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Light curve solution and orbital period analysis of the contact binary V842 Herculis

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Abstract. New photoelectric BV light curves were obtained for the neglected eclipsing binary V842 Her at the *TÜBİTAK National Observatory (TUG)* and studied for the first time in detail to determine the orbital parameters and geometry of the system. The solutions obtained simultaneously for the new light curves and the radial velocity curves in the literature by using the Wilson-Devinney code reveal a typical W-type contact system. The light curves exhibit the so-called O'Connell effect which the level of the primary maxima being higher than that of the secondary ones in both pass-bands. The O'Connell effect in the light curves is explained in terms of a dark-spot located on the more massive component which makes the more massive larger component slightly cooler than the less massive smaller one. The $O-C$ diagram constructed for all available times of minima of V842 Her exhibits a cyclic character superimposed on a quadratic variation. The quadratic character yields a orbital period increase with a rate of $\mathrm{d}P/\mathrm{d}t = 7.76 \times 10^{-7}$ days yr^{-1} which can be attributed to the mass exchange/loss mechanism in the system. By assuming the presence of a gravitationally bound third body in the system, the analysis of the cyclic nature in the $O-C$ diagram revealed a third body with mass of $0.4M_{\odot}$ orbiting around the eclipsing pair. The possibility of magnetic activity cycle effect as a cause for the observed cyclic variation in the $O-C$ diagram was also discussed.

Key words: binaries: close – binaries: eclipsing – stars: individual (V842 Her) – stars: fundamental parameters

1. Introduction

The variability of V842 Her (NSV 07457 = BD+50° 2255 = BV 0103 = CSV 7268) was discovered by Geyer et al. (1955) on Bamberg photographic survey plates taken between 1929-1939. They indicated that the star has a maximum photographic magnitude of 9.7 and rapid light variations with an amplitude of $0\overset{\mathrm{m}}{.}7$. Shortly after this discovery, Filatov (1960) has suggested RR Lyr-type variability for that star based on his inspections of photographic plates taken between 1939-1959 at the Tadjikistan Observatory and gave a list of 17 photographic times of maxima. But, the real nature of this variable star as a contact binary was identified recently by Vandenbroere (1993a, 1993b) and, apparently independently, by Nomen-Torres & Garcia-Melendo (1996) with their own photometric observations. Diethelm (1994) has also confirmed the typical EW-type light variation based on his BV photometry obtained in Rosemary Hill Observatory. Vandenbroere (1993a, 1993b) has performed an extensive period-search study with all available times of extrema (both minima and maxima) and suspected a period increase. She has obtained the following best-representing linear ephemeris from her own visual and photoelectric observations:

$$\mathrm{Min}\, I = \mathrm{HJD}\;\; 2447643.1786(23) + 0\overset{\mathrm{d}}{.}4190306(25) \times E . \tag{1}$$

Independently, Nomen-Torres & Garcia-Melendo (1996) have published a different ephemeris based on their 1996 observations as:

$$\mathrm{Min}\, I = \mathrm{HJD}\;\; 2450177.4767(4) + 0\overset{\mathrm{d}}{.}41906(3) \times E\ . \tag{2}$$

Both Vandenbroere (1993a, 1993b) and Nomes-Torres & Garcia-Melendo (1996) have mentioned that their light curves exhibit the so-called O'Connell effect which the primary maximum at orbital phase $\phi = 0.25$ being higher than that of the secondary one at phase $\phi = 0.75$. Nomen-Torres & Garcia-Melendo (1996) have applied the *Binary Maker* Code (Bradstreet 1993) to their V-band light curve and found a preliminary set of parameters of the system ($q = 3.8\pm0.2$, $i = 79\overset{\circ}{.}0\pm2\overset{\circ}{.}0$ and $f = 0.25\pm0.10$) resulting with a W-type contact system. They have preferred to explain the O'Connell effect with a hot spot located on the secondary (less massive) component. Csizmadia (2001) has also observed V842 Her photometrically on four nights in

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April and May 2000 and tried to explain the orbital period behaviour of the system.

The first radial velocity curves of the both components of V842 Her has been obtained and analysed by Rucinski & Lu (1999). They have also estimated the spectral type of the system as F9V from their spectra. Their radial velocity curve solution yields a W-type contact system with a mass ratio of $q_{\mathrm{sp}} = 3.852 \pm 0.024$. Rucinski & Lu (1999) have pointed out that the orbital period of about $0\overset{\mathrm{d}}{.}42$ is somewhat long, and the spectral type of F9V is relatively early for a typical W-type contact system. They have noted that the system has the potential of an excellent combined light and radial velocity curve solution. Thus, we have obtained new photoelectric BV light curves of V842 Her and analysed them simultaneously with the radial velocity curves by Rucinski & Lu (1999) to obtain a more reliable set of parameters of the system.

2. Observations

New photoelectric BV observations of V842 Her were obtained at the *TÜBİTAK National Observatory (TUG)* on the nights of 3 and 4 July 2003, by using an SSP-5A photometer attached to the 0.4m Cassegrain telescope. GSC 03497-00310 and GSC 03497-00349 were chosen as comparison and check star, respectively. The relevant catalogue data for the observed stars are given in Table 1. A total of 135 and 146 observations were obtained in B and V passbands, respectively. The nightly extinction coefficients for each band were determined from the observations of the comparison star. The magnitude differences in the sense of variable minus comparison star together with their heliocentric Julian dates are listed in Table 3. The probable error of a single observation point was estimated to be ±0.021, and ±0.014 in B and V bands, respectively. The differential B, V band light curves and $B-V$ colour curve are given in Fig. 1. Our new observations obtained at *TUG* cover two minima, the timings of which were calculated by using the method of Kwee & van Woerden (1956) as Min I = 2452825.3883±0.0002 and Min II = 2452826.4379±0.0002. Furthermore, we have obtained new photoelectric observations of the system on the nights of 24 and 27 July 2004 in UBV filters at *Ankara University Observatory (AUO)* to have additional minima times for the system. The 0.3m Maksutov-Cassegrain telescope with an SSP-5A photometer head was used during this observing run. Two additional minima times from these observations were also calculated by using the method of Kwee & van Woerden (1956) as Min I = 2453211.3187±0.0005 and Min II = 2453214.4648±0.0004. The photometric phases of the light and colour curves were calculated with the following linear ephemeris which is corrected by using recent photoelectric and ccd minima times including our new times of minima:

$$\mathrm{Min}\ I = \mathrm{HJD}\ \ 2450177.4857(4) + 0\overset{\mathrm{d}}{.}41904(3) \times E\,. \qquad (3)$$

