Determining the nature, size, and age of the Universe

Suggested Grade Level(s): 10-12
Estimated class time: 1-2 class periods

Summary

A key component of the 1929 poster is the idea that through advances in telescope technology, our understanding of the size and nature of the universe has changed. The ideas presented in the 1929 poster lead to the idea that the universe was not a stable entity and has been changing over the years. The goal of this lesson is to give students the chance to simulate the process that led to the notion that the universe is expanding and give them an insight as to how this idea was reached as well as teach them the nature of our universe.

Objectives

- Students will be able to make measurements in the metric system.
- Students will be able to create a graph from collected data.
- Students will be able use a scientific model to explain collected data.
- Students will be able describe the motion of the universe.
- Students will be able to describe the age of the universe.
- Students will be able to explain how the scientific process can be used to make conclusions about empirical data.

National Science Standards

- NS.9-12.1 SCIENCE AS INQUIRY

  As a result of activities in grades 9-12, all students should develop
  - Abilities necessary to do scientific inquiry
  - Understandings about scientific inquiry
- NS.9-12.2 PHYSICAL SCIENCE

  As a result of their activities in grades 9-12, all students should develop an understanding of
  - Motions and forces
  - Interactions of energy and matter
- NS.9-12.4 EARTH AND SPACE SCIENCE

  As a result of their activities in grades 9-12, all students should develop an understanding of
  - Origin and evolution of the earth system

- NS.9-12.7 HISTORY AND NATURE OF SCIENCE

  As a result of activities in grades 9-12, all students should develop understanding of
    - Science as a human endeavor
    - Nature of scientific knowledge
    - Historical perspectives

Knowledge Prerequisite

- Students should have basic background knowledge about astronomical vocabulary.
- They should also be able to make measurements and create graphs.
- They should be familiar with how to apply a scientific model to a graph.
- They should also have an understanding of the scientific method and vocabulary.
- They should also have some understanding that our Sun is one of many stars in our Galaxy and that there are many other galaxies in the Universe, each of which is made up from many stars. The 1929 Cosmic Times articles can be used to help them understand this concept.

Teacher Background

Throughout the lesson pay attention to the **Teacher background** sections. These sections are for your benefit, with information to be revealed to the students as you deem necessary to facilitate the flow of the lesson.

Materials

- Rulers for measurement in centimeters
- Calculator
- Graph Paper
- Copies of the handouts located in the appendixes

Procedure:

I. Engagement

The main theme of this lesson revolves on trying to understand the nature of the universe. Along the way, an estimated size and age can be determined. To start getting the class thinking along these terms, pose the following question: "What possible ways can the universe behave?" List the ideas on the board. The idea here is to challenge them to think about the nature of the universe. Make references to the world around us if necessary. Lead the class to 3 ideas:

1. A steady universe where nothing moves or changes relative position
2. A constantly expanding or contracting universe
3. A random universe with no pattern

An analogy to the world around us to explain why it is one of these three models may be necessary. Have them think about the world around them and try and explain if it is a static environment where everything remains the same or one that changes, either randomly or with some type of pattern. Extrapolate this idea to the universe.

From here, now pose the question to the class: "What variable can we measure to create a model of the behavior of the universe?" Remind the class that in a scientific investigation variables are what we can measure to explain the world around us so what describes how the universe is behaving. Have the class brainstorm, in either small groups or as a class, and then list them on the board.

Teacher background: Depending on the level of the class, they may have difficulty with this step. The idea here is to try and come up with ways of measuring what the universe is doing. You could try to illustrate with an analogy to how we could describe what they do during the day. We could measure where you go and how fast you get there. We could also measure what types of clothing you wear and what you eat. This would be analogous to the distance to stars, the relative speeds of stars, the composition of the stars and their sizes.

Make sure that the distance to a galaxy and the relative speeds of the galaxies are listed on the board. Then go through each variable and through discussion, cross off the extra variables so that you are left with the distance to the galaxy and the relative speed of the galaxy.

Teacher background: One key to understanding the nature of what the universe is doing depends on these two variables: Where is everything and where is it going? Is it standing still or moving and if it is moving is there a pattern to where it is going?

From here, explain to them how we are going to make measurements of these variables.

In order to determine the relative speed of the galaxies, the red shifting of their light can be used. Relative speeds for this activity will come from information in the astronomical database.

