Discovering the Milky Way

Suggested Grade Level(s): 9-12
Estimated class time: one or two class periods

Summary

Students will read the original paper written by Henrietta Leavitt in which she compared the apparent brightness and period of some variable stars called Cepheids. The students will prepare graphs just as she did and compare their data to hers. They will discover that there is a relationship between the period and luminosity of the variable stars she observed and experience for themselves how scientists really collect data.

Objectives

- Students will prepare graphs from numerical data using standard technique.
- Students will compare those graphs with additional logarithmical graphs they prepare from the same data.
- Students will use both sets of graphs to find relationships between the variables.

National Standards

National Science Standards

- NS.9-12.1 SCIENCE AS INQUIRY
  As a result of activities in grades 9-12, all students should develop
  - o Abilities necessary to do scientific inquiry
  - o Understandings about scientific inquiry
- 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
  - o 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
  - o Science as a human endeavor
  - o Nature of scientific knowledge
  - o Historical perspectives

National Language Arts Standards
(From the National Counsel of Teachers of English)

- NL-ENG.K-12.3 EVALUATION STRATEGIES
  Students apply a wide range of strategies to comprehend, interpret, evaluate, and appreciate texts. They draw on their prior experience, their interactions with other readers and writers, their knowledge of word meaning and of other texts, their word identification strategies, and their understanding of textual features (e.g., sound-letter correspondence, sentence structure, context, graphics).

Knowledge Prerequisite

Students should be familiar with the following general terms:
- Origin- point where X and Y axis cross
- Abscissa- X axis
- Ordinate- Y axis
- Apparent magnitude- brightness of a star as seen from the earth
- Absolute magnitude- the actual brightness of a star, or the apparent brightness if all stars were 32.6 light years away.
- Variable stars – stars whose brightness changes over a regular period of time. There are many kinds of variable stars but the most important to this story are the Type I Cepheids, the Type II Cepheids, and the RR Lyrae stars. Originally the differences were not understood and resulted in some major miscalculations that persisted until the 1950s.
- Globular star clusters – Dense groups of stars containing 100,000 to 1 million stars that are held together by the influence of their own gravity. They are only about 75 Light years in diameter and are found mostly in the vicinity of the central spherical portion of the galaxy. Using a Cepheid variable in such a star cluster could give the approximate distance to the cluster because all of the stars in the group are about the same distance away.
- Small Magellanic Cloud – An irregular galaxy of stars that is one of several in the Local Group of galaxies to which our own Milky Way belongs.
- Period-Luminosity Relation – principle that variable stars with longer periods will have a higher intrinsic brightness than stars with shorter periods.

Materials

1. a copy of Leavitt's original paper (supplied)
2. standard quarter inch graph paper
3. logarithmic graph paper (template supplied, or download template at various sites on the web, http://www.printfreegraphpaper.com/ for example)

Teacher background notes

Be sure the students' progress through the activity from the Engagement point noted below. They should not know until later that they are plotting actual data collected by a "real scientist."

This activity can be done using Excel or some other computer graphing program; however, it might be more meaningful for students to actually plot the points on paper just as Henrietta Leavitt did originally. For younger students, the practice in doing the graphs "by hand" is very valuable.

When students plot the first set of data they should begin to see a trend in the relationship between the magnitude and period variables. If they plot both the maximum and minimum apparent magnitudes separately, they should see the same trend developing. Addition of more data should make them more confident of the trend they see. Using the

log 10 of the period will help to straighten and condense the trend line on the graph. Some students will be reluctant to conclude that a firm relationship exists unless all of the data falls on a perfectly straight line. Others will happily accept a conclusion if as few as three points fall in the same general area. Discuss with students that scientist are always faced with this kind of problem. The original data in Leavitt's paper did not take into account that all variable stars do not behave exactly the same way on the Period-Luminosity Relation diagrams. Shapley's calculations of distance using the Cephied variables lead to the discovery of the Milky Way Galaxy, but improvements in technology, measurements and understanding which came later expanded our universe even more.

