ASTRONOMY LABORATORY

THE INCREDIBLE EXPANDING RUBBER BAND[1]

Also on the web at: "http://www.astro.psu.edu/users/stark/ASTRO11/labinfo/rubberband.html"

I. Objectives

You will demonstrate how Hubble's Law describes the expansion of the universe by using a more "down to earth" example. You will prove by demonstration that, as space expands, every point in space moves away from all other points, and the farther away they are the faster they appear to move (which is the same thing we see from the galaxies in our universe).

II. Procedure

- Work in groups of two[2]
- Group member #1 will act as the "stretcher"
- Group member #2 will act as the "measurer and recorder"

III. Equipment for each group

- 1 rubber band with several (5–8) black marks on it (the marks will be referred to as *mark 1*, *mark 2*, . . . — from one end of the rubber band to the other).
- 1 ruler

IV. Experimental steps

1. One group member holds the *unstretched* rubber band flat, while the other records the distances between *mark 1* and all of the other marks on the rubber band (i.e. the distance from *mark 1* to *mark 2*, *mark 1* to *mark 3*, etc.).
2. Slowly the "stretcher" stretches the rubber band until the distance between *mark 1* and *mark 2* doubles (i.e. if it was 1cm then stretch until it becomes 2cm).
3. While the rubber band is stretched, carefully remeasure the distances between *mark 1* and all the other marks as in step 1.
4. Calculate the change in the distance for each point (this will be the total distance the point traveled while the rubber band was stretched)

$$\text{Change in Distance} = (\text{Stretched Distance}) - (\text{Original Distance})$$

[1]Written by M. Stark, modified Feb 2005 by M. Stark.

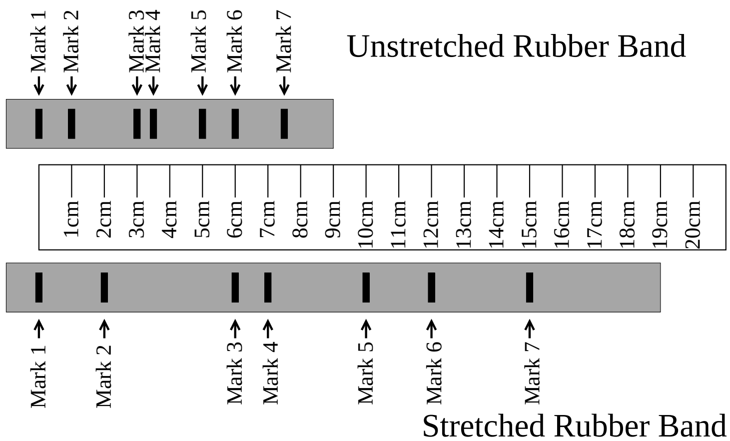
[2]Modification for individual use: Instead of doing this activity in groups of two, it can be done individually by stretching the rubber band around a hard, flat object such as a book.

5. Calculate the speed each of the points traveled at to get to their new (stretched) positions assuming that it took the "stretcher" 2 seconds to stretch the rubber band and the distance the point traveled is equal to the change in distance just calculated in step 4.

$$\text{Speed} = \frac{\text{Distance traveled}}{\text{Time it took}}$$

6. Example

   - Given the following setup:



   - These are the values recorded and calculated:

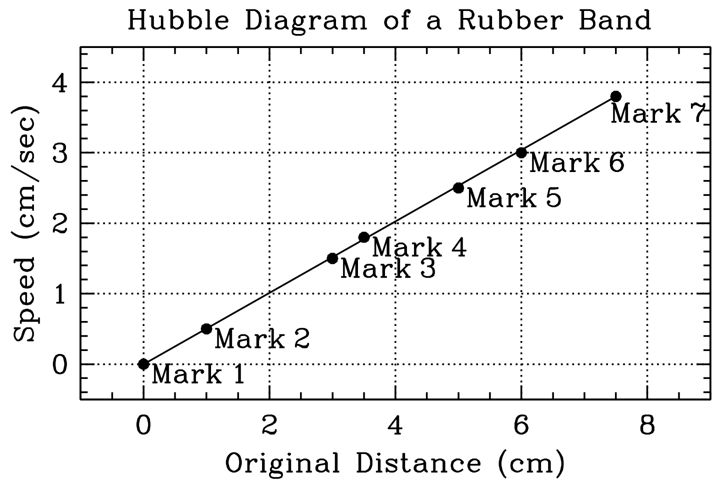
Point Number	Original Distance	Stretched Distance	Change in Distance	Speed
1	0.0 cm	0.0 cm	0.0 cm	0.0 cm/sec
2	1.0 cm	2.0 cm	1.0 cm	0.5 cm/sec
3	3.0 cm	6.0 cm	3.0 cm	1.5 cm/sec
4	3.5 cm	7.0 cm	3.5 cm	1.8 cm/sec
5	5.0 cm	10.0 cm	5.0 cm	2.5 cm/sec
6	6.0 cm	12.0 cm	6.0 cm	3.0 cm/sec
7	7.5 cm	15.0 cm	7.5 cm	3.8 cm/sec

