Parameters of the eclipsing variable star V523 Cassiopeiae

Ivayla E. Kalcheva
Department of Physics, Durham University, DH1 3LE Durham
ivayla.kalcheva@durham.ac.uk

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Abstract. Photometric observations of the eclipsing dwarf variable star V523 Cassiopeiae were performed with the telescopes of Durham University, UK, as a Level 3 project. In the period 26.10.2012 - 23.11.2012, a total of 5077 images of the binary were obtained in three colour bands. Calculations of the period, apparent and absolute magnitudes in B, V and R and distance to the system were made. Zero-point calibration was performed using data from the APASS catalogue. The final result for the period of the binary - 0.2336944±0.0000016 days - was found in agreement with literature values and consistent with the long-term system trends discussed in previous studies by means of constructing an O-C diagram. The parabolic shape of the diagram indicated constant rate of period change, possibly due to thermal relaxation oscillations.

The astrophysical parameters of the system were modelled using the application Nightfall, based on the Wilson-Devinney code. A reasonable fit of the synthetic light curve to the data with a small discrepancy at one of the maxima of different height was obtained, with an overall mean residuals *(O-C)* = - 0.0010 and σ_{est} = 0.0002 . This indicated that, in agreement with previous studies, V523 Cas is an over-contact binary of the type W Ursae Majoris, spectral class K4V, of the W subtype, and supported the studies that indicate the system is exhibiting a noticeable O'Connell effect.

Key words: stars:binaries: close-binaries, eclipsing variables, O'Connell effect

1. Introduction

1.1. V523 Cassiopeiae

This study focuses on V523 Cassiopeiae (also WR16, CSV 5867, GSC3257-167, with J2000 coordinates α = 00 40 06.264 and δ = +50 14 15.53) - a close binary of W UMa type with one of the shortest periods in this class of systems ($\sim$ 0.234 days, Brandstreet et al. (2004)). V523 Cas is a late-type (K4V) binary star classified as an eclipsing variable by Weber (1957) and identified as an EW system by Haussler (1974a,b). As the prototype that gave the name of the subclass - W Ursae Majoris - the system is short-period, over-contact, with two similar-size components sharing a common envelope and having similar surface temperatures. The system also exhibits both long and short term light curve variations (Zola (2010)).

According to many studies of the system, beginning with Zhukov (1985a), the shape of the light curve shows typical signs of a phenomenon called the O'Connell effect - maxima of different brightness - often observed in W UMa systems, and thought to be usually caused by a spot cycle (Davidge and Milone (1984)).

1.2. Project and aims

During this study, 5077 exposures of the object of interest, V523 Cas, were obtained in three photometric bands - V, R and B, and the gathered data were suitably processed. The V light curve was used to obtain the best period estimate and thus to model stellar parameters, as it was the best constrained. The error on the period was obtained using statistical jackknifing. The period was used to set all three light curves to the same time system. Using this method, it was possible to calculate the B-V and V-R colour indices and constrain the global minimum for the physical system out of all non-unique model solutions. Thus, a solution for the most likely observed system was obtained and compared to results from previous studies. In order to test our solution again and to investigate the possibility for long-term variability of the system and the physical processes responsible, an O-C diagram was constructed using online archival data and possible fits were explored.

2. Observations and methods

2.1 Telescopes and detectors

Two telescopes were used for the observations of V523 Cas - a 14-inch Meade LX200-ACF and, on two occasions, a 12-inch Meade "Advanced" Ritchey-Chretien LX200R. Both telescopes were situated on LX-200 computer-operated fork mounts and each was equipped with an OPTEC temperature compensating focuser (TCF) to automatically adapt to variations of the telescope tube length with temperature. The tracking of the domes and the telescopes was automated. Both telescopes used QSI 583ws CCD cameras with a field of 18'× 13' as detectors (Table 1).

Telescope	Focal Length (mm)	Pixel Width (μ m)	Plate Scale ("/pixel)	Position Angle (°)
12"+QSI 583ws CCD West Dome	3500	16.2 × 16.2	1.02 × 1.02	180
14"+QSI 583ws CCD East Dome	3208	16.2 × 16.2	0.98 × 0.98	177.3

Table 1. Main characteristics of the CCD detectors of the telescopes used for the study.

