

Exercise

12

Introduction to Cepheid
Variable Stars

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Cepheid variable stars are members of the pulsating variable class of variable stars. Cepheids are similar to RR Lyrae variable stars, but are relatively rare when compared to the population density of other types of variable stars.

Recalling the discussion of apparent and absolute brightness of stars presented earlier in this logbook, if a 100 watt light bulb is placed next to you it will appear very bright. If the bulb is moved to the other side of the room it is not as bright. Likewise, if you place a 100 watt bulb and a 250 watt bulb on the other side of the room the 250 watt bulb will appear much brighter.

If you know the distance to the bulb and measure its apparent brightness then you can calculate the wattage of the bulb. Likewise, if you know the wattage of the bulb and measure the observed brightness you can calculate the distance to the bulb. This can be applied to stars, if you determine the apparent magnitude of the star and you know the absolute magnitude then you can calculate the distance to the star.

Miss Henrietta Leavitt (1868 - 1921), working at the Harvard Observatory, determined the apparent magnitude and periods of 25 cepheid variables in the Large and Small Magellanic Clouds. Miss Leavitt noted that when the cepheids were ordered by increasing period that the variable stars were also ordered by increasing brightness. Because both the Small Magellanic Cloud and the Large Magellanic Cloud are each a single galaxy nearby then the cepheid variables within each cloud are relatively the same distance from earth. It seemed therefore that a relationship existed between the period of the cepheid and its absolute magnitude.

The next step was to determine the absolute magnitude of a cepheid and compare it with the period. H. Shapley used eleven cepheid variables nearby whose proper motion was known and therefore their distances. Knowing the distance and the apparent magnitude the absolute magnitude for each cepheid was then determined. Comparing the period of each cepheid with the absolute magnitude the now famous Period-Luminosity law was established and could now be used for calculating distances to cepheid variables.

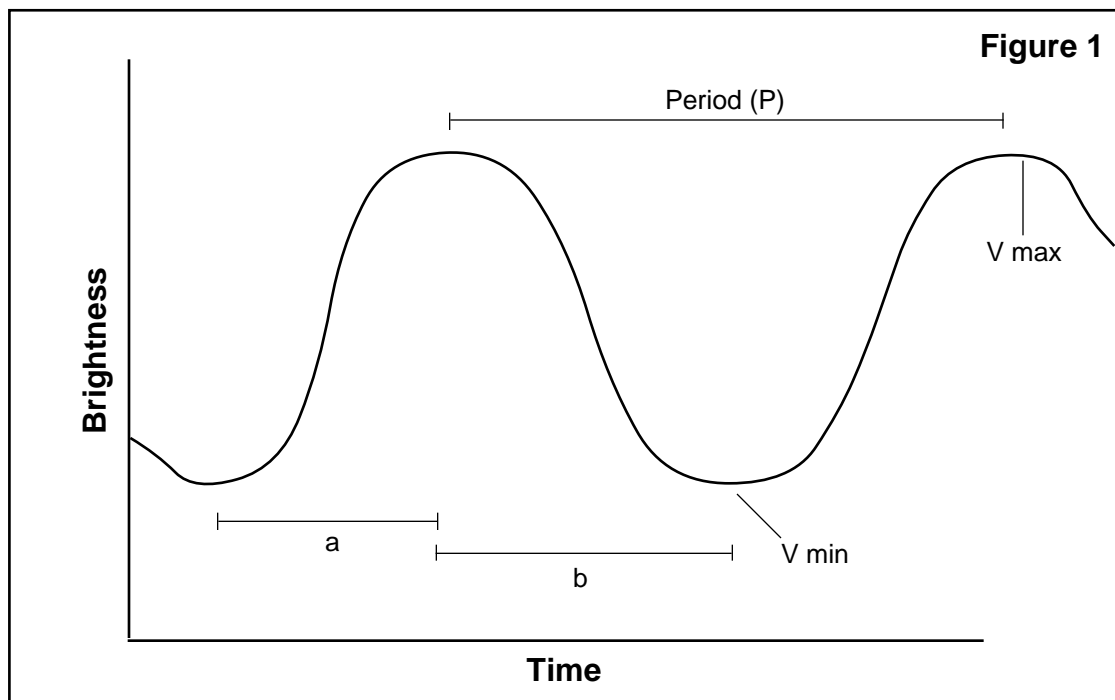
The Period-Luminosity law states that if a cepheid variable is found and the period and apparent magnitude is determined then the distance to the cepheid can be calculated. The absolute magnitude is determined from the period of the cepheid using the Period-Luminosity law. Comparing the absolute magnitude and the apparent magnitude the distance is then determined.

