The Mean Light Curve of a Variable Star

Abstract

A variable star in the Large Magellanic Cloud is studied using data from the MACHO Collaboration[1]. The star is found to have a period of 14.18975±0.00025 days and a sawtooth light curve typical of a classical Cepheid variable. Its position on the period-luminosity plot is consistent with this interpretation.

The abstract should summarise the main features of the report, including the main results. Don't confuse the abstract with the introduction.

1. Introduction

The introduction should motivate the analysis: explain why it is important, why you have chosen this particular object to study, and why you are using this particular method.

Although the Sun's light output is nearly constant, there are many stars whose luminosity varies with time. Some vary over a regular and predictable cycle, while others have irregular outbursts. In some cases the variation is intrinsic to the star itself, while in other cases it is caused by a binary companion. Variable stars have many uses in astronomy: for example, eclipsing binary systems can be used to calculate stellar masses, while some types of regular variable stars can be used as distance indicators.

The period of the variation, and the shape and regularity of the light curve, are of critical importance in understanding variable stars. Therefore it is necessary to be able to determine these from observation. Because of weather and other constraints, variable star observations are usually made on a rather irregular schedule, so methods that assume regular sampling of the curve (e.g. many applications of Fourier series) will not work.

In this report, a method of successive approximation is used to determine the period and extract the light curve for a variable star in the Large Magellanic Cloud, based on data collected by the MACHO gravitational lensing experiment[1]. The MACHO experiment collected a great deal of variable-star data as a by-product of its search for gravitational lensing events, and all of this information is available online, making this a very suitable test of the method.

Note the reference here. If you use data from a published source, you should tell the reader where it came from. Don't plagiarise!

2. The Light Curve

There's no "theory" section in this report, because we don't need one. This section is a combination of "data collection" and "analysis".

The data consist of a time series of observations through blue and red filters. They cover the date range from Julian Date 2448917 (October 1992) to 2451431 (September 1999), and the magnitude range −9 to −9.5 for the red filter and −8.4 to −9.1 for the blue filter (these are instrumental values and not true apparent magnitudes). Successive observations are typically about a day apart.

The time series is plotted in Figure 1. It is clear that the star is variable, but not at all clear what the period is. However, on selecting points near maximum light and plotting the time between successive points (Figure 2), a periodicity of about 14

days was seen. Averaging 16 pairs of maxima separated by ~14 days (one period) gave 14.05±0.07 days (standard error).

Note that you don't usually give detailed calculations in a formal report, but you do explain the sources of uncertainty and how they are estimated.

This period was refined by considering pairs of maxima with larger separations, obtaining 14.20±0.02 days from 6 pairs of maxima each separated by 9 periods. A folded light curve was then produced by calculating the location of each point within its cycle, i.e. all points were referred to a single period, and the period was further adjusted until the points formed as narrow a band as possible. Finally, the zero time was adjusted so that the period started at the minimum.

More detail could have been given here. It would be reasonable to include Graph 3 from the lab diary. But one should not overemphasise the technical details of calculation.

Figures, tables, etc. are numbered to that they can be referred to in the text. Graphs and diagrams are "figures"; tables are numbered separately (Table 1, 2, etc.). Equations are also numbered separately.

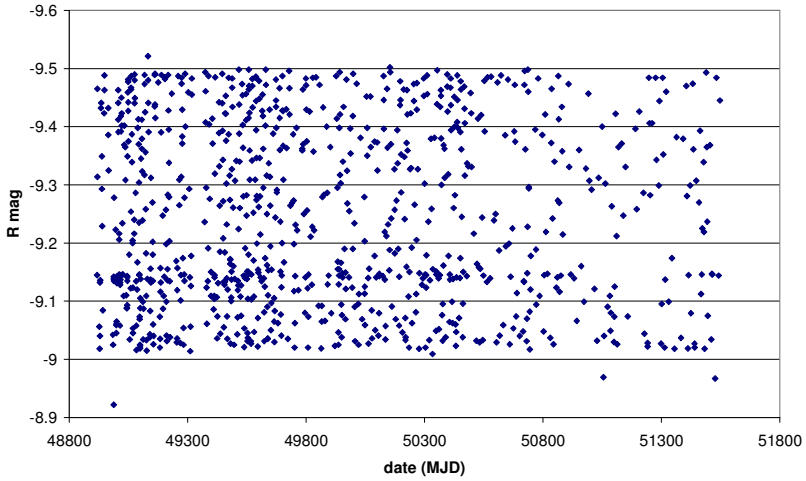

Figure 1: The red magnitude of MACHO 82.8408.22 as a function of time.

