September 2023

OPEN EUROPEAN JOURNAL ON VARIABLE STARS
http://oejv.physics.muni.cz
DOI: 10.5817/OEJV2023-0240

ISSN 1801-5964

Estimating the periods of four Luminous Blue Variables (LBVs): η Car, AG Car, HR Car, and S Dor

BASU, SANTANU [1]

1) Amateur Solar Observer, Nangi Station Rd, P.O Parbangla via Batanagar, Kolkata 700 140, West Bengal, INDIA, sbasu4783@gmail.com

Abstract: This article discusses four Luminous Blue Variables (LBVs): η Car, AG Car, HR Car in the Milky Way and S Dor in the LMC. LBVs are difficult stars to understand because of their sudden eruptions. Time scales for these "great eruptions" are uncertain, possibly hundreds to thousands of years. Historical data on some of these stars from the AID International Database have been analysed using the AAVSO Vstar program, with the date-compensated discrete Fourier transformation (DCDFT) and with the CLEANest algorithm. The results show that there are multiple periods in the range of ten to thirty years, in addition to the much longer time scales of the significant eruptions, which are beyond the scope of this research.

1 Introduction

In the history of astronomy, variable stars are essential for the most straightforward reason: the stars that change. But good evidence suggests this is a very modern idea. Over the millennia, past astronomers have viewed stars as eternal and unchanging, forever fixed in time and space – "the Celestial Dance was a celebration of order, reason, and stability". But everything changed in the period between Copernicus and Newton. According to tradition, two New Stars announced the birth of the New Science. Blazing across the celestial stage, Tycho's Star (1572) and Kepler's Star (1604) appeared dramatically - and just as unexpectedly - disappeared forever. But variable stars were different. (R.A HATCH; 2012). In the past, variable stars were only observed visually; however, now, alongside the visual observations, we can analyse stars using photometry and spectroscopy. Astronomers must organise, make continuous observations, track changing magnitudes, and explain stellar phases. Amateur astronomers can do practical scientific study of variable stars by visually comparing the star with other stars within the same telescopic field of view of which the magnitudes are known and constant. A visual light curve can be constructed by estimating the variable's magnitude and noting the time of observation. The American Association of Variable Star Observers collects such observations from participants worldwide and shares the data with the scientific community. For regular variables, the periods of variation can be well established; for many variable stars, though, these quantities may vary slowly over time or even from one period to the next.

Luminous Blue Variables are massive, evolved stars. There is very limited knowledge about LBVs because only a few "true" LBVs are known compared to other stellar classes and phases. (Weis and Bomans, 2020). These stars interest amateur observers and professional researchers

September 2023 OPEN EUROPEAN JOURNAL ON VARIABLE STARS ISSN 1801-5964
http://oejv.physics.muni.cz
DOI: 10.5817/OEJV2023-0240

