Lecture 20: Introduction to Cosmology

Note Title 4/12/2011

→ Copernican principle – We do not occupy a special place in the universe.

We have good evidence that the universe is roughly homogeneous on large scales, and it looks isotropic around us.

Homogeneous: At any pt in the universe, the average matter, radiation, vacuum energy density is the same for suitably large boxes

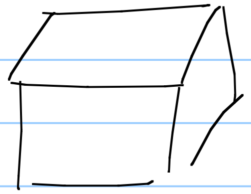
Isotropic: the universe looks the same in every direction.

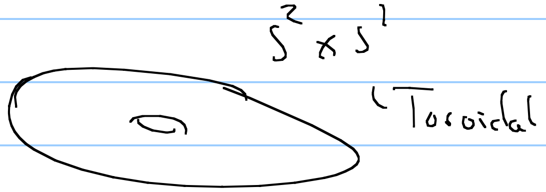
If we do not occupy a special place in the universe, and the universe is isotropic for us, it must be isotropic everywhere.

→ We seek solutions to the Einstein Field Eqns that are everywhere homogeneous and isotropic.

Possible geometries of 3-D space: hyperbolic, flat, spherical

→ If you abandon the Copernican Principle (or if data one day say it is not true), then you can get other geometries ...





But, current evidence does not support these, and the Copernican idea seems valid.

Evidence for the Copernican Principle

(1) Hubble recession of galaxies: in every direction, galaxies appear to recede from us – along the line of sight – by Hubble's law

$$V = H_0 d$$

$$H_0 = 72 \pm 7 \text{ km/s/Mpc}$$

(Evidence for isotropy about our location)

(2) Distribution of galaxies: Roughly, we see equal numbers of galaxies in all directions on the sky. Further, on a scale of ~ 100 Mpc galaxy density is approximately constant

(3) Cosmic Microwave Background Radiation: After subtracting out our local motion, we see extremely uniform radiation at $T = 2.73$ K with variations of 10's per millionth of a K.

This radiation fits a model of a big-bang universe where hot radiation and particles early in the universe cooled. Eventually, atoms formed and the cross-section for radiation / matter interaction dropps to zero. These photons streamed through the universe until present and make up the CMB.

What is in the universe?

→ Ordinary matter (baryons) ... mostly in stars.

Typical galaxy mass $\sim 10^{12} M_\odot$

→ we observe $\sim 10^{11}$ galaxies

· Spread out all that matter evenly,

$$\rho_{visible} \sim 10^{-31} \, g/cm^{-3} \quad \text{(today)}$$

(1 proton per cm^3)

→ Radiation: Mostly CMB, but others that are weak – mass $\emptyset$ particles or gravitational waves

$$\rho_r \sim 10^{-34}\ \mathrm{g/cm^3} \quad \text{(today)}$$

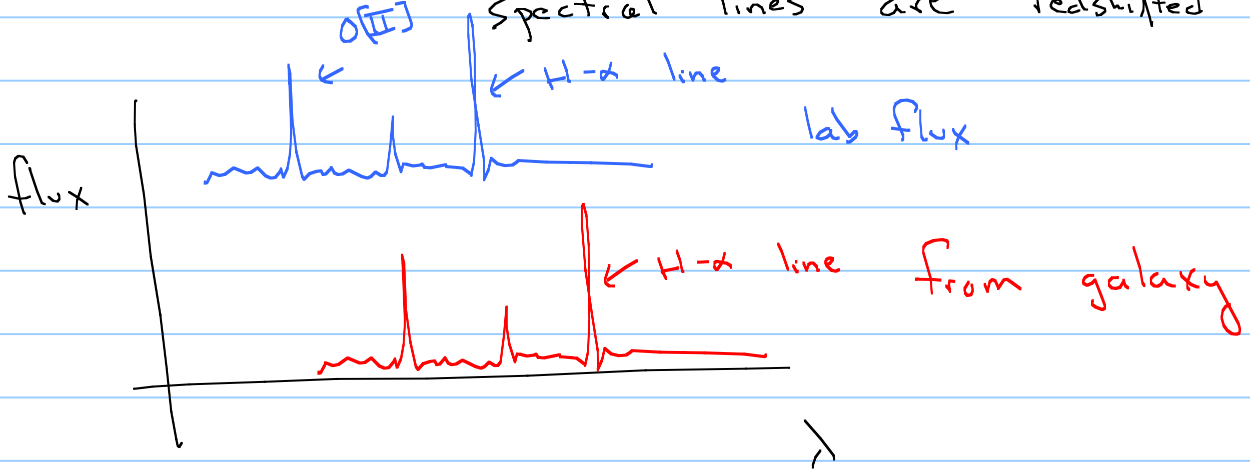
→ Dark Matter: From spiral galaxy rotation curves, gravitation lensing (Mass to light ratios) there is a lot of matter w/ mass not in stars or gas... "dark matter"

Energy density of Dark matter ~ 4-5 times higher than baryonic matter.

→ "Dark Energy": An internal energy density associated with empty space – currently viewed as likely to be a repulsive energy density.

Measures of distance

- Redshift: As galaxies recede from us, there spectral lines are redshifted

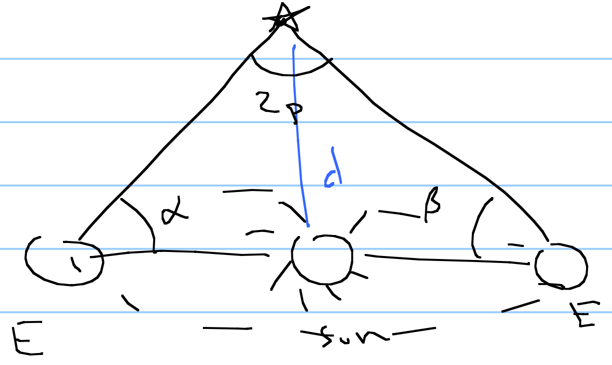


$$\lambda_{obs} = \lambda_{lab}(1+z) \quad \text{for } z = \text{"redshift"}$$

$z = 0$ ← close, or light recently emitted

$z = 1$ ← far, light emitted when universe about ½ it's current "size"

- Paralax – for stars



$d = \dfrac{1\,AU}{p}$ p in radians

$d = \dfrac{1\,pc}{p}$ p in seconds

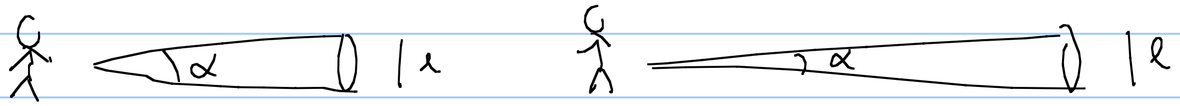
(Really hard to measure...)

Luminosity distance: based on measuring a flux of a "standard candle" of Luminosity L

$$f = \frac{L}{4\pi d_L^2} \implies \boxed{d_L = \sqrt{\frac{L}{4\pi f}}}$$

This is useful only if you trust your standard candle ... SN Ia or certain star types.

Angular diameter distance: Suppose you have a disk of a known size. At different distances, it subtends different angles



$$d_A = \frac{l}{\alpha}$$

Proper distance: A metric calculation – $d_p = \sqrt{g_{ab}\,dx^a dx^b}$

Note: $d_L = (1+z)\,d_p = (1+z)^2\,d_A$ (flat universe)

due to how energy in light measured changes w/ the universe's expansion.