The student read the lab diary comments! The units have now been included.

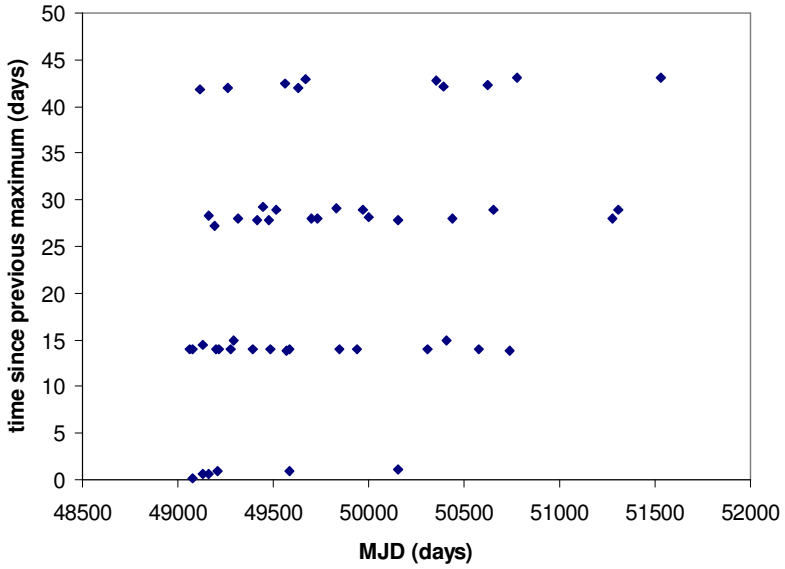

Figure 2: The time between successive maxima (defined as red magnitude <−9.48). A periodicity of about 14 days is clearly visible.

The final period was 14.18975±0.00025 days, where the best period and error were derived from visual inspection of the

folded light curve for the red filter. The zero point was chosen as JD 2448928.5. This light curve is shown in Figure 3. The same parameters were used to analyse the data from the blue filter, and a good light curve was produced (also shown in Figure 3).

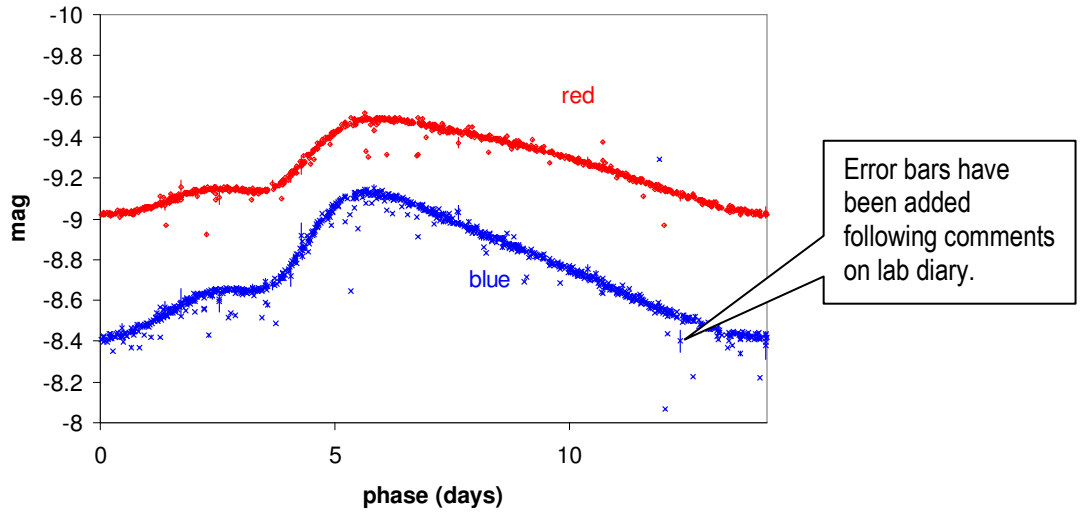

Figure 3: The final light curve, for a period of 14.18975 days.