See additional historical notes to share with students at the end of the activity.

Included with this lab is an Excel document which shows the graphs. They are examples only, and the student graphs, done manually, should look similar.

Procedure:

I. Engagement

Since the days of the earliest astronomers, the faint band of light that we now call the Milky Way has been visible in the night sky. However, no one knew what it was. The biggest discoveries in science start with the collection of the smallest bits of information. Then scientists build on the work of their predecessors, refining the information collected earlier until a new picture of our natural word unfolds. Careful observation, painstaking recording, and thoughtful analysis are the foundation of science.

II. Exploration

Suppose that you have been taking photographs of the same region of the night sky over a long period of time and notice that some stars seem to be brighter on some nights than they are on others. What is the term for the brightness of stars as they APPEAR from Earth? (Remember that lower star magnitude numbers represent brighter stars than higher numbers.) By comparing the nightly photographs you see that the period from brightest to dimmest can vary from slightly more than one day to as long as 127 days. The table below shows the information collected for 14 of these variable stars.

Star	Maximum Brightness	Minimum Brightness	Period (days)
A	14.8	16.1	1.25
B	14.8	16.4	1.76
C	15.1	16.3	1.88
D	14.6	16.1	4.29
E	14.3	15.3	4.54
F	14.3	15.5	4.99
G	14.4	15.4	5.31
H	14.3	15.2	5.32
I	14.1	14.8	6.65
J	13.9	15.2	8.39
K	13.6	14.7	10.34
L	13.4	14.6	16.75
M	12.2	14.1	31.94
N	11.2	12.1	127

While a list of data is useful, sometimes a graph reveals relationships between the bits of information, which may not be obvious when viewed as a simple list. Draw a graph with the apparent brightness on the Y axis. **Because higher numbers represent dimmer stars, your graph should show numbers on the Y-axis in reverse numerical order (i.e. 16 at the origin of the graph and 10 at the top).** Show the period of brightest to dimmest, in days, on the X-axis. Use one color to represent the maximum brightness and another to represent the dimmest. Or you may want to make two separate graphs, one for the maximum brightness and another for minimum brightness.

Teachers: here is a sample of what that the graph should look like:

**Maximum Luminosity vs. period**
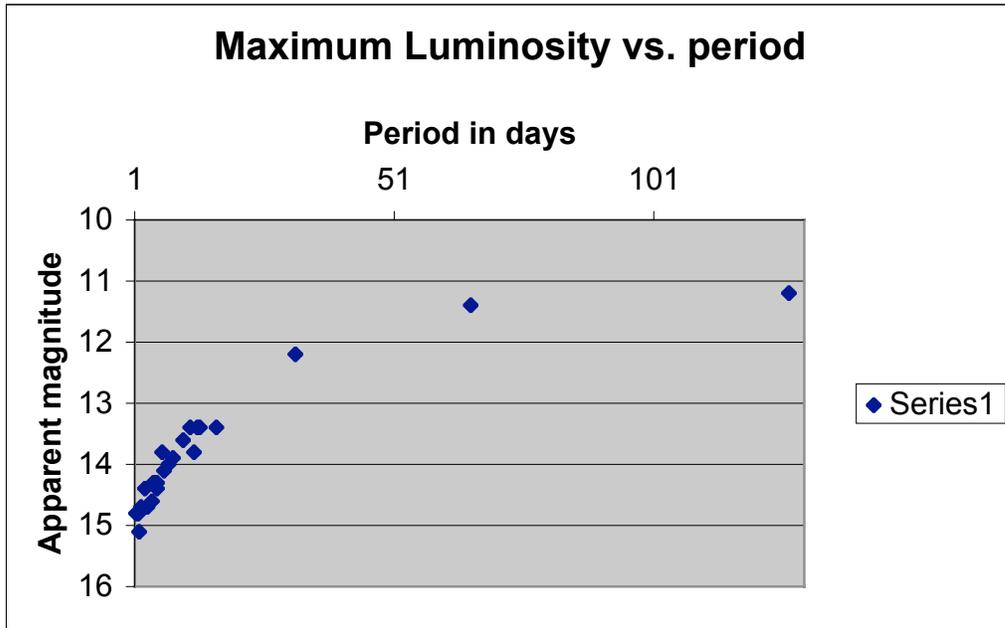
Do your graphs show any trends or patterns? What would make you more confident?

