Lab 5 – Leavitt's Law: The Period-Luminosity Relation

ASTR 1020

Name:

Overview

In this activity, you will explore the relationship between the period of pulsation of Cepheid variable stars and their intrinsic luminosity, and how to utilize that relation for distance measurement.

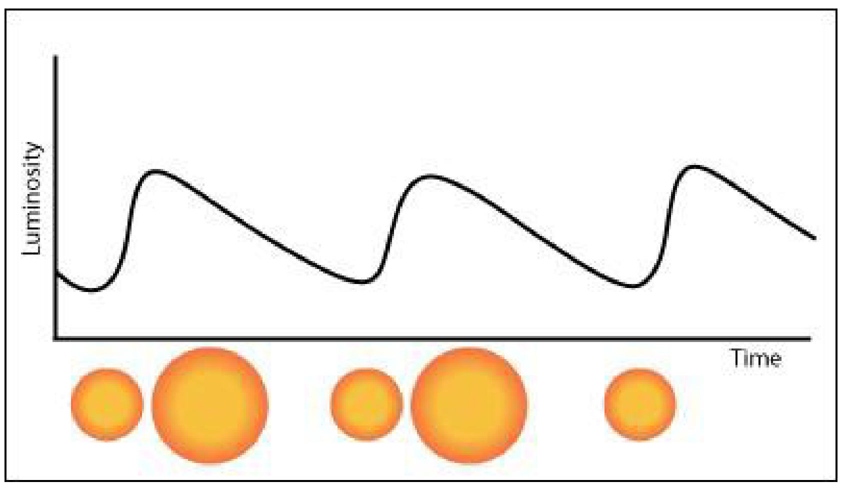
Objectives

After completing this activity students will be able to:

- Calculate the absolute magnitude for a Cepheid variable with a known distance
- Plot a period-luminosity diagram for classical Cepheids
- Use Leavitt's Law to determine the distance to another galaxy

Definitions

- **Cepheid** – a star that varies in brightness with a recurring cycle of pulsations in brightness and size
- **Period** – *P*; the time required to complete one cycle; in the case of Cepheid variable stars, the time between cycles of varying brightness
- **Leavitt's Law** – also known as the Period-Luminosity Relation; a relationship discovered by Henrietta Leavitt which relates a Cepheid variable star's period of pulsation to its absolute magnitude.
- **Apparent magnitude** – *m*; the apparent brightness of a celestial object as measured from Earth.
- **Parsec** – equal to 3.26 light-years; the distance an object must be to have a parallax angle of 1 arcsecond.



- **Absolute magnitude** – *M*; the brightness of a celestial object as measured from 10 parsecs.
- **Distance Modulus** – *m*-*M*; the difference between an objects apparent and absolute magnitudes.

Part 1. Calibrating Leavitt's Law

In Table 1, some observations of Cepheids in the star cluster χ Persei are listed. The technique of main sequence fitting gives a distance to χ Persei of about **2600 parsecs**. Use the distance modulus shown in Equation 1:

$$M = m + 5 - 5*\log(D) \qquad (Equation\ 1)$$

where *M* is the absolute magnitude, *m* is the apparent magnitude, and *D* is the distance, to calculate *M* for each of these stars. Complete Table 1 with the results.

Table 1: Cephieds in χ Per

STAR	Period (days)	log(*P*)	*m*	*M*
VY Persei	5.37	0.73	8.36	
V Persei	5.53	0.74	7.99	
VX Persei	10.89	1.04	7.56	
SZ Cassiopeiae	13.61	1.13	7.19	

Table 2: Other Galactic Cepheids

STAR	Period (days)	log(*P*)	*M*
EV Scuti	3.09	0.49	-2.90
CE Cassiopaiae A	5.14	0.71	-3.84
CF Cassiopeiae B	4.48	0.65	-3.78
U Sagittarii	6.73	0.83	-3.63
DL Cassiopeiae	8.00	0.90	-3.62
S Normae	9.75	0.99	-4.27
RS Puppis	41.40	1.62	-6.25

A. Plotting Leavitt's Law in Excel

In Table 2 are data on 8 additional Cepheids which are found in 6 other star clusters. Their absolute magnitudes have been determined by the same method you just used in Part 1.

You will now use Excel to create some plots.