2.2 Aperture photometry and choice of calibration stars

Two reference stars were chosen from the star field to perform differential photometry. These were TYC 3257-1326-1 and TYC 3257-1068-1 - of apparent magnitudes comparable to the object to ensure no overexposure (or, on the contrary, the stars being too dim) within the 15 s frames (ESA (1997)). A careful photometry check was performed, using the Starlink package GAIA, to ensure neither of the reference stars was variable.

2.3 Data analysis

The phase dispersion minimisation software fast_solve allowed the "stitching together" of the light curve (Durham University AstroLab). The light travel distance was taken into account by conversion to Heliocentric Julian Dates (HJD). B_force (AstroLab) was used to find the best period and phase zero-point of the data.

Data from the APASS catalogue (Henden et al., (2009, 2010, 2011)) for the apparent magnitudes and errors of 12 stars were used to determine whether there exists a mismatch between the filters used for this study and the standard system. This allowed for the zero-points for each colour band to be calculated by χ^2 minimisation (Table 2). A correction was introduced to the obtained magnitudes and B-V colour index to take into account extinction: 2MASS infrared data (Skrutskie et al. (2006)) for the J and K magnitudes and errors for 12 stars from the field were plotted against our B-V data to find the B-V offset.

2.4 Modelling V523 Cas with nightfall

The light curve solution of the binary system V523 Cas was obtained with Rainer Wichmann's programme Nightfall, based on the Wilson-Devinney code for modelling eclipsing binary stars (Wichmann (1998)). The sum of the gravitational forces and the centrifugal force due to the orbital motion give the components their shapes. For simplifying the computation of the binary star light curve, the forces are replaced by Roche potentials (Devinney and Wilson (1973)). The starting mass ratio was determined from a two-parameter fit of the temperature ratio and the mass ratio. Fewer constraints were applied when modelling the hot spot parameters (introduced to the solution to model the O'Connell effect), as no systematic variability of the spot cycle could be concluded from previous study results. For the colour-based effective temperature from the B-V index, the empirical relation (Zwitter (2005b))

$$T_{eff} = \sum_{i=0}^{7} c_i \, (B - V)^i \tag{1}$$

was used, where the c_i coefficients are taken from a table (Kallrath and Milone (2009)).

For an over-contact binary, the Roche lobe filling factor is set to be larger than one (and less than 1.3), in units of the polar radius of the Roche lobe. When computing the light curve, it was important to take into account the fact that for over-contact systems, the blackbody approximation is much less successful in describing the atmospheric emittance. Apart from the temperature, the light flux also depends on surface gravity and chemical composition of the atmosphere. Therefore, a PHOENIX model atmosphere was used in Nightfall (Hauschildt (2006)).

To improve the accuracy, detailed reflection was used in the model, iterating four times, as the default treatment of the companion star as a point source lead to incorrect results for V523 Cas due to the components proximity and large Roche fill factors. The reflection N^2 algorithm calculated the mutual irradiation of all surface elements pairs. Asynchronous rotation was not included, as for over-contact binaries, the system is synchronized by the tidal forces and friction (Kallrath and Milone (2009)).

For all stars, the limb appears cooler and darker than the centre. In the case of V523 Cas, the simple linear function gave the best results to approximate this effect:

$$I(\mu) = I(1) \times [1 - u(1 - \mu)] \ , \tag{2}$$

where μ is the cosine of the angle between the emergent radiation and the perpendicular to the surface of the star, and u is a limb darkening coefficient (Claret (2000)).

2.5 O-C diagram

Data for V523 Cas were found from 1901 onwards (Paschke and Brat (2006)). An O-C diagram was constructed using archive data and adding our data to the plot. For placing the data along the x-axis, the measured times of eclipses were extrapolated to the present in order to calculate the elapsed time in HJD and then converted into epochs (number of orbits) since the time of the past data. For the y-axis, it was necessary to obtain the difference between the times of eclipse in the past data and the result from our period. To calculate our observed time of eclipse, the calculated values were subtracted at the present epoch, allowing us to adjust the dataset to our period and create a new O-C diagram. The O-C residuals were plotted in days (Fig. 2).

