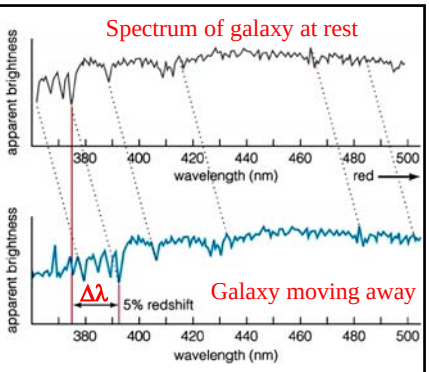
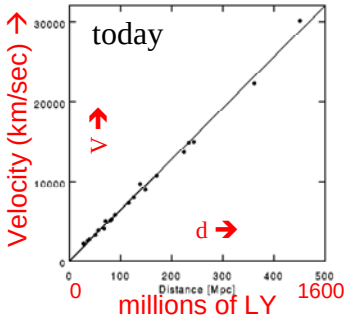
Measuring Distances using Redshifts

v = velocity of recession
d = distance



[Fig. 15.14]



- Measure Doppler shift from emission or absorption lines:

  Redshift $z = \Delta\lambda/\lambda = v/c$

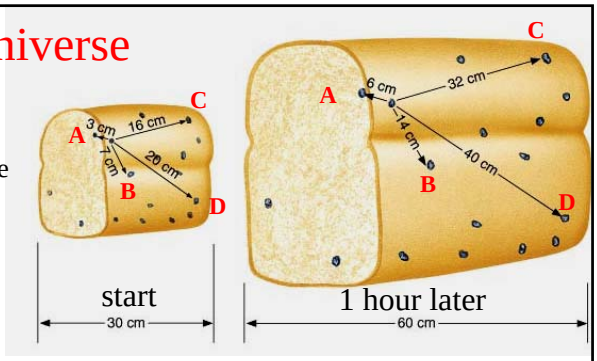
- Plug v into Hubble's Law:

  $v = H_o\, d$

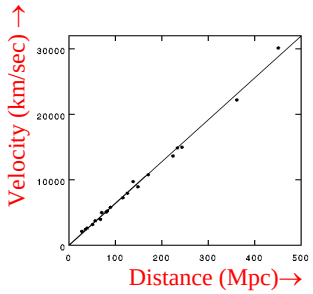
  $d = v/H_o$

The Expanding Universe

- We are unlikely to be at exact center.
- ➔ Scale of the whole universe is expanding.
- Galaxies all recede from each other
  - Except for small random motions.



Looks same from any raisin



Homework 7 – due late Friday Apr 23

Open House – Campus Observatory
Fri/Sat 9-11 PM, if *NO* clouds.
S. on Farm Lane to end,
then 100 yds to R.