For the distance to the galaxies, ask the question, "How do we know how far galaxies are from us?" Ideas could be random but hopefully someone will point out that the information must come from telescope observation. Have the students present ideas to the class for discussion. Lead the discussion to the idea that the only information we have about galaxies comes from photographs taken with a telescope. Follow up with questions about what information we need to know about a picture to determine how far away objects in a photograph are. Lead the students to the idea that they need to answer these three questions about the picture:

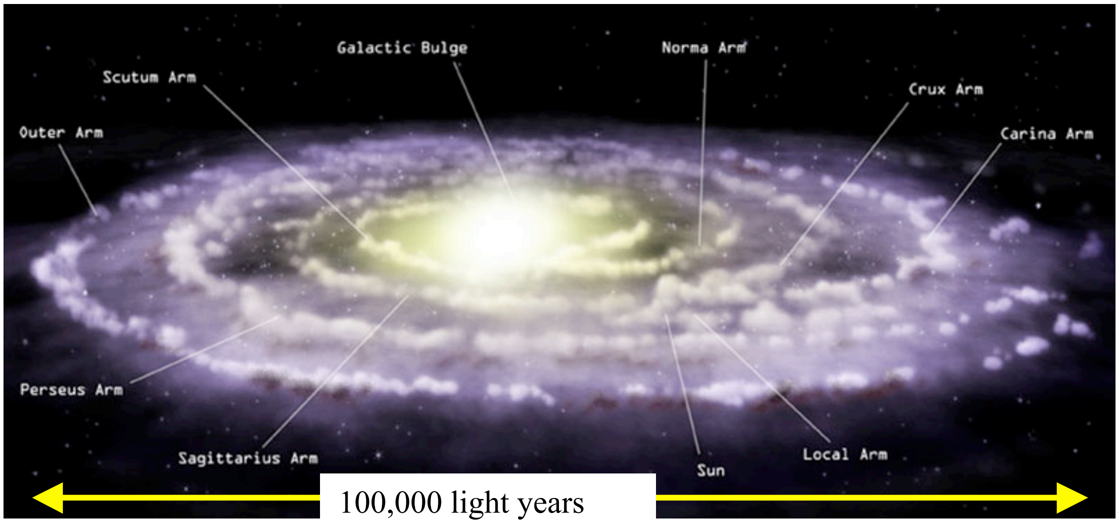
1. How big are the objects being photographed?
2. How much magnification does the camera have and how big of a section of sky is being captured?

How can I determine the relationship between the distance to an object in a photograph and the size of an object?

Teacher Background: A handy analogy there might be to refer to a photograph they have seen. How can you tell how far away objects in it are? Have them think about how they inadvertently make use of the size of people in the photo to estimate their distance from the camera. Also point out how a magnified image (or "zoomed-in" image) might affect their estimate on range. Lastly think about how much is captured in the photograph. You could compare a standard photo to a panoramic here.

II. Exploration

1. For the purposes of this activity explain to the class that the assumption that all spiral galaxies are about the size of our Milky Way galaxy can be made. This can be done because based on the scale of our measurement, differences in the size of the galaxies will be negligible. The Milky Way galaxy is approximately 100,000 light years across. The Milky Way is a spiral galaxy, which means that it is shaped a bit like a pancake, and this measurement of 100,000 light years is the width of the galaxy at its widest (see image below). This takes care of requirement 1.



Since we live in the Milky Way galaxy, we can't take a picture of it from outside the galaxy. This image is an illustration of what the Milky Way galaxy might look like if we could take a picture. The distance from one side of the Milky Way's disk to the other side is approximately 100,000 light years. (Image credit: NASA / CXC / M. Weiss)

2. All galaxy images were taken using the Harvard-Smithsonian's MicroObservatory. This means that all the images have the same field of view so all images are 0.9 degrees wide and 0.7 degree high, so that every image contains the same "amount of sky." This also means that the effects of magnification are the same for all objects. Using this information a ratio can be set up:

$$\frac{Size\_of\_the\_Object(cm)}{Size\_of\_the\_Image(cm)} = \frac{Angular\_Size\_of\_the\_Object(Degree)}{Angular\_Size\_of\_the\_Image(Degree)}$$

   Where the Angular size of the image is 0.9 degrees. This takes care of requirement 3. They are using this equation to determine the angular size of the image from measurements of both the size of the image and size of the object with a standard metric ruler.

Teacher Background: See the sample distance calculation at the end of this lesson if this step is confusing. Also note that it will help your students to report the distances in millions of light years instead of just light years – the numbers will become very large otherwise.

