Current Light Elements of the δ Scuti Star V393 Carinae

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Abstract V393 Carinae is a 7th magnitude δ Scuti star which has a principal period of 0.1413 d and an amplitude of 0.2 magnitude in V. Previous publications have suggested the existence of a second period, but its duration has so far evaded discovery. In view of the uncertainty, and since the only two papers on this star were published in 1984 and 2001, DSLR photometry was performed to obtain time series data. Images were taken during 6 nights from December 2013 to March 2014. The data were analyzed using a discrete Fourier transform, which yielded a principal frequency of 7.07727 (±0.00005) cycles/day, corresponding to a period of 0.141297 (±0.000001) day. Prewhitening for this frequency revealed a harmonic frequency precisely twice that of the principal, but no further dominant frequencies could be found. O–C diagrams suggested that it would appropriate to derive a new linear ephemeris from three times of maximum obtained by another author from 1977 to 1979, combined with the 6 new times of maximum reported in this paper. The light elements are: T_{max} = HJD 2456732.0484 (6) + 0.14129328 (1). It is concluded that the current principal period of this star is almost identical to the period determined approximately 37 years ago. The issue of a second period is unresolved. None was detected, but it cannot be excluded that a second pulsation frequency of low amplitude could be hidden due to a low signal to noise ratio.

1. Introduction

V393 Car is a δ Scuti star with an average magnitude in V of 7.45, an amplitude of 0.2 magnitude, and a period of 0.1413 d, or 3 hours, 23 minutes approximately. The first detailed study of this star was published by Helt in 1984 (hereafter referred to as Helt). She performed uvby photoelectric photometry from 1977 to 1979, determined its principal period, and considered that there was strong evidence of a second period of lower amplitude. The second frequency could not be isolated, but its most likely value was stated to be either 12.58 or 13.58 cycles per day. Helt determined the light elements to be:

$$\text{HJD } 2443597.001\ (1) + 0.1412937\ (2)\ E \quad (1)$$

The only other detailed study of this star was published by Garcia *et al.* in 2001 (hereafter referred to as Garcia), who performed CCD photometry and used a discrete Fourier transform to calculate a period of 0.1462828 (2) d, which is 7.18 minutes longer than the period calculated by Helt about 23 years earlier. Garcia suggested that a phase shift had occurred, and that the phase shift supported the existence of a second period, although it could not be identified directly.

2. Observations

DSLR photometry was performed on RAW images taken with a Canon EOS 500D DSLR camera through a refracting telescope with an aperture of 80 mm at f/7.5, mounted on a Losmandy GM8 German equatorial mount. Exposures were of two minutes duration, with a gap of fifteen seconds between successive exposures. The comparison and check stars were HD 65578 and HD 66656, respectively. Photometric reduction of images of the star field, dark frames, and flat fields utilized the software package AIP4WIN (Berry and Burnell 2011). Raw instrumental magnitudes were calculated, and differential photometry allowed the calculation of transformed magnitudes in V of the variable and check stars, using transformation coefficients previously determined from images of standard stars from the E Region (Menzies *et al.* 1989). 778 measurements of the magnitude of the variable star were made over six nights from 21 December 2013 to 22 March 2014.

3. Analysis

Figure 1 is an example of a light curve from one night's observations. The heliocentric correction was calculated for the mid point in time of the observations for any one night, and applied to the times of all measurements for that night.

Six times of maximum in heliocentric Julian days were identified from regions around the peaks in the light curves, calculated from sixth-order polynomial functions fitted to the light curve segments by the software program PERANSO (Vanmunster 2013).

A discrete Fourier transform in the software program PERIOD04 (Lenz and Breger 2005) was used to examine the frequency of pulsation of the star (Figure 2). A principal frequency of 7.07727 (± 0.00005) cycles/day was found (Figure 2a), and after pre-whitening for that frequency a second frequency, 14.155 cycles/day, was identified (Figure 2b), but since it is almost exactly twice the principal frequency it represents a Fourier harmonic of that frequency. After pre-whitening again, no further dominant frequency could be identified (Figure 2c). The principal frequency, 7.07727 cycles/day, represents a period of 0.141297 (± 0.000001) day. This period is only 0.33 second longer than the period of 0.1412937 (± 0.0000002) d determined by Helt from observations made from 1977 to 1979.

In view of these results, a series of O–C (observed minus computed) diagrams were constructed to investigate the relationships among the data of

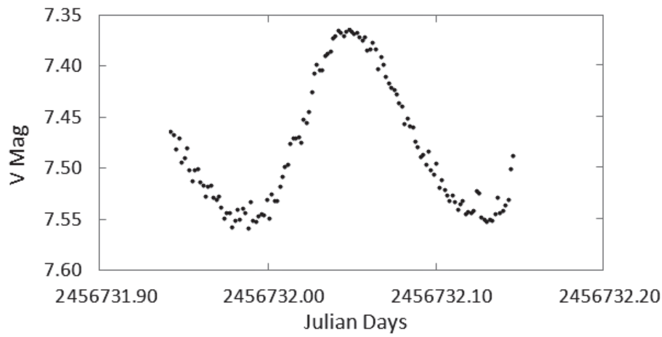

Figure 1. Example of a light curve of V393 Car derived from a single night's observations.