2.6 Absolute magnitude and distance estimation

Unlike detached binaries, from which a distance estimate can be obtained with virtually no calibration, contact binaries require empirical luminosity calibrations (Rucinski (2003)). From Kepler's third law, and defining a mean density, ρ , the pulsation equation is obtained, demonstrating the similarity to the properties of pulsating stars. The unknown orbital size, a, is replaced by using the period P , as it is well-known.

The best relation in Rucinski's paper for W UMa binaries was derived using HIPPARCOS data. The absolute magnitude in the V band was obtained from the empirical formula by Rucinski:

$$M_V = -4.44 \log_{10}(P) + 3.02\,(B-V)_0 + 0.12 \ , \tag{3}$$

where M_V is the absolute magnitude in V, P is the period and the zero denotes the use of the dereddened colour index (Rucinski (2003)).

Using the absolute magnitude, the distance d to the binary system was obtained from the equation (Wilson (2001))

$$m_V - M_V = 5 \log_{10}\left(\frac{d}{10pc}\right) \ . \tag{4}$$

3. Results and discussion

3.1 Best period estimate

The final value for the period of the eclipsing binary system V523 Cas was found from the best-constrained light curve (in V) to be 0.2336944±0.0000016 days. Photometric data were preferred to spectroscopic data to determine the period, as the eclipses provide more accurate timing, and a greater number of photometric observations than radial velocity data points can be obtained (Kallrath and Milone (2009)).

The brightness of V523 Cas allowed obtaining good data with high SNR using 15 second exposures in all filters, allowing us to obtain a large number of exposures, which increased the precision of the period determination. The final period result is accurate, as it agrees with most recent literature values and sets the correct trend to the O-C curve. Instead of calculating the period separately for the R and B curves, they were set to the V-period, as no significant variation due to physical changes was expected in this case. The period error due to the dimmer B curve and especially the R curve built from less data and lacking data for one minimum would have obscured any small variations between the periods obtained from all light curves.

However, in future studies a more accurate period estimate could be obtained by comparing and combining the period results from the V curve and a complete R curve, containing as much data as the V curve, as the star is brightest in R.

3.2 APASS filter natching and extinction correction. Apparent magnitudes

There was a good agreement between the Johnson filters used for this study and the data from the APASS catalogue, indicating good photometry. The results after χ^2 minimisation for each band gave the zero-point correction necessary to obtain the B, V and R apparent magnitudes (Table 2).

m_R	m_V	m_B
10.19±0.01	10.670±0.005	12.04±0.02

Filter	Zero-Point	$P(\chi^2_{\min};\nu)$
R	3.97±0.01	0.49
V	3.820±0.005	0.41
B	3.38±0.01	0.39

Table 2. Upper part - Apparent magnitude results for V523 Cas in each band. Lower part - Cumulative distribution function estimates to test the goodness of the three APASS fits.

Using 2MASS infrared data, an extincion estimate of -0.601 was obtained. Thus, a correction of E(B-V) = 0.188±0.02 to take into account the colour excess was included in the results.Converting all data in phase allowed a plot of all three light curves to be produced. They exhibit the typical shape for W UMa variables of the W subtype with similar minima depths and similar brightness of the components.

In Fig. 1, the zero-points are also applied to set the plots in the correct order. The star is brightest in the R band. Apart from the expected difference in minima brightness (Δm = 0.110 in V and 0.115 in B), all three curves exhibit a difference between the brightness of the two maxima, suggesting an on-going physical phenomenon intrinsic to the binary star rather than a dip in magnitude due to any significant atmospheric variations. For the R, V and B bands, Δm of the maxima were found to be 0.028 mag, 0.033 mag 0.029 mag, respectively. The differing maxima were observed in recent literature (Latkovic et al. (2009), Eliasii (2000), Samec et al. (2004), Zhang and Zhang (2003)).

From the data in three bands, the B-V and V-R colour indices were obtained: 1.36±0.02 and 0.48±0.01, respectively. This allowed to constrain the temperature for the model fit in Nightfall and determine of the stellar class of V523. The B-V and V-R residual plots show no obvious underlying structure, showing that the two stars are very similar (due to the common envelope and the low mass ratio). Despite the fact that the V-R colour index of V523 CAS is 0.47 in SIMBAD (Wenger et al., (2000)), which is within our 2-σ range, other sources suggest a higher V-R of 0.8. The B-V index (dereddened and in a better agreement with literature) led to a more accurate temperature estimate than V-R.