The light levels were estimated by averaging data around the maxima and minima (by taking a $\Delta\phi = \pm 0.02$ interval) and their differences are listed in Table 2. The magnitude differences between the two maxima exhibit the so-called O'Connell effect amounts to Δm = Max I – Max II = 0.033 and 0.032 for B and V bands, respectively. Nomen-Torres & Garcia-Melendo (1996) and Vandenbroere (1993a) have also mentioned that their V light curves exhibit O'Connell effect as Δm = Max I – Max II = 0.03 and Δm = Max I – Max II = 0.1, respectively. This kind of light curve asymmetries are generally attributed to inhomogeneities in surface brightness distribution (cool or hot stellar spots) of the component stars in late-type contact binaries.

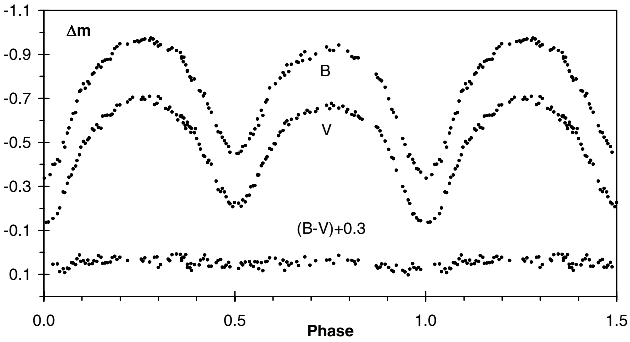

Fig. 1. Differential B, V light and $B-V$ colour curves of V842 Her.

Table 1. The catalogue information for V842 Her, comparison and check stars

Parameter	V842 Her	Comparison	Check
GSC	03497-00263	03497-00310	03497-00349
TYC		3497-310-1	3497-349-1
α_{2000}	$16^{\mathrm{h}}\ 06^{\mathrm{m}}\ 02^{\mathrm{s}}$	$16^{\mathrm{h}}\ 06^{\mathrm{m}}\ 04^{\mathrm{s}}$	$16^{\mathrm{h}}\ 05^{\mathrm{m}}\ 16^{\mathrm{s}}$
δ_{2000}	$+50^\circ\ 11'\ 12''$	$+50^\circ\ 07'\ 49''$	$+50^\circ\ 06'\ 47''$
B_T	$10\overset{\mathrm{m}}{.}729$	$11\overset{\mathrm{m}}{.}574$	$12\overset{\mathrm{m}}{.}169$
V_T	$10\overset{\mathrm{m}}{.}177$	$10\overset{\mathrm{m}}{.}710$	$11\overset{\mathrm{m}}{.}180$
$B-V$	0.512	0.758	0.857

Table 2. The light levels and their differences in the light curves of V842 Her

	ΔB	ΔV
Max. light at $\phi = 0.25$	–0.965±0.015	–0.698±0.015
Max. light at $\phi = 0.75$	–0.932±0.015	–0.666±0.015
Δmax $(m_{0.75} - m_{0.25})$	0.033	0.032
Depth of Min. I	0.584	0.566
Depth of Min. II	0.515	0.471

3. The light curve analysis

Our new photoelectric light curves and radial velocity curves by Rucinski & Lu (1999) were analyzed simultaneously with the aid of revised version of light curve analysis method (WD-2003) by Wilson & Devinney (1971) to obtain a consistent set of physical and orbital parameters of V842 Her. All photometric observation points and radial velocity data were considered during the analysis. Some parameters of the model were fixed to their theoretical values according to the known physical nature of the component stars such as bolometric albedos $A_1 = A_2 = 0.5$ (Rucinski 1969) and gravity-darkening coefficients $g_1 = g_2 = 0.32$ (Lucy 1967). The mass ratio ($q = 3.852$) and the velocity of the center of mass ($V_\gamma = -57.98$ km s^{-1}) were set to the corresponding values determined by Rucinski & Lu (1999) and kept constant during the solution. The effective temperature of the primary component (T_1) was adopted from effective temperature calibration for dwarf stars by Gray & Corbally (1994) according to the spectral type F9V indicated by Rucinski & Lu (1999). Square-root law limb-darkening coefficients x_1, y_1, x_2 and y_2 were interpolated from van Hammes's (1993) tables. Synchronous rotation for both components ($F_1 = F_2 = 1.0$) and a circular orbit ($e = 0.0$) for the system have been assumed. The orbital inclination angle (i), the surface potentials of the both components ($\Omega_{1,2}$), the effective temperature of the secondary component (T_2) and the relative monochromatic luminosity of the primary component (L_1) were chosen as adjustable parameters and the relative monochromatic luminosity of the secondary component L_2 was coupled to L_1 during the iterations. Although the profiles of the light curves provide us some clues about Roche lobe filling components and contact configuration of the system, we have initially demonstrated different possible modes of WD code (i.e., contact, semi-detached and detached configurations). The differential corrections proposed by different modes always yield an over-contact configuration during these test runs. Therefore, we have performed the final analysis in MODE-03 of the WD code which is convenient for contact binaries.

