red (lower frequency, longer wavelength).

Calculating Velocities from the Doppler Shift

- Since most objects are moving away from us, astronomers use the symbol z to denote the redshift.

$$z = \frac{\lambda observed - \lambda emitted}{\lambda emitted} = \frac{\Delta\lambda}{\lambda emitted}$$

- The redshift and the velocity of recession are related by:

$$1 + z = \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}}$$

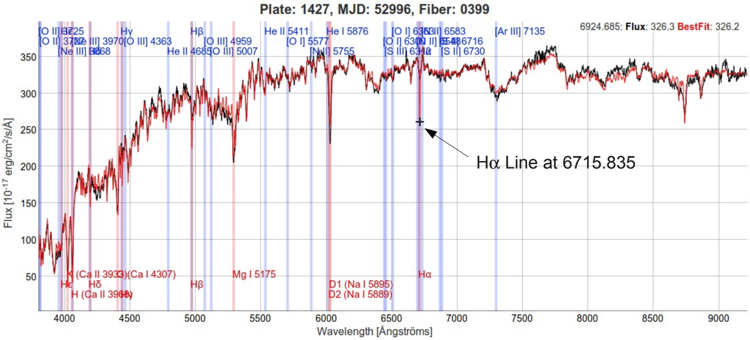
- Solving for v:

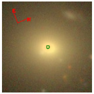
$$\frac{v}{c} = \frac{(1+z)^2 - 1}{(1+z)^2 + 1}$$

- For small v:

$$\frac{v}{c} = z$$

Redshift Example - Sloan Digital Sky Survey



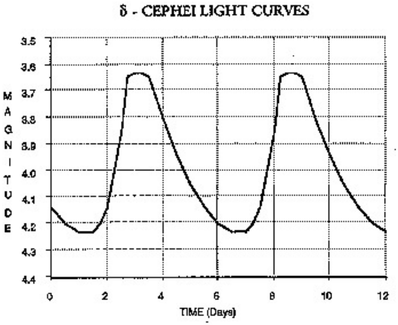


- Measured wavelength of H_α line = 6715.835 Angstroms.
- Lab wavelength of H_α line = 6562.81 Angstroms.
- $\Delta\lambda = 6715.83 - 6562.81 = 153.0$ Angstroms.
- $\mathrm{z} = \Delta\lambda/\lambda = 153.0/6562.81 = 0.023$
- $\mathrm{V} = 0.023 * \mathrm{c} = 0.023 * 299,792 \mathrm{km/sec} = 6895 \mathrm{km/sec}$

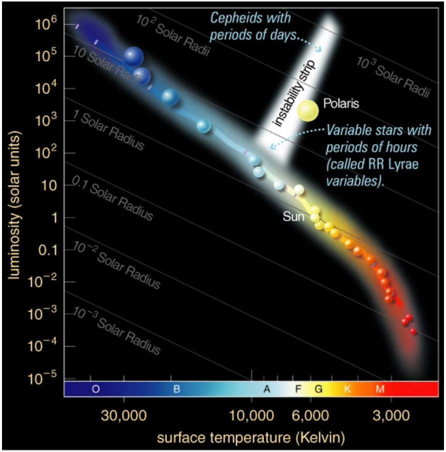
Standard Candles

If we know intrinsically how bright something is, then by measuring its apparent brightness, we can calculate how far away it is.

Cepheid Variables



Delta Cephei - the first Cepheid



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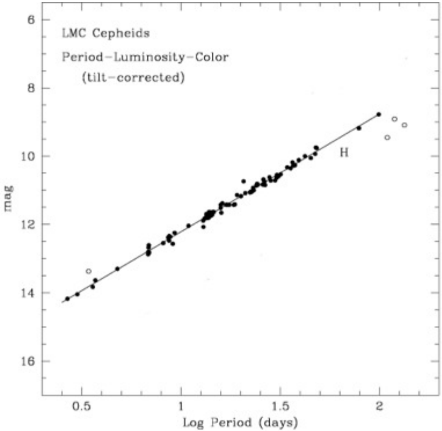
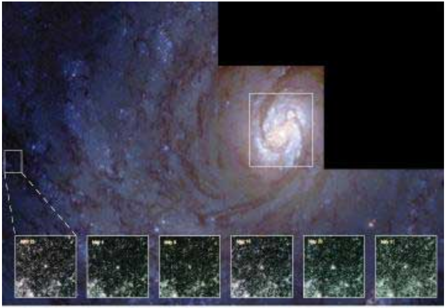
- Cepheid Variables are unstable stars that pulsate.
- Their brightness varies in a regular fashion.

Using Cepheids to Measure Distance - I



Period - Luminosity relation for Cepheids in the LMC.