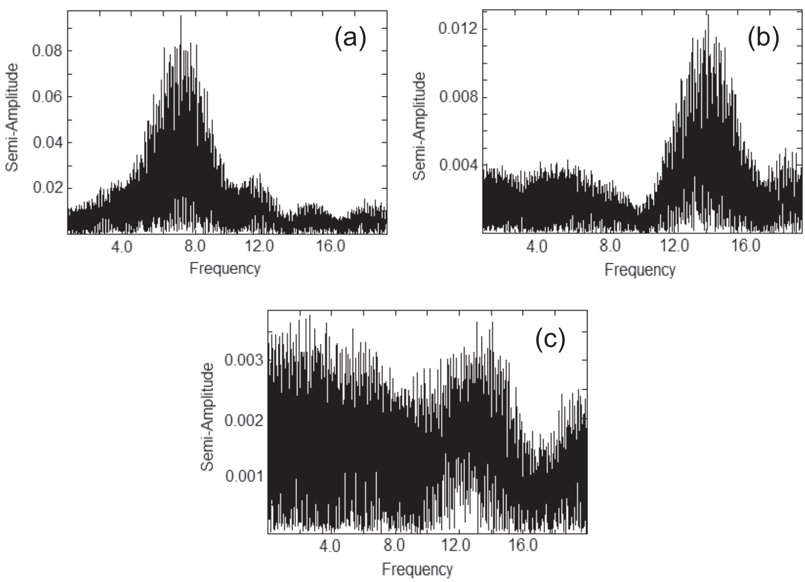

Figure 2 (a–c). Periodograms of V393 Car from a discrete Fourier transform in the software package PERIOD04 (Lenz and Breger 2005). (a) The principle frequency is 7.07727 c/d. (b) After prewhitening for the principle frequency, a second frequency 14.155 c/d is found, but as this is almost exactly twice the principle frequency, it represents a Fourier harmonic. (c) After further prewhitening, no additional dominant fequency could be found.

Helt, Garcia, and the author of this paper. For the calculation of the epochs and the O–C values, the initial period and the initial time of maximum chosen were those of Helt, with zero epoch being the first time of maximum determined by her.

The values for the O–C diagrams and the published sources of the data are listed in Table 1, and the O–C diagrams themselves are shown in Figure 3. The diagram in Figure 3a at the top left represents an attempt to apply a linear

Table 1. Data for O–C diagrams.

Max	T_{max} *(HJD)*	*Epoch*[1]	*O–C*	*Source*[2]
1	2443403.85220	0	0.00000	1
2	2443778.84730	2654	0.00162	1
3	2443939.63770	3792	–0.00021	1
4	2451953.73100	60511	0.05572	2
5	2456647.97863	93735	–0.03854	3
6	2456669.17052	93885	–0.04070	3
7	2456675.10847	93927	–0.03709	3
8	2456700.96365	94110	–0.03866	3
9	2456705.06099	94139	–0.03884	3
10	2456732.05019	94330	–0.03673	3

1. The initial epoch at HJD 2443403.8522 and the initial period 0.1412937 d for the calculation of the epochs and the O–C values were those of Helt. 2. The sources of the values of the times of maximum—T_{max} (HJD) in the 2nd column—are listed in the 5th column: 1. Helt (1984); 2. Garcia (2001); 3. Present paper.