By using the adopted effective temperature for the primary component as $T_1 = 6000$ K which is corresponding to the spectral type F9V by Rucinski & Lu (1999), no reasonable solution could be obtained during the iterations. The spectral type of the system was mentioned in *New Catalogue of Suspected Variable Stars* as G0 (Kukarkin et al. 1982) and Rucinski & Lu (1999) emphasized that the spectral type of F9 V is relatively early for a typical W-type W UMa system. Taking into account this discrepancy on spectral type of the system we have made a trial search on the effective temperature of the primary component and have reached a reasonable solution only by decreasing the effective temperature of the primary component to $T_1 = 5700$ K which is correspond to G2 spectral type according to the effective temperature calibration for dwarf stars by Gray & Corbally (1994).

The observed light curve asymmetry in maxima (i.e., the O'Connell effect) is attributable to inhomogeneities of surface brightness distribution of the component stars and can be tackled by invoking cool and/or hot spots on the surface of one or both component stars after a reasonable geometric solution was obtained during light curve analysis. In their preliminary analysis Nomen-Torres & Garcia-Melendo (1996) have found that the O'Connell effect in their light curve could be best modelled with a hot spot on the secondary component. We have used two different spotted-solution; a cool spot on the primary component and a hot spot on secondary component during our analysis and found that the model with a cool spot placed on the primary component is converged very quickly to a solution with a better $\Sigma(O-C)^2$ residual after several iterations. The resulting spot parameters were co-longitude $\lambda = 290.5°$, co-latitude $\beta = 28.9°$, spot radius $\theta = 17°$, and the temperature factor $T_f = 0.75$.

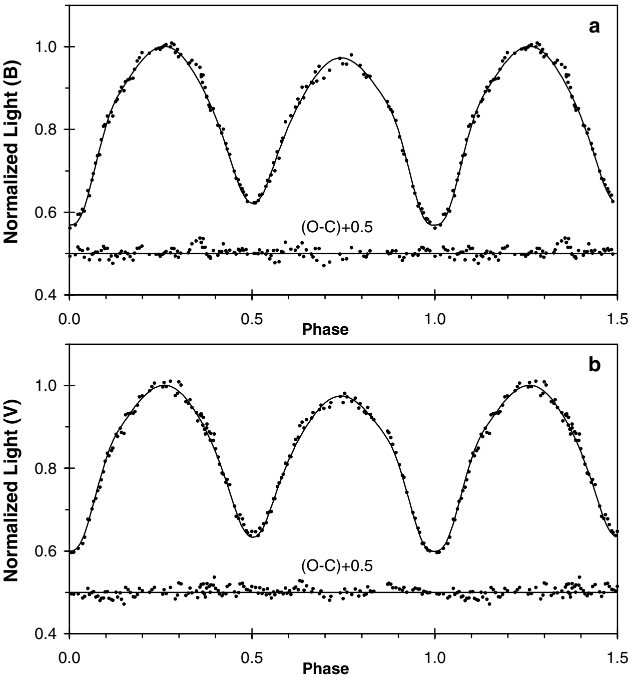

Fig. 2. a) Observational and theoretical light curves with the $O-C$ residuals of V842 Her in B-Band **b)** same as a) but for V-Band.

The results derived from our simultaneous light and radial velocity curve modelling of V842 Her are given in Table 4 and represented graphically in B and V bands with Fig. 2 a) and b), respectively. These figures also containing $O-C$ residuals from the model at the bottom of each light curve for visual inspections about the goodness of fit. We believe that the scatter in these residuals are mainly arise from the measurement errors.

4. The orbital period of the system

The behaviour of the orbital period of V842 Her was recently studied by Vandenbroere (1993a, 1993b) and Csizmadia (2001). Vandenbroere (1993a, 1993b) has suspected a period increase by analysing all available extrema of the system while Csizmadia (2001) has stated that the orbital period of V842 Her has been constant in the last decade. However he also pointed out that sudden period change or changes in the past cannot be excluded for the system but the available data is not sufficient to give a decision on that matter. V842 Her is a neglected system after its' discovery in 1955 and therefore the number of minima times of the system are rather low in the literature. The interval of the available minima times of V842 Her only cover the last 15 years by the end of year 2004. All available times of minima in the literature were collected from their original sources and listed in Table 5 together with our newly determined ones.

Nomen-Torres & Garcia-Melendo (1996) haven't published the minima times relevant to their 1996 photometry of the system. These times of minima were listed in the minima table by Csizmadia (2001) after a private communication between them and show rather large scatter in the $O-C$ diagram. We have also privately communicated with Garcia-Melendo (2003) and he has kindly sent us their photometric data. We have recalculated the times of minima from their original observations by using the method of Kwee & van Woerden (1956) and found slightly different values from the published ones (compare the values in our Table 5 and Table 1 by Csizmadia (2001)). We should also note that the minimum time listed as 2450228.5892 in the Table 1 by Csizmadia (2001) couldn't be recalculated by us from the Garcia-Melendo's (2003) original data due to the insufficient data points in the relevant night's observations (ascending branch of the minimum profile is absent for that night's observations). Three of the visual minima by Vandenbroere were also showed very large scatter in our initially formed $O-C$ diagram. Csizmadia (2001) have changed the type of minima from primary to secondary or vice versa for two of them and omitted one of them in his minima list. We have privately communicated with Vandenbroere (2003) about this three problematic minima and confirmed the corrected values of them. The change of type for the minimum 2451327.534 by Csizmadia (2001) was confirmed by Vandenbroere (2003) but not for the minimum 2449205.367 which is actually a misprint in BBSAG Bull no.105 and should be read as 2449206.367. The same situation is also true for the minimum 2449112.391 which was omitted by Csizmadia (2001) and should be read as 2449112.504. There is another misprint in the literature for the minimum time 2453111.80053 by Nelson (2005) in which the type of minimum was listed as primary instead of secondary. After the recalculations and corrections we had a data set of 56 visual, 2 photographic and 30 photoelectric+ccd minima timings as listed in Table 5.