Cepheid variables have been discovered in star clusters and other galaxies and using the Period-Luminosity relationship the distance to those objects have been determined. Using cepheid variables to determine the distance to nearby galaxies resulted in the "calibration" of the famous Hubble law for determining the distances to very faint galaxies which in turn established the size of the known universe.

In 1952, W. Baade, studying RR Lyrae stars in the great Andromeda galaxy (M31), discovered an error in the Period-Luminosity law which resulted in the distances to cepheid variables to double which also caused the distance to nearby galaxies to double. Since the distance to these galaxies doubled then so did the Hubble law and the distance to all other galaxies was doubled. In one quick stroke the entire universe doubled in size!

From this discovery it became obvious that the correctness of the Period-Luminosity relationship was a cornerstone for galactic research and our knowledge of the universe. Since 1952, much effort has gone into the study of cepheid variable stars and further correcting the accuracy of the Period-Luminosity law.

Figure 1, next page shows a typical light curve for a cepheid variable star. Comparing the light curve with the light curve for an RR Lyrae variable star the two light curves appear identical. Although the shape of the light curve is nearly identical the physical characteristics of both stars is different and can be used to differentiate the two stars.



The period of a cepheid variable ranges from 2.5 to 25 days compared to the day or less for an RR Lyrae. The period is the most significant characteristic that separates a cepheid variable from a RR Lyrae variable.

The asymmetry of the light curve for a cepheid is similar to that of a RR Lyrae variable star ranging from 0.20 to 0.35. Using an asymmetry value of 0.20 and the shortest period of 2.5 days the best rise time from minimum to maximum would still be more than 12 hours. Unlike an RR Lyrae variable it is not likely that the entire event from minimum to maximum brightness can be observed during the four hour observing period at the telescope.

The change in brightness of a cepheid is also similar to a RR Lyrae variable ranging from 0.8 to 1.2 magnitude. If the time from minimum to maximum is 12 hours and the change in brightness is 1.2 magnitude then the brightness will change about 0.1 magnitude per hour during the rise time. During the four hour observing period the change in brightness will be 0.4 magnitude. This is the best that can be expected. In most instances the change per hour will be much less.

The temperature of a cepheid varies from 7,000°K at maximum brightness to less than 4,700°K at minimum brightness. The corresponding variation in spectral class is F3 at maximum brightness and G3 at minimum brightness. The B-V color index ranges from 0.38 at maximum brightness and 0.88 at minimum brightness. This means that a cepheid variable is cooler than a RR Lyrae variable and therefore the temperature together with the period can be used to distinguish a cepheid variable from a RR Lyrae variable.

