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V1898 CYGNI: AN INTERACTING ECLIPSING BINARY IN THE VICINITY OF NORTH AMERICA NEBULA[1]

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RESUMEN

Presentamos observaciones espectroscópicas de la binaria eclipsante tipo Algol, de doble línea, V1898 Cygni. El análisis de las curvas de luz en las bandas BV nos lleva a una determinación de los parámetros fundamentales de las componentes de V1898 Cygni. Los parámetros absolutos son: $M_1 = 6.054 \pm 0.037\ M_\odot$, $M_2 = 1.162 \pm 0.011\ M_\odot$, $R_1 = 3.526 \pm 0.009\ R_\odot$, $R_2 = 2.640 \pm 0.010\ R_\odot$, $T_{\mathrm{eff}_1} = 18000 \pm 600$ K, y $T_{\mathrm{eff}_2} = 6200 \pm 200$ K. Analizamos los residuos entre los tiempos observados y calculados para el eclipse medio y obtenemos una tasa de cambio del período de $\dot{P}/P = 6.68 \times 10^{-7}$ yr^{-1}. Estimamos una tasa de transferencia de masa de $1.88 \times 10^{-7}\ M_\odot$ por año. Utilizando las magnitudes infrarojas JHK y las correcciones bolométricas para la estrella primaria, calculamos la distancia al sistema V1898 Cyg como 501 ± 5 pc. Las componentes de los movimientos propios del sistema presentan alguna información sobre su pertenencia a la Nebulosa de Norteamérica.

ABSTRACT

We present spectroscopic observations of the double-lined Algol type eclipsing binary V1898 Cyg. Analyses of the BV light curves and RVs led to determination of the fundamental stellar parameters of the V1898 Cyg's components. The absolute parameters for the stars are derived as: $M_1 = 6.054 \pm 0.037\ M_\odot$, $M_2 = 1.162 \pm 0.011\ M_\odot$, $R_1 = 3.526 \pm 0.009\ R_\odot$, $R_2 = 2.640 \pm 0.010\ R_\odot$, $T_{\mathrm{eff}_1} = 18000 \pm 600$ K, and $T_{\mathrm{eff}_2} = 6200 \pm 200$ K. The residuals between the observed and computed times of mid-eclipses were analysed and a rate of the period change $\dot{P}/P = 6.68 \times 10^{-7}$ yr^{-1} was obtained; a mass transfer rate of $1.88 \times 10^{-7}\ M_\odot$ in a year is estimated. We have calculated the distance to the system V1898 Cyg as 501 ± 5 pc using the infrared JHK magnitudes and bolometric corrections for the primary star. The components of the system's proper motions present some indications about membership to the North America nebula.

Key Words: binaries: close — binaries: eclipsing — binaries: general — binaries: spectroscopic — stars: individual (V1898 Cyg)

1. INTRODUCTION

V1898 Cyg (HD 200776, BD +45° 3384, 2MASS J21035377+4619499, HIP 103968, $V = 7^m.81$, $(B-V) = +0^m.01$) was discovered to be a single-lined spectroscopic binary by Abt, Levy, & Gandet (1972). HD 200776 was included in the list of bright OB stars to be observed for the determination of galactic rotation constants and other galactic parameters. Their spectroscopic observations yield that HD 200776 is a spectroscopic binary with an orbital period of 2.9258 days. They also calculated the preliminary elements and mass function for the system. McCrosky & Whitney (1982) searched for photometric variations in some short-period spectroscopic binaries (including HD 200776) given in the Seventh Catalogue of the Orbital Elements of Spectroscopic Binary System (Batten, Fletcher, & Mann 1978). They observed abrupt drops, amounting to

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$0^m.2 - 0^m.4$, in the brightness of the system which were inconsistent with the orbital period proposed by Abt et al. (1972). Photometric observations in the B and V-bandpass made by Halbedel (1985) revealed that HD 200776 is an eclipsing binary with both eclipses nearly identical, in contrast to the spectroscopic observations. He proposed a new orbital period of 3.0239 days, 3 percent longer than that given by Abt et al. (1972). Caton & Smith (2005, hereafter CS) published a new light curve and new times of mid-eclipses as well as a new orbital period of 1.5131273 days, nearly half that of given by Halbedel (1985). Later, Dallaporta & Munari (2006, hereafter DM) presented complete and accurate BV light curves of HD 200776 as well as three times for the mid-primary eclipse. Fortunately the same comparison star was used in the photometric observations of Halbedel (1985) and DM. No further spectroscopic observations were made for this eclipsing-spectroscopic binary after Abt et al. (1972).

