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.
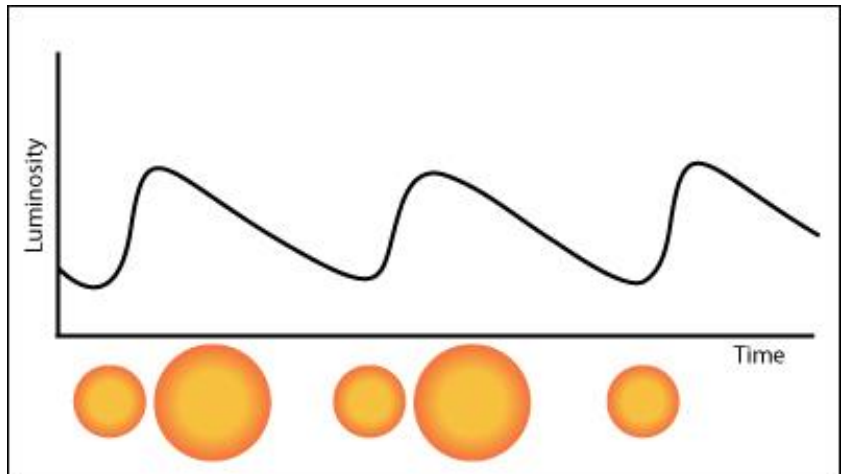
Part 1. Calibrating Leavitt's Law

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 a spreadsheet program of your choosing to create some plots. If you have any questions, please be sure to meet your lab TA during their office hours!

Open Excel (or Numbers, Google spreadsheets, any spreadsheet software) 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' (just 'Charts' in Numbers) and select 'Scatter' (or '2D Scatter' in Numbers).
          i. **Note:** Make sure none of the columns are in the first column on the left if using Numbers
     d. Click on your plot and then click on 'Chart Design' Tab in the upper left (if using Numbers, click on plot and the menu bar to the right will list plot options)
     e. Need to label axes. Click on 'Add Chart Element'. Select 'Axis Titles'. Select both 'Primary Horizontal' and 'Primary Vertical'. This will create textboxes next to each axis. (If using Numbers, select 'Axis' in the right menu bar, click the box 'Axis Name' under both 'Value (X)' and 'Value (Y)'). Label the x-axis as log(P) and the y-axis as M.
     f. Finally, to best represent the period-luminosity relation, we will draw a trendline that best fits the data. In Excel, select your chart, click 'Add Chart Element', 'Trendline,' then 'Linear' (in Numbers, select your chart, under the 'Series' tab in the menu bar on the right, click the bar under 'Trendlines,' then select 'Linear').
     g. **LEAVE THE GRAPH ON THE SPREADSHEET**. You will submit your final spreadsheets with all graphs at the end of the lab.

Part 3. 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.

1. 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.'

LEAVE THE GRAPH ON THE SPREADSHEET.

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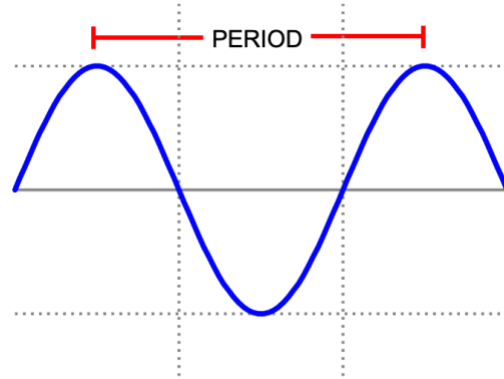
Reminder. The period is the amount of time between the peaks of a periodic function and it looks something like this →

If using Excel, simply hover your curser over the peaks, and the x,y coordinates will pop up, telling you the times of the peaks (If you are using Numbers, click on your chart, go to 'Series' in the menu tab on the right, under 'Value Labels' click on 'Values:,' then select 'X' as its option. Now every m point will have its corresponding time labeled. Record your value of *P* below:

2. **P =**

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

3. **log(P) =**

Look up your value for log(*P*) on your first plot in your Excel sheet. From your trendline, estimate the Cepheid's *M*. In other words, at your log(*P*) value, go straight up the graph to the trendline of the P-L relation and read off the corresponding *M* on the y-axis. Record your answer below.

4. **M =**

From Table 3, calculate the average *m*, and record your results below.

5. **m =**

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

6. **m − M =**

5

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 65000 parsecs. Record your answer below.

7. **D =** [   ]

To complete this assignment for grading:

- Save this file: File -> Save As... -> Rename the file 'YourLastName – LeavittLab'
- Save your spreadsheet: File -> Save As... -> Rename the file 'YourLastName – LeavittLabSpreadsheet' -> File format: -> PDF (If using Numbers: File -> Export To -> PDF).
- **UPLOAD BOTH FILES** to 'Lab 5 – Leavitt's Law: The Period-Luminosity Relation' assignment in iCollege (click Add Attachments -> Upload -> upload renamed saved file -> Update).
- Complete the Reflection activity on iCollege
- Have a beverage of your choice in celebration!