3. The final requirement is to determine the relationship between the size of an object being photographed and the distance to the object. This can be resolved by using the

rule of 57. This states that an object that takes up less then 1 degree of your field of view is 57 times further away than it is big. The derivation of this is shown in appendix A.

Teacher Note: The key to the rule of 57 is a ratio is created between the 360 degrees in a complete circle around an observer and the amount of degrees the object takes up. Using the results of this ratio, the distance can be calculated.

4. Using all of the ideas listed above, the distance of galaxies can be calculated. To do this, divide the class into groups of 2-4 students. This is done completely on the basis of class size. Give each student the worksheet found at the end of this lesson plan.

5. Set up stations with the images of the galaxies. There are 20 images located in appendix B. Use at least 2 images per station, but make sure the students have at least 10 points for the graphs they will complete later. Have one station contain the astronomical facts contained in appendix C.

6. Have the students measure the size of the spiral galaxy in each photograph as well as the size of each image. While the students are waiting for other groups to finish their measurements, they can begin their calculations for the distance of each galaxy. The group at the astronomical data station should record the speed and direction of motion for each galaxy being used in the lesson.

7. Give each group 3-5 minutes at each station to complete their measurements. Then have the groups rotate stations. When finished give the students time to complete their calculations and data table.

8. To complete the data table, follow the examples above the table. The first item that needs to be calculated is the angular size of the galaxy. From there, the distance can be calculated using the rule of 57.

Teacher Note: This part of the activity is meant to simulate the data collection portion of a scientific investigation. All the students have data that would have been new in 1929. The next part of the activity will involve looking for patterns in the data and trying to apply a model to describe what the data represents.

III. Explanation

9. Have the students now recall that the ultimate goal of this activity is to create a model for the behavior of the universe. Discuss with them that in order to determine which of our three models is correct, we should graph our data. Then, depending on class level, either have the class in small groups determine what a graph of each of the three models would look like or show them examples of what the three models would look like and discuss them.

a. For the steady state, make sure you indicate that since the universe is not changing, there should be zero relative velocity for every galaxy, regardless of distance.

b. For the random universe, make sure you discuss the idea that there should be no pattern between relative velocity and distance and the graph should look like a scatter plot.

c. For an expanding or contracting universe, talk about the idea that all of the galaxies should be either getting farther away or closer together. Also, since the universe has always been in motion, the farther away a galaxy is, the faster it should be moving for an expanding universe, while the opposite should be true for a contracting one.

10. Then on a piece of graph paper, create a graph of speed versus distance. On the y-axis go from –3000 to 3000 km per sec and count in increments of 500 km/s. On the x-axis, scale from 0-250 millions of light years in increments of 10 million light years.

11. Have each group discuss what model they believe applies to the motion of the galaxies. Then discuss with the entire class. Answers could vary but lead them to the idea that the universe must be expanding. Point out the fact that with few exceptions, the farther out you go the faster the galaxies are moving and that only near-earth galaxies are in fact getting closer together.

12. During the course of your discussion bring up the fact that not all galaxies are following the pattern. For the galaxies that are close to our own, some are moving closer. Discuss with the class why these galaxies don't fit the model. Lead them to the idea that since they are close to our own, that even though everything is still spreading out, our two galaxies can still be getting closer.

13. Have each student then complete the question sheet located in appendix D. Then review the answers to these questions with the class.

IV. Extension

A possible extension from this point is to have the class conduct an age and size estimate of the universe.

1. Size:

To determine the size, they should identify the farthest galaxy. Since according to their data this is the farthest recorded item in the universe, according to their results, the universe is at least this large. This is a good point to identify about the nature of science. Since this is the furthest data point they have, they would not be wrong to make this conclusion. Since then, however, scientists have identified farther objects and hence a larger universe.

2. **Age:**

To determine the age of the universe have the class think about the relationship that was determined. If the universe is expanding and the farther out the faster, shouldn't there be a point in the past when they were all together if we rewind the clock? To determine when this occurred, have them select a point in the middle of the plot. Then using the traditional speed relationship, speed equals distance over time; have them use their distance and speed information for a point in the middle of their plot to determine the age of the universe.