An $O-C$ diagram with all these timings is plotted in Fig. 3a by using the light elements given in Eq. (3). The time span of the data is only 15 years, but systematic deviations from the linear ephemeris is present in the current $O-C$ diagram. Although, the visual timings follow the same variation character with the others they were omitted during the further $O-C$ analysis due to their large amount of scatter. This removal does not reduce the overall time span covered by all available minima times and the remaining photographic, photoelectric and ccd minima are again cover an interval of about 15 years. The new form of $O-C$ diagram excluding the visual minima and formed by the rest of the data is shown in Fig. 3b which has a obvious upward curving parabolic character indicating a period increase of the system. The existence of this structure has also been suspected by Csizmadia (2001), but he has shown that the sums of squared residuals are not significantly different for linear and parabolic approximations to the $O-C$ data by using the limited number of minima times available to him. Therefore he has concluded that it is too early to mention about a period change for V842 Her. However, with the current data, one additional structure in the $O-C$ dia-

Table 3. Observational data for V842 Her

HJD 2400000+	ΔB	ΔV	HJD 2400000+	ΔB	ΔV
52825.3029	-0.9134	-0.6487	52825.5291	-0.9277	-0.6382
52825.3075	-0.8886	-0.6262	52825.5340	-0.9165	-0.6244
52825.3099	-0.8800	-0.6218	52825.5355		-0.6006
52825.3114	-0.8845	-0.6381	52825.5381	-0.9081	-0.6182
52825.3145	-0.8829	-0.6185	52825.5396	-0.8826	-0.6204
52825.3162		-0.6105	52825.5420	-0.8864	-0.6101
52825.3187		-0.6040	52825.5435		-0.5760
52825.3342	-0.8089	-0.5710	52825.5459	-0.8253	-0.5799
52825.3358	-0.7932	-0.5658	52825.5498	-0.7925	-0.5441
52825.3382	-0.7840	-0.5516	52825.5546		-0.5618
52825.3401	-0.7780	-0.5309	52825.5561		-0.5171
52825.3439	-0.7501	-0.5049	52826.3777	-0.8876	-0.6152
52825.3479	-0.6972	-0.4668	52826.3795	-0.8654	-0.5885
52825.3513	-0.6493	-0.4318	52826.3823	-0.8510	-0.5622
52825.3532	-0.6367	-0.4247	52826.3841	-0.8222	-0.5910
52825.3562	-0.6143	-0.3728	52826.3868	-0.7982	-0.5687
52825.3634	-0.5165	-0.2987	52826.3885	-0.7821	-0.5641
52825.3658	-0.4887	-0.2775	52826.3917	-0.7875	-0.5433
52825.3693	-0.4353	-0.2380	52826.3969	-0.7344	-0.4913
52825.3709	-0.4445	-0.2214	52826.3986	-0.7328	-0.4686
52825.3740	-0.4229	-0.1742	52826.4014	-0.7098	-0.4393
52825.3757	-0.4070	-0.1755	52826.4031	-0.7224	-0.4355
52825.3784	-0.3806	-0.1564	52826.4061	-0.6743	-0.4080
52825.3803	-0.3775	-0.1465	52826.4076	-0.6547	-0.4180
52825.3829	-0.3645	-0.1430	52826.4103	-0.6362	-0.4000
52825.3890	-0.3370		52826.4158	-0.5753	-0.3229
52825.3909		-0.1352	52826.4178	-0.5472	-0.2843
52825.3935		-0.1372	52826.4204	-0.5426	-0.2758
52825.3953	-0.3519		52826.4222	-0.5222	-0.2905
52825.3984	-0.3990	-0.1538	52826.4249	-0.5070	-0.2746
52825.4005	-0.4005		52826.4265	-0.4935	-0.2522
52825.4035	-0.4213	-0.1746	52826.4294	-0.4808	-0.2272
52825.4057	-0.4137	-0.2017	52826.4309	-0.4541	-0.2202
52825.4096	-0.4995	-0.2740	52826.4340		-0.2077
52825.4113	-0.4777	-0.2708	52826.4358		-0.2254
52825.4144	-0.5414	-0.3129	52826.4385	-0.4487	
52825.4161	-0.5655	-0.3410	52826.4401	-0.4496	-0.2234
52825.4187	-0.6044	-0.3518	52826.4431	-0.4587	-0.2079
52825.4207	-0.6308	-0.3793	52826.4448	-0.4804	-0.2384
52825.4234	-0.6351	-0.3912	52826.4476	-0.4845	-0.2295
52825.4250	-0.6866	-0.4169	52826.4494		-0.2562
52825.4276	-0.7313	-0.4430	52826.4521	-0.5160	-0.2596
52825.4292	-0.7366	-0.4782	52826.4537	-0.5395	-0.2976
52825.4320	-0.7649	-0.5031	52826.4563	-0.5363	-0.3017
52825.4339	-0.7449	-0.4953	52826.4580	-0.5608	-0.3031
52825.4366	-0.7763	-0.5115	52826.4608	-0.6060	-0.3508
52825.4383	-0.7649	-0.5195	52826.4623	-0.5761	-0.3508
52825.4418	-0.8088	-0.5608	52826.4651	-0.6453	-0.3932
52825.4435	-0.8156	-0.5544	52826.4670	-0.6222	-0.4054
52825.4464	-0.8383	-0.5794	52826.4699	-0.6820	-0.4244
52825.4482	-0.8518	-0.5672	52826.4716	-0.6928	-0.4347
52825.4511	-0.8411	-0.5639	52826.4743	-0.7464	-0.4719
52825.4528	-0.8673	-0.6181	52826.4763		-0.4671
52825.4556	-0.8727	-0.6218	52826.4790		-0.4943
52825.4583	-0.8755	-0.6224	52826.4806	-0.7656	-0.4921
52825.4615	-0.8781	-0.6224	52826.4842		-0.5301
52825.4633	-0.9029	-0.6268	52826.4859	-0.7920	-0.5458
52825.4664	-0.9258	-0.6445	52826.4889	-0.8168	-0.5526
52825.4689	-0.9344	-0.6674	52826.4908	-0.8048	-0.5870
52825.4718	-0.9478	-0.6701	52826.4934	-0.8519	-0.5967
52825.4804	-0.9463	-0.6833	52826.4954	-0.8207	-0.5797
52825.4830		-0.6946	52826.4983	-0.8540	-0.6041
52825.4859		-0.7040	52826.5043	-0.8652	-0.6085
52825.4881	-0.9573		52826.5059	-0.8637	-0.6240
52825.4913	-0.9603		52826.5086	-0.8958	
52825.4928	-0.9566		52826.5103	-0.8698	
52825.4955	-0.9627	-0.6937	52826.5131	-0.9105	-0.6320
52825.4970	-0.9655	-0.7052	52826.5152		-0.6446
52825.4993	-0.9693	-0.6948	52826.5184	-0.8774	-0.6361
52825.5044	-0.9635	-0.7085	52826.5250	-0.9005	-0.6390
52825.5060	-0.9734		52826.5267		-0.6519
52825.5085	-0.9691		52826.5370	-0.9325	-0.6679
52825.5100	-0.9478	-0.6707	52826.5403	-0.9182	-0.6521
52825.5124	-0.9563	-0.6771	52826.5422		-0.6772
52825.5138	-0.9371	-0.7069	52826.5447	-0.9173	-0.6672
52825.5163	-0.9432	-0.6992	52826.5502	-0.9420	-0.6555
52825.5220		-0.6539	52826.5545		-0.6642
52825.5250	-0.9187	-0.6499	52826.5585		-0.6370
52825.5266	-0.9209	-0.6597			