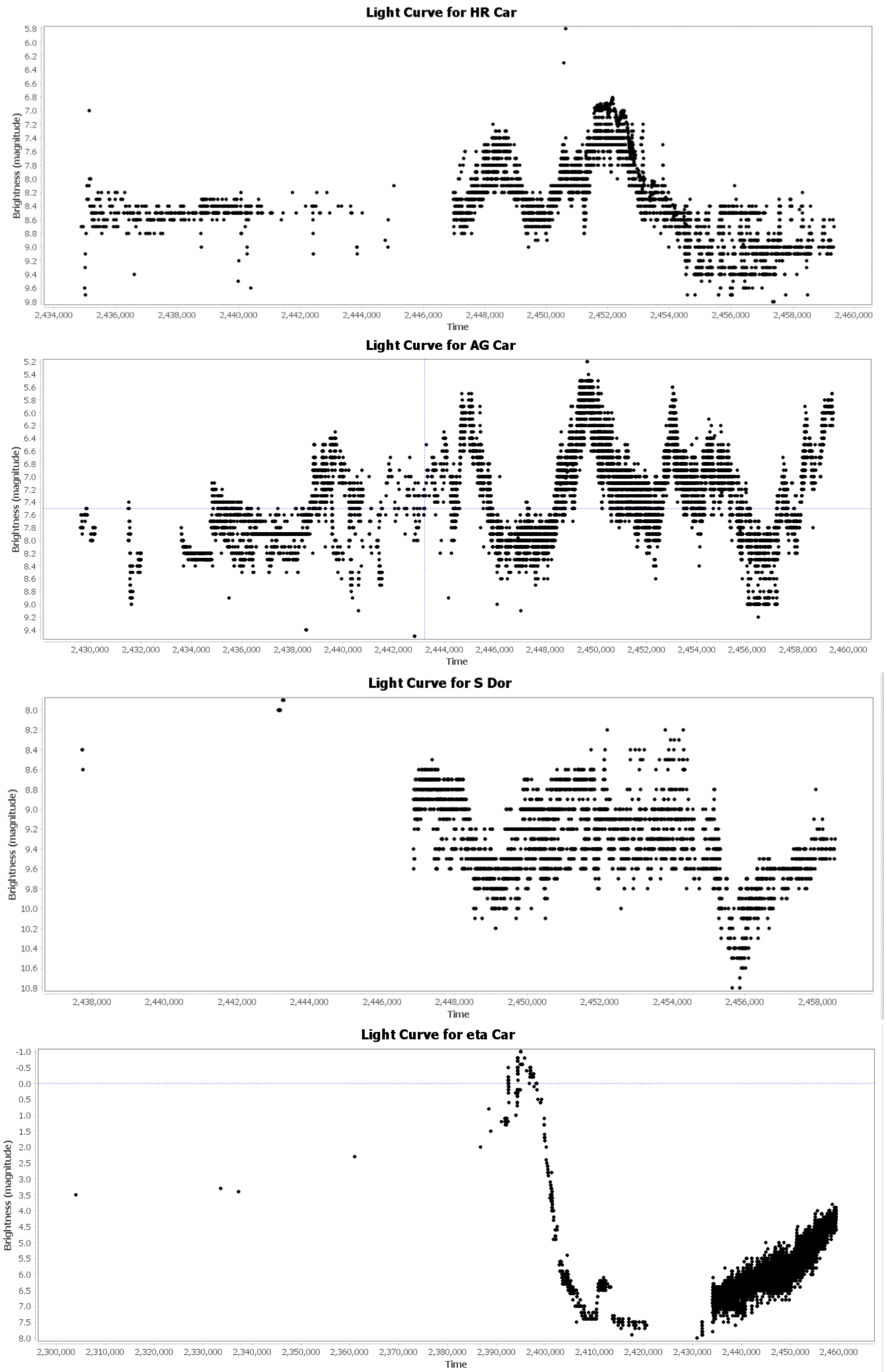

Figure 1: The light curves of LBVs Eta Car, AG Car, HR Car, S Dor. All light curves show peaks of eruption. The light curve of Eta Car includes the eruption of 1874. S Dor, HR Car, AG Car also show sudden brightening. All the data are from AAVSO visual observations.

OPEN EUROPEAN JOURNAL ON VARIABLE STARS
http://oejv.physics.muni.cz
DOI: 10.5817/OEJV2023-0240
ISSN 1801-5964

because of their eruptions**.** Time scales for the significant eruptions are uncertain; hundreds to thousands of years are adequate estimates about the frequency of some of these events. The eruption of 1-2 magnitude amplitude is usually observed in comparably small periods of 10 to 30 years. The star can illuminate up to two magnitudes from the minimum or quiet stage, usually within a few months. Both minima and maxima can take several years. (Humphreys and Davidson, 1994).

2 Data

Analysis of the long-term periods used the maximum available visual series in the AID for Eta Carinae from the year 1595 to 2021, AG Carinae from the year 1939 to 2021, HR Carinae from the year 1954 to 2021 and S Doradus from the year 1962 to 2018 with Vstar.
Figure 1 shows the light curves of these four LBV stars.

