

Cosmology: The Expansion of the Universe

•Materials

one balloon per person
string
rulers

•Introduction

In this exercise, you will use a two-dimensional model to explore the expansion of the universe.

Before 1917, many scientists thought the universe always existed. But Einstein's revolutionary theory of gravity changed all the rules. It opened up the mind-boggling possibility that space itself - the permanence of which had never been questioned - might actually be expanding. If space is expanding, the universe we inhabit today could once have been infinitely smaller.

In 1929, astronomer Edwin Hubble made the amazing discovery that distant galaxies are speeding away from us. This means that the galaxies we see today were once much closer together - originating from a tiny region of space.

The origin of the universe remains one of the greatest questions in science. Current scientific evidence supports the Big Bang model, which states that about 13.7 billion years ago, the entire universe began expanding from a very hot, dense state. This sudden expansion is known as the Big Bang.

What does it mean to say that the universe is expanding? The Big Bang was an expansion of space itself. Every part of space participated in it. Space is not simply emptiness; it's a real, stretchable, flexible thing. Galaxies are moving away from us because space is expanding. Galaxies are moving *with* space, not *through* space. (There is also a local motion through space as galaxies interact with their neighbors, but on larger scales, the expansion of space dominates.) The model in this activity demonstrates how the motions of the galaxies reveal the continuing expansion of the universe.

In the 1920s, Edwin Hubble measured the motion of the galaxies. By measuring a galaxy's distance from us and how fast that galaxy is receding (its recession velocity), he found a simple relationship: double the distance, double the velocity; triple the distance, triple the velocity. This is Hubble's Law. In equation form, it is written:

$$v = H \times d$$

Recession velocity = Hubble's constant x distance from us

The slope of the graph of distance vs. velocity represents the Hubble Constant for the universe.

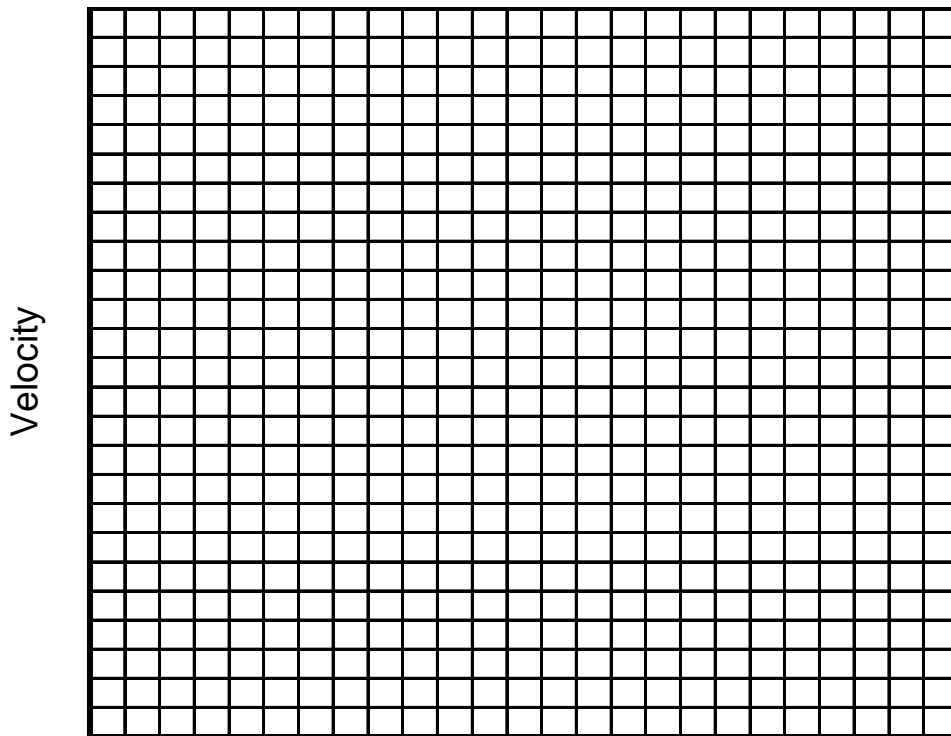
The **Hubble Constant** describes how fast the universe is expanding. By measuring the rate of expansion, the size and age of the universe can be calculated. Interpreting recent observational results from space-borne and ground-based telescopes, scientists have determined different values of Hubble's constant. Determining the precise value of the Hubble constant is key to understanding the origin of the universe, and there are several factors that affect this determination. For example, the universe may not have been expanding at the same rate throughout time; that is, the expansion itself may be accelerating. Questions like these make the age of the universe a hot topic - one of the most controversial in the study of cosmology. The age of the universe is currently estimated to be about 13.7 billion years, and the Hubble constant is estimated to be about 70 km/s/Mpc.

The age of the universe can be calculated from the Hubble constant; it is its reciprocal. However, this assumes that the universe expands at a constant rate, and that may not be accurate.

•Procedure

- 1) Blow up the balloon a little bit. DO NOT TIE IT SHUT!
- 2) Draw and number ten galaxies on the balloon. Mark one of these galaxies as the reference galaxy.
- 3) Measure the distance between the reference galaxy and each of the numbered galaxies. The easiest way to do this is to use a piece of string. Stretch it between the two points on the balloon, then measure the string. Record these data in the table. Be sure to indicate the units you are using.
- 4) Now blow up the balloon. You can tie it shut this time if you like.
- 5) Measure the distance between the reference galaxy and each of the numbered galaxies. Record these data in the table.

Galaxy Number	First Measurement	Second Measurement	Difference	Velocity



- 6) Subtract the first measurement from the second measurement, record the difference in the data table.
- 7) Estimate the amount of time it took you to blow up the balloon (in seconds). Divide the distance traveled (the difference) by this time to get a velocity.
- 8) Plot velocity versus the second measurement to get the "Hubble Law for Balloons". Don't forget to label the units on your axes.
- 9) Fit a line to your data.
- 10) Find the slope. Slope is the change in y over the change in x . This is exactly the way that we find the value of Hubble's Constant from Hubble's Law.
- 11) Find the age of your balloon universe from

this slope. Remember that the age is one over the Hubble Constant.

•Questions

- 1) How does the age of the balloon found from the Hubble law compare to the time it took you to blow up the balloon the second time?
- 2) What assumptions do you make about your balloon universe when you find it's age by this method? Are these sensible assumptions?
- 3) How would your results change if you used a different reference "galaxy" on the balloon? If you are not sure, try it!