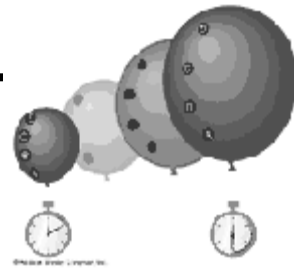


A Simple Model of an Expanding Universe



Objective

To investigate the principles underlying the calculation of the Hubble Constant by deriving a value for a two-dimensional analogy: a "balloon universe."

Materials

- Balloons, black felt markers (fine point) or sticky stars, string, rulers

Background and Theory

The Hubble Law tells us that our Universe is expanding. We observe those galaxies outside of our local group, find their distances and their velocities, and find that they are all moving away from us. The more distant the galaxy, the faster it is moving away. From this information, we can estimate the age of our Universe. If we assume that the Universe has always been expanding at the same rate, then we can figure out how long distant galaxies have been traveling in order to get where they are today.

Your first mission is to read and follow these instructions carefully!

Procedure

1. Blow up the balloon about half way. **DO NOT TIE IT SHUT!**
2. Draw and number 11 galaxies on the balloon. [In spite of what the image in the corner indicates, it is not a good idea to line up your galaxies.] Mark one of these galaxies as the reference galaxy.
3. Measure the distance between the reference galaxy and each of the numbered galaxies.
4. Record these data in the table. **THIS IS YOUR FIRST MEASUREMENT.**
5. Now blow up the balloon, **estimating the time it takes you to blow it up**, and tie it shut.
6. Measure the distance between the reference galaxy and each of the numbered galaxies. Record these data in the table. **THIS IS YOUR SECOND MEASUREMENT.**
7. Subtract the first measurement from the second measurement and record the difference in the data table.
8. Divide the distance traveled (the difference between the first measurement and the second measurement) by the estimated time it took you to blow up the balloon (in seconds) to get a velocity. Your units will be either mm/sec or cm/sec.
9. Plot the velocity (*y axis*) versus the first measurement (distance, *x axis*) to get the "Hubble Law for a Balloon". The units for this "Hubble constant" will be mm/sec per mm or cm/sec per cm. Don't forget to label your axes!
10. Fit a straight line to your data; remember that your line must pass through (0,0).
11. Find the slope. (Remember that the slope is "the change in *y* over the change in *x*".) This is exactly the way that we find the value of H from Hubble's Law.
12. Find the age of your balloon universe from this slope. The age of your universe is simply the inverse of **your balloon universe Hubble constant, and will be given in seconds.**

Length of time it took to blow up your universe _____ sec

Galaxy Number	First Measure	Second Measure	Difference (2 nd - 1 st)	Velocity
(Don't forget you are making your measurements from a reference galaxy to each of the 10 other galaxies.)				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

V e l o c i t y (last column)										
Distance units _____ (2 nd column or "first measure")										

Slope of the line: _____

Age of the balloon universe: _____ seconds

Questions

1. Why does the best-fit line need to pass through (0,0)? Where is this data point on your balloon universe? If this were the real universe, this data point would correspond to what location?
2. Draw a best-fit line through your points, and calculate the slope of this line. Why is a best-fit line better than just connecting the dots? [Hint: Think of what it would mean if you “connected the dots” and had a “zig-zaggy” line. How would you calculate a slope under those circumstances? What does a “best-line fit” do to errors?]
3. Name one way in which the surface of a balloon is a good analogy to the Universe and one way in which this analogy is limited (Hint: see text).
4. How would your results change if you used a different reference "galaxy" on the balloon? Explain your answer. How would this question relate to using a different reference galaxy in the real universe?
5. State the *real* Hubble's Law in your own words, giving the meaning of each of the terms. What are the units of Hubble's constant, H_0 ?

In the balloon universe, you found its age by taking the inverse (reciprocal) of the balloon Hubble constant. Let's apply this step to the real universe. Let's assume a Hubble constant of 70 km/sec per Mpc.

6. Take the inverse of this number: _____ The units here are 'seconds.'

We need to convert the Mpc's into kilometers to cancel the distance measure (you will have a Mpc/km included if you don't).

7. Multiply the inverse by 3.09×10^{19} km/Mpc to get the age: _____ seconds

8. Convert this time to years by dividing by 3.16×10^7 seconds/year: _____ years

9. Convert to billions of years by dividing this number by 10^9 : _____ billion years.

10. How effective has this exercise been for you in understanding that the Universe is expanding and because of this expansion, we can determine its age? Relate what you did with your balloon universe to how astronomers work with real data in determining the age of the real Universe.