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PHOTOMETRIC STUDY OF THE LIGHT CURVE OF THE EARLY TYPE BINARY V1898 CYG

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Abstract: The photoelectrical (BV) lightcurve of the eclipsing binary V1898 Cyg obtained by Dallaporta & Munari (2006) are here analyzed. The Wilson-Devinney Differential Correction program was used in the analysis and the results shows that the star is a semi-detached system with the secondary component that accurately fills its Roche lobe. The best fit was obtained at photometric mass ratio $q = 0.3018$ and inclination $i = 70°$.

V1898 Cyg = HD 200776 was discovered as a single lined spectroscopic binary by Abt et al. (1972) with a period of 2.9258 days, they calculated also a preliminary orbit. Photoelectric observations by McCrosky & Whitney (1982) were unable to fit this period with a reasonable light curve. Halbedel (1985) obtained (BV) photoelectric measurements and indicated an orbital period of 3.0239 days with nearly equally deep eclipses. New photoelectric observations by Dallaporta & Munari (2006) provides a complete light (BV) curves of this early type binary B2III (Fehrenbach & Rebeirot, 1962). Their data shows that the correct orbital ephemeris for primary minimum is :

$$Min(I) = HJD2452901.3740 + 1.51311E. \quad (1)$$

The new light curve shows well visible the secondary minimum, and widely differing depths of minima, that implying a significant temperature difference between the components.

The preliminary derived mass function for the system (Abt et al., 1972) $f(M) = 0.07M_\odot$ leads us to derive very small masses of the stellar components of V1898 Cyg in strong conflict with those expected for the spectral type derived (B2III). For this reason we decided to made a photometric analysis of the new (BV) light curves of V1898 Cyg, using the 2003 version of the Wilson & Devinney (1971) Differential Correction program. The convergence of the minimization procedure was obtained by means of the method of multiple subsets (Wilson & Biermann, 1976). To begin we used trial and error with the Wilson & Devinney (1971) Light Curve program. After many trials we derived a set of parameters which marginally represented the observed light curves. With this data, serving as started parameters, we proceeded with the computation using the Differential Correction program. The calculations were started in Mode 2 - a detached configuration with no constrains on the potentials (Leung & Wilson, 1977) to test the semi-detached configuration. After few iterations the solution converged to Mode 5 - a semi-detached configuration with star 2 accurately filling its Roche Lobe.

The unadjustable parameters we employed in Mode 5 were: the temperature of the primary component (star eclipsed at Min.I), T_1 = 20183 K using the given spectra B2III and the tables of de Jager & Nieuwenhuijzen (1987); the gravity-darkening exponents, g_1= 1.0 and g_2 = 0.32 (Lucy, 1967); the bolometric and wavelength-dependent limb darkening coefficients ($x_{1bolo}, x_{2bolo}, y_{1bolo}, y_{2bolo}, x_{1V}, x_{2V}$), using the square root law (LD = 3), taken from Van Hamme (1993) for log g = 4.0 and solar abundances, and the Ω_2 potential. A fine surface grid, N1 = N2 = 30 , N1L = N2L = 25 and symmetrical partial derivatives for each of the adjustable parameters (ISYM = 1) were adopted during all calculations. The simple reflection model (Wilson, 1990)

Table 1: Parameters combinations used.

solution	$IFAT_1$	$IFAT_2$	A_1	A_2
I	0	0	1	free
II	1	1	1	free
III	1	0	1	1
IV	1	1	1	1

