Measuring Dark Energy

Suggested Grade Level(s): 11-12
Estimated class time: 1 class period

Summary

The purpose of this lesson is to simulate an experiment in which the discovery of dark energy can be made. It will follow a check of Hubble's law on objects with greater distance than those used to derive Hubble's law using nearby objects. Through the investigations they will find that distant objects do not behave the same as the closer objects and, in fact, the older, distant objects are farther then they should be for their current speed, implying that they were traveling faster in the past then they are now.

Objectives

- To describe how current astronomical data supports a model in which the universe is expanding at an increasing rate.
- To describe how data is used to support scientific claims and how our model of the universe flows from the data collected.
- To explain the scientific process, particularly how collected data and theories are related.

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 universe
- 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

The lesson on Hubble's law from the 1929 edition of Cosmic Times might provide a good background for this lesson. It is not necessary, but many of the ideas in this lesson follow from it. Students should also be familiar with the concepts of absolute luminosity, apparent luminosity, and Doppler shift (particularly redshift).

Teacher Background

It is also particularly important that students understand the idea that when astronomers look at distant objects, they are really looking at how those objects looked in the past. This is a fundamental concept based on the fact that light does not travel infinitely fast. In this way, by looking at more and more distant objects, astronomers are really tracing our universe's past.

Materials

- A computer graphing program (recommended but not required)
- Graph paper

Procedure:

I. Engagement

1) Begin the class talking about Hubble's law. If the 1929 lesson was done prior, discuss and recall the previous lesson. If not, put an image of a Hubble's graph on the board (given at the end of the lesson below). Explain how the graph describes a model of a universe in which an expansion is occurring. Make the point of mentioning that the slope of this line is the expansion rate.

2) Now tell the class that since the theory of Hubble's law was put forth, new data of more distant objects has been collected. If Hubble's law is going to continue to be held valid, then this new data should agree with the model created by the older data. If not, a new theory will have to be created. In this manner science is an ongoing process with new observations and data having to agree with accepted theories. If necessary, continue with discussion about how data supports theories in science.

3) Before they begin their exploration, ask student if anyone can think of a reason why the universe would not be expanding at a constant rate. *They should answer gravity.* What effect would this have on the Hubble curve? *The curve should start to slope down. In other words, as you get farther away, things should eventually start appearing below the line as they slow down.*

II. Exploration

4) Tell students that recent astronomical distance data has been done using type Ia supernovae. That data has suggested that all type Ia supernovae explode with the same luminosity. Since the absolute (actual) luminosity is known, it is a simple matter of using the observed luminosity to determine a precise distance to the object. Tell the students that they will use this data to construct a Hubble plot for supernovae using modern data.

Teacher Note: A good example to use here is how you can tell distances to people in a photograph. If you know how tall they actually are you can guess how far from the camera everyone is standing. If everyone is the same in a photo, you could derive an equation that could be used to determine how far they are from the camera based on how tall they appear and how tall they actually are.

Teacher Note: You may want to explain the supernovae naming system at this point. They are named for the year of their discovery plus a letter denoting the count for the year. Hence 1995D is the fourth supernova found in 1995. After the first 26 supernovae in a year, then two letter designations are used: aa, ab, … az, ba, bb, … etc. So 1990af was the 32nd supernova discovered in 1990.

5) Have students construct a data table of Distances and Redshifts. Give them the redshift data found in Appendix A (and the Excel file, Measuring_DE_Data_File.xls; see notes at the end of the lesson for more information on the Excel data file). You may want to have them calculate the distances or give them this data as well, depending on the level of the class. If you choose, have them calculate the distances from the luminosity distance data, using the following mathematical equation:

$$D = 10^{\left(\frac{L-25}{5}\right)}$$

   Where D is the distance and L is the "luminosity distance." The "luminosity distance" is actually the difference between the apparent and absolute magnitude of the supernova. Knowing this difference allows astronomers to compute the distance using the above equation. The distance D is in units of megaparsecs (= 1 million parsecs = 3.26 million light years).

6) Have students construct a plot of their data up to redshift 0.3 using a computer-graphing program (or this may be done by hand). Tell them the reason they are doing this is because the data up to redshift 0.3 is from nearby supernovae and they are confirming whether the newer redshift data beyond 0.3 fits the Hubble's law model. Have them put Distance on the Y-axis and Redshift (Speed) on the X-axis. Make sure they properly format their graph with a title, and axes labels and units.

