The Expanding Universe

Adapted from *The Universe at Your Fingertips* Activities H-4 & H-6 by S. Kannappan (The University of Texas at Austin)

Introduction

Early in the 20th Century Edwin Hubble discovered that the universe is expanding, with every galaxy receding from every other galaxy. He found that the greater the distance between two galaxies, the faster they are moving apart from each other. The result of his research is known as the Hubble law.

One fascinating aspect of this proportional expansion is that the universe has no center and no edges. Spacetime itself is expanding at every point between galaxies. Galaxies do not fly apart however, because gravity holds them together. The competition between gravity and the universal expansion has left vast empty bubbles or "voids" between the regions where galaxies cluster together.

Activity Summary

You will use two "snapshots" of the universe to discover that its expansion has no center. By measuring galaxy positions in the two snapshots, you will discover the Hubble law. These measurements will also provide an estimate of the age of the universe. Finally, you will use a balloon to explore how the inhabitants of an expanding universe see the center and edges of their universe.

Reference:

The Universe at Your Fingertips: Astronomy Activity and Resource Notebook. Project ASTRO, The Astronomical Society of the Pacific,1995. ISBN 1-886733-007

Materials for each student/group:

- dot pattern representing the universe 1 billion years ago, copied onto white paper
- dot pattern representing the universe today, copied onto a transparent overlay
- metric ruler
- balloon
- small stickers to represent galaxies (alternatively, you can draw galaxies on the balloon with a pen)

Science Standards

National Science Education Standards

Grade 9-12 content standard -

–Abilities necessary to do scientific inquiry

–Forces and motions

–The origin and evolution of the universe

Texas Essential Knowledge and Skills

Astronomy

(5) Science concepts. The student knows the scientific theories of the evolution of the universe. The student is expected to

(A) research and analyze scientific empirical data on the estimated age of the universe;

(B) research and describe the historical development of the Big Bang Theory

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I. Are we at the center of the universe?

The white sheet represents the universe one billion years ago (for flat creatures living in a two-dimensional universe). The transparent sheet represents the universe today. Put all answers in your notebook.

1. Inspect each sheet separately. Do you see a "center" to the pattern of dots? Now place the overlay on the white sheet, being careful not to turn one relative to the other. Note that a clear center appears. Measure its location in cm from the top and left edges of the paper.

2.Shift the overlay without turning it. What happens to the center? Shift again in different directions. What happens to the center?

3. Pick any dot to be your home galaxy. Shift the overlay to make that dot the center. Can you see how to move the overlay so that any point you choose becomes the center? Describe your method. Test your method by having another student pick a dot for you.

4. Center on your home galaxy. The dots on the paper and the overlay mark galaxy positions one billion years ago and today, respectively. The differences in dot positions between the paper and the overlay represent how far galaxies have moved in one billion years relative to the "center" galaxy. What pattern do you see in the direction of motion of the galaxies?

5. Measure the original and final distances from the central galaxy for three galaxies roughly 2, 5, and 10 cm away from the center. Make a data table in your notebook similar to the one in the next column. Assume 1 cm represents 60 million light years (1 LY = the distance light travels in 1 year). Remember to keep track of your zeros. One billion = 1,000,000,000 and one million = 1,000,000. After making the table, do you see a pattern?

NOTE: make measurements to the nearest millimeter (0.1 cm).

	Galaxy 1	Galaxy 2	Galaxy 3
Original	____cm	____cm	____cm
Distance	____LY	____LY	____LY
Final	____cm	____cm	____cm
Distance	____LY	____LY	____LY
Change in	____cm	____cm	____cm
Distance	____LY	____LY	____LY
Speed of	____cm/year	____cm/year	____cm/year
Expansion	____LY/year	____LY/year	____LY/year

6. The proportionality of expansion speed and distance is called the Hubble law. *READ CAREFULLY*: using the full distance to each galaxy (either original or final), you can estimate the ratio of expansion speed to distance (called the Hubble constant). The units are LY/year ÷ LY = 1/year.

	Galaxy 1	Galaxy 2	Galaxy 3
Speed/Distance	____1/year	____1/year	____1/year

Look back at the introduction to this activity. Why do we NOT use the change in distance here?

Compare with someone who chose a different home galaxy. Should your answers be the same? Why or why not?

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II. How old is the universe?

You can roughly estimate the age of the universe by computing how long ago the galaxies in today's universe were all compressed into a single point. Imagine time running backward. Galaxies rush toward each other. Because of the Hubble law, galaxies ten times further away move ten times faster, and all galaxies converge at the same moment. This moment was the Big Bang, when the universe was born as a dense, hot fireball. Dividing any galaxy's current distance by its current speed gives roughly the time it would take to "un-expand" the universe. Calculate this number for galaxies 1, 2, and 3 from part I.

	Galaxy 1	Galaxy 2	Galaxy 3
Time since the Big Bang	____ years	____ years	____ years

Can you think of some reasons why this calculation gives only a rough approximation of the age of the universe? (Hint: how does gravity affect the motions of galaxies?)