Collecting the information about these stars is very difficult because the stars appear to be very crowded in the regions where they occur. The variable stars are very faint at best and long camera exposures are needed to capture them at all. The number of photographs is very small. However with much care and the fortune of having some clear weather and "good seeing," you collect information about 11 more variable stars. Add the new information from the table below to the graphs you have already begun.

Star	Max	Min	Period
O	14.8	16.4	1.66
P	14.7	15.6	2.17
Q	14.4	15.7	2.91
R	14.7	15.9	3.5
S	13.8	14.8	6.29
T	14	14.8	7.48
U	13.4	14.6	11.64
V	13.8	14.8	12.41
W	13.4	14.4	13.08
X	13.4	14.3	13.47
Y	11.4	12.8	65.8

Does the additional information help to confirm or deny a pattern or relationship between apparent brightness and period? Sometimes a mathematical operation can help to clarify the collected raw data. Redraw your graph using the log of the respective periods on the X-axis instead of the actual number of days. Find the log (base 10) of each period using your calculator. **Teacher:** Instead of taking the log of the periods, your students could plot the semi-log paper with the log axis as the x-axis.

Teacher: Here is a sample of the second, log-based plot:
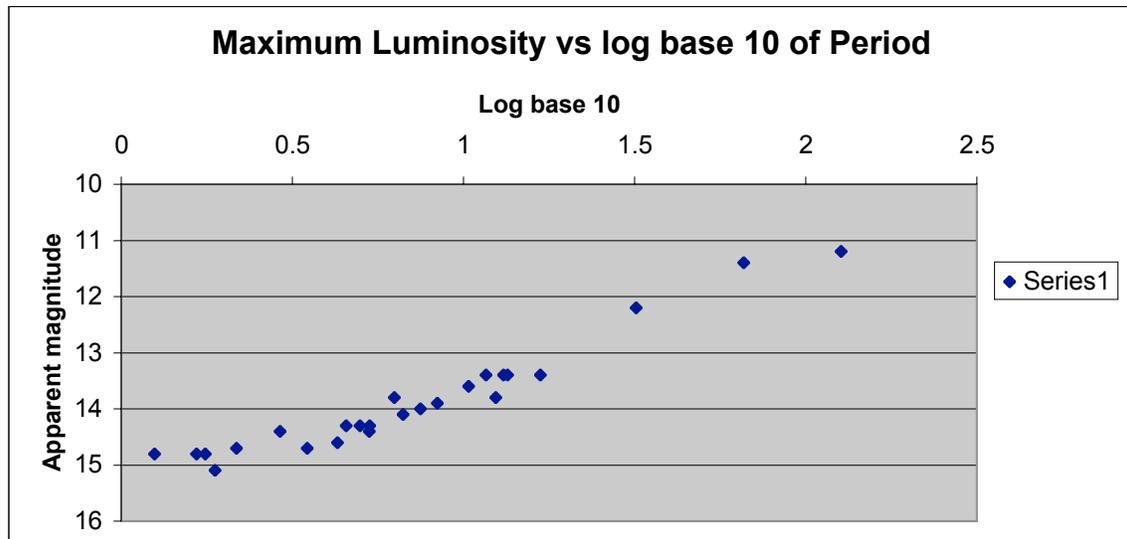
III. Explanation

What effect did using Logs have on the shape of your graphs? Do you see a pattern emerging from the data? What else do you need to know before you can draw any conclusions? Hint: What factors can affect the brightness of a star? Remember that you are viewing the Apparent Magnitudes. Find a definition for the term Absolute Magnitude. Do you know the absolute magnitude for the stars on your graphs? If you knew that all of the stars on both tables were in the same group and approximately the same distance from Earth, could you now draw a conclusion about the relationship between maximum brightness of a variable star and the length of its period? How confident would you be about the validity of your conclusion? How could this pattern of period- apparent brightness of variable stars be used? Your teacher will show you a research paper prepared by a Harvard University researcher. Compare your graphs and conclusions to hers. Would you have reached the same conclusion she did?