This material was adapted from the Beyond the Solar System curriculum developed by the Harvard-Smithsonian Center for Astrophysics. More information about Beyond the Solar System can be found on the web: http://www.cfa.harvard.edu/seuforum/btss/dvd/

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Data sheet

Use this worksheet to obtain the distance to the galaxies. Use the angular size of the photographs and the Rule of 57 to calculate the distances to the galaxies. It will help to report the distances in millions of light years (in other words, divide your distance result by a million, and report the result).

To convert from centimeters to angular size:

$$\text{Angular size} = \frac{(\text{width of galaxy in cm}) \times (0.9 \text{ degrees})}{(\text{width of image in cm})}$$

To calculate the distance to the objects:

$$\text{Distance} = (\text{size of galaxy in light years}) \times \frac{1 \text{ degree}}{\text{Angular size}} \times 57$$

Galaxy	Width (in cm)	Width (in degrees)	Distance (in millions of light years)	Speed (km/s)

Galaxy	Width (in cm)	Width (in degrees)	Distance (in millions of light years)	Speed (km/s)

Example galaxy size calculations

Measurements listed are based on the **full printed size** of these images as taken from Appendix B. The image width depends on your printer, and whether you are printing from the Word file or from the PDF file. Note that the measurements below are approximate, and there is no exact right answer for them. The “edge” of the galaxy is fuzzy, so each group will probably define that edge somewhat differently.

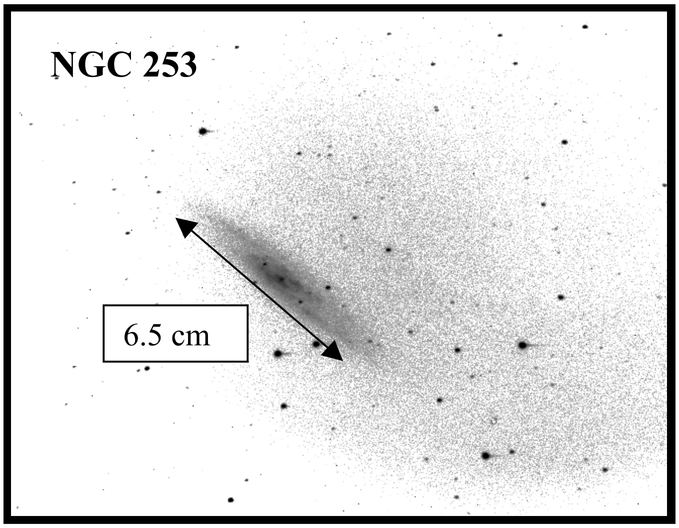

Image Width = 16.5 cm

Measurements:

Image width = 16.5 cm
Galaxy width = 6.5 cm (measure at the widest point)

Calculations:

Angular size
= 6.5 cm×(0.9 degrees)/16.5 cm
= 0.35 degrees

Distance
= 100,000 ly × (1 deg/0.35 deg) × 57
= 16,300,000 ly
= 16.3 million light years

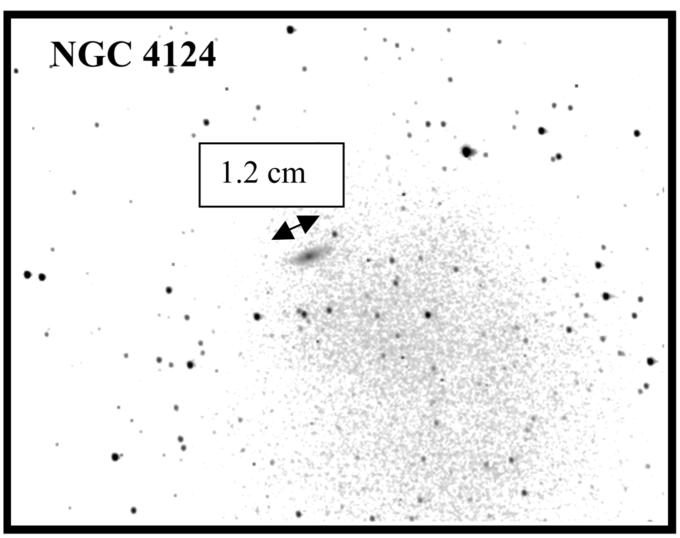

Image Width = 16.5 cm

Measurements:

Image width = 16.5 cm
Galaxy width = 1.2 cm (measure at the widest point)

Calculations:

Angular size
= 1.2 cm×(0.9 degrees)/16.5 cm
= 0.065 degrees

Distance
= 100,000 ly × (1 deg/0.065 deg) × 57
= 87,600,00 ly
= 87.6 million light years