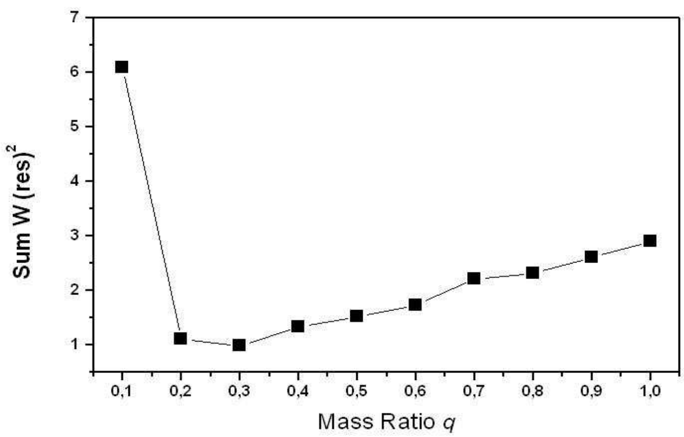

Figure 1: $\sum(res)^2$ versus mass ratio in Mode 5 solution I (see the text).

was used with a single reflection (MREF = 1 , NREF = 1) . No third light was allowed for , l_3 = 0.0, circular orbit and synchronous rotation were assumed ($F_1 = F_2 = 1$).

A search for solution was made for several fixed values of mass ratio q in the range between 0.1 and 1.0. A sufficient number of runs of the DC programme was made until the sum of the residual $\sum(res)^2$ showed a minimum and the corrections to the parameters became smaller then the probable errors.

Due to the light curve features, the reflection effect is clearly visible (Kallarath & Milone, 1999), and due to the statement of Abt et al. (1972) in their paper (e = 0.06) we made different Wilson-Devinney working session with different adjustable parameters.

In the first session the adjustable parameters employed were: the inclination i, the mean surface temperature of secondary component T_2, the non-dimensional surface potential Ω_1, the monochromatic luminosity of the primary component L_1 (the black-body option was used in the computing code), and the eccentricity e. After few iterations the value of the eccentricity e tends to 0. So we decided to left fixed also this parameter to the value of 0. We made also an analysis simultaneously for both the light curves and the redial velocity curve but without good results in fact, due to the poor quality of the Abt et al. (1972) spectroscopic observations the results didn't fit well the observed light curves.

Others WD sessions were made with different combinations of the IFAT parameter and the value of the bolometric albedo of the secondary A_2. In the Differential Correction programme the control IFAT is used to switch between the black body or stellar atmosphere formulation. The bolometric albedo of the primary A_1 was fixed to its theoretical value of 1.0 (Rucinski, 1969).

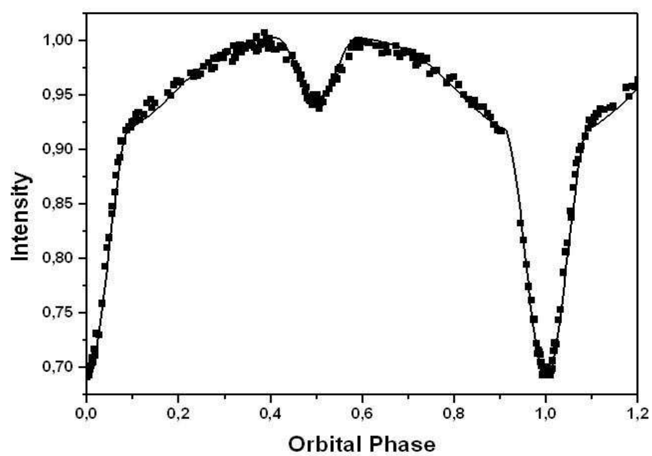

Figure 2: The observations (points) and the theoretical (line) light curve of V1898 Cyg in *B* filter.