7) Now have students add a trend line, either with the computer or by hand with a ruler. Then have them plot the remaining data and see if the new data points agree with the model presented by the old data. They should find that the new points all fall above the existing trend line.

8) Now first point out that all of the data still more or less obey Hubble's law. Nothing is way off the mark. But have them look closer. Why are the distant objects consistently above the Hubble line? *They should not be able to answer; they may guess gravity.* Is this consistent with what our understanding of gravity would indicate? *They should answer no, gravity would place them below. For a given redshift, these objects are farther than they should be. This indicates that they are gaining speed or accelerating.*

Teacher Note: The students should be surprised by the result and be unable to answer why this is occurring. It should also be noted that Hubble's law predicts that objects will be at a certain distance based on their redshift. So another way of looking at the graph would be to say that we are comparing theoretical ranges (Redshift) to actual ranges based on supernovae distances. It should be clear to them that more distant objects are farther from us than they should be based on our understanding of the expansion. This indicates that they must be gaining speed. The key concept is that we are currently observing a phenomenon that we do not have an explanation as to why it is occurring.

III. Explanation

9) Now explain to them that this is exactly what scientists found. To date, science has no explanation about why the universe's expansion is accelerating. Indeed, prior to its discovery in 1998, scientists thought the expansion was slowing down. Scientists attribute the expansion to "dark energy", but they don't know exactly what dark energy is.

   Science is based on the concept that you collect data of a physical system and then reason an explanation to explain why the observed phenomenon is taking place. At one point it was not understood why the moon orbits the earth or why the planets revolve around the sun. It was observed that they did and Newton's Law of Gravity provided the theory to support this data. The current task of science is to find a theory to explain this data about the universe's expansion.

IV. Evaluation

10) Have students read the 2006 Cosmic Times articles about dark energy ("Faster Walk on the Dark Side," "Sorting out the Dark Stuff," and "Biggest Mystery: What is Dark Energy?"). Have them write a paragraph relating what they have done in class to what is discussed in the articles.

11) **OR**, have the students research other areas where data was found that disproved or modified an accepted theory. Have them write a 3-5 minute summary to present to the class or to make into a podcast. Have them share their results.

Note on Accompanying Excel File (Measuring_DE_Data_File.xls)

The accompanying spreadsheet presents the data in several different ways so that you can choose the best one to present to your class.

The data is presented so that you can use the “luminosity distance” or “distance” data with your students. The spreadsheet also gives sample plots. Each data set is given on a different “sheet,” as defined by Excel. To access different sheets, use the tabs at the bottom of the window (labeled “Sheet 1”, “Sheet 2”, etc.).

In the Excel file:

- Sheet 1 contains the Supernova, Redshift (with Log Redshift), Luminosity Distance, and Distance data (The Distances are derived from the Luminosity Distances, using the equation given in the Exploration Section (above))
- Sheet 2 contains the Supernova, Redshift (with Log Redshift) and Distance data
- Sheet 3 contains a sample plot using the Distances vs Redshift; this goes along with Sheets 1 and 2
- Sheet 4 contains the Supernova, Redshift, and Luminosity Distance data
- Sheet 5 contains plots of the “Luminosity Distances vs Redshift” to accompany Sheet 4. The top plot is linear, and the bottom plot is semi-log. Both show the linear relationship for redshifts below 0.3 and the deviation from that line for points above redshift = 0.3

Appendix A: Distance, Luminosity Distance, and Redshift Data.

Supernova	Redshift	Luminosity distance	Distance (MegaParsec)
1995D	0.008	32.79	36.14
1995E	0.012	33.73	55.72
1992al	0.014	34.13	66.99
1995bd	0.016	34.00	63.10
1996C	0.028	35.82	145.88
1992bh	0.045	36.87	236.59
1990af	0.050	36.67	215.77
1993O	0.052	37.31	289.73
1992bs	0.064	37.63	335.74
1992bp	0.080	37.96	390.84
1992aq	0.101	38.33	463.45
1996ab	0.124	39.10	660.69
1996J	0.300	40.99	1577.61
1996K	0.380	42.21	2766.94
1996E	0.430	42.03	2546.83
1996U	0.430	42.34	2937.65
1997ce	0.440	42.26	2831.39
1995K	0.480	42.49	3147.75
1997cj	0.500	42.70	3467.37
1996I	0.570	42.83	3681.29
1996H	0.620	43.01	3999.45
1997ck	0.970	44.30	7244.36

Appendix B: Sample Graph