A Cepheid in M100.

Using Cepheids to Measure Distance - II

- All of the stars in the Large Magellanic Cloud (LMC) are about the same distance from us.

- Since the period is correlated to the apparent magnitude, we know that the period is correlated to the absolute magnitude. Recall:

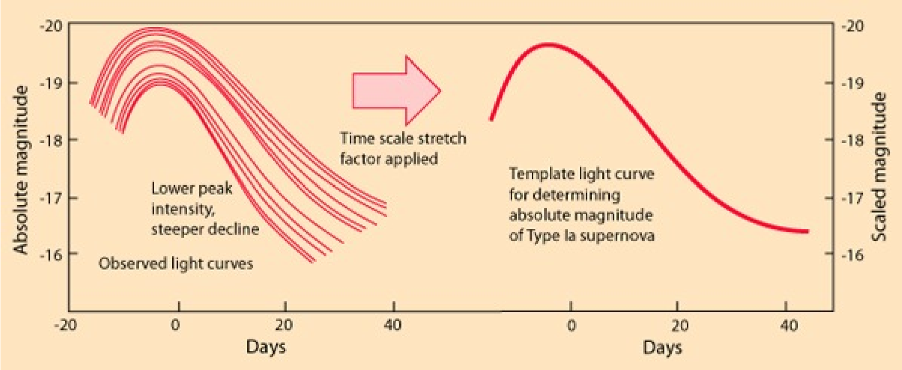
$$m = M - 5 + 5\log_{10}(D)$$

- By measuring the period of the oscillation and the apparent magnitude, we can calculate the distance.

- This assumes that we know how far away the LMC is.

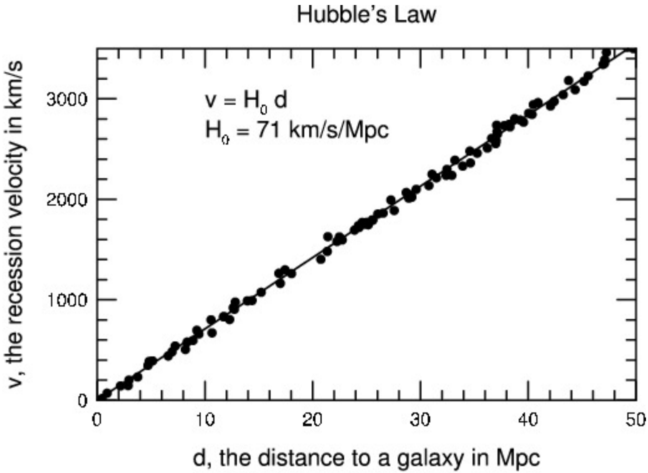
- Measuring the distance to the LMC is an important part of the *Cosmic Distance Ladder*.

Type 1A Supernovae as Standard Candles



- Type 1A supernovae are exploding white dwarf stars.
- They all have a similar intrinsic peak brightness.
- We can use them as standard candles.

Hubble's Law and the Expansion of the Universe



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Today's best value - 68 km/sec/Mpc

Calculating Distance from Hubble's Law

- Suppose a galaxy is measured to have a redshift z = 0.01.
- Since this is a small redshift, we can write:

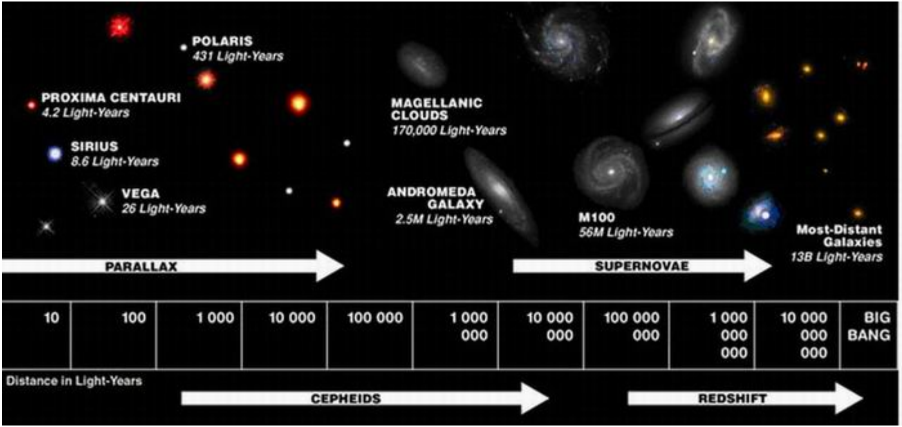
$$V = z \times c = 0.01 \times 3.0 \times 10^5 \, km/sec = 3,000 \, km/sec$$

- Now we apply Hubble's Law, assuming a Hubble constant of 70 km/sec/Mpc. The distance of the galaxy is just the speed of recession divided by the Hubble constant:

$$D = \frac{3,000 \frac{km}{sec}}{70 \frac{km}{sec \, Mpc}} = 43 Mpc$$

- You can compare this to the graph of Hubble's law and see that they agree.