Each of the reduced light curves contains a small number of points that do not fit (most but not all are fainter than expected). The quoted errors on these points are very small and do not account for their positions. It is possible that these are poor quality images or poorly calibrated; the MACHO data base does not give access to the original images, so this cannot be verified.

The amplitude of the variation was measured to be 0.468±0.007 magnitudes in red and 0.720±0.007 in blue (errors estimated from scatter). As the blue amplitude is significantly larger, the star must change colour, and therefore surface temperature, through its cycle (see Figure 4). The star appears to be hottest fractionally before maximum light.

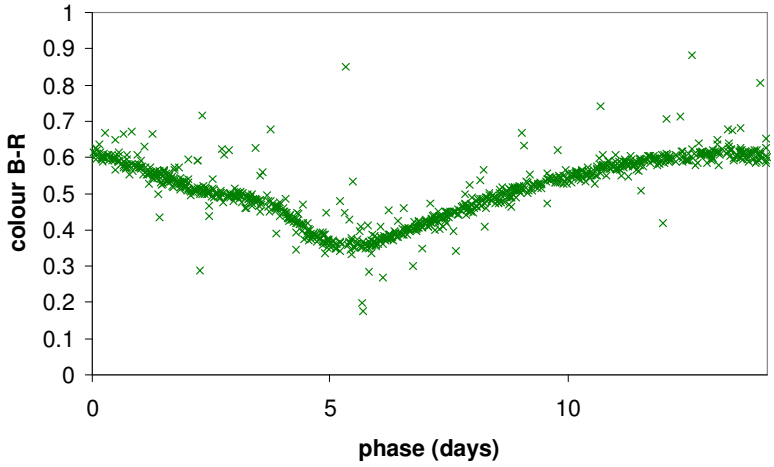

Figure 4: Colour index B – R through the cycle.

3. *Comparison with previous results*

Reports should always include a comparison of results with accepted values or theory. It would have been useful to include the student's own values in this section, though as the report is quite short it is not essential.

The MACHO variable star database[2] gives for this star:

- period 14.1895 days
- amplitude in red 0.463 magnitudes
- amplitude in blue 0.711 magnitudes

Always give a reference for the standard values that you compare with. Just saying "textbook value" is not enough.

No errors are given. The values are in good agreement with those calculated above.

The MACHO database also specifies the true apparent magnitude of the star in the Kron-Cousins system as $V = 15.545$, $R = 14.78$.

4. *Interpretation*

Not all reports need a "discussion" section, but this one does. The light curve and period are not much use unless we identify the type of star.

This star has a "sawtooth" light curve and a period of about 14 days. The variation is clearly very regular, since points from many different cycles all fall on exactly the same folded curve. These properties are characteristic of Cepheid variables. The location of this star on the MACHO period-luminosity plot is appropriate for a classical Cepheid (see Figure 5).

