You will be doing an activity with a partner.
(Yay! Activity! I miss 6th grade!)

Each group of two will need:

- 7-8 paperclips
- an elastic band
- one expansion data table
  (you both might want a copy)
- one graph page
  (you both might want a copy)

(Katie and I will hand out instructions when we're ready.)

The distances found using Cepheid Variable stars are much more accurate than using a Type Ia Supernova measurement. They can be calibrated with great precision, since the relationship between their luminosity and period is constantly precise. The problem with Type Ia supernova is that, while all observations point to them having the same brightness if the distance is known, it isn't known why this is so, so it's possible that distant type Ia supernovae have different properties than nearby type Ia supernovae.

Not really the right answer to the question that was posed – but an interesting and valid point nonetheless.

"Supernova evolution" – were thermonuclear supernovae different in the early Universe than they are now? (Far away = looking back in time.) If so, that would muck up distance measurements.

Current indications are that this is not a problem, but it is something that cosmologists have to keep in mind, and which is a potential serious source of "systematic error"!

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

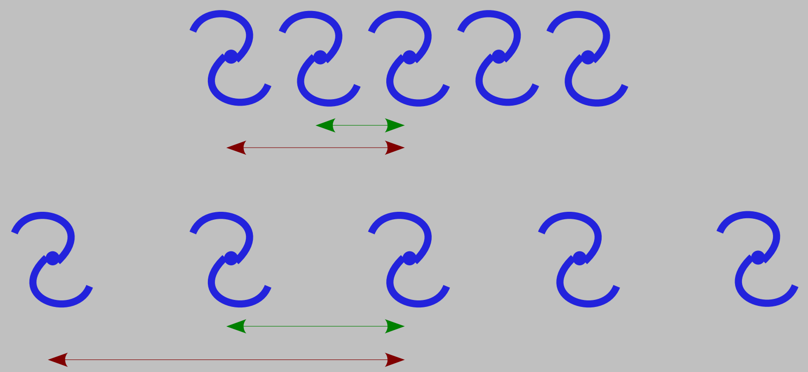
Some uniform expansions have a center from which they are expanding; *some do not*!

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. (We'll do this shortly!)
- 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.

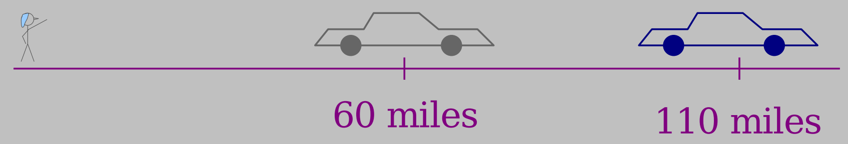
A “uniform” expansion



$$\frac{\text{Change in Distance}}{\text{Distance}} = \text{Constant}$$

The greater the initial distance,
the greater the change in distance.

With galaxies, how can we measure “change in distance”?



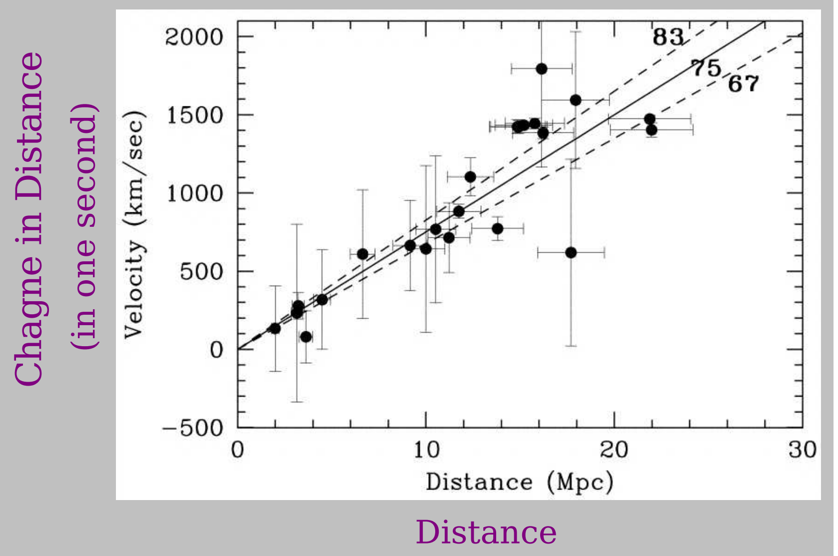
Final Distance = 110 miles
Start Distance = 60 miles

Change in Distance = 110 – 60 miles = 50 miles

Speed = 50 miles / 1 hour = 50 miles per hour

$$\text{Speed} = \frac{\text{Change in Distance}}{\text{Time}}$$

The “Hubble Diagram” of Galaxies Moving Away From Us



Note : ***in reality, galaxies are not “flying apart!”***
However, if we constrain ourselves to local (nearby) galaxies, it looks just the same as if that were happening.