The Cosmic Distance Ladder



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We use a variety of techniques to calculate distances.

Expansion of the Universe - Key Ideas

- Key points:
  - Everything is expanding away from everything else
  - The velocity of expansion is proportional to distance.
  - The expansion is only apparent at very large scales - the Solar System is not expanding!
- Expansion of the Universe is a difficult thing for our minds to grasp.
- A few analogies can help.
  - The balloon analogy - a 2D version of our 3D Universe.
  - The raisin bread analogy.
- It is important to remember that the analogies are just tools to help us understand. Don't take them too far!

The Balloon Analogy

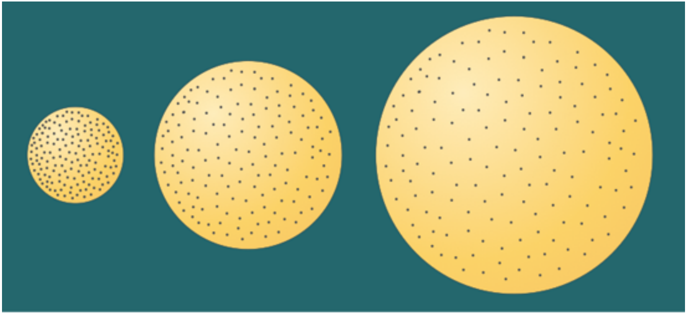
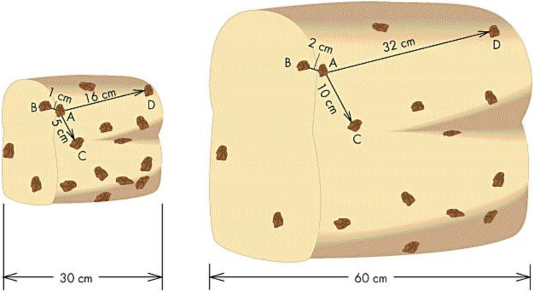


Figure 1. Expansion of a baloon

- Pretend we are ants stuck to the surface of the balloon.
- Forget about the 3rd dimension!!!
- Everything is moving away from everything else.
- The further away it is, the faster it is moving away.

The Raisin Bread Analogy

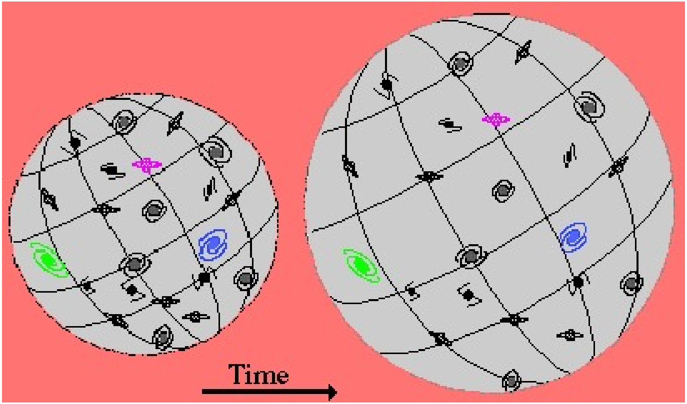


A Raisin bread dough before rising

B Raisin bread dough after rising

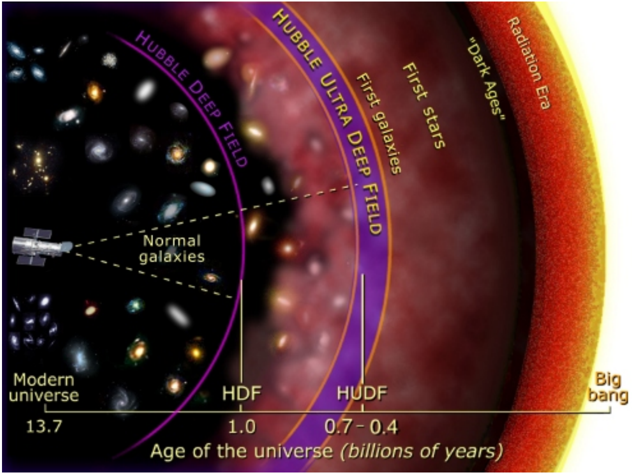
- Every raisin is moving away from every other raisin.
- The further away it is, the faster it is moving away.

Another Picture of Expansion



- Galaxies are moving away from each other.
- Individual galaxies are not growing in size.