Open Excel and create columns for log(*P*) and *M*. Record values for log(*P*) and *M* from Tables 1 & 2 into your Excel spreadsheet.Use Excel's graphing abilities to plot these two columns to make your period-luminosity relation.

a. Select the log(*P*) and *M* columns
b. Click on 'Insert' tab
c. Click on 'Recommended Charts' and select 'Scatter'
d. **Click on your plot and then the plus on the upper right corner of the plot to bring up the window.**
e. Need to label axes. Check *Axes Titles* and edit your axes labels. The x axis should be log(P) and the y axis should be M.
f. Need to flip the magnitude axis. Click the numbers of the mag axis. *Axis → More Options → Axis Options* Check *Values in Reverse Order*
g. Finally, to best represent the period-luminosity relation, we will draw a trendline that best fits the data. Check *Trendline → Linear*. Then *Trendline → More Options* and scroll down to check *Display Equation on Chart.* Write down your equation below. Make sure to write your equation in terms of M and log(P).
h. **Have your TA check your graph before moving on to Part 2.**

1. **TA Graph check:**

2. **Best Fit Equation:**

Part 2. Distance Determination Using Leavitt's Law

In Table 3 gives data obtained for a Cepheid in the Large Magellanic Cloud, a nearby irregular galaxy (LMC image credit: ESO/VMC Survey). Column 1 lists the time in fractional days of each observation. The second column gives the apparent magnitude measured at each time.

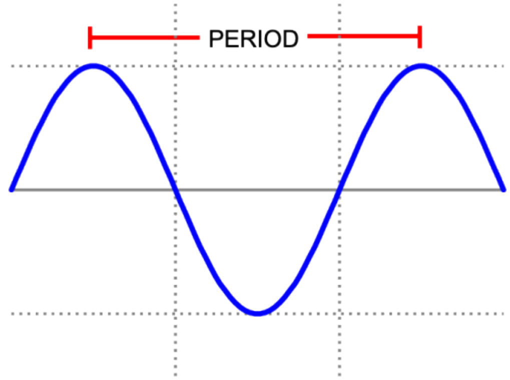
Plot the light curve for the Cepheid data in Table 3 in Excel in the same method you used to graph Leavitt's Law in Problem 1. Label the x-axis as'Days' and the y-axis as 'm.'

Table 3: A Cepheid in the LMC

Time (days)	m
1.28	15.83
1.37	15.95
1.56	15.59
1.84	15.26
2.16	15.20
2.33	15.23
2.67	15.32
3.20	15.41
3.98	15.51
4.17	15.56
4.22	15.63
4.54	15.70
5.20	15.84
5.38	15.84
5.94	15.85
6.04	15.93
6.31	15.61
6.50	15.30
6.92	15.19
7.45	15.33
7.88	15.39
8.65	15.53
8.83	15.56
8.88	15.64
9.21	15.70

From your graph, determine the time for each maximum brightness, i.e. the times of the lowest m (remember the magnitude system is reversed, so m=3 is brighter than m=4). The difference in time is the pulsation period (P).

Reminder. The period is the amount of time between the peaks of a periodic function and it looks something like this →



Using Excel, simply hover your curser over the peaks, and the x,y coordinates will pop up, telling you the times of the peaks. Have your TA check your graph, then record your value of each peak and P below:

3. **TA Graph Check:** ______

4. **First Peak:** ______ days

5. **Second Peak:** ______ days

6. **P =** ______ days

Use a calculator to determine the value of log(P) and record the answer below.

7. **log(P) =** ______

Using your best fit equation from Question 2, calculate the absolute magnitude. This is Leavitt's Law! Show your work.

8. **M =** ______

From Table 3, calculate the average m, and record your results below. To do this in Excel, do =AVERAGE() and select all the cells that contain your m data.

9. **m =** ______

Use m and M to compute the distance modulus, m-M. Record your answer below.

10. **m – M =** [ ]

Use the distance modulus equation (Equation 1) to determine the distance to this Cepheid. This is the distance to the Large Magellanic Cloud. Currently, the distance to the LMC is believed to be between 57000 and 67000 parsecs. Show your work and record your answer below.

To solve for D in equation (1):

$M = m + 5 - 5*\log(D)$	*Equation 1*
$5*\log(D) = m + 5 - M$	Isolate D on one side of the equation by subtracting
$\log(D) = (m - M + 5)/5$	Divide both sides by 5. Note: m-M is the dist. mod.
$D = 10^{((m-M+5)/5)}$	Remove logs

11. **D =** [ ] **parsecs**