3 Method & Analysis

All data are from the AAVSO international database (AID), using the maximum available data and analysing the periods with the AAVSO's Vstar application. (Benn, 2012). I estimated periods using the date-compensated discrete Fourier transformation, DcDFT. (Ferraz-Mello, 1981). I utilized the DcDFT standard scan with the visual series to generate a power spectrum plot. By identifying the frequencies/periods at the peaks of the plot with the highest power values, represented by small brightly coloured squares in Figure 2, we can determine the top hits. These frequencies/periods are the most likely candidates for the actual frequency (period). To further refine the results and eliminate any false peaks, I employed the CLEANest algorithm, a relatively novel method for removing false peaks from a power spectrum (Foster; 1995). Figure 2 showcases the CLEANest peak of the power spectrum for the four LBVs. To determine the most accurate frequencies for the LBVs, I selected the three best hits from the raw power spectrum scan and employed the CLEANest algorithm. This combination allowed me to identify the best frequencies for the LBVs and suggested additional promising periods.

4 Result & Conclusion

The application of DcDFT using the CLEANest power spectrum analysis reveals long-term and short-term periods for the LBVs discussed.

OPEN EUROPEAN JOURNAL ON VARIABLE STARS
http://oejv.physics.muni.cz
DOI: 10.5817/OEJV2023-0240
ISSN 1801-5964

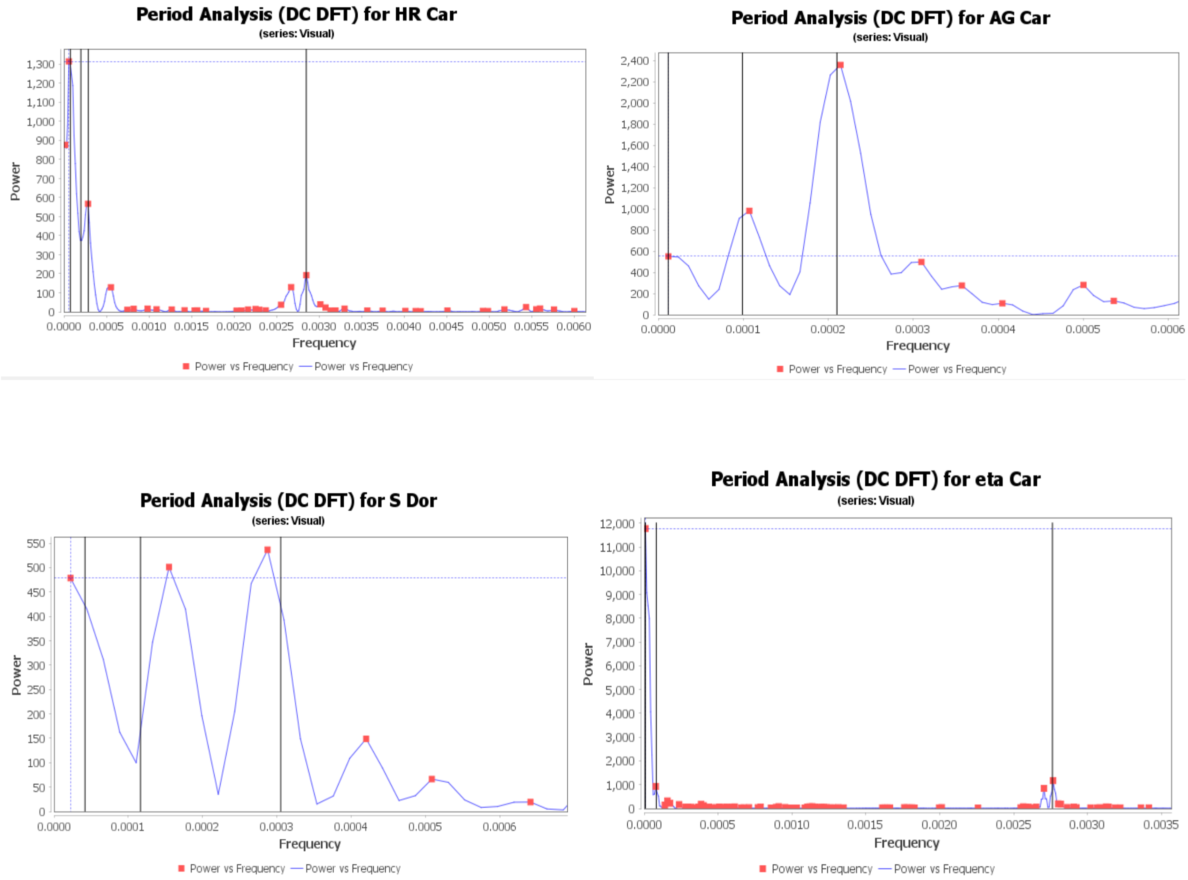

Figure 2: CLEANest peak of the power spectrum for the four LBVs Eta Car, AG Car, HR Car, S Dor

