First detailed analysis of multiple system V2083 Cyg

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ABSTRACT

The main aim of this paper is the first detailed analysis of multiple system V2083 Cyg, to reveal its basic physical properties. The system was studied using the methods of light-curve and radial-velocity curve analysis, together with interferometric data from the visual pair obtained during the last century. It was found that the close subsystem contains two very similar stars of spectral type A7–8. Moreover, a third body is orbiting around this pair with a period of about 177 yr. Due to the discrepancy in the total mass derived with the two methods, the possibility arises that the third body is perhaps also a binary, or some object with lower luminosity but higher mass than a normal main-sequence star. Another explanation is that the Hipparcos value of parallax is incorrect and the system is much closer to the Sun.

Key words: binaries: eclipsing – binaries: visual – stars: fundamental parameters – stars: individual: V2083 Cyg.

1 INTRODUCTION

Eclipsing binaries as members of more complex multiple systems can provide us with important information about their physical properties, derived using different methods. This is the case for V2083 Cyg, which is a system in which the close components form an eclipsing binary and the third distant body orbiting the close pair is detected as a visual component. Thanks to combined analysis, we are able to derive the radii, masses and evolutionary status of the close components and also some properties of the distant one. Such systems are still very rare and mostly lie relatively close to the Solar system. Nowadays, only 33 such systems are known in which a close eclipsing binary is a member of a wide visual binary and we know both orbits, mutual inclinations, ratio of periods, etc. Such unique systems are the most suitable ones for studies of dynamical effects, such as the short- and long-term evolution of the orbits (see e.g. Söderhjelm 1975).

2 THE SYSTEM V2083 CYG

The system V2083 Cyg (= HD 184242 = HIP 96011, RA 19h31m16.36, Dec. +47°28′52″24, \( V_{\text{max}} = 6.86 \text{mag} \)) is an Algol-type eclipsing binary with an orbital period of about 1.87 d. It is also the primary component of a visual double star designated as WDS J19313+4729 in the Washington Double Star Catalog (WDS)1 (Mason et al. 2001). The secondary component of this double star is about 220 mas distant and is a little fainter. On the other hand, the magnitude difference is not very certain, because different authors list different values. The WDS catalogue itself gives 7.50 and 7.93 mag for both components.

The system is a rather neglected one and there have only been a few papers published regarding it. It was discovered as an eclipsing binary from Hipparcos data (Perryman et al. 1997), which also reveal that the light curve (hereafter LC) shows two similar minima and the classical features of an Algol-type star.

The spectral type of the system is not known very precisely at present. Abt (1985) presented the spectral classification of the whole AB system as Am (K/H/M=A3/A8/A9), Renson, Gerbaldi & Catalano (1991) give a composite spectral type of A3–A9, while the spectral type A3 was presented by Cannon & Pickering (1918), Ochsenbein (1980) and many others. This could indicate that the combined spectrum is composed from components of slightly different spectral types. The photometry of V2083 Cyg obtained from the Hipparcos mission gives a colour index \( B – V = 0.279 \text{mag} \) (indicating spectral type A9, Popper 1980), while the infrared \( J – H \) and \( H – K \) indices, which are less influenced by interstellar reddening, as derived from the 2MASS survey give spectral types of about A4 and A7 (Cox 2000).

The visual orbit of the two components was derived by Seymour et al. (2002). They presented an orbital period of the double of about 372 yr, an angular semimajor axis of about 498 mas and an eccentricity of 0.16. However, as they mention, the orbit is still only a preliminary one.

3 PHOTOMETRY AND SPECTROSCOPY

We started collecting photometric data for the system in 2008 April. In total there are 31 nights of observations, but for the light-curve
4 LC AND RV ANALYSIS

The complete LC (in BVR filters) and RV curves were analysed simultaneously, using the program PHOEBE (Prša & Zwitter 2005), which is based on the Wilson–Devinney algorithm (Wilson & Devinney 1971). The derived quantities are as follows: semi-major axis $a$, mass ratio $q = M_2/M_1$, systemic velocity $\gamma$, secondary temperature $T_2$, inclination $i$, luminosities $L_i$, gravity-darkening coefficients $g_i$, limb-darkening coefficients $x_i$, albedo coefficients $A_i$, and synchronicity parameters $F_i$. The limb darkening was approximated via a linear cosine law and the values of $x_i$ were interpolated from van Hamme’s tables (see van Hamme 1993).

