SIERRA COLLEGE OBSERVATIONAL ASTRONOMY
LABORATORY EXERCISE

Lab N14: Cepheid variables extra credit

NAME	GROUP

OBJECTIVE:

- Learn about Cepheid variables, and their use in astronomy.

INTRODUCTION:

There are many stars in the sky that are variables—they change over time in some important character—usually brightness. The star *Delta Cephei* is a type of variable star that pulsates in size and temperature, resulting in a regularly varying brightness. Any star that pulses in the same way is called a *Classic Cepheid variable*, in deference to Delta Cephei.

The reason Classic Cepheid variables are so important is because it has been discovered that the period of brightness change is related to how luminous, or powerful, such stars are. This relationship is called the *Period-Luminosity relationship*. It was very difficult for astronomers to calibrate this relationship, but once they did, they had a way of determining how powerful a Classic Cepheid variable was, just by timing how long it took for such a star to go through its full brightness cycle.

Once the star's absolute magnitude (M) is determined from the Period-Luminosity relation, its apparent magnitude (m) can be measured, and then the *distance modulus* (m-M) coan be calculated.

A star's apparent magnitude (m), absolute magnitude (M), and distance (d, in parsecs) are related by Equation 1:

Equation 1

$$d = 10 \times 10^{(m-M)/5}$$

Once a Classic Cepheid variable's distance is calculated, astronomers also know how far away the galaxy is that contains the variable. So these stars are very important for cosmology.

As astronomers first studied these variables, they realized that Classic Cepheid variables are related to stars like our own sun, which have a high metal content (also called population I stars). Cepheid-type variables associated with low-metal stars (also called population II stars) are called *Type II Cepheids*. While Type II Cepheids have their own Period-Luminosity relationship, it is mathematically slightly different.