gram came out which can be seen in the residuals from the parabolic approximation in Fig. 3c. This additional structure has a smooth cyclic character superimposed on the general quadratic trend. We have quickly tested the significance of this cyclic character by looking the difference in the values of sum of squared residuals of the fits to the $O-C$ data with only a parabolic and a parabolic+cyclic approximations. The sum of squared residuals $\Sigma(O-C)^2$ turns out to be 0.00139 day^2 and 0.00042 day^2 for pure parabolic and parabolic+cyclic fits, respectively. There are two groups of outliers of minima times in our data set which are encircled in Fig. 3c; one by Garcia-Melendo (2003) (4 minima) and the other by Agerer et al. (2003) (2 minima) around epoch numbers $E\sim 0$ and $E\sim 2990$, respectively. If we have excluded these outliers from the current analysis, we have reached an improvement in the $\Sigma(O-C)^2$ by a factor of about 8. In this case the resulting sum of squared residuals are 0.00055 and 0.00007 for pure parabolic and parabolic+cyclic approximations, respectively. As seen from these values the sum of squared residuals substantially improved when the cyclic variation has been taken in account and we believe that the observed cyclic variation is real in the $O-C$ diagram.

The cyclic character has one minimum and almost two maxima with the present observational data which could not be realized by Csizmadia (2001) due to the insufficient coverage of data in time. Four years of addition of new minima times to the list of Csizmadia (2001) give the possibility to see that variation. By assuming the presence of a gravitationally bound third body in the system, we were performed an analysis of this variation and derived the parameters of the light-time orbit with the following equation which is based on formulation by Irwin (1952):

$$(O-C) = O - [T_0 + P_{\rm orb}\times E + \frac{1}{2}\frac{{\rm d}P}{{\rm d}E}\times E^2 + \frac{A}{\sqrt{1-e'^2\cos^2\omega'}}\{\frac{1-e'^2}{1+e'\cos\nu'}\sin(\nu'+\omega')+e'\sin\omega'\}]\,, \quad (4)$$

where

$$A = \frac{a'_{12}\sin i'\sqrt{1-e'^2\cos^2\omega'}}{2.590\times 10^{10}}$$

is the semi-amplitude of the light-time effect in days, a'_{12}, e', i' and ω' are the semi-major axis, eccentricity, inclination and the longitude of the periastron passage of the orbit of the eclipsing pair around the mass center of the system, respectively, ν' is the true anomaly of the position of the eclipsing pairs' mass center on the orbit, 2.590×10^{10} is the speed of light in km/day. E, $P_{\rm orb}$, T_0 and ${\rm d}P/{\rm d}E$ are stand for the cycle number, orbital period, the reference epoch for the primary minimum and the rate of the secular period change of the eclipsing pair, respectively. The epoch T' of the periastron passage and the period P_{12} of the third body orbit can be derived from the parameters in Eq. (4).

We used the computer code called OC2LTE30 by Ak et al. (2004) to determine the eight free parameters (namely T_0, $P_{\rm orb}$, ${\rm d}P/{\rm d}E$, P_{12}, T', $a'_{12}\sin i'$, e', ω') by least-squares fitting the $(O-C)$ values with the theoretical function given in Eq. (4). By applying this procedure, we have found the parameters and their standard errors given in Table 6. The estimated errors of these parameters arise from the non-linear least-squares method, on which the inverse problem solving method is based. Therefore, the real uncertainties of these parameters may be larger than the estimated ones, because this method does not taking into account the noise of the individual data points and possible correlation between the fitted parameters. So, the current values of standard errors listed in Table 6 should be taken in account as lower limits for their corresponding parameters. These parameters were used to obtain the theoretical $O-C$ curve which is plotted with a solid curve in Fig. 3b along with the observed values. The value of the sum of the squares of the residuals from Eq. (4) is $\Sigma(O-C)^2 = 0.00042$ day^2. The residuals from the overall fit can be seen in Fig. 3d.