Figure 2 depict the CLEANest power spectrum, which displays the frequencies associated with the LBVs. Eta Car stands out with its giant eruption in the recent past, while HR Car, AG Car, and S Dorados exhibit minor eruptions reflected by the peak magnitudes. The reason behind these mysterious eruptions in LBVs remains an ongoing debate among astronomy and astrophysics researchers.

Specifically, the CLEANest power spectrum analysis reveals that Eta Car exhibits a long-term period exceeding 100 years (approximately 300 years, assuming it is a periodic variation), alongside a short-term period of around 30 years. AG Car showcases a long-term period exceeding 100 years and a short-term period of approximately 10 years. HR Car exhibits a long-term period of over 100 years and a short-term period of 40 years. Similarly, S Dor exhibits a long-term period exceeding 100 years and short-term periods of approximately 17 years. All the LBVs exhibit long-term periods exceeding 100 years, while their short-term periods range from 40 years or less.

This observation aligns with the findings presented in the articles by Humphreys and Davidson. They emphasise the uncertainty surrounding the time scale of significant eruptions in Luminous Blue Variables, which can occur sporadically over hundreds of years, lacking precise frequency estimates. On the other hand, eruptions of smaller magnitudes (around 1-2 magnitudes) tend to manifest in a more regular pattern within a relatively confined time frame of 10 to 30 years. The periods obtained from our analysis are consistent with these reported patterns.

5 Discussion and Acknowledgement

In conducting my research, I employed various statistical tests to determine the significance threshold. Upon utilising Pearson's product-moment correlation, it yielded a very low p-value. The result was such that the p-value was less than 0.05, indicating a rejection of the null hypothesis (H0) in favour of the alternative hypothesis (H1) when subjected to Pearson's product-moment correlation test. The precise p-value in this scenario was 1.575e-05(0.00001575). Similarly, when implementing the Two-sample Kolmogorov-Smirnov test, a low p-value was observed, precisely, 1.941e-05 (0.00001941).

Both tests show that the results are statistically significant and reject the Null Hypothesis.

This entire test is done by R code, I thank Mr. Rodney Howe (AAVSO, Chair, Solar), who helped me with R code for the test part. These periods do not wholly reproduce the observed light change but describe the typical timescale of the variations very well. There are additional irregularities on top of the light changes.

Here is the result part of the R code.

Pearson's product-moment correlation

data: tmp[, 2] and tmp[, 4]

t = 4.3262, df = 2561, p-value = 1.575e-05

alternative hypothesis: true correlation is not equal to 0

Two-sample Kolmogorov-Smirnov test

data: tmp[, 2] and tmp[, 4]

D = 0.067109, p-value = 1.941e-05

alternative hypothesis: two-sided

OPEN EUROPEAN JOURNAL ON VARIABLE STARS
http://oejv.physics.muni.cz
DOI: 10.5817/OEJV2023-0240
ISSN 1801-5964

References

Benn, D. 2012, JAAVSO, 40, 2, 852, 12, 2012JAVSO..40..852B

Ferraz-Mello, S. 1981, A.J, 86, 619, 1981AJ.....86..619F

Foster, G. 1995, AJ, 109, 1889, 1995AJ....109.1889F

Hatch, R.A. 2012, JAAVSO, 40, 1, 151, 2012JAVSO..40..151H

Humphreys, R.M., & Davidson, K. 1994, PASP, 106, 1025, 1994PASP..106.1025H

Humphreys, R.M., Davidson, K., Smith, N. 1999, PASP, 111, 1124, 1999PASP..111.1124H

Weis, K., & Bomans, D.J. 2020, Luminous Blue Variable. Galaxies; 8(1), 20
https://www.mdpi.com/2075-4434/8/1/20