For the whole analysis, we followed this procedure: at the beginning we fixed the temperature of the primary component at $T_1 = 7930 \, K$ (corresponding to spectral type A7, Cox 2000). We were trying to find the best LC+RV fit according to the lowest value of root-mean-square (rms). A solution was reached, but this one was unacceptable due to the fact that resulting values of $M_1, M_2, L_1, L_2, T_1$ and $T_2$ are in contradiction with each other. In particular, the resulting spectral types as derived from $M_1, M_2, L_1, L_2, T_1$ and $T_2$ differ significantly from each other. For this reason, we tried a different starting value of $T_1$. With this method we were changing the temperature $T_1$ in the range from 8520–7020 K (spectral types A3 to F0) and trying to find a consistent solution. For all of these attempts, the value of $T_1$ remained fixed.

Our final parameters as derived from the LC+RV fit are given in Table 2. The plot of the LC is shown in Fig. 1, while the RV curves with the fits are given in Fig. 2. The value of eccentricity was fixed at 0. For discussion about the physical parameters of the components (eclipsing and also the third one), see Section 6.

For the entire computation process, the values of parameters $A_i, g_i$ and gravity-darkening coefficients were set at their appropriate values ($A_i = 1$ or 0.5 and $g_i = 0.1$ or 0.32) according to the component’s temperature ($T_i < 7200 \, K$ or $T_i > 7200 \, K$).

### Table 1. Radial velocities of V2083 Cyg as derived from the spectra from the Elodie archive and from the Ondřejov observatory.

| HJD    | RV1  | RV2  | RV3  | Ref. |
|--------|------|------|------|------|
| 51405.3658 | 95.594 | -81.861 |      | Elodie |
| 51407.4156 | 129.872 | -117.06 |      | Elodie |
| 55316.5290 | 20.920 | 2.771 | -16.272 | OND |
| 55380.5210 | -122.394 | 142.771 | -16.336 | OND |
| 55385.5370 | 122.946 | -99.062 | -16.775 | OND |
| 55385.5530 | 56.001 | -29.860 | -18.397 | OND |
| 55383.3640 | -73.970 | 99.094 | -14.986 | OND |
| 55386.5650 | -4.42 | 25.184 | -17.640 | OND |
| 55405.3670 | 55.349 | -26.402 | -16.327 | OND |
| 55425.3970 | -117.384 | 141.598 | -16.145 | OND |
| 55496.2990 | -121.010 | 140.992 | -16.273 | OND |
| 55496.4630 | -99.677 | 124.485 | -16.277 | OND |
| 55497.2890 | 141.451 | -119.863 | -15.212 | OND |
| 55622.5420 | 116.769 | -96.782 | -15.048 | OND |
| 55622.6370 | 89.474 | -66.160 | -14.284 | OND |
| 55671.4500 | -18.008 | 36.024 | -14.574 | OND |
| 55671.5840 | -72.089 | 92.471 | -14.950 | OND |
| 55671.6310 | -86.135 | 105.183 | -14.784 | OND |
| 55689.5750 | 144.545 | -122.291 | -16.380 | OND |
| 55692.3700 | -119.493 | 143.646 | -15.231 | OND |
| 55692.5540 | -98.435 | 122.422 | -15.080 | OND |