As we look out in Space, we look back in Time



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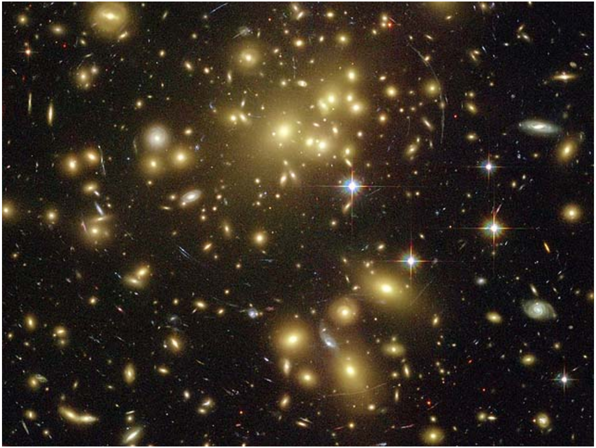
- We cannot see past the radiation dominated era, because the Universe was opaque before then.

More Key Ideas

- There is no center!!!!!
- Everyone sees the Universe expanding away in all directions.
- Everyone sees themselves at the center of their Observable Universe.
- There is no need for the Universe to be “expanding into” anything.
- We do not know whether the Universe is finite or infinite in extent.

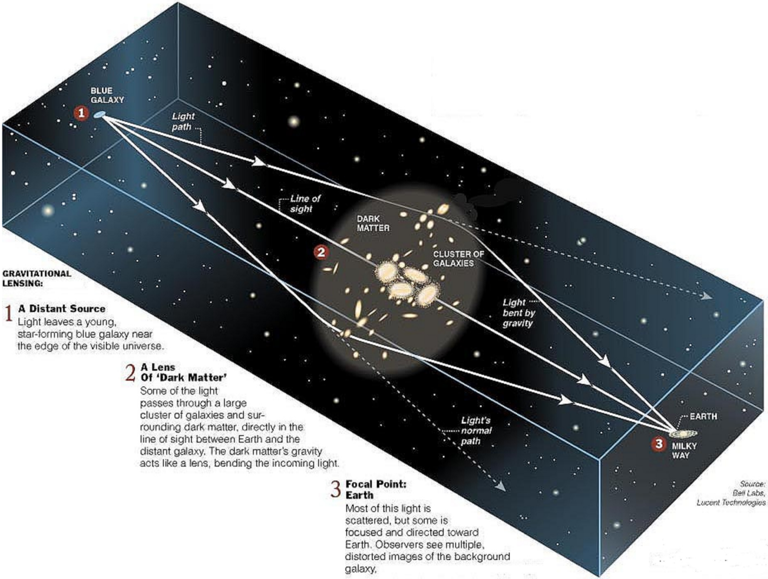
Galaxy Clusters



Abell 1689 - a large cluster of galaxies.

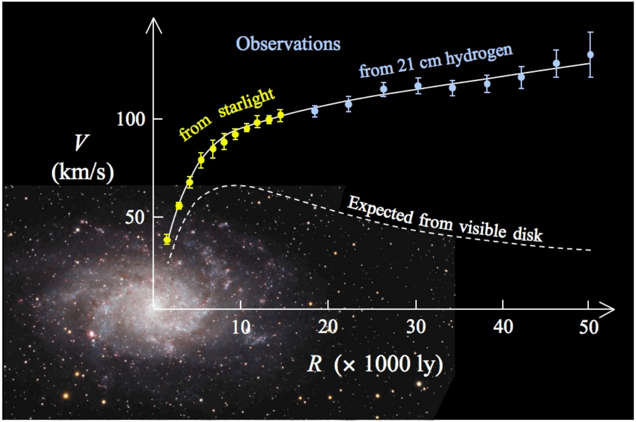
- Gravity causes galaxies to collect in groups called clusters.

Gravitational Lensing



Images of Gravitational Lensing

M33 Rotation Curve



- Galaxy rotation curves look very different from what is expected given the mass of visible matter.
- Some type of "unseen matter" is required to explain the curves.

Need for Dark Matter

- Gravitational Lensing measurements allow us to calculate how much matter is in clusters.
- Much more matter is present than what we see.
- Galaxy rotation curves also require the presence of some “unseen” or “dark” matter.
- There are other reasons (next week) to believe that this dark matter is not made up of ordinary atoms.
- Most physicists believe that the dark matter is an undiscovered type of sub-atomic particle.
- So far, attempts to see this particle on Earth have been unsuccessful.
- Some astronomers believe that a modification to the laws of gravity at large distance can explain these results, but they are in the minority.

Our Current Picture of the Composition of the Universe