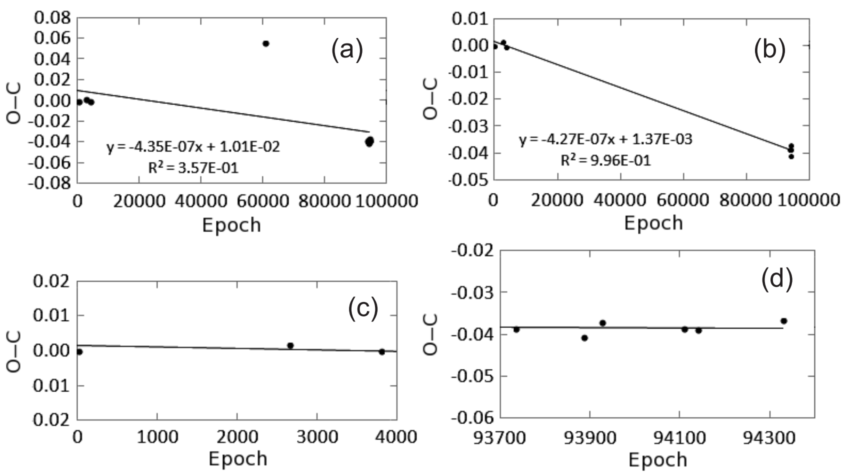

Figure 3 (a–d). O–C diagrams for V393 Carinae. All of the diagrams use the period and the time of maximum of Helt (1984) for the calculations of the epochs and the O–C values. (a) Based on the data of Helt (1984), Garcia (2001), and this paper, and using data from all eight rows of Table 1. The linear fit is not ideal. (b) Based on the data of Helt and the author of this paper, and using data from rows 1 to 3 and rows 5 to 10 of Table 1. The linear fit, as would be expected, passes through both sets of data. (c) Same as Figure 3b, but showing only part of the diagram, with only the data of the Helt being visible; i.e., it is a "zoomed in" view of the earlier part of the O–C diagram in Figure 3b. (d) Same as Figure 3b, but showing only part of the diagram, with only the data from the present paper being visible; i.e., it is a "zoomed in" view of the later part of the O–C diagram in Figure 3b.

function to the times of maximum of Helt, Garcia, and our own data, but the linear function is not an ideal fit. Figure 3b at the top right shows a linear function fitted to the data of Helt and our own data, which (as would be expected) passes through both sets of data. Figure 3c at the bottom left represents a small part of the diagram in Figure 3b, after "zooming in" to the data of Helt. Figure 3d at the bottom right also shows only a small part of the diagram in Figure 3b, after "zooming in" to the data of the present author. It is clear from Figures 3c and 3d that the linear function passing through the two sets of data is a good fit to both. It is our opinion that this result is evidence that the period of V393 Car now is almost identical to the period investigated by Helt 37 years ago.

In view of the results of the O–C analysis, it was concluded that it would be reasonable to calculate a new linear ephemeris for V393 Car by combining our own data with those of Helt. When that is done, with the most recent of our own observations (row 10 in Table 1) nominated as zero epoch, the light elements are:

$$T_{max} = \text{HJD } 2456734.0484\ (6) + 0.14129328\ (1)\,E \qquad (2)$$

Finally, the various determinations of the period of V393 Car from the literature and our own calculations are summarized in Table 2.

Table 2. The period of V393 Car, from the literature and from calculations performed during the present study.

Source	*Period (d)*	*SE**
Helt 1984	0.1412937	0.0000002
Discrete Fourier transform, Garcia 2001	0.1462828	0.0000002
Discrete Fourier transform, this paper	0.141297	0.000001
Linear ephemeris, Helt 1984 and this paper	0.14129328	0.00000001

** The value for the period from the linear ephemeris of Helt 1984 and this paper (last row of table) employed a least squares linear function to the times of maximum 1–3 and 5–10 from table 1, plotted against epoch.*

4. Conclusions

The only publications dealing with the period of V393 Car have been those of Helt in 1984 and Garcia in 2001. Helt's data were obtained during 1977–1979, 36–38 years ago, and Garcia's data were obtained in the year of publication. The period calculated from our own observations using a discrete Fourier transform is 0.141297 d, only 0.33 second longer than Helt's period of 0.1412937 d. In contrast, the period of 0.1462828 d determined by Garcia is 7.18 minutes shorter than Helt's, a dramatic change for a δ Scuti star over approximately 23 years. In the presence of such differences, O–C diagrams were used to analyze the times of maximum of this star.

When all of the data in the literature are combined in an O–C diagram, a linear function does not provide an ideal fit, as is seen in Figure 3a. When our own data are combined with those of Helt (with Garcia's 2001 data omitted for the purposes of this particular analysis), a linear function is found to provide a good fit (Figures 3c and 3d). In view of the latter result, it was considered reasonable to derive a new linear ephemeris for V393 Car based on Helt's data combined with our own. The validity of that decision would be supported if observations in future observing seasons, using methods similar to those of the present paper, showed no significant change in the period of this star.

If the maximum of Helt at HJD 2443403.8522 is taken as zero epoch (in September 1977), the phase shift for Garcia's best time of maximum at HJD 2451953.731 (in February 2001) is 0.05572 day. The average phase shift between our own data between HJD 2456647.97863 and HJD 2456732.05019 (between January and March 2014) and that of Helt is –0.0384 day. The average phase shift between our own data and the best maximum of Garcia is –0.0941. The other issue is the question of a second period. Helt stated with conviction that a second period existed, but its frequency could not be determined precisely. Garcia reported finding a phase change in 2001, and cited this as evidence of a second period, but again it could not be isolated. New observations reported in the present paper again failed to find a second period, but if it does exist, it would appear to be of low amplitude. This conclusion is supported by the periodogram in Figure 3c, in which the semi-amplitude of remaining (non-dominant) frequencies after prewhitening is 0.0035–0.0040 magnitude, too small to be resolved by the sensor of the DSLR camera used in the present study.

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