### Table 2. The final LC and RV parameters of V2083 Cyg.

| Parameter | Value | Parameter | Value |
|-----------|-------|-----------|-------|
| $a$ [\(R_\odot\)] | 9.57 ± 0.15 | $L_1$ (B) [per cent] | 26.7 ± 0.7 |
| $q = M_2/M_1$ | 0.97 ± 0.07 | $L_2$ (B) [per cent] | 34.9 ± 0.9 |
| $\gamma$ [km s\(^{-1}\)] | 10.78 ± 0.68 | $L_3$ (B) [per cent] | 38.4 ± 0.8 |
| $T_1$ [K] | 7630 (fixed) | $L_1$ (V) [per cent] | 26.7 ± 0.6 |
| $T_2$ [K] | 7623 ± 45 | $L_2$ (V) [per cent] | 34.7 ± 0.9 |
| $e$ | 0 (fixed) | $L_3$ (V) [per cent] | 38.6 ± 0.8 |
| $i$ [deg] | 80.47 ± 1.60 | $L_1$ (R) [per cent] | 26.4 ± 0.6 |
| $x_1 = x_2$ (B) | 0.412 | $L_2$ (R) [per cent] | 34.2 ± 0.9 |
| $x_1 = x_2$ (V) | 0.356 | $L_3$ (R) [per cent] | 39.4 ± 1.0 |
| $x_1 = x_2$ (R) | 0.356 | Derived physical quantities: |
| $g_1 = g_2$ | 1.000 (fixed) | $R_1$ [\(R_\odot\)] | 2.12 ± 0.17 |
| $A_1 = A_2$ | 1.000 (fixed) | $R_2$ [\(R_\odot\)] | 2.45 ± 0.20 |
| $F_1$ | 0.81 ± 0.13 | $M_1$ [\(M_\odot\)] | 1.71 ± 0.11 |
| $F_2$ | 0.84 ± 0.11 | $M_2$ [\(M_\odot\)] | 1.66 ± 0.09 |

2 See http://c-munipack.sourceforge.net/
issue was the values of $F_i$, which tended to decrease down to 0 for both components for each of the $T_i$ values, dropping down very quickly after a few steps of iterations. For this reason we tried a different approach. From the spectra of the system we estimated the values $v \sin i$, which were used to derive the values of $F_i$ for both components. Therefore, the values of $F_i$ as given in Table 2 are not derived from the combined LC and RV analysis but from the spectra.

The fitting process with PHOEBE was carried out assuming three luminosities. Besides the luminosities of the primary and secondary components of the eclipsing binary pair, the additional third light $L_3$ was also considered. This luminosity corresponds to the visual component B and is presented in the combined light for the entire time period (the two visual components are too close). From this value one can speculate about some physical parameters of the third body in the system; see Section 6 below.

5 VISUAL ORBIT

The close eclipsing pair is orbiting around a common barycentre with the third distant component of the system. Recent precise interferometric observations are to be used for determining the parameters of this visual orbit. Since its discovery as a double star by Aitken (1904), 61 astrometric observations of the double (i.e. position angle and separation) have been obtained. We took these data from the WDS data base. The very last observation was obtained in 2009.

Since its discovery, the position angle of the pair has changed by about 88°. Thanks to this movement, the orbit of the pair around a barycentre has been derived. The orbit was published by Seymour et al. (2002), who computed an orbital period of about 372 yr. However, since this most recent study three new interferometric observations have been published, so we decided to perform a new analysis with the complete data set.

Our new computation led to the visual orbit parameters given in Table 3 and the orbit plotted in Fig. 3. For the computation we used the following approach. Starting with the orbital parameters as published by Seymour et al. (2002), the final fit reached a very different solution. Moreover, several different minima in the parameter space were found, as derived from this astrometric data set. Some minima were found with very long orbital periods, but this solution seems to be less probable due to the poor coverage of the data. The most significant minimum (the deepest one) was found near the period of 177.4 yr. However, we would like to emphasize that the orbital solution is still a preliminary one. New precise observations secured every year would be very welcome to aid in derivation of the orbital parameters more conclusively and especially in setting more solid constraints on $p_1$ and $\alpha$ values. These values are the most important for discussion about the nature of the third component (see Section 6 below).

In Fig. 4 a plot of total mass versus period is shown, as well as the rms of the particular fit versus period. For our final solution reached (minimum rms with $p_1 = 64778.357$ d), the value of total mass was computed (using the Hipparcos parallax); this is shown as the dashed lines in Fig. 4. The relation between the two vertical axes (parallax and total mass) is defined via Kepler’s third law using our final solution. As one can see from the bold line of the mass–period relation, the total mass as derived from our final solution is close to the minimal mass in this period range (the uncertainty of the Hipparcos parallax $\pi_{\text{Hip}} = 4.32 \pm 0.57$ is shown as a grey area). Of course, this analysis is very sensitive to the input weighting.