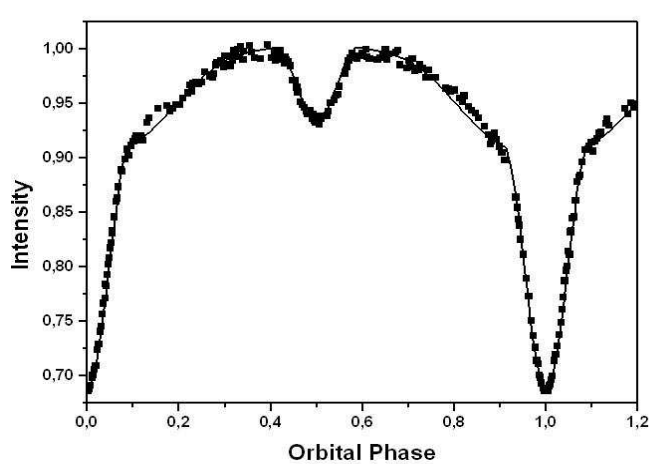

Figure 3: The same of Fig.2 but for the *V* filter.

Table 2: Light curve solution of V1898 Cyg for the different combinations of parameters.

Parmeter	I	II	III	IV
i	70°.256 ±0°.055	70°.863 ±0°.064	68°.860 ±0°.037	69°.767 ±0°.039
$T_1(K)$	20183*	20183*	20183*	20183*
$T_2(K)$	7491 ± 5	6682 ± 4	7538 ± 3	7045 ± 4
f	-0.284 ± 0.004	-0.216 ± 0.007	-0.275 ± 0.003	-0.280 ± 0.007
Ω_1	3.4679 ± 0.0095	3.3537 ± 0.0100	3.7981 ± 0.0080	3.5881 ± 0.0105
Ω_2	2.4737*	2.3953*	2.7316*	2.5692*
$q = m_2/m_1$	0.30184 ± 0.0029	0.37022 ± 0.0031	0.42738 ± 0.0023	0.34813 ± 0.0024
A_1	1.0*	1.0*	1.0*	1.0*
A_2	0.867 ± 0.016	0.625 ± 0.015	0.5*	0.5*
g_1	1.0*	1.0*	1.0*	1.0*
g_2	0.32*	0.32*	0.32*	0.32*
$L_{1V}/(L_1+L_2)$	0.878 ± 0.002	0.893 ± 0.002	0.841 ± 0.002	0.869 ± 0.020
$L_{2V}/(L_1+L_2)$	0.056 ± 0.002	0.043 ± 0.001	0.097 ± 0.003	0.067 ± 0.001
$L_{1B}/(L_1+L_2)$	0.906 ± 0.001	0.914 ± 0.001	0.882 ± 0.002	0.899 ± 0.002
$L_{2B}/(L_1+L_2)$	0.036 ± 0.002	0.024 ± 0.002	0.061 ± 0.002	0.041 ± 0.002
X_{1V}	-0.074*	-0.074*	-0.074*	-0.074*
X_{2V}	+0.334*	+0.334*	+0.334*	+0.334*
X_{1B}	-0.091*	-0.091*	-0.091*	-0.091*
X_{2B}	+0.643*	+0.643*	+0.643*	+0.643*
L_3	0	0	0	0
Primary component				
$r(pole)$	0.3138 ± 0.0010	0.3234 ± 0.0011	0.2947 ± 0.0007	0.3070 ± 0.0010
$r(side)$	0.3205 ± 0.0010	0.3307 ± 0.0014	0.3003 ± 0.0007	0.3133 ± 0.0011
$r(back)$	0.3247 ± 0.0011	0.3349 ± 0.0010	0.3050 ± 0.0008	0.3177 ± 0.0012
Secondary component				
$r(pole)$	0.2620 ± 0.0007	0.2532 ± 0.0009	0.2874 ± 0.0004	0.2720 ± 0.0005
$r(side)$	0.2728 ± 0.0007	0.2635 ± 0.0009	0.2997 ± 0.0004	0.2833 ± 0.0005
$r(back)$	0.3055 ± 0.0007	0.2961 ± 0.0010	0.3323 ± 0.0004	0.3161 ± 0.0006
$\sum(res)^2$	0.81422	0.92756	0.84796	0.94636

* assumed

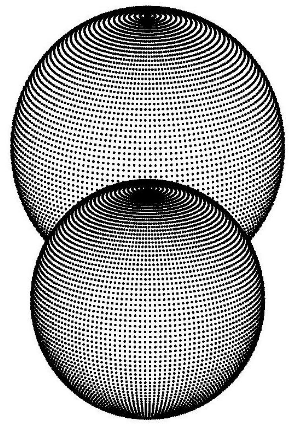

Figure 4: A three-dimensional model of V1898 Cyg at phase 1. The hotter, more massive component is eclipsed.