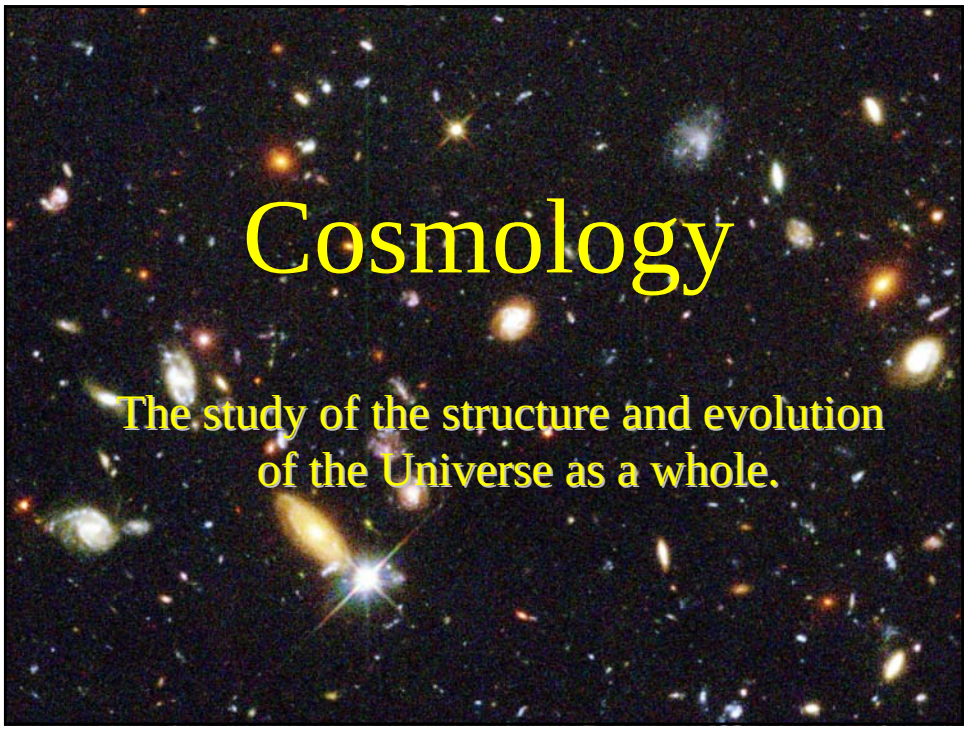
Modern methods of determining distances

Method	Distance Range (millions of LY)
Pulsating variable stars (Cepheids)	0-65
Brightest star in galaxy	0-150
Globular clusters	0-150
Rotation velocities	0-300
Supernovae	0-8000
Redshifts (Hubble Law)	**300 – 13,000**

Calibrated with pulsating variables

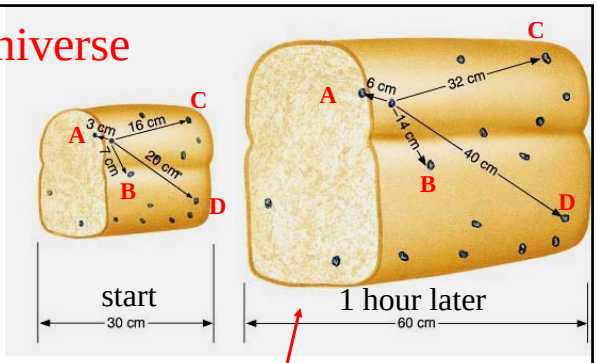
But these are still calibrated with parallaxes!

H_o calibrated with supernovae, rotation velocities, etc

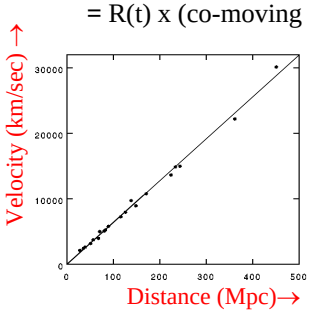


The Expanding Universe

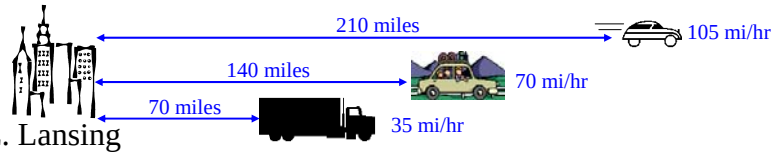
- Cosmological principle
  - Universe looks the same from any point.
- Expanding Universe
  - Hubble's Law
- Scale Factor = R(time) = R(t)
  - Proper Distance = R(t) x (co-moving distance).



