UNIT 14 - CEPHEID VARIABLE STARS

Cepheid Variable Stars as Distance Markers
Although the light output from most stars is essentially constant, the light from intrinsically variable stars changes in a predictable manner. The variation in the light output from the star is related to the properties of the star itself, and is driven by regular pulsations in the size of the star. In the case of Cepheid variable stars, the period of the variation in the light intensity is related to the absolute magnitude of the star.

For stars which are too far away for their distances to be measured using stellar parallax, estimation techniques must be used instead. Many of these techniques rely on the relationship between:

- The relative magnitude of the star - a measure of the amount of light from the star which is received at the Earth's surface. (Also called apparent magnitude.)
- The absolute magnitude of a star - a measure of how much light a star is actually radiating into space, or luminosity.
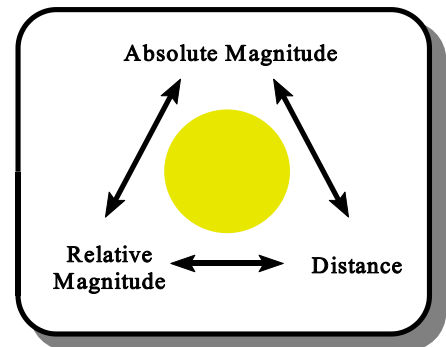- The star's distance from us.

Figure-1: Relationship between absolute magnitude, relative magnitude, and distance

In principle, if the first two of these quantities are known, then the distance can be calculated. The first is usually easy to measure, all that is needed is to equip a telescope with a calibrated light detector. The absolute magnitude is harder to obtain, since we cannot travel to the correct distance from the star (defined as 10 pc) in order to measure it. Instead we must rely on other measurable properties of the star to obtain an estimate of its absolute magnitude. In the case of the Cepheid variable stars, this other property is the frequency with which the luminosity changes.

Studies of Cepheid variable stars shows that there is a simple relationship between absolute magnitude and the time it takes for the star to go through its cycle of changing brightness. This relationship is shown in figure-2. All that is needed to find the absolute magnitude of the star is the period. Once this is measured, we can read off the (average) absolute magnitude.

Exercise
Select *Cepheid Variable Stars* from the *Start Lab* menu. The field of view shows a section of sky which contains ten Cepheid variable stars along with a number of ordinary stars. You should be able to identify which of the stars are the Cepheid variables. If you place the cursor over a Cepheid variable star, then an identification number for that star will appear at the bottom of the window. If you click on the star, you will be shown a plot of the brightness of the star as a function of time. Note that, since this plot is identical to that which might be obtained for a star using a telescope fitted with a detector, the vertical axis represents the **relative** magnitude <u>**not**</u> the **absolute** magnitude. Click anywhere on the plot to be returned to the view of the sky.

For each star, you will need to make two measurements from the relative magnitude vs. time plot:
- The (average) relative magnitude. Measure the maximum and minimum relative magnitude of the star for at least one full cycle, and then compute the average.
- The period over which the star's brightness changes. If the period is short, an accurate result can be obtained by making measurements over more than one cycle, then dividing by the number of cycles.
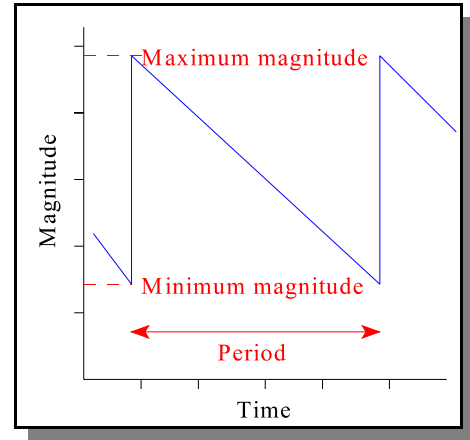
To assist you in making accurate readings, the time and relative magnitude corresponding to the cursor's current location are shown at the bottom of the screen. Make sure that you also make a note of the star's identification number.

Figure 2 Definition of measurements

Absolute Magnitude and Distance

From your measurements, you will now determine the absolute magnitude and distance for each one of the Cepheid variable stars. When you have finished, select *Check Your Answers* from the overhead menu and enter your results. Correct results will be indicated with a check mark.

Absolute Magnitude - Graphical Method

To use the graphical method, use the graph shown in figure-3 to determine the (average) absolute magnitude. Find the period of the star on the horizontal axis. (Note: Since the axis is logarithmic, the scale is not uniform. In the period between 1 and 10 days each interval corresponds to 1 day; between 10 and 100 days each interval corresponds to 10 days.) Then use the plotted line to find the corresponding absolute magnitude on the vertical axis.
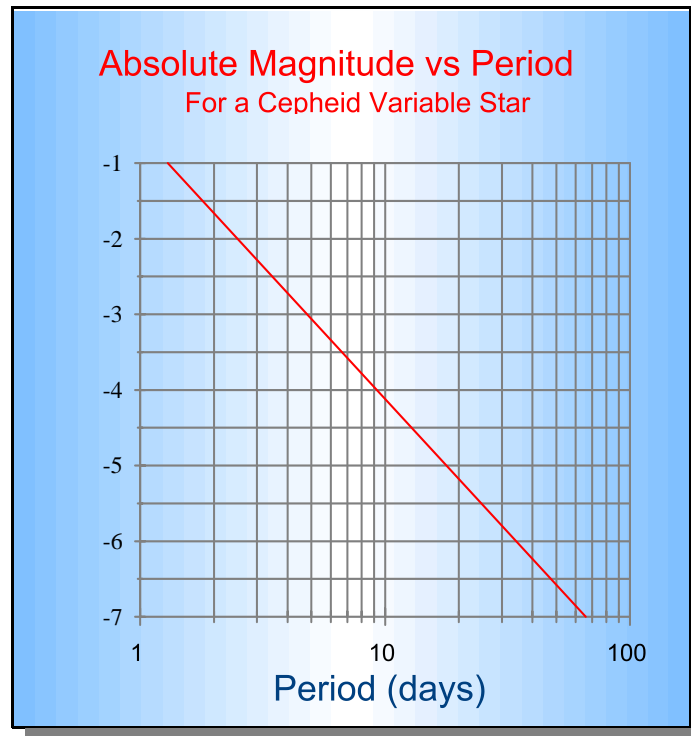