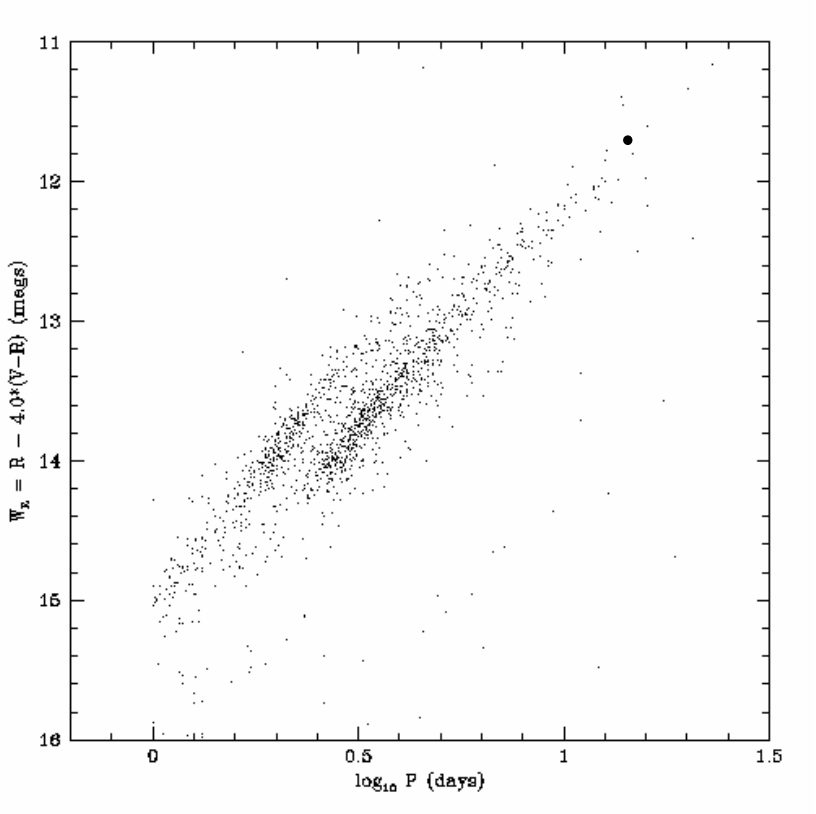

Figure 5: Period-luminosity plot for classical Cepheid variables, from MACHO data[3]. The position of the star studied in this report is shown by the large dot.

The light curve of 82.8408.22 as shown in Figure 3 is very comparable to light curves of Cepheids of similar period as

obtained from the MACHO website (see Figure 6). All four examples show the same secondary bump in the rising edge of the light curve. Examination of a diagram in Payne-Gaposchkin[4] shows that the position of this bump depends on the period of the Cepheid.

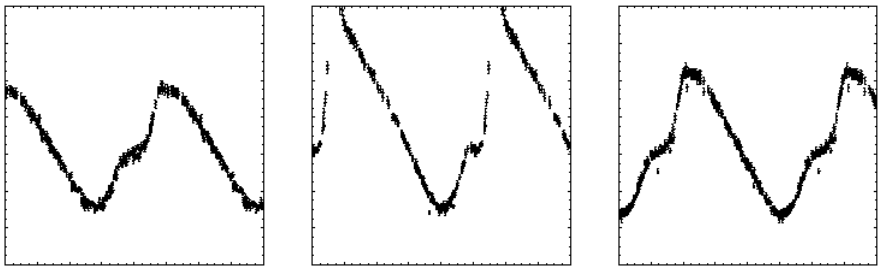

Figure 6: Example Cepheid light curves with similar periods to the star studied in this report, from [3]. The diagrams are presented for comparison of shape only.

All reports should end with a conclusion. This should refer back to the introduction: to what extent have the aims of the study been achieved? What do the results mean?

5. Conclusion

Analysing the light curve data by studying the separation of maxima and then refining a trial period based on the appearance of the folded light curve proved to be an effective way of determining the period. The accuracy of the method seems to be very good, although unfortunately the MACHO database does not give the uncertainty of its quoted period.

The star studied appears to be a classical Cepheid: its light curve is comparable to identified Cepheids of similar period and it lies on the appropriate period-luminosity relation. The identification of this star as an eclipsing binary in the MACHO Variable Star Catalog[2] is presumably an error by the automatic classification program.

Note that the references are linked by number to the text – we don't just give a bibliography without saying which source was used for what purpose.

References

1. MACHO home page, http://wwwmacho.mcmaster.ca/
2. MACHO Variable Star Catalog, http://store.anu.edu.au:3001//cgi-bin/varstar.pl; this star can be found by doing a search based on the period.
3. MACHO Interactive PL plot, http://www.macho.mcmaster.ca/Demos/Cepheids/WebPL.html
4. Cecilia Payne-Gaposchkin, *Stars and Clusters*, Harvard University Press, 1979, page 121.

For online references, give title, author if specified, and full URL

For books, give author(s), title, edition if specified, publisher, date and page or chapter.