Matheson *et al*, NOAO Proposal 07A-0389

Constraining the Hubble Constant with a Type II Supernova

Abstract: We propose to obtain... observations of a Type II supernova in the Hubble flow. These observations will enable us to measure the Hubble Constant, H_0, to ~10%, independent of the distance to the Large Magellanic Cloud.....

Introduction : ...The current preferred value for the Hubble Constant, H_0=72±8 km s^{-1}, is that determined by the Hubble Key Project (Freedman *et al*. 2001). While this value is a combination of five different measurement methods, it ultimately depends on the Cepheid period-luminosity relation in the LMC and other nearby galaxies. ...

A Uniform Expansion

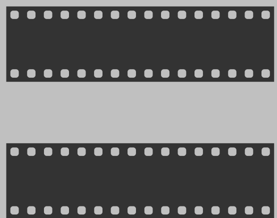
Every point is moving uniformly away from every other point.

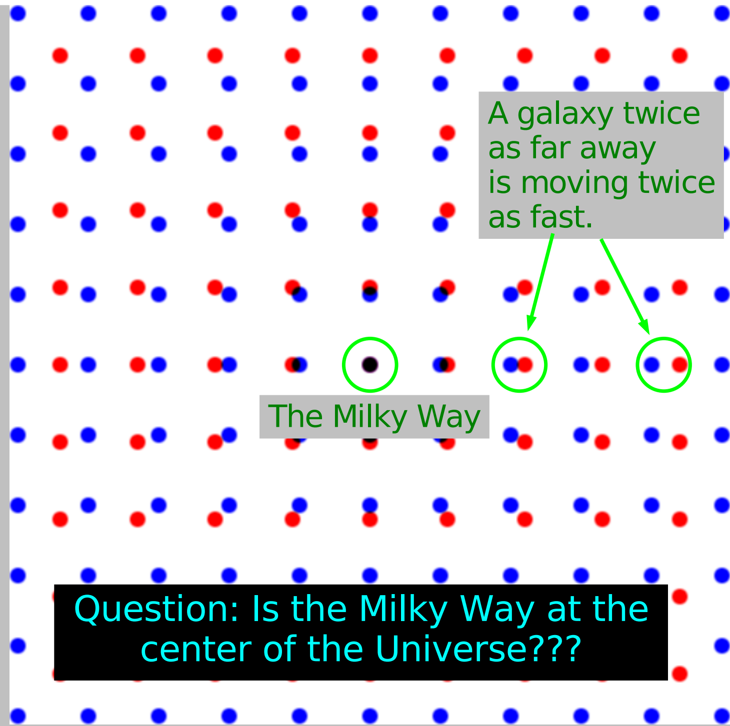
Examples:

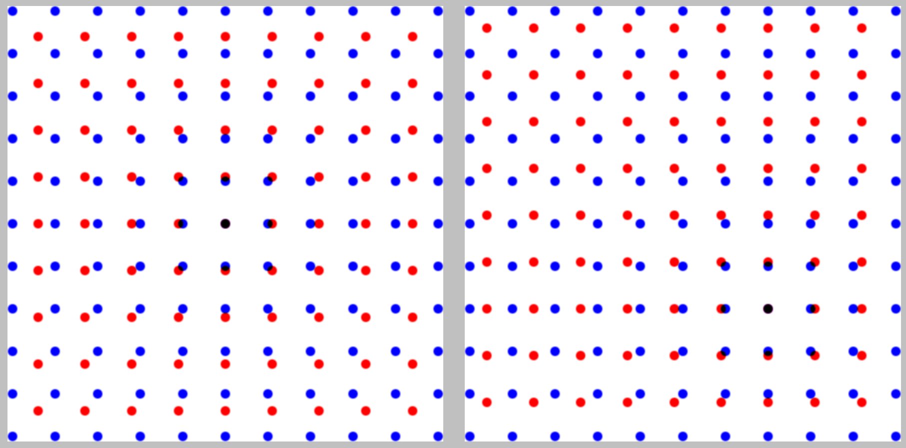
- An explosion in space. (Bits of shrapnel fly away from the explosion point, not slowed by air resistance.)
- Paper clips on a stretching rubber band
- Pennies on a balloon.
- Raisins in rising bread
- The expansion of the Universe after the Big Bang

Some uniform expansions have a center from which they are expanding; *some do not*!