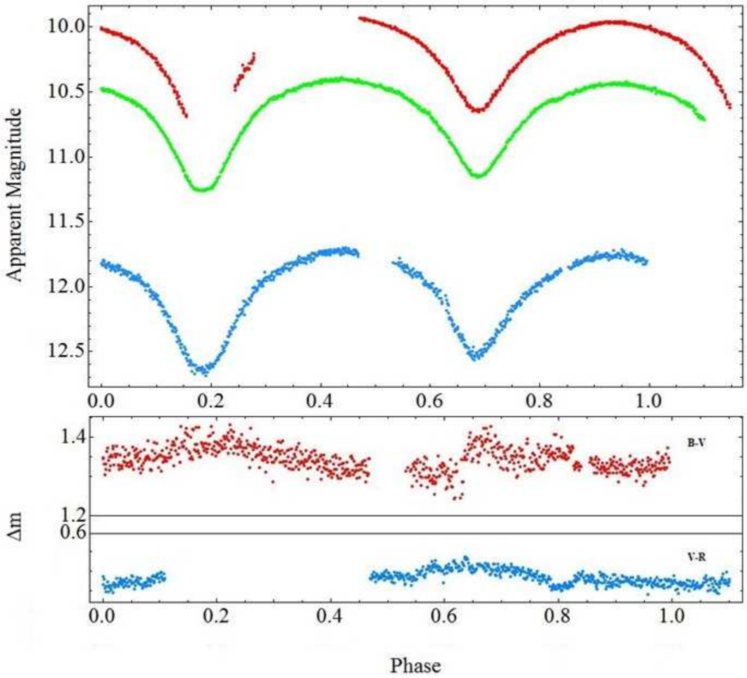

Fig. 1. Upper panel: the zeropointed light curves in R, V and B (in this order) are plotted against phase, using the best period. Lower panel: a plot of the B-V (upper plot) and V-R (lower plot) colour indices against phase.

3.3 Absolute magnitude from the Johnson empirical formula and final distance result

The absolute V magnitude, M_V, obtained from the Rucinski empirical formula (Eq. 3), was calculated to be 6.85±0.25 mag. Using this relation, a smaller error can be obtained only when studying a great number of objects instead of one. The absolute magnitude in literature is 6.79 mag (Samec et al. (2004)) . As another check, using the obtained extinction correction, the correct absolute bolometric magnitude is obtained: $M_{bol} = 6.19$, in agreement with the literature values of 6.21±0.02 (Latkovic et al.(2009)), 6.18 (Samec et al. (2004)).

From this result, using Eq. 4, the distance to the binary system was estimated to be 58.1±9.4 pc. The error was dominated by the absolute magnitude error. This result is in agreement with the literature estimate of 69±2 pc (Samec et al. (2004)). The system should be close as it is bright but consists of two red dwarf stars. In principle, very accurate distances can be obtained from eclipsing binaries (Wilson (2001)), but extinction decreases the result, whereas if a third body is present, the result increases. Even though a reddening correction was applied to obtain our estimate (and a third star was not confirmed), the accuracy of the distance result can significantly be affected by a small deviation in the colour index and therefore in the absolute magnitude value. As for the absolute magnitude estimate, the accuracy can be improved by studying many such systems found in a star cluster, although much simpler methods exist. The many assumptions necessary demonstrate why W UMa-s are not often used for distance estimation (Rucinski (2003)).

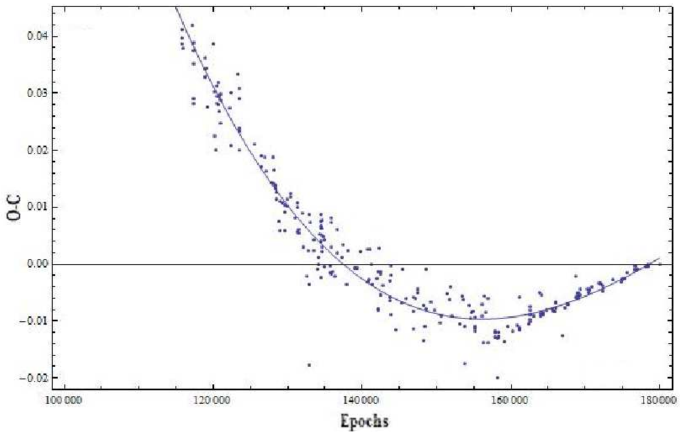

Fig. 2. Cubic fit to the O-C residuals of V523 Cas. Such a long-term variation is typical for W UMa stars and is possibly due to thermal relaxation oscillations.