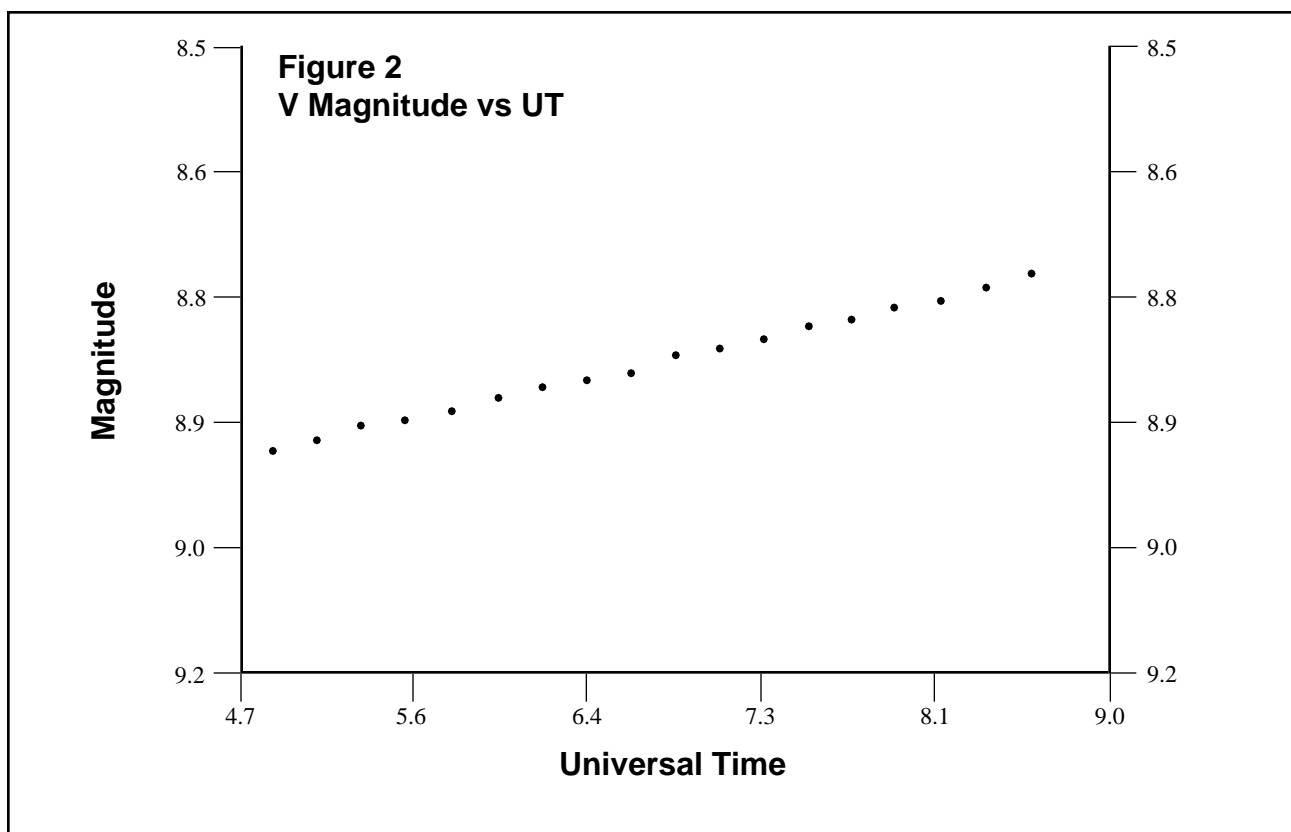
The graph (Figure 2) on the next page is an actual light curve of the cepheid variable star that is studied in Activity 12. The graph was printed using the APT-2 data analysis program. Each point on the graph represents the brightness of the star measured on the evening of November 4, 1989 using the 24" telescope (TS-24). The brightness of the star was measured every fifteen minutes during the four hour observing period.

The follow data summarizes the physical characteristics of a cepheid variable star:

P: 2.5 - 25 days
 ΔV : 0.8 - 1.2 mag
 D: 0.20 - 0.35

Maximum brightness:
 Temperature: 9,000°K - 6,000°K
 B-V Color Index: 0.17 - 0.58
 Spectral Class: F0 - F8

Minimum brightness:
 Temperature: 5,500°K - 4,200°K
 B-V Color Index: 0.67 - 1.08
 Spectral Class: G0 - G5



Activity 1: Cepheid Variable Star: 6h 26m 42.5s 21° 55' 28.0"