Table 4. Results derived from the simultaneous light and radial velocity curve modelling of V842 Her in MOD-03 of the WD code. The parameters without errors are coupled to the other parameters or fixed

Parameter	Value±Error
Fixed parameters:	
$A_1 = A_2$	0.5
$g_1 = g_2$	0.32
$F_1 = F_2$	1.0
e (eccentricity)	0.0
V_γ [km s^{-1}]	−57.98
$q(m_2/m_1)$	3.852
T_1 (K)	5700
$x_1(B,V)$	0.539, 0.275
$y_1(B,V)$	0.347, 0.568
$x_2(B,V)$	0.694, 0.403
$y_2(B,V)$	0.177, 0.441
Adjusted parameters:	
i [°]	77.74±0.74
$\Omega_1 = \Omega_2$	7.566±0.020
T_2 (K)	5362±20
L_1/L_1+L_2 (B)	0.297±0.006
L_1/L_1+L_2 (V)	0.278±0.005
L_2/L_1+L_2 (B)	0.654
L_2/L_1+L_2 (V)	0.677
Roche geometry related dimensions:	
r_1 (pole)	0.261±0.001
r_1 (side)	0.273±0.002
r_1 (back)	0.314±0.003
r_2 (pole)	0.476±0.001
r_2 (side)	0.517±0.002
r_2 (back)	0.544±0.002
f (fill-out factor)	25.4 %
$\Sigma(O-C)^2$	0.02

5. Results and conclusions

New B and V light curves of V842 Her were obtained and analysed simultaneously with the radial velocity curves by Rucinski & Lu (1999). Revised version of the Wilson-Devinney (WD-2003) code was used during this analysis. The analysis yield that the more massive component is 338 K

Table 5. All available minima times of V842 Her

HJD Min (2400000+)	Type	Meth	$O-C$	Ref	HJD Min (2400000+)	Type	Meth	$O-C$	Ref	HJD Min	Type	Meth	$O-C$	Ref
47646.5258	1	vis	0.0293	1	49074.6000	1	vis	0.0254	3	51433.3550	1	ccd	0.0211	14
47666.4470	2	ptg	0.0462	2	49075.4300	1	vis	0.0173	3	51660.4646	1	vis	0.0127	15
47670.4210	1	ptg	0.0394	2	49076.4590	2	vis	-0.0013	3	51664.4431	2	ccd	0.0103	16
47724.4573	1	vis	0.0199	1	49112.5040	2	vis	0.0065	3	51668.4211	1	ccd	0.0075	16
47758.4179	1	vis	0.0385	1	49124.4590	1	vis	0.0190	3	51670.5306	1	vis	0.0218	15
48072.4829	2	vis	0.0353	1	49124.6595	2	pe	0.0099	4	51722.4750	1	vis	0.0056	17
48086.5102	1	vis	0.0248	1	49206.3670	2	vis	0.0052	3	51782.4020	1	vis	0.0103	18
48148.3332	2	vis	0.0399	1	49237.3750	2	vis	0.0045	3	51786.3870	2	pe	0.0144	14
48513.3116	2	vis	0.0370	1	49296.2650	1	vis	0.0198	5	51816.3550	1	vis	0.0213	18
48622.6629	2	pe	0.0197	1	49780.6620	1	vis	0.0100	6	52053.5100	1	vis	0.0014	18
48661.6339	2	vis	0.0202	1	49799.5080	1	vis	-0.0006	6	52087.4550	1	vis	0.0044	19
48714.6430	1	vis	0.0212	1	49929.4182	1	ccd	0.0081	7	52113.4560	1	vis	0.0251	19
48732.4452	2	vis	0.0143	1	50144.3803	1	ccd	0.0042	8	52215.2800	1	vis	0.0231	17
48733.4994	1	vis	0.0209	1	50144.5898	2	ccd	0.0042	8	52321.4980	2	vis	0.0152	17
48746.4931	1	vis	0.0245	1	50151.5038	1	ccd	0.0041	8	52347.4840	2	vis	0.0209	19
48747.5362	2	vis	0.0200	1	50171.6103	1	ccd	-0.0032	9	52359.4217	1	ccd	0.0160	20
48749.4341	1	vis	0.0322	1	50177.4767	1	ccd	-0.0033	9	52367.3780	1	vis	0.0106	19
48755.5041	2	vis	0.0262	1	50178.5243	2	ccd	-0.0033	9	52426.4670	1	ccd	0.0154	14
48756.5507	1	vis	0.0252	1	50200.5350	1	vis	0.0080	10	52427.5141	2	ccd	0.0149	21
48759.4833	1	vis	0.0245	1	50207.4403	2	ccd	-0.0008	9	52452.4460	1	ccd	0.0141	14
48760.5381	2	vis	0.0317	1	50516.4872	1	ccd	0.0063	11	52764.4150	2	vis	0.0101	2
48763.4631	2	vis	0.0235	1	50538.4860	2	vis	0.0056	10	52825.3883	1	pe	0.0135	22
48768.4776	2	vis	0.0095	1	50541.4204	2	ccd	0.0068	11	52826.4379	2	pe	0.0155	22
48803.4718	1	vis	0.0141	1	50556.4990	2	vis	0.0000	12	53081.8388	1	ccd	0.0134	23
48811.4271	1	vis	0.0077	1	51030.4410	2	vis	0.0112	13	53111.8005	2	ccd	0.0139	23
48862.3545	2	vis	0.0221	1	51326.4894	1	pe	0.0099	14	53134.6371	1	ccd	0.0130	24
48877.4339	2	vis	0.0162	1	51327.5340	2	vis	0.0070	13	53211.3187	1	pe	0.0108	22
48888.3267	2	vis	0.0140	1	51425.3880	1	vis	0.0158	13	53214.4648	2	pe	0.0141	22
48983.6534	1	pe	0.0098	1	51430.4120	1	vis	0.0114	13					
49061.5912	1	vis	0.0067	1	51430.4190	1	ccd	0.0184	14					