3.4 O-C diagram. Long-term periodicity and variability of the system. Future fate of the system

Examining past O-C data (1901-2011) suggests that V523 Cas shows period changes of 0.2 days over the whole observed time interval. Since the dataset was obtained over such an extended time span and using different detectors (before the 1960s), a clearer trend is observed from the later data. Figure 2 shows the O-C plot after adding our data to the 1960 - 2011 data and adjusting for our obtained period. The O-C diagram, as well as other literature results (Samec et al. (2004), Shengbang (2001)) show a period variation over this time period of about 0.1 days. This good agreement was obtained using the lower bound of our period result.

The O-C diagram exhibits a shape close to parabola, which demonstrates that there is a long-term period variation in the system, which was not taken into account in our model. A parabolic fit was avoided, as it forces strict symmetry to the data, and a cubic model was found to be a reasonable fit. The cubic polynomial worked well as it dealt with the slight asymmetry. The fit residuals are shown in Fig. 3. Using a fourth order polynomial added more skewness and a slightly worse fit than the cubic fit. A sine curve to test a model with a third body orbiting the system was fitted. Since this model was questioned but not rejected, it remains a possibility. The presence of a third body (a star or planet) would affect the total system brightness and thus make the system appear nearer (Sterken (2005)). It would also dilute the eclipses, tides and all other variations, decreasing the total amplitude of the light curve, and the induced long-term shifts of the system barycentre would lead to sinusoidal long-term period changes. A parabola implies a constant rate of period change and a sinusoid implies apsidal motion due to perturbations to the 1/r gravitational potential and therefore deviations from Keplerian elliptic motion over long time periods (Kallrath and Milone (2009), Sterken (2005)).

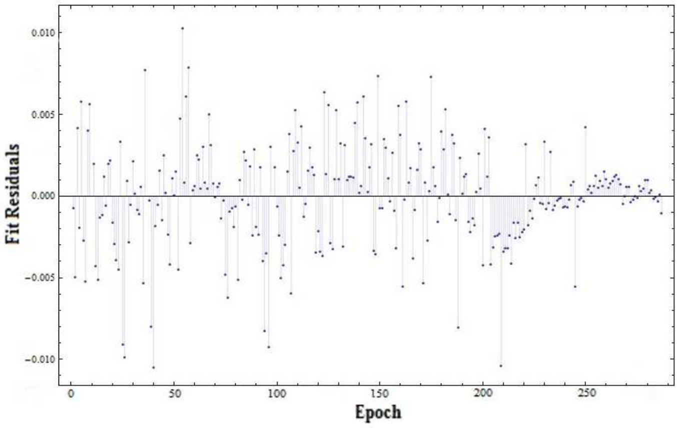

Fig. 3. Residuals of the cubic fit.

Even without the presence of a third body, the shape of the O-C diagram of such a close binary system would inevitably be affected by the system evolution. The curve suggests repeating events over longer timescales rather than a one-directional process or a deviation from strict periodicity from an occasional disturbance. These events are possibly due to the dumbbell of the over-contact binary undergoing oscillations via increasing and decreasing the component separation over longer time intervals (more than one century). This is not surprising, but a typical effect for W UMa stars of the W subclass, as they undergo thermal relaxation oscillations (Shengbang (2003)). From the O-C diagram, the system even exhibits noticeable variations between the periods measured from the primary and secondary eclipses over the course of one year, due to the fact that the system is not an ideal model, e.g. the "neck" connecting the stars is not rigid. The mass-transfer rate through L1 is therefore also affected by these variations and further contributes to the characteristic shape of the curve. Another contribution might be due to magnetic activity from the rapid rotation of V523 Cas. In order to determine the origin of the variations, spectroscopic analysis is required.