Figure-3: Relationship between absolute magnitude and period of a Cepheid variable star

Absolute Magnitude - Algebraic Method

For those students with sufficient mathematical skills, an alternative to the graphical method is to calculate the (average) absolute magnitude from the period using the formula:

$$\text{absolute magnitude} = -0.60081 - 3.51605 \log_{10}(\text{period})$$

(This empirical formula is the best fit linear regression line for the data taken from Cepheid variable stars, and was used to produce figure-3.)

Determining the Distance - Graphical Method

The distance can be readily determined once the absolute and relative magnitudes have been determined. Figure-4 shows the relationship between the distance to a star and the difference between its absolute and relative magnitudes.

First compute this difference for each of the stars whose properties you have measured. Locate this value on the vertical axis, then read the distance on the horizontal axis. This scale is calibrated in parsecs (pc).
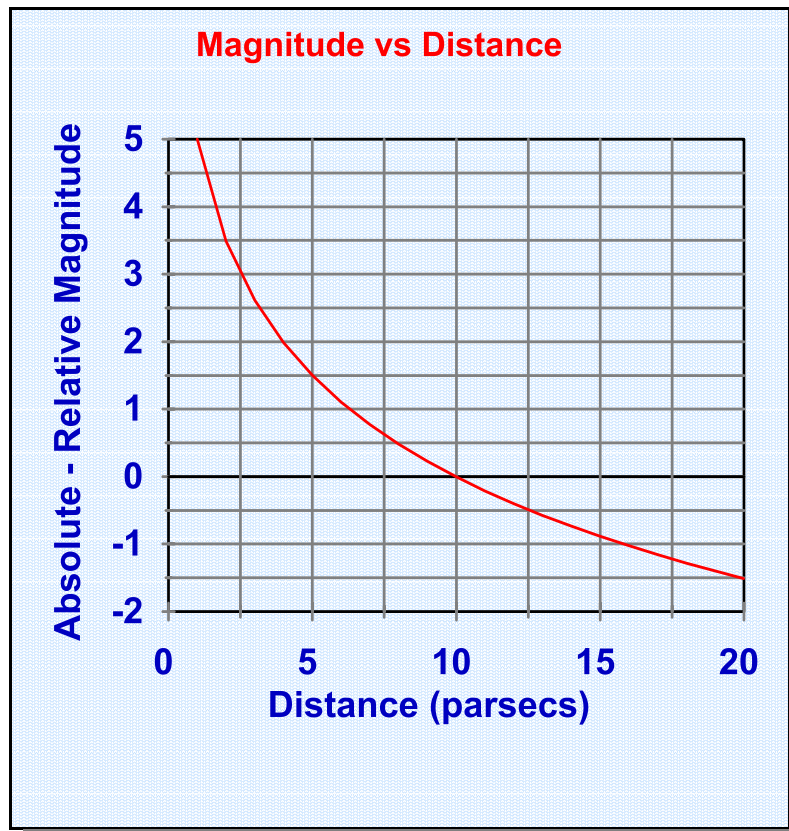

Figure-4: Obtaining the distance from the absolute and relative magnitudes.

Determining the Distance - Algebraic Method

If you wish to use an algebraic method, then we can make use of the relationship that the intensity of light from a star decreases with distance according to the inverse square law. If we also remember that the absolute magnitude is defined as the relative magnitude at a distance of 10 parsecs, then:

$$\frac{\text{Intensity of light at the Earth}}{\text{Intensity of light emitted by the star}} = \left(\frac{10}{\text{distance}}\right)^2$$

where the distance is also measured in parsecs.

The magnitude scale is a logarithmic one, in which five orders of magnitude correspond to a change in the intensity of the light by a factor of 100. This allows us to re-write equation (2) in the form

$$\frac{100^{\frac{\text{Relative Magnitude}}{5}}}{100^{\frac{\text{Absolute Magnitude}}{5}}} = \left(\frac{10}{\textbf{distance}}\right)^2$$

Taking logarithms of both sides yields the final result:

$$\text{Relative Magnitude - Absolute Magnitude} = 5 \log_{10}(\text{distance}) - 5$$

UNIT 14 APPENDIX: WORKSHEET

You will need to fill in this worksheet for each Cepheid variable star you measured.

Cepheid variable star identification number CV#_____

Measurement of Star Parameters

Maximum Relative Magnitude	_____	A
Minimum Relative Magnitude	_____	B
Average Relative Magnitude	_____	C = ½(A + B)

Number of cycles for measurement	_____	D
Total time (days)	_____	E
Period (days)	_____	F = E ÷ D
Average Absolute Magnitude	_____	G (from figure-3)

Calculation of Distance

Average Absolute Magnitude	_____	G from above
Average Relative Magnitude	_____	C from above
Absolute - Relative Magnitude	_____	= G - C
Distance (parsecs)	_____	(from figure-4)