In Table 1 we resume the IFAT and bolometric albedos combinations used for the different solutions, while all the results obtained for each WD session are showed in Table 2. As one can see from the Table 2 the minimum of the $\sum(res)^2$ for the different solutions was obtained for the first one (I). The sum of weighted square deviations $\sum(res)^2$ versus mass ratio q for this solution (I) is shown in Figure 1, a sharp minimum of $\sum(res)^2$ is found at the mass ratio 0.3. Then we used q = 0.3 as the initial value of the mass ratio in the Differential Correction procedure with q treated as an additional free parameter. The synthetic light curves, corresponding to the best solutions, are shown with the continuous lines in Figure 2 (B filter) and in Figure 3 (V filter), the agreement between the computed and the observed light curves is not very satisfactory in the (V) passband, due this to the asymmetry of the secondary minimum, which must be due to surface inhomogeneities of the components. We remark that the probable errors provided by the WD code are unrealistically small (Maceroni & Rucinski, 1997).
From the light curves we can see widely differing depths of minima, that implying a significant temperature difference between the components. The primary eclipse is due to the transit of the cooler, less massive secondary component across the face of the hotter primary (Figure 4).

The solutions for detached configuration reveal that the secondary is slightly inside the inner critical Roche lobe. Figure 5 shows this configuration in the orbital plane. The distance between the surface of the secondary and its Roche lobe is very small, indicating that, for the system V1898 Cyg, the semi-detached solution, near-contact binary system (NCBs), is the correct one. NCBs are considered to be an evolutionary precursor of the A-subtype W UMa binaries (Qian, 2002), inside the Thermal Relaxation Oscillation (TRO) model (Lucy, 1976); (Flannery, 1976); (Robertson & Eggleton, 1977).

Shaw (1994) divided the near-contact systems into two subclasses: (a) V1010 Ophiuchi systems, in which the primary components are almost or completely filling its Roche lobe whereas the secondary components are inside it. The light curves are always asymmetric with the primary maxima brighter than secondary maxima, and both components are slightly evolved; and (b) FO Virginis binaries, in which the primary components are inside its Roche lobe, whereas the secondaries are close to or filling their Roche lobes, the light curves show no asymmetry, and the components may be very evolved.

From the photometric solution of V1898 Cyg, we find that the secondary component is closer to its Roche lobe than the primary one. However the light curve of the system is clearly asymmetric in (V) filter. Hence, is not simple to include V1898 Cyg in the FO Virginis or V1010 Oph subclass of near-contact binaries.

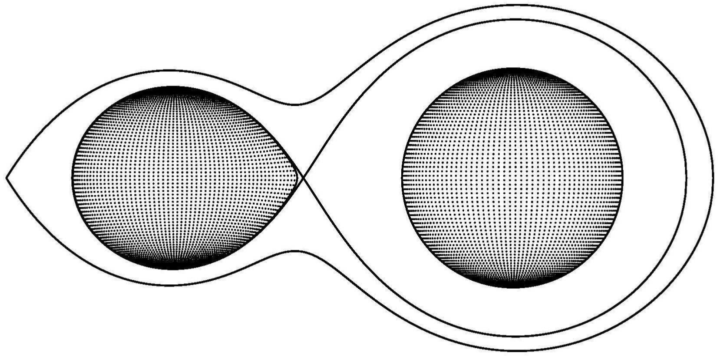

Figure 5: Configuration of the components of V1898 Cyg in the orbital plane according to our solution I.

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