At present, the period of V523 Cas is increasing again, indicating that the stars are oscillating away from each other. However, these oscillations might eventually reach critical damping and lead to an equilibrium state - the system will merge into one object.

3.5 Nightfall fit to synthetic model

3.5.1 Results and predictions. The fitted parameters provided information about the system geometry, the integrated flux in the observer's direction and the surface radiative properties of the stars.

A reasonable fit of the synthetic light curve to the data with $\chi^2_\nu = 1.84480$ was obtained, with very good agreement at the primary and secondary minima. The deeper minimum in the light curve is the primary minimum, as the brighter star is eclipsed. The minima difference in the light curve of V523 Cas is small, which is typical for W UMa stars. The minima depth also strongly depends on the system inclination, mass ratio and temperature (and therefore luminosity), and modelling with Nightfall allowed to explore these dependences and the strong relations between them. The overall mean residual has a value of -0.0010, with SDV residuals of 0.0002. The residuals show no structure, apart from a small discrepancy at one of the maxima due to the difference in height of the maxima, minimised by adding a spot. This indicated that the obtained parameters of the fit give not just a minimum of the solution, but most likely the global minimum for the parameters.

A possible exception is the solution for the chromospheric spot, which significantly improved the fit, as it might not be unique. Our model predicts it is situated on the primary star with dim factor of 1.136, in agreement with the theoretical explanation (Eliasii (2000), Liu et al. (2003)), the value of 1.165±0.015 (Samec et al. (2004)) and other literature (Shengbang (2001)). The temperature factor value is larger than 1, indicating the spot is hotter than the primary star surface (Table 5). However, there is a large discrepancy between the results for the position, size and dim factor of the spot or the number of spots of the system in most studies of the O'Connell effect observed on V523 Cas, explained by a spot cycle. For example, the study by Latkovic et al. (2009) reports a value of 1.09±0.01 for a spot on the cooler secondary as well as previous results from 2005 and 2006, when the spot was found on the primary and then the secondary. No good fit was obtained from an attempt to introduce a third light to the system, which is in agreement with a 15-year monitoring of the star (Zhang and Zhang (2003)) and in contradiction to the study of Samec et al. (2004).

Effects such as tidal distortions, limb darkening, gravity brightening, accretion hot spots, etc. are at present considered important indicators of the characteristics of eclipsing systems and therefore essential to the light curve solution. Proximity effects and gravity brightening were automatically calculated in Nightfall and a reasonable value for limb darkening was obtained.

In Fig. 5, the fitted V-curve is shown, with a view of the orientation and phase of the binary components for an observer on Earth below the minima and maxima. The primary eclipse shows the deeper minimum. Almost complete totality is reached during primary eclipse.

The final result is a system with a primary component of spectral class K4 and a secondary of spectral class K4-K5 (in agreement with Zhang and Zhang (2003), Bradstreet (1981), whereas most literature values found suggest slightly higher temperatures and classify the primary as K3 and the secondary as K4 (Brandstreet et al. (2004), Samec et al. (2004), Latkovic et al. (2009)). Our obtained stellar class is K4V, with the luminosity class V added to indicate main sequence stars. Therefore, the system belongs to the same numerous luminosity class as the Sun. The final Nightfall estimate for the total mass and separation between the components are in agreement with literature, the latter in perfect agreement with the result 1.687 $R_{\odot}$ (Latkovic et al. (2009)).

The calculated mass ratio $M_1/M_2 = q = 0.529$ agrees with the results of $q = 0.53$ by Lister (2000), and with the general trend of $q = 0.52$ by Samec (2004), 0.59 by Bradstreet (1981), 0.571 by Samec (1989), 0.56 by Kim and Jeong (2002), whereas radial velocity curves from spectroscopic data give a lower result, e.g 0.42 from Milone (1985). This indicates a good result for the inclination angle as well, due to the parameter relation.