Figure 1: Period-Luminosity Relations

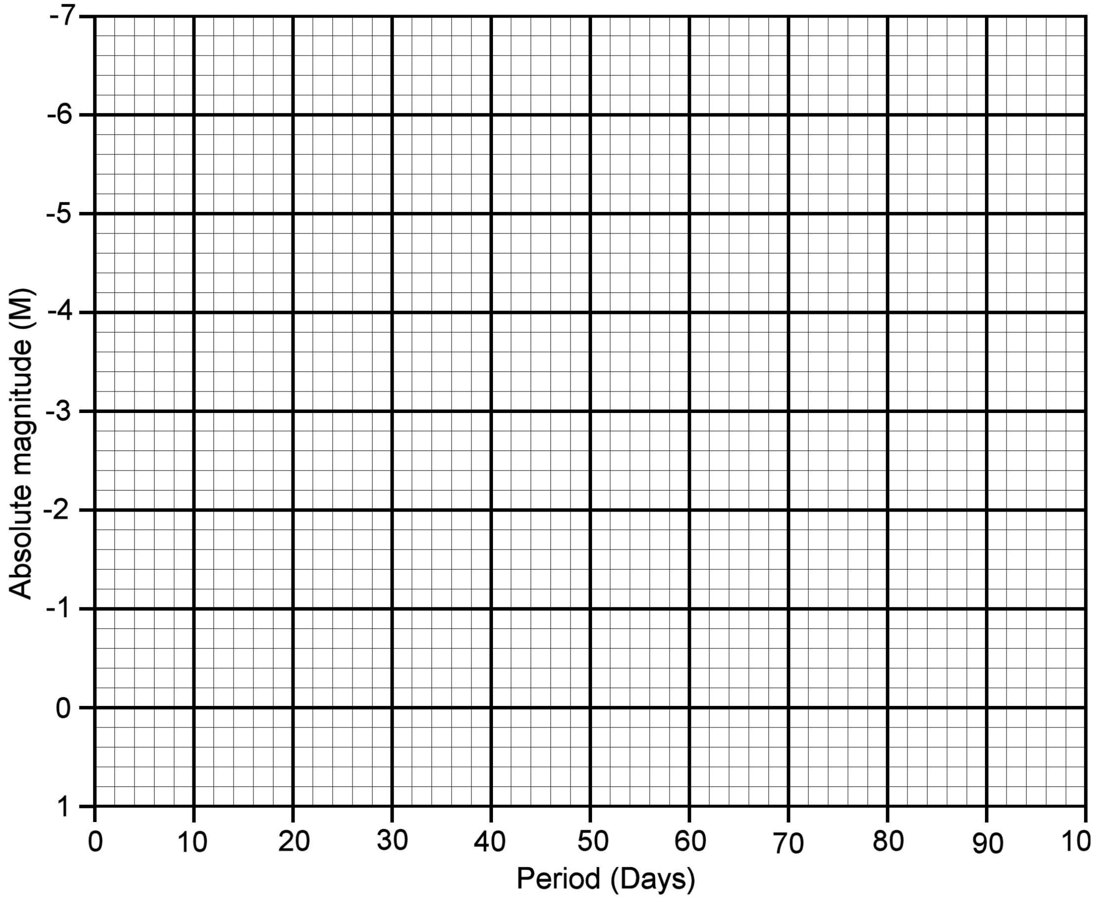
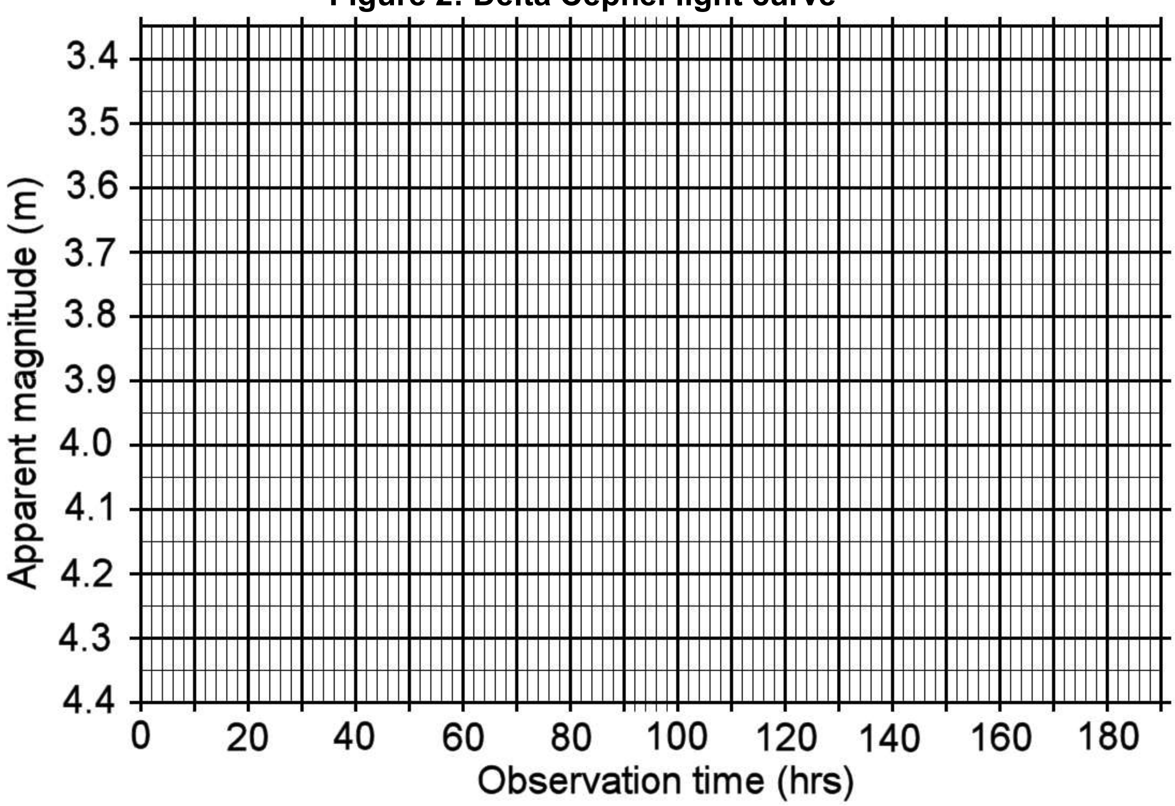


Figure 2: Delta Cephei light curve



PROCEDURE I: The Period Luminosity Relationship

Note: The more of this procedure you complete correctly, the more points you will get. If you make a mistake which makes the rest of the lab incorrect, you will not get points for the latter parts of the lab.

1. Table A gives the absolute magnitudes of Classical Cepheid Variables as a function of period. Plot these data in Figure 1. Once you have done that, fit the points with a smooth, continuous, curving line. Do NOT "connect the dots." Label the curve, "Classical Cepheids."

2. Table A also gives the absolute magnitudes of Type II Cepheids. Plot those on Figure 1, but using a different color. Using this second color, fit the points with a smooth continuous line. Label the curve, "Type II Cepheids."

3. Table B gives apparent magnitude for Delta Cephei, as a function of time, over a period of 180 hours. Carefully plot all these points on Figure 2.