Visualizing the Expanding Universe







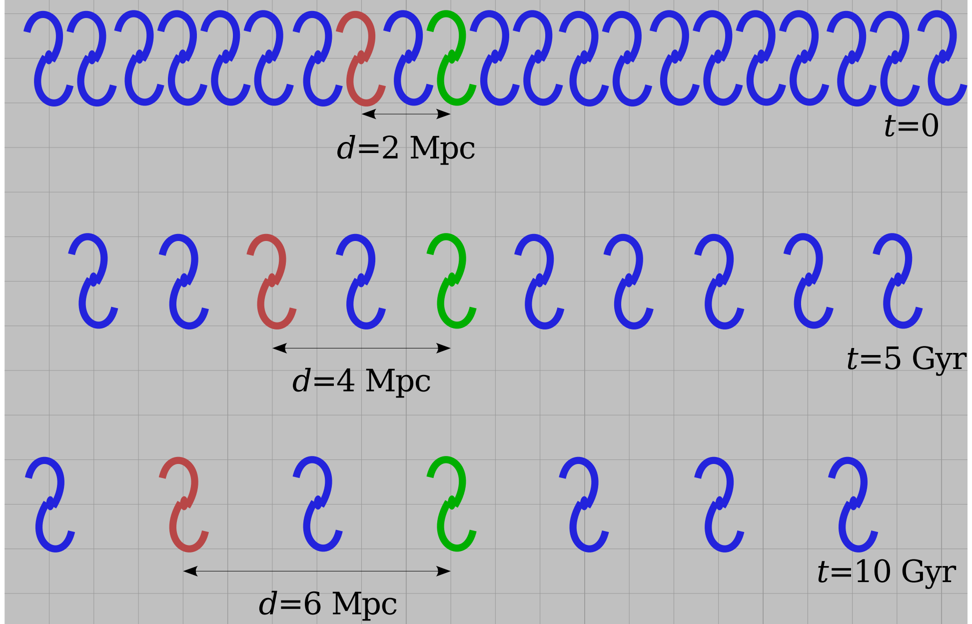
Observations from within a Uniform Expansion:

1) Rate of recession increases with distance
2) Every point is equivalently the center

How to detect a uniform expansion

- In a given amount of time, the increase in distance between two objects should be proportional to the distance. (Activity from last time.)
- Or : if you measure the rate of increase of distance (which might, but isn't always, be a classical “speed”), it should be proportional to distance.
- Or : the fractional increase in distance (change in distance divided by distance) should be proportional to the time taken. (This is ultimately how we'll describe the Universe.)

For any of the above, you should measure the *same expansion rate* at a given time from any point in the expansion. Each point should also (at least locally) look like the center of the expansion.



Initial Distance : *d* – measure time from time of this *d*!!
Change in distance : *Δd*

Constant expansion rate : *Δd* = 2 Mpc in 5 Gyr (both steps)

0 Gyr to 5 Gyr : $\frac{\Delta d}{d} = \frac{4\text{ Mpc} - 2\text{ Mpc}}{2\text{ Mpc}} = 1$

(Same for all galaxies!)

0 Gyr to 10 Gyr : $\frac{\Delta d}{d} = \frac{6\text{ Mpc} - 2\text{ Mpc}}{2\text{ Mpc}} = 2$

(Same for all galaxies!)

0 Gyr to 5 Gyr : $\frac{\Delta d}{d} = 1 \quad \Delta t = 5 \text{ Gyr}$

0 Gyr to 10 Gyr : $\frac{\Delta d}{d} = 2 \quad \Delta t = 10 \text{ Gyr}$

A Uniform Expansion : $\frac{\Delta d}{d} = \frac{t}{t_H}$

d = distance to some object "now"

Δd = change in distance to the same object during time t

t_H = expansion timescale (for the Universe, the "Hubble Time"); t_H will be different at different times with a constant expansion rate!!!!

Here : t_H = 5 Gyr

If the expansion rate of a uniform expansion has always been constant, and right now we have an expansion timescale of t_H, how long has it been since any two objects were right on top of each other?

$\Delta d = -d$ Change in distance compared to now

$$\frac{\Delta d}{d} = -1 = \frac{t}{t_H}$$

$$t = -t_H$$

t = time from now until distance changes Δd ; here, that time is negative because we're looking into the past (from now until the expansion started is backwards).

t_H = how old the Universe would be if the expansion rate had always been constant!

$$\frac{\Delta d}{d} = \frac{t}{t_H}$$

A Universe right now has expansion timescale t_H = 13.6 Gyr. Assume the expansion rate has always been constant. A certain galaxy is 100 Mpc away. How long will it be until that galaxy is 200 Mpc away?

A 3.4 Gyr
B 6.8 Gyr
C 13.6 Gyr
D 27.2 Gyr
E 54.4 Gyr

t_H can also be thought of as the "doubling time", with care

$$\frac{\Delta d}{d} = \frac{t}{t_H}$$

A Universe right now has expansion timescale t_H = 13.6 Gyr. Assume the expansion rate has always been constant. A certain galaxy is 100 Mpc away. How long has it been since that galaxy was 50 Mpc away?

A 3.4 Gyr
B 6.8 Gyr
C 13.6 Gyr
D 27.2 Gyr
E 54.4 Gyr

$$\frac{\Delta d}{d} = \frac{t}{t_H}$$

A Universe right now has expansion timescale t_H = 13.6 Gyr. Assume the expansion rate has always been constant. A certain galaxy is 100 Mpc away. When that galaxy was only 50 Mpc away, what was t_H?

- A 3.4 Gyr
- B 6.8 Gyr
- C 13.6 Gyr
- D 27.2 Gyr
- E 54.4 Gyr

$$\frac{\Delta d}{d} = \frac{t}{t_H}$$

A Universe right now has expansion timescale t_H = 13.6 Gyr. Assume the expansion rate has always been constant.
Galaxy A is twice as far away as Galaxy B. How will t_H as measured for Galaxy A compare to t_H as measured from for Galaxy B?

- A t_H(A) = ¼ t_H(B)
- B t_H(A) = ½ t_H(B)
- C t_H(A) = t_H(B)
- D t_H(A) = 2 t_H(B)
- E t_H(A) = 4 t_H(B)