V. Creating a "Hubble Diagram" and finding "Hubble's Constant" for the rubber band

1. Create a plot of Speed (cm/sec) vs. Original Distance (cm), with "Speed" on the y-axis and "Original Distance" on the x-axis. Label all your points.

2. Draw a single straight line through all of the points in your Hubble Diagram that best fits the points (NOTE: it just has to go past all of the points as close as possible to them, but it does not have to touch all of them).

3. For the example given above, the Hubble Diagram would look like the following:



4. "Hubble's Constant" for the rubber band is equal to the slope of the line you just drew through the points. To find the slope of a line:

   (a) Choose two points widely separated on the line

   (b) Find the x- and y-coordinates of each of these points — point 1 (x_1, y_1), and point 2 (x_2, y_2)

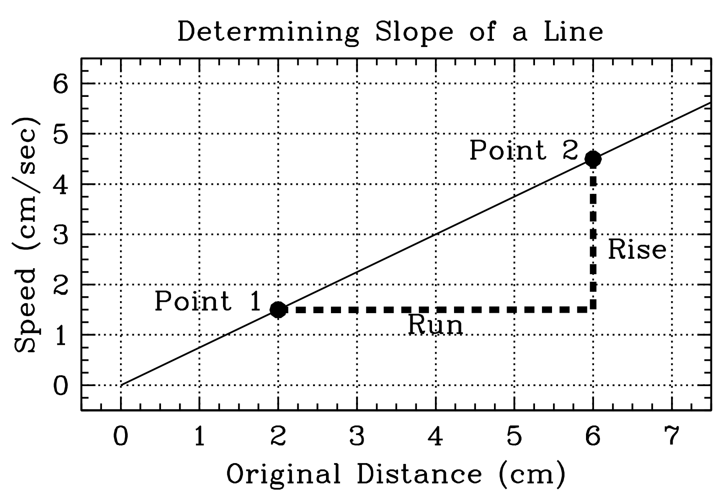
   (c) Find the "Rise" and "Run":

$$\text{Rise} = y_2 - y_1$$
$$\text{Run} = x_2 - x_1$$

   (d) Find the slope of the line:

$$\text{Slope} = \frac{\text{Rise}}{\text{Run}}$$

   (e) For example (NOTE: this is *NOT* the same line shown in the previous example):