Table 3. Final parameters of the long orbit.

| Parameter | Seymour et al. (2002) | This work |
|-----------|-----------------------|-----------|
| $p_1$ [day] | 135869 | 64778 ± 427 |
| $p_1$ [yr] | 372 | 177.4 ± 1.2 |
| $\alpha$ [mas] | 498 | 291.9 ± 1.4 |
| $T_0$ | 2438395 | 2400006 ± 375 |
| $\Omega$ [deg] | 73.6 | 174.54 ± 2.9 |
| $\omega$ [deg] | 189 | 334.89 ± 5.3 |
| $i$ [deg] | 64 | 48.73 ± 3.6 |
| $e$ | 0.16 | 0.471 ± 0.018 |
scheme. The individual weights of the data points were set equal to each other, because for most of the observations $\sigma$ or some other error estimations are missing. No minimum of rms near a period of 372 yr, as proposed by Seymour et al. (2002), is seen. One might ask why such a different solution was reached using only three new interferometric observations. The main reason (besides perhaps different weighting) is that these three new measurements provide strong constraints on the fit. This is due to the fact that the position angle between our most recent data and those from Seymour et al. (2002) has changed by about 20°, which is about a quarter of the total position-angle range covered. All of these calculations (e.g. Kepler’s law) used the set of recommended values of fundamental parameters as proposed by Harmanec & Prša (2011).

On the other hand, we also tried to compute the predicted change in the third-body velocities over the time span of more than 11 yr covered by our spectroscopic data. Taking into account some assumptions (masses), the change in velocity that resulted was greater than 20 km s$^{-1}$. Such a large velocity difference should be easily detectable in our RV3 data. Unfortunately, we were not able to identify the third-component lines in the Elodie spectra and in newer data from Ondřejov there is no such difference; hence we can only speculate about our findings. The reason could be either different masses or a much longer orbital period. Another explanation is an incorrect identification of the third-body lines in the spectra.

6 PHYSICAL PARAMETERS

Taking into account all results as presented above, one can build up a picture of the system, its geometry and orientation in space. From the combined LC and RV analysis it appears that both eclipsing components are probably main-sequence stars, located well within their respective Roche lobes. According to their masses and temperatures, it seems that their individual spectral types are probably A7 and A8 (e.g. Popper 1980; Harmanec 1988; Andersen 1991) for the primary and secondary, respectively. However, according to their luminosities, it seems as though the stars are of slightly earlier spectral type (about A5).

Another task was to derive the value of the third light $L_3$ from the LC solution and to obtain a magnitude difference between the two visual components. The value resulting was about 0.49 mag, which is in rough agreement with the value $\Delta m = 0.43$ mag presented in the WDS catalogue.

Discussion regarding the third body is still difficult due to certain aspects of the problem. The most problematic issue is still the uncertainty of the Hipparcos value of parallax. The relatively high error of about 13 per cent could lead to distances in a wide range from 204–267 pc. Thanks to this uncertainty, the value of total mass as computed from the visual orbit (see Table 3) could also lie between 6.54 and 15.41 $M_\odot$, with a mean value of 9.81 $M_\odot$.

Subtracting the masses of both eclipsing components, we obtain an interesting result for the mass of the third body of about 6.44 $M_\odot$ (with upper and lower limits of about 12.24 and 2.97). Such a massive third body cannot easily be a main-sequence A star as predicted from the $\Delta m$ value. One possible explanation for this discrepancy is that this component is also a double star. If we speculate that there are two identical stars, then such stars have to be of only slightly later spectral type than the eclipsing components (because of the total mass). Assuming two F0 stars, we can hardly satisfy the magnitude difference between the components. However, this explanation is still questionable because the third lines in the spectra do not show a double profile.