You made a simple estimate of the age of the universe by assuming a constant rate of expansion for all time. Astronomers now believe that throughout its history, the universe has expanded at different rates, sometimes accelerating and sometimes slowing. Their current best estimate of the time since the Big Bang is about 14 billion years.

III. What's at the edge of the universe?

Most people imagine the Big Bang as if a tiny nugget of material exploded, expanding into space. But space itself is expanding, and you can't be "outside" space. Either space is infinite in size or it closes back on itself.

You can model a universe that closes back on itself with a balloon. Suppose that the two-dimensional universe from part I is curved in a third dimension, unseen by its flat inhabitants, so that the universe covers the surface of a balloon. Using stickers or a pen, add galaxies to your balloon universe, spacing them about 1-2 cm apart. Now blow up the balloon and watch the universe expand.

1. What will happen if the flat creatures living in the balloon universe fly in a super-fast flat spaceship to try to reach the edge of the universe? (Suppose they can travel as long as they need to.) Does your answer depend on how fast the universe expands? Explain.

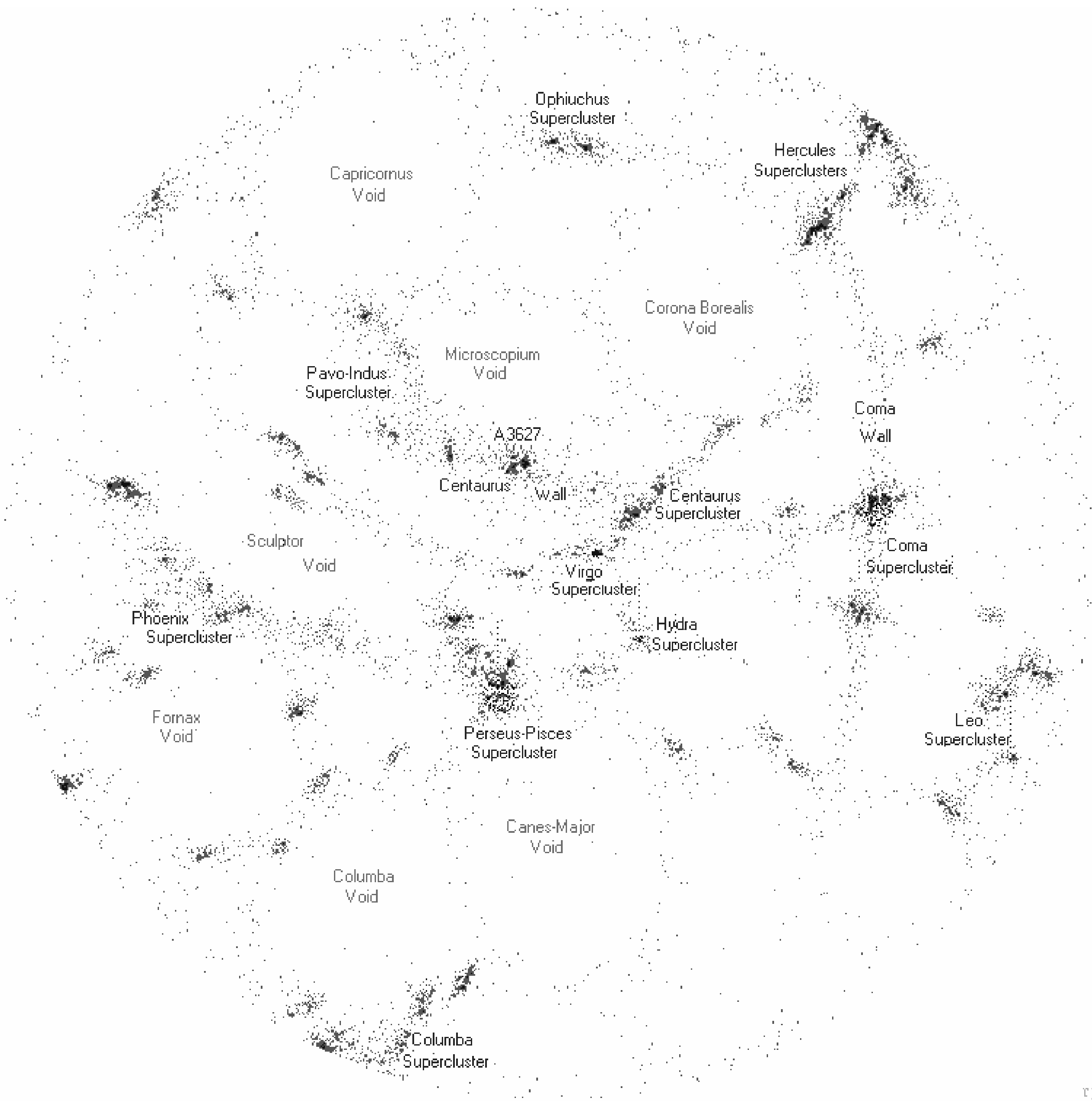
2. Choose any galaxy, and describe the center of expansion from the point of view of a flat creature living in that galaxy. As a three-dimensional creature outside the balloon, how do you perceive the center of expansion of the balloon universe differently than the flat creatures do?