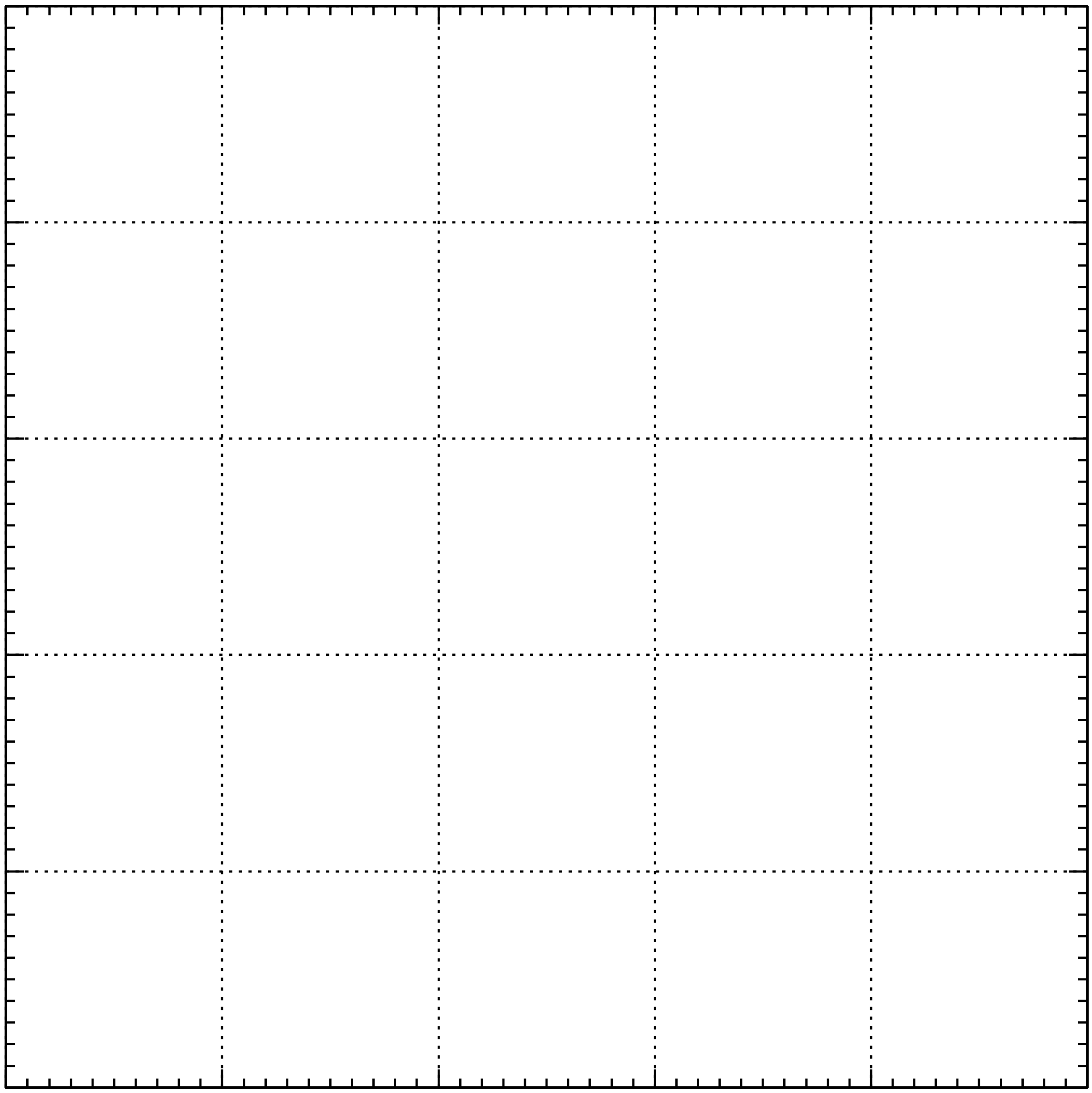
In this example the two points marked are:
point 1 = (2.0 cm, 1.5 cm/sec)
point 2 = (6.0 cm, 4.5 cm/sec)
Then...
Rise = 4.5 cm/sec – 1.5 cm/sec = 3.0 cm/sec
Run = 6.0 cm – 2.0 cm = 4.0 cm
So the slope of the line would be:
Slope = (3.0 cm/sec) ÷ (4.0 cm) = 3/4 cm/sec/cm or 0.75 cm/sec/cm
(NOTE: the slope has units!!! cm in the units would actually cancel out leaving 1/sec or "per sec" in this example, I've left cm in for a reason that should become obvious when you do the lab, since the true astronomical Hubble's Constant is usually written with the units of "kilometers per second per megaparsec", or "km/s/Mpc").
For this example the value of "Hubble's Constant" (H) would be: H = 0.75 cm/sec/cm — this number describes how the rubber band expanded, much like the real Hubble's Constant describes how the universe is expanding. The best part is, Hubble's Constant tells you *how long* it took for the rubber band universe to expand from a size of zero (where all points were right on top of each other) to its original size. How you say? Well, $H = \frac{\text{Rise}}{\text{Run}}$, but Rise = speed, and Run = distance, so... $H = \frac{s}{d}$ or rearranging, $\frac{1}{H} = \frac{d}{s}$. Also, from the beginning of the lab you know that $\text{s} = \frac{\text{d}}{\text{t}}$ or rearranging, $t = \frac{d}{s}$. Combine these two and you find that: $t = \frac{1}{H}$! (Just be careful with the units of H!)

VI. Your Data

1. Record your measurements, calculated distance changes, and speeds here:

Point Number	Original Distance	Stretched Distance	Change in Distance	Speed

2. Graph your "Hubble Diagram" here (choose the best scale to plot your points on, fill in the numbers, and be sure to label your axes!), then draw the "best-fit" line through your points:



3. Calculate the slope of your "best-fit" line. What is the value of "Hubble's Constant" for your rubber band universe?

VII. Questions

1. How did the distances of all the points from *mark 1* change when you doubled the distance between *mark 1* and *mark 2*?

2. Which points "moved" the fastest relative to *mark 1*? (which had the largest speed?)

3. What would have happened to this experiment if we had chosen a different mark on the rubber band to be *mark 1*? Would the results be the same or different? Why?