References: 1- Vandenbroere (1993a), 2- Hübscher et al. (2003), 3- Vandenbroere, BBSAG Bull no.105, 4- Diethelm (1994), 5- Vandenbroere, BBSAG Bull no.107, 6- Vandenbroere, BBSAG Bull no.110, 7- Diethelm, BBSAG Bull no.109, 8- Agerer et al. (1997), 9- Garcia-Melendo (2003) 10- Vandenbroere, BBSAG Bull no.115, 11- Agerer et al. (1998), 12- Vandenbroere, BBSAG Bull no.116, 13- Vandenbroere, BBSAG Bull no.121, 14- Agerer et al. (2003), 15- Meyer (2000), 16- Csizmadia (2001), 17- Diethelm (2004), 18- Hübscher et al. (2001), 19- Hübscher et al. (2002), 20- Blaetter, BBSAG Bull no.128, 21- Diethelm, BBSAG Bull no.128, 22- This study, 23- Nelson (2005), 24- Dvorak (2005)

Table 6. Parameters derived from $(O-C)$ analysis

Parameters	Value	Standard Error
T_0 [HJD]	2450177.48750	0.00025
$P_{\rm orb}$ [days]	0.419034924	0.000000078
$\frac{\mathrm{d}P}{\mathrm{d}E}$ [days/cycle]	8.90×10^{-10}	0.14×10^{-10}
$a_{12}\sin i'$ [AU]	1.275	0.075
e'	0.480	0.039
ω' [°]	196.0	2.1
T' [HJD]	2453140.0	37.1
P_{12} [year]	12.35	0.08
A [days]	0.0064	0.0002
$f(m_3)$ [$M_\odot$]	0.01267	0.00218

cooler than the less massive component due to a dark-spot on its surface. The results of the light curve analysis indicate that V842 Her is a rather evolved (fill-out $f=25.4\%$) W-type W UMa contact binary where the less massive and smaller but slightly brighter component is occulted at the primary minimum. A view of the system's Roche geometry at orbital phase 0.75 based on our final model can be seen in Fig. 4. The parameters from light curve analysis and the precise mass ratio from radial velocity curve analysis by Rucinski & Lu (1999) allows us to determine absolute parameters of the V842 Her system as listed in Table 7. Moreover, we estimated the distance to the system by using these absolute parameters. Taking the bolometric magnitudes of the components and a bolometric correction of $-0\overset{\mathrm{m}}{.}07$ for the corresponding spectral type, a distance modulus could be calculated as $5\overset{\mathrm{m}}{.}90$ with the assumption of $A_V=0$. The dynamical parallax derived in that way yields a distance of 151.48 ± 2.30 parsecs which is the first distance estimate for V842 Her in the literature.

Table 7. Absolute dimensions of V842 Her

Parameter	Value
$a[R_\odot]$	2.881±0.010
$R_1[R_\odot]$	0.812±0.009
$R_2[R_\odot]$	1.474±0.010
$M_1[M_\odot]$	0.378±0.004
$M_2[M_\odot]$	1.455±0.026
Logg_1[cgs]	4.196±0.004
Logg_2[cgs]	4.264±0.002
$M_{\rm bol,1}$	5.263±0.023
$M_{\rm bol,2}$	4.234±0.031

It is obvious from the $O-C$ analysis that the orbital period of V842 Her is changing with a cyclic character superimposed on a monotonically increasing structure. The secular character which was represented with a quadratic term in the light elements during the analysis corresponds to a rate of orbital period increase by $\mathrm{d}P/\mathrm{d}t=7.76\times10^{-7}$ days yr^{-1} and can be attributed to mass exchange/loss mechanism in the system. If the period increase is originated from the conservative mass transfer phenomenon, then the direction of the mass transfer should be from the less massive to the more massive component with a rate of about $\mathrm{d}M/\mathrm{d}t=3.15\times10^{-7}$ $M_\odot$ yr^{-1}. In case of conservative mass transfer one can also es-

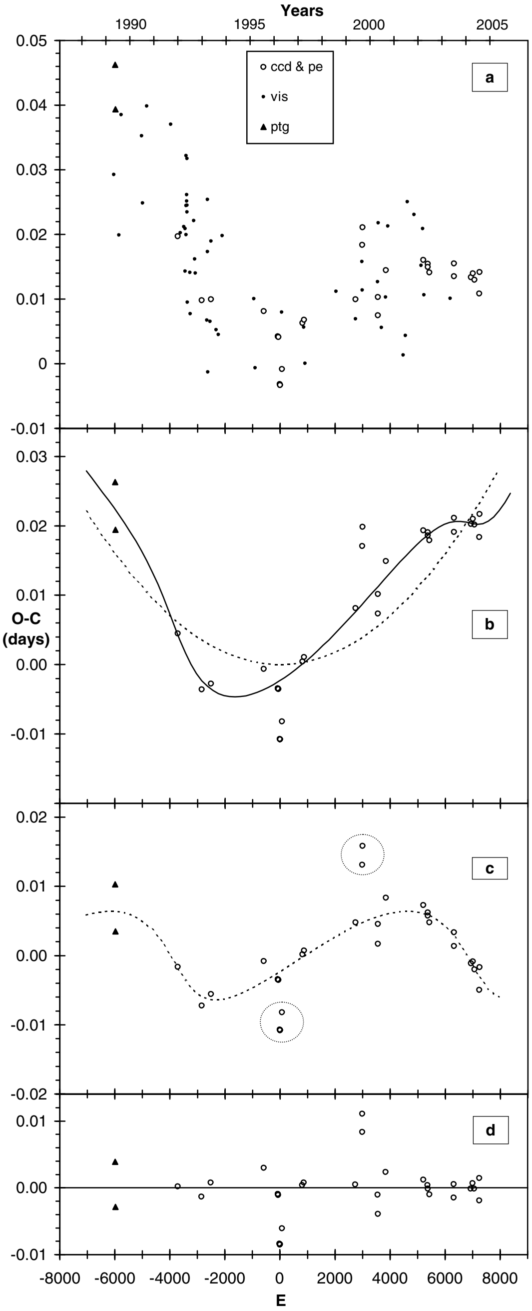

Fig. 3. a) The $O-C$ diagram for all available minima times of V842 Her, b) same as in a) but for photographic and photoelectric&CCD minima. The dashed curve representing the quadratic part of the fitted function, while the solid curve is the overall fit, c) the residuals from the quadratic fit. The dashed curve representing the cyclic part of the fitted function. See text for the encircled minima, d) final residuals from the fitted curve.

timate the rate of change of the mass ratio using the formulation given by Yang & Liu (2003). We calculated the rate of change of mass ratio for V842 Her due to the mass transfer in the system as $\mathrm{d}q/\mathrm{d}t = -2.73 \times 10^{-7}$ yr^{-1}. However, it should be noted here that the secular period change, studied in the present paper, may be part of a long-period cyclic variation, which needs more photoelectric or CCD times of light minimum to ascertain.