3. For a flat creature living in a particular galaxy, describe the motion of the other galaxies. Does the Hubble law of part I apply to the balloon universe? Explain.

4. Suppose the flat creatures use telescopes to try to see the edge of the universe. As in our universe, light travels at a finite speed of 1 LY per year. What will be the greatest distance to which they can see if their universe is the same age as ours? (Hint: light from the visible edge of the universe must have been traveling since the Big Bang.) Is the visible edge of the universe a physical edge? How was the visible edge of the universe different 10 billion years ago?

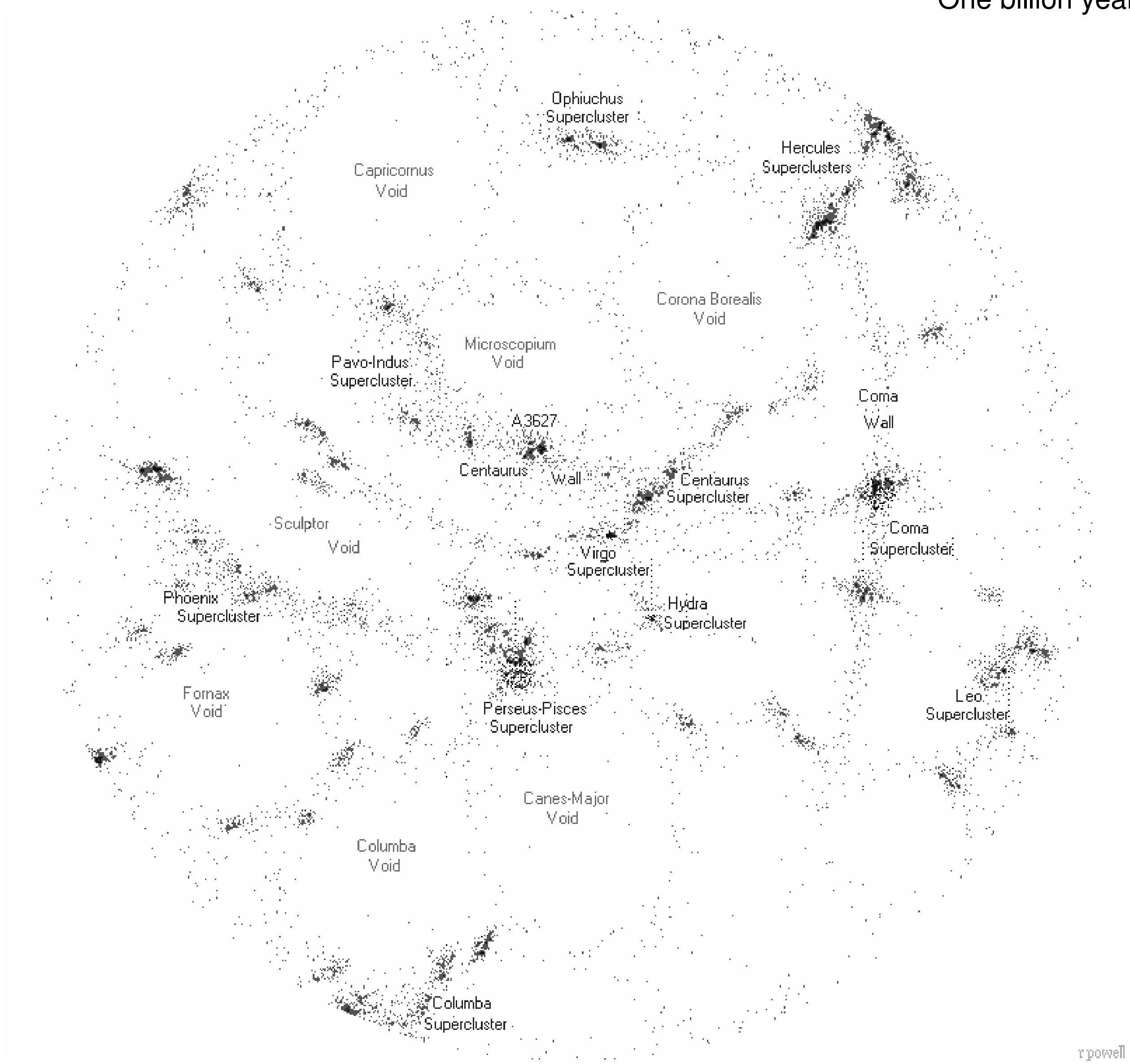
5. If your galaxies are drawn with a pen, they probably seem to expand when you blow up the balloon. Why doesn't this happen in the real universe?

Today



Adapted from www.anzwers.org/free/universe by S. Kannappan

One billion years ago



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