4. Fit the points in Figure 2 with a smooth, continuous, curving line.

Table A: Period Luminosity curves

Period (days)	Absolute Magnitude	
	Classical Cepheids	**Type II Cepheids**
2	-2.3	--
3	-2.8	-1.2
4	-3.1	-1.5
5	-3.3	-1.7
6	-3.5	-1.9
7	-3.7	-2.1
8	-3.8	-2.2
9	-3.9	-2.3
10	-4.1	-2.5
15	-4.5	-2.9
20	-4.8	-3.2
30	-5.2	-3.6
40	-5.5	-3.9
50	-5.8	-4.1
60	-6.0	-4.3
70	-6.1	-4.5
80	-6.2	-4.6
90	-6.4	-4.8

Table B: Delta Cephei light curve

Time (hrs)	M	Time (hrs)	M	Time (hrs)	M
2	4.22	62	3.48	122	4.12
4	4.24	64	3.53	124	4.14
6	4.26	66	3.56	126	4.15
8	4.27	68	3.58	128	4.17
10	4.26	70	3.60	130	4.20
12	4.28	72	3.65	132	4.21
14	4.27	74	3.70	134	4.23
16	4.32	76	3.73	136	4.25
18	4.33	78	3.75	138	4.27
20	4.34	80	3.76	140	4.27
22	4.35	82	3.78	142	4.28
24	4.34	84	3.82	144	4.29
26	4.36	86	3.85	146	4.31
28	4.33	88	3.86	148	4.33
30	4.30	90	3.85	150	4.34
32	4.28	92	3.84	152	4.35
34	4.25	94	3.87	154	4.37
36	4.23	96	3.88	156	4.33
38	4.19	98	3.91	158	4.30
40	4.11	100	3.94	160	4.28
42	4.05	102	3.95	162	4.26
44	3.96	104	4.00	164	4.22
46	3.86	106	3.99	166	4.18
48	3.75	108	4.03	168	4.11
50	3.70	110	4.05	170	4.03
52	3.63	112	4.06	172	3.98
54	3.57	114	4.08	174	3.94
56	3.50	116	4.08	176	3.83
58	3.45	118	4.10	178	3.74
60	3.45	120	4.11	180	3.65

VOCABULARY:

Delta Cephei
Classic Cepheid variable
Period-Luminosity relationship
Distance modulus (m-M)
Type II Cepheids

QUESTIONS/ANALYSIS:

Note: The more of this analysis you complete correctly, the more points you will get. If you make a mistake which makes the rest of the lab incorrect, you will not get points for the latter parts of the lab.

1. Note that in Figure 2, the curve reaches a minimum brightness, a maximum brightness, then again a minimum brightness. Looking at your curve (and not the raw data points), harvest the magnitudes, and the times at which they occurred, to complete Table C.

Table C: Min-Max photometric data

Event	Time (hours)	Magnitude
Minimum #1		
Maximum		
Minimum #2		

Table D: Delta Cephei's variability

Minimum brightness	
Maximum brightness	
Average brightness	
Brightness Change	

2. Calculate the time difference between Minimum #1 and Minimum #2 in hours, and also in decimal days (d.dd). Write your values here:

   Period (hrs): ________________ Period (days): ________________

3. Using a ruler, draw a vertical line through your Figure 1 at the period you calculated in Step #2. Read off the absolute magnitude (M) that a Classical Cepheid variable with this period must have, and write it below:

   Absolute magnitude: ____________________

4. Average the two minimum magnitudes you obtained for Delta Cephei, at Minimum #1 and Minimum #2 (Table C). This is your best estimate for the minimum brightness of the star. Record it in Table D.

5. Record the maximum brightness you obtained for Delta Cephei (Table C) in Table D. Average the maximum and minimum magnitudes from Table D, recording it in Table D. Also, calculate the brightness change (minimum brightness - maximum brightness) for Table D.

6. Using the absolute magnitude (M) you calculated in Step 3, and the average apparent magnitude you calculated for Table D, use the distance modulus formula (Equation #1) to calculate the distance to Delta Cephei. Supply the correct units.

   D: _________________________

7. Does it take longer for Delta Cephei to change from minimum brightness to maximum brightness, or to change from maximum brightness to minimum brightness? Answer with a complete sentence:

8. Suppose you believed that Delta Cephei was a Type II Cepheid. Redo your calculations (as needed) to determine the star's estimated absolute magnitude (M), average apparent magnitude, and distance in parsecs:

M: _______________ m_{ave}: _______________ d: _______________________

9. Delta Cephei is at a distance of approximately 272 pc. Does your analysis suggest that Delta Cephei is a Classical Cepheid variable or a Type II Cepheid variable? Explain.

10. If Delta Cephei had another star orbiting around it, and this companion star had an apparent magnitude of 6.3, what would its absolute magnitude be (using your Classical Cepheid variable analysis).

11. What would be the absolute magnitude of a Classical Cepheid variable that had a period of 85 days?

12. Classical Cepheid variables have been observed in other galaxies. What would be the apparent magnitude of such a star, if it had a period of 65 days, and was in the Andromeda Galaxy, at a distance of approximately 2,500,000 LY?

12. The Hubble Space Telescope can see stars as faint as about m=31. How far away from us could a Classical Cepheid be, for it to be barely detected by the Hubble. Assume this Classical Cepheid has a period of approximately 63 days. Give your answer in both parsecs and megaparsecs.

D= ______________________________pc = _____________________________Mpc