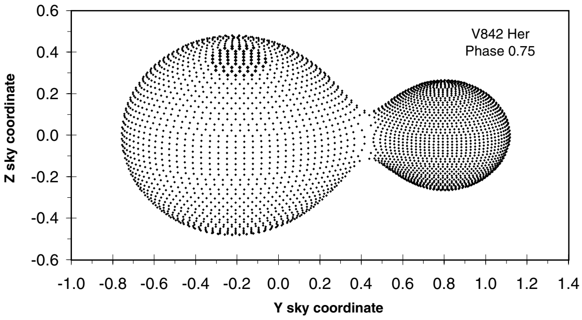

Fig. 4. The Roche geometry of V842 Her seen at phase 0.75.

Under the assumption of presence of a gravitationally bound third body in the system as a cause of observed cyclic character in the $O-C$ we calculated the third body specific parameters. The eclipsing pair completes a revolution on this wide orbit in 12.35 ± 0.08 yrs. The projected distance of the mass center of the eclipsing pair to the center of mass of the triple system should be 1.275 ± 0.075 AU. These values lead to mass function of $f(m_3) = 0.0127 \pm 0.0022 \mathrm{M}_\odot$ for the hypothetical third body. If the third body orbit is co-planar with the systemic orbit (i.e., $i^{'} = i = 77\overset{\circ}{.}74$), its mass would be 0.41$\pm$0.03 M$_\odot$. Then, Kepler's third law gives the semi-major axis of the orbit to be 7.01$\pm$0.04 AU. By adopting the distance to V842 Her $d = 151.48$ parsecs obtained in this study, we get the maximum angular separation of the third body from the eclipsing pair to be $0\overset{\prime\prime}{.}0462 \pm 0.0005$. Using the mass-luminosity relation for main-sequence stars given by Demircan & Kahraman (1991), we can estimate the bolometric absolute magnitude of the third body for the given distance to be about $M_{\mathrm{bol}} = 8\overset{\mathrm{m}}{.}4 \pm 0.2$ which is about $4\overset{\mathrm{m}}{.}5$ fainter than the combined brightness of the binary system. Thus, the third star, if it exist, is just at the detection limit of various observational techniques. Especially, the mass of the hypothetical third body which is comparable with mass of the secondary component of V842 Her, turn out to be large enough to permit its spectroscopic determination. However, Rucinski & Lu (1999) have not mention a trace of a third component in their work. Therefore the hypothetical third body, if it exist, should be a very under-luminous compact object in comparison to the main sequence stars or it may also be a low-mass close binary system.

W UMa-type contact binaries, especially W-subtypes, are well known to be magnetically very active, e.g. with starspots, chromospheric emission, coronal X-ray emission, and generally, the primary components of them are dominant in the level of this activity. Applegate (1992) has shown that any cyclic change in the activity level of one component in a close binary system can produce cyclic variation in the orbital period of the system. The basic idea of the magnetic activity cycle effect on the orbital period of a binary system depends on the existence of the spin-orbit coupling. Any change in the rotational regime of a binary star component due to the magnetic activity, will be reflected to the orbit as a consequence of the spin-orbit coupling. As an alternative for the cause of the observed cyclic variation in the O-C diagram of V842 Her, we have calculated the activity related parameters by following the Applegate's (1992) formulation as; the cycle length $P_{\rm cyc} = 12.35$ years, the amplitude of the cyclic period variation $\Delta P = 0.323$ sec cycle^{-1}, the angular momentum transfer of $\Delta J = -3.56 \times 10^{47}$ g cm^2 s^{-1} required to produce the observed cyclic effect on the orbital period, required energy $\Delta E = 1.25 \times 10^{41}$ ergs for the ΔJ transfer, the corresponding luminosity change $\Delta L = 1.01 \times 10^{33}$ ergs s^{-1} and the brightness variation $\Delta m = 0\overset{\rm m}{.}10$ of the primary component, and finally the subsurface magnetic field $B = 12.6$ kG of the primary component. Applegate (1992) also predicts that *i)* the long-term light variation and the O-C curve formed by the times of minima should have the same cycle length, *ii)* extrema in one should coincide with extrema in the other, and *iii)* the colour of the system should become bluer as the active star brightens. Unfortunately, we do not have enough precise and long-term photometric observations for V842 Her to check such brightness variations. But there is an evidence about the variable amount of O'Connell effect in the light curves of V842 Her (see Section 2). So, the system deserves to long-term photometric monitoring to clarify its plausible magnetic activity cycle characteristics.

It is important to distinguish the responsible mechanism for the observed cyclic variations in the O-C diagrams of the close binary stars. The light-time effect should give more strict periodicities than the magnetic activity cycle in the O-C diagrams. From the analogy of magnetic activity cycles in the Sun and chromospherically active stars, we know that the cycle periods and amplitudes can vary even from cycle to cycle. Therefore, their reflections in the O-C diagrams should have a quasi-periodic character. We can not discriminate the responsible mechanism for the cyclic variation in the O-C diagram of V842 Her at the moment due to the short time-span of the observational data. Only long-term systematic observations will give us a chance to decide on this matter.

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