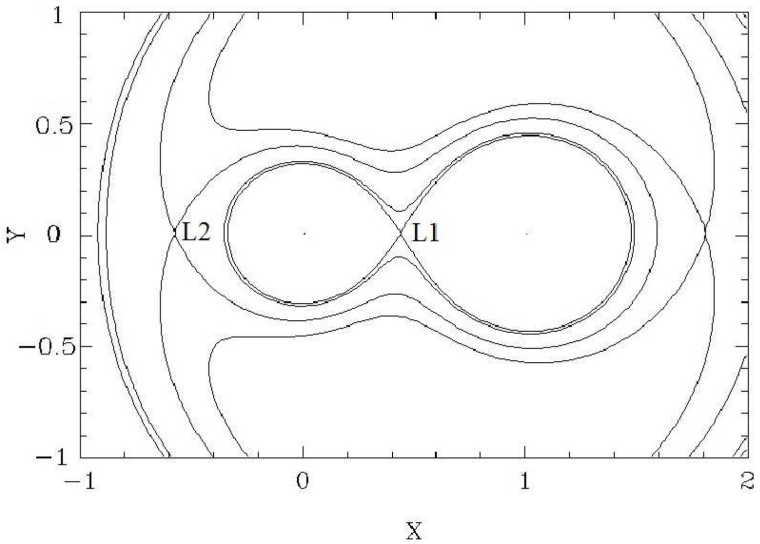

Fig. 4. The plot shows the Roche potential of the binary system V523 Cas. The Lagrangian points L1 and L2 are labelled, as they are particularly important in contact binary systems - mass transfer can occur.The model shape of V523 Cas obtained with Nightfall is characteristic for W UMa stars.

The Nightfall parameter fit is summarised in Table 3. The most important features of the system of V523 Cas are a low mass ratio, distorted (teardrop) shape of both components, very similar effective temperatures due to sharing a common envelope, high fill factor.

Fig. 4 shows the predicted shape of the observed binary system - demonstrating it is an over-contact system of two similar distorted stars.

3.5.2 Reason for differences in maxima - typical O'Connell effect?
A difference in maxima is generally not expected for eclipsing binary stars, as in a perfect model there is no difference in the system brightness between eclipses, when no light from the surface of any of the components is obscured. However, it is commonly observed in late-type short-period systems such as W UMa binaries (Liu et al. (2003)). Therefore, the difference can be explained by either a difference in the data quality at the two eclipses, or a physical characteristic of the system. For this study, there is little doubt the latter is the case, as photometric data for the minima and maxima was gathered on

several occasions and the phenomena was reported in many past studies of the observed system.

The O'Connell effect gives a physical reason for such a difference. Most commonly, this effect is explained with the presence of stellar surface spots. The result of a single hot spot on the primary component was found satisfactory for the fit. However, this result is only an approximation for the physical situation, as a spot continuously varying in size is a good way to take into account the presence of many surface spots.

System Parameters	Fit Estimates
Orbit	Circular
Inclination	82°
Mass Ratio (M_2/M_1)	1.890
Flux	Model Atmosphere
Limb darkening	Linear
Detailed reflection	4
Total Mass	1.180 $M_\odot$
Distance between Centres	1.687 $R_\odot$
L1	0.734 $R_\odot$
Secondary eclipse begin	116.56±0.31 min
Secondary eclipse end	219.35±0.31 min
Primary eclipse begin	284.82±0.31 min
Primary eclipse end	387.62±0.31 min
L1 Potential	5.0953
L2 Potential	4.5017

Table 3. Table of the most important parameters of V523 Cas that were fitted or obtained from the light curve solution.

The difference in the literature results for the size and position of the spot over the years suggests that if present, a spot cycle could explain the change in the difference between the curve maxima. More realistically, elliptical spot regions can be modelled using the work of Hill and Rucinski (1993) for further exploration of the issue and a better fit to the maxima difference, as the present result still shows a small discrepancy with the data at one maximum.

System Parameters	Primary	Secondary
Max Velocity	236.550 km/s	125.159 km/s
Mass	0.408 $M_\odot$	0.772 $M_\odot$
Gravity	318.848 m kgs^{-2}	176.943 m kgs^{-2}
Polar Radius	0.528 $R_\odot$	0.706 $R_\odot$
Temperature	4420.6 K	4224.9 K
Fill Factor	1.030	
Albedo	0.500	0.500
Grav. Dark.	0.092	0.084
Surface Potential	4.9949	2.8782

Table 4. Table of the parameters of the primary and secondary component of V523 Cas that were fitted or obtained from the light curve solution.