Step 1 Open the observatory on the evening of Nov 1 1989 with seeing conditions better than 8.0:

[TS24 Nov 1 1989]

Record the date and seeing conditions:

Date _____ Seeing Conditions _____

Step 2 Point the telescope at the star at:

RA = 6h 26m 42.5s DEC = 21° 55' 28.0"

Switch the telescope to EYEPIECE viewing:

[F5]

Step 3 There should be three stars fairly close to the center of the 80mm eyepiece. The top star, by itself, is the Cepheid variable to be studied. The two stars close to each other below the Cepheid can be used as reference stars.

Step 4 Switch the eyepiece to 12.5mm and activate cross-hairs. Center star in cross-hairs

Step 5 The APT is used to measure and record the brightness of the Cepheid variable. If you are not sure how to use the APT please refer to Section 2 or Appendix C.

The APT requires that the stars to be measured must have their coordinates stored into the DT-7 memory. If you are not sure how to do this please refer to Appendix A.

Store the coordinates of the Cepheid variable into the DT-7 memory.
Use the following DT-7 parameters to store the coordinates:

DT-7 Program: 1

Object: 1 Cepheid Variable

Step 6 Use the APT to measure and record the brightness of the variable star on the following evenings:

November 1, 1989 through Novemebr 10, 1989

On each evening, setup the APT operating parameters as follows:

DT-7 Program **[F4]**: 01

Recording Limit **[F2]**: 3 hours

Recording Interval **[F8]**: 15 minutes

Integration Count **[F7]**: 1.0

Analysis:

Step 1 Use the APT-1 program to "reduce" each of the data files generated by the APT. If you are not sure how to use this program please refer to appendix C.

Step 2 Use the APT-2 program to display the apparent magnitude and color indices for the Cepheid variable. Notice that the Cepheid variable does not show any dramatic changes in brightness during a single evening.

Use the crosshairs to determine the apparent magnitude and color indices at UT = 7.0.

Step 3 Using the **JULIAN.EXE** utility program, calculate the modified julian date (MJD) for each date using UT = 7.0

Step 4 For each evening, record the date, modified julian date (at 7h UT), apparent magnitude, B-V and U-B color indices in the table below:

Table 1 Cepheid Variable Data	Date	MJD	Magnitude	B-V	U-B	

Notice that on the evening of November 3rd and November 8th the star had a magnitude approximately the same. This would indicate that the Period of the Cepheid is approximately 5 days. Also, from the data above it appears that the brightness of the star on those dates is a minimum (star is expanded).

Next, notice that on the evenings of November 9th and 10th that the star has nearly the same brightness which appears to be near a maximum. Because the star was fainter on November 8th then it appears that the star was going through a contraction phase and sometime between November 9th at UT 7 hours and 24 hours later the star had reached maximum brightness and began its expansion phase.

Step 5 Using ordinary graph paper (see page 104), plot the data recorded in Step 4. Set the x-axis as the modified julian date (MJD) and the y-axis as magnitude. Separate each date on the y axis by about a half inch so that the ten days of data recorded above will take up about 5 inches of horizontal space on your graph.

Plot the apparent magnitude data from above on your graph. Knowing that the light curve is similar to an RR Lyrae light curve, connect the dots.

Using your graph, determine the physical characteristics of the variable star and record below:

P: _____

ΔV : _____

D: _____

Referring to Figure 1 on page 100 the graph shows a typical light curve for an Cepheid variable.

The light curve of a Cepheid variable is very asymmetric which means the ratio of the time to go from minimum brightness to maximum brightness (a, in figure 1) divided by the period, P, is much less than 0.5. Or, the time to go from minimum brightness to maximum brightness (a, in figure 1) is much less than the time to go from maximum brightness to minimum brightness (b, in figure 1).

The asymmetry of the light curve, D, is calculated by dividing the time from minimum to maximum, a, by the period, P:

$$D = a / P$$