IV. Extension

Read the included document about some interesting history to see how this data laid the groundwork for additional new knowledge.

Some Interesting History:

The activity which the students will be doing uses the original data collected by Miss Leavitt in 1912. Originally she had data for only 17 variable stars and noticed that there did seem to be a relationship between the period and the apparent brightness. After much more very careful observation she found 8 more stars which could also be measured and seemed to conform to the same **principle**, that the brighter the maximum luminosity the longer the period of variation. In addition to the actual astronomy of this lesson, the purpose for having the students work through it is to see how important scientific conclusions are formed. Have the students compare the graphs they have prepared to the ones in her paper. Her data was based on only the apparent magnitude of the Cepheids. To be more useful it was necessary to know the absolute magnitudes as well. Ejnar Hertzsprung was the first to try to calibrate Leavitt's Period-Luminosity relation using statistical parallaxes in 1913.

Harlow Shapley later used her data to "calibrate" the Cepheid variable stars for the determination of distance. Other scientists since then have used their presence in star groups to determine distance without the need to go through the entire calculations again. Emphasize to students how important it is to get those calculations correct. Not all variable stars behave the same way and the discrepancies led to some serious errors in distances. Some of the biggest errors in science have been due to errors in calibration.

Henrietta Leavitt was one of the women "computers" who worked with Edward Pickering at the Harvard College Observatory in 1912. It was an interesting product of the times that, although Leavitt did the research and analyzed the data, Pickering is the listed author of the paper. Leavitt had been working with photographs of stars in the Small Magellanic Cloud (which is actually an irregular galaxy itself located in the same Local Group as our own Milky Way galaxy). Her task was to calculate the periods of some variable stars which changed apparent brightness in a regular way over a period of time. It is her data which the students will plot. This **Period-Luminosity Relation** became a powerful tool for finding distance to stars, which are very far away and was the key to discovering the nature of our Milky Way.

Harlow Shapley was studying star clusters and noticed that different kinds of star clusters have different distributions in the sky. He saw that many globular clusters were highly concentrated near the constellation Sagittarius and assumed that the combined gravitational field of what was then considered the entire "star system" controlled them. He needed to know the distances to as many of the globular clusters as possible.

Globular clusters are too far away to have measurable parallaxes, but they do contain variable stars and Shapley knew of Leavitt's work. She knew only the apparent magnitudes of the variable stars she had studied. All stars are moving through space, and over a relatively short time of a few years these **proper motions** can be observed as small shifts in the position of the stars in the sky. Very distant stars have undetectable proper motions but nearer stars have larger and more detectable ones. Shapley found 11 Cepheid variables with measurable proper motions and was able, through statistical methods, to find their average distances and thus their absolute magnitudes. Now he could replace Leavitt's apparent magnitudes with absolute magnitudes on the period-luminosity diagram. The Inverse square relation shows that the brightness of a light source is inversely proportional to the square of its distance from the observer. When Shapely had both the apparent magnitudes and the absolute magnitudes of many variable stars he could calibrate them as distance measurements for the globular clusters. Shapely wrote that it was late at night when he made his final calculation and found that the star clusters did indeed form a great swarm, but it was not centered on our sun as previously thought. Instead the center lay thousands of light years away in the direction of Sagittarius. He called the only other person in the building, a cleaning lady, and the two stood looking at his graph as he explained that we live not at the center of a small star system, but in the outlying suburbs of a vastly larger wheel of stars, the Milky Way. The very term galaxy comes from a Greek term that means "milky circle." (Michael Seeds, *Horizons, Exploring the Universe,* 2000, Thomas Learning, Brooks/ Cole)

Semi-log graph paper

Here is a template for semi-log graph paper