To solve this discrepancy we tried to use the program KOREL (Hadrava 2004) to disentangle the spectra taken at Ondřejov observatory. However, it was not able to solve the problem either. The final parameters on one hand confirmed our findings about the LC+RV solution (the mass ratio $q$ from KOREL was about 0.993) but on the other hand also resulted in a value of mass ratio $q_3 = M_3/M_{12} > 1$. This would indicate that the third body is more massive than the eclipsing pair, but also less luminous. Solving the problem of its lower luminosity and higher mass by introducing a degenerate object is a highly speculative solution. Hence, the nature of the third body still remains an open question. The KOREL radial velocities of the third body were also used and these are the values presented in Table 1 in the RV3 column.

7 DISCUSSION AND CONCLUSIONS

The multiple system V2083 Cyg is still rather neglected and this is the first detailed analysis of it. The components of the eclipsing binary are of spectral type A and are well-detached, with no evidence of circumstellar matter, emission in the spectra, etc. This close pair is also orbiting around a common barycentre with a third component with a period of about 177 yr. The mutual inclination of the two orbits is 31:8; therefore we can only speculate about a common origin of the system.

The nature of the third component is still rather problematic to derive. From the combined LC and RV analysis it appears that the third body is slightly less luminous than the eclipsing pair. However, the Hipparcos parallax indicates a higher total mass of the system than computed from all component masses. A possible explanation is that the value of the Hipparcos parallax is underestimated and the real distance of V2083 Cyg is lower (even outside the error bars of the Hipparcos data). This would not be an exceptional case, because for some systems Hipparcos data yield an incorrect parallax due to the presence of a close visual companion (e.g. Docobo et al. 2008). Another possible explanation is that this body is also a binary, but there are some problems with this explanation too (luminosity and the spectral lines of such a body). For this reason, new more detailed observations would be greatly welcome.

However, if the hypothesis of binarity of the third component is proven, it will shift the triple system to a quadruple one. On one hand, such systems of higher multiplicity are of great interest, but on the other hand we would then have to deal with the very
incomplete statistics of such systems among stars (see e.g. Eggleton & Tokovinin 2008; Eggleton 2009).

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APPENDIX A

The minima obtained using the Kwee–van Woerden method (Kwee & van Woerden 1956) are here given in Table A1.

| HJD: 240 0000 | Error   | Type | Filter | Observer |
|--------------|--------|------|--------|----------|
| 54609.69354  | 0.00179| prim | –      | SWASP    |
| 54638.63794  | 0.00035| sec  | B      | SWASP    |
| 54639.57227  | 0.00042| prim | –      | SWASP    |
| 54652.64554  | 0.00089| prim | –      | SWASP    |
| 54668.51720  | 0.00046| sec  | B      | SWASP    |
| 54669.44747  | 0.00046| prim | –      | SWASP    |
| 54683.46156  | 0.00027| sec  | V      | SWASP    |
| 54684.39467  | 0.00095| prim | –      | SWASP    |
| 54994.39887  | 0.00091| prim | B      | PS       |
| 54994.39888  | 0.00113| prim | V      | PS       |
| 54994.39948  | 0.00128| prim | R      | PS       |
| 55049.49292  | 0.00110| sec  | B      | PS       |
| 55049.49015  | 0.00104| sec  | R      | PS       |
| 55049.49055  | 0.00062| sec  | V      | PS       |
| 55051.35585  | 0.00081| sec  | B      | PS       |
| 55051.35567  | 0.00078| sec  | V      | PS       |
| 55051.35645  | 0.00107| sec  | R      | PS       |
| 55064.43157  | 0.00091| sec  | B      | PS       |
| 55064.43162  | 0.00057| sec  | V      | PS       |
| 55064.43102  | 0.00064| sec  | R      | PS       |
| 55076.57570  | 0.00116| prim | B      | PS       |
| 55076.57197  | 0.00108| prim | V      | PS       |
| 55076.57194  | 0.00165| prim | R      | PS       |
| 55093.37749  | 0.00087| prim | B      | PS       |
| 55093.37848  | 0.00068| prim | V      | PS       |
| 55093.37624  | 0.00063| prim | R      | PS       |
| 55374.43431  | 0.00021| sec  | I      | RU       |
| 55429.52450  | 0.00028| prim | I      | RU       |
| 55740.46289  | 0.00056| sec  | R      | PS       |
| 55797.42284  | 0.00043| prim | I      | RU       |

Note: PS – Petr Svoboda, RU – Robert Uhlaf.

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