The obtained dimfactor indicated a hot spot, possibly due to heating as a result of mass transfer (Sterken (1996)). Too high or too low values (2.0 or 0.5) were avoided, as too great temperature variations are not realistic. The spot size is also not improbable for such types of stars, due to the surface and magnetic activity (Sterken (1996), Samec et al. (1987)).

Longitude ϕ	Latitude ϑ	Ang. Radius ρ	DimFactor
74.200°	82.400°	36.700°	1.136

Table 5. Parameters of hot spot on primary component.

Other physical reasons for the O'Connell effect are possible, but they can all be approximated by the spot model, as they all manifest in similar ways. Matter can leave the common envelope through L2 and gas clouds regions of colliding stellar winds can form. They can redirect the light by scattering or absorption and re-emission, and can rotate with the system, thus causing changes during one of the maxima (Liu et al. (2003)).

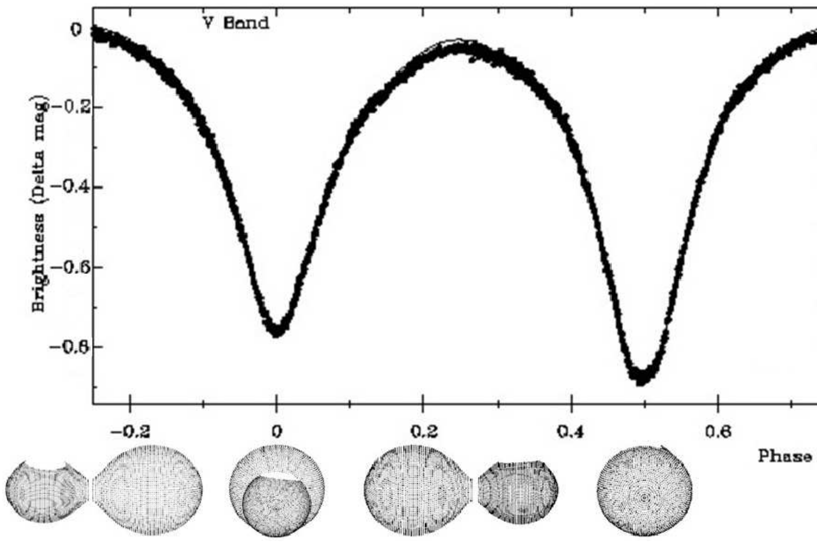

Fig. 5. The plot shows the best synthetic curve fit to the data obtained with Nightfall and the orientation of the system at the maxima and eclipses. The smaller primary star is brighter and therefore the primary eclipse is deeper. The parameters of the hot spot on the primary star affect the maxima heights.

4. Conclusions

In this study, the eclipsing variable star V523 Cas was observed in the R, V and B standard photometric filters. The best period of 0.2336944±0.0000016 days was found using the best-constrained V band light curve. This result is both accurate and precise, demonstrating that the obtained method and used software led to no systematic errors and that the quality and quantity of photometric data was sufficient to obtain a small error.

The binary system parameters were determined from a good synthetic curve fit (mean residuals = - 0.0010±0.0002) to our V band curve using Nightfall - astronomical package based on the Wilson and Devinney code and based on Roche geometry. The initial constraints for the fit were determined using the relations between some of the system parameters: the obtained colour index and the temperature, the temperature ratio and the mass ratio, the mass ratio and the system inclination. In this way, the absolute parameters of the binary system were determined instead of the relative ratios. Most of the fitted parameters were in agreement with literature values, demonstrating an accurate result.

Our result for one chromospheric spot on the primary component confirmed results from previous studies that V523 Cas is displaying the O'Connell effect. Constructing an O-C diagram suggested that there is an underlying long-term physical process not included in our model, but also that our result is in agreement with the current trend for period increase. The intriguing long-term variation has several possible physical explanations, the most likely of which is thermal relaxation oscillations. From the light curve solution it was confirmed that V523 Cas is a W Uma binary of the W subtype, spectral class K4 and luminosity class V. The obtained absolute magnitude was accurate but not precise. It was confirmed that W UMa systems can be used for distance estimates, although there is some hesitation for our result due to its high sensitivity to the colour index and other discussed reasons. This issue could be explored in future studies.

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