R(t) increased by factor 2

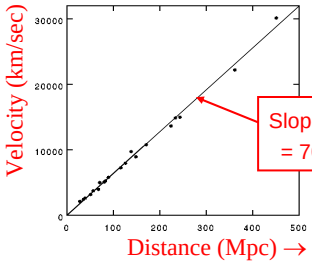


The Age of the Universe

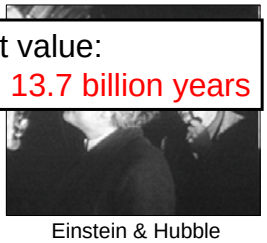


0 – 70 = -70 mi/hr

- Cars:
  - 140 miles/70 mph = 2 hrs
- Galaxies
  - H_o = 70 km/sec/Mpc = 156,000 mph/1.9x10^{19} miles
  - $1/H_o$ = 1.9x10^{19} miles/156,000 mph = 14 billion years



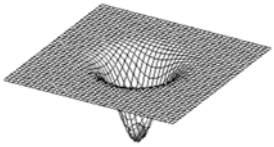
Current best value:
Age of U. = 13.7 billion years



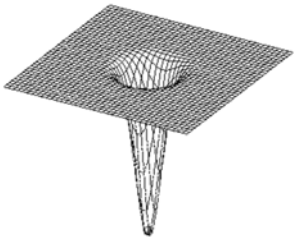
Einstein & Hubble

General Relativity

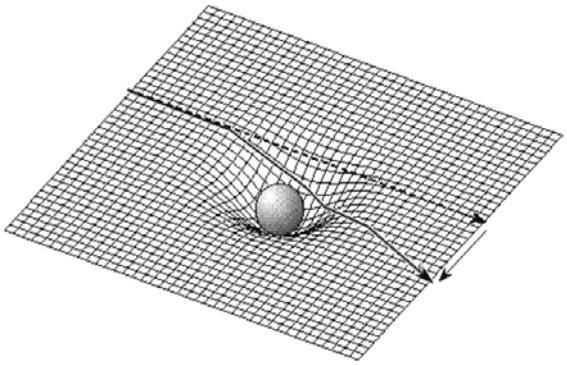
Gravity = distortion into extra space-like dimension.



Low mass star

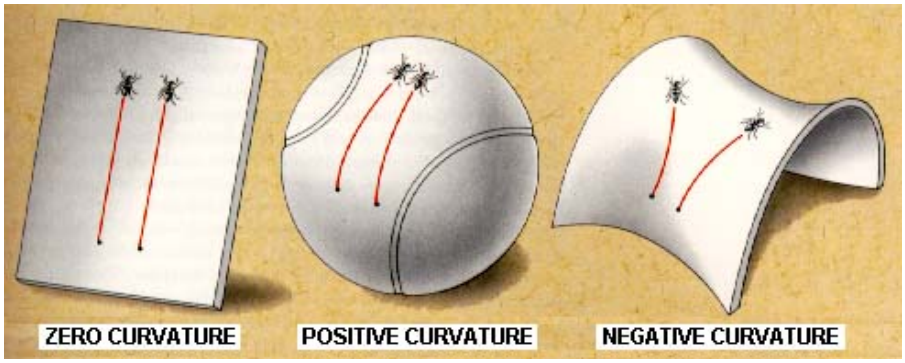


High mass neutron star



Analogy having 1 less dimension

The Shape of the Universe

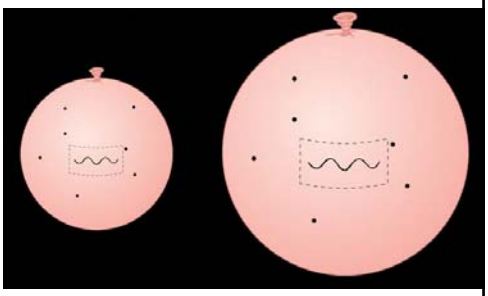


Some possible geometries

Analogy having 1 less dimension

The Expanding Universe

- Individual galaxies do not get stretched.
- Light waves *do* get stretched ➔ redshift.



doppler demo applet

Redshift ➔ scale factor R(t) at time light was emitted.

Analogy having 1 less dimension

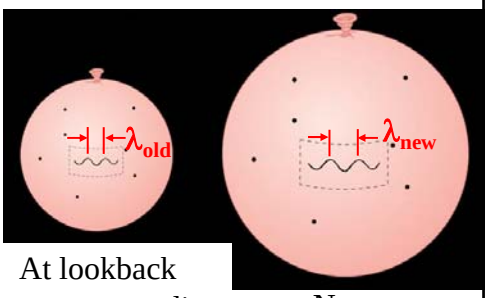
The Expanding Universe

- Individual galaxies do not get stretched.
- Light waves *do* get stretched ➔ redshift.

Redshift

$$z = \frac{\lambda_{new} - \lambda_{old}}{\lambda_{old}} = \frac{\lambda_{new}}{\lambda_{old}} - 1$$

$$R(t) = \frac{\lambda_{old}}{\lambda_{new}} = \frac{1}{1+z}$$



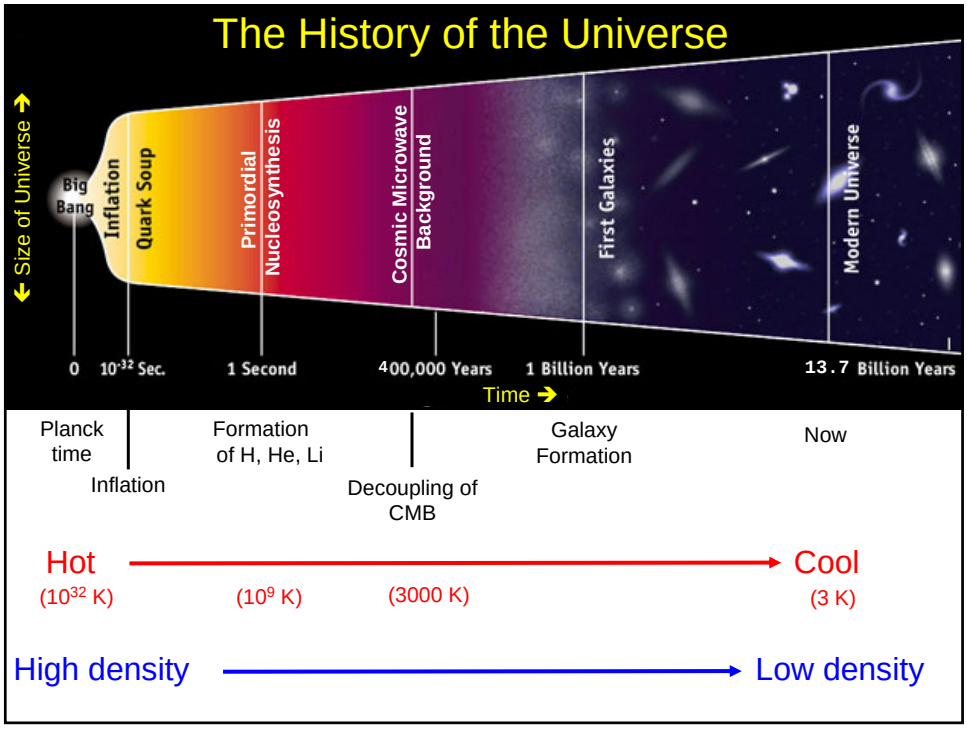
At lookback time corresponding to redshift z

Now

doppler demo applet

Redshift ➔ scale factor R(t) at time light was emitted.

Analogy having 1 less dimension


The History of the Universe
Size of Universe
Big Bang
Inflation
Quark Soup
Primordial Nucleosynthesis
Cosmic Microwave Background
First Galaxies
Modern Universe
0
10-32 Sec.
1 Second
400,000 Years
1 Billion Years
13.7 Billion Years
Time
Planck time
Inflation
Formation of H, He, Li
Decoupling of CMB
Galaxy Formation
Now
Hot
(10^32 K)
(10^9 K)
(3000 K)
Cool
(3 K)
High density
Low density