The main aims of this study are: (1) to detect some lines of the secondary component; (2) to reveal radial velocities for both components; (3) to solve the radial velocity curves for the primary and secondary components on the basis of new observations in order to obtain accurate masses and radii; and (4) to determine the rotational velocities of the components and compare them with those expected for orbital synchronization.

2. SPECTROSCOPIC OBSERVATIONS

The spectra were obtained with several telescopes over the course of three years, beginning in 2007. Table 1 lists the full set of observations. The first set was observed with the Échelle spectrograph (FRESCO) at the 91 cm telescope of Catania Astrophysical Observatory. Spectroscopic observations were performed with the spectrograph fed by the telescope through an optical fibre (UV-NIR, 100 μm core diameter) and located, in a stable position, in the room below the dome level. Spectra were recorded on a CCD camera equipped with a thinned back-illuminated SITe CCD of 1k×1k pixels (size 24×24 μm). The cross-dispersed échelle configuration yields a resolution of about 22000, as deduced from the full width at half maximum of the lines of the Th-Ar calibration lamp. The spectra cover the wavelength range from 4300 to 6650 Å, split into 19 orders. In this spectral region, and in particular in the blue portion of the spectrum, there are several lines useful for measuring the radial velocity, as well as for spectral classification of the stars.

The system was also observed with the Turkish Faint Object Spectrograph Camera (TFOSC) attached to the 1.5 m RTT150 telescope on August 07–20, 2010 under good seeing conditions[4]. The wavelength coverage of each spectrum was 4100–9000 Å in 11 orders, with a resolving power of $\lambda/\delta\lambda$ 7000 at 6563 Å.

The electronic bias was removed from all spectra and we used the CRREJECT task of IRAF[5] for cosmic ray removal. The échelle spectra were extracted and wavelength calibrated by using a Fe-Ar and Th-Ar lamp source with help of the IRAF echelle package. The stability of the instruments was checked by cross-correlating the spectra of the standard star against each other using the FXCOR task in IRAF. The standard deviation of the differences between the velocities measured using FXCOR and the velocities in Nidever et al. (2002) was about 1.1 km s^{-1}.

Twenty-eight spectra of V1898 Cyg were collected during the two different seasons. Typical exposure times for the V1898 Cyg spectroscopic observations were between 2400 and 2600 s for the Catania telescope and 1200 s for the RTT150 telescope. The signal-to-noise ratio (S/N) achieved was between 70 and 115, and ∼150 depending on atmospheric condition. α Lyr (A0V), 59 Her (A3IV), ι Psc (F7V), HD 27962 (A2IV), and τ Her (B5IV) were observed during each run as radial velocity and/or rotational velocity templates. The average S/N at the continuum in the spectral region of interest was 150–200 for the standard stars.

3. SPECTROSCOPIC ANALYSIS

Double-lined spectroscopic binaries reveal two peaks in the cross-correlation function (CCF) between variable and the radial velocity template spectrum, which displace back and forth, as seen in Figure 1. The location of the peaks allows to measure the radial velocity of each component at the time of observation. The cross-correlation technique applied to digitized spectra is now one of the standard tools for the measurement of radial velocities in close binary systems.

The radial velocities of V1898 Cyg were obtained by cross-correlating échelle orders of the V1898 Cyg spectra with the spectra of the bright radial velocity standard stars α Lyr (A0V), 59 Her (A3IV) and ι Psc (F7V) (Nordström et al. 2004). For this purpose the IRAF task FXCOR was used.

[4]Further details on the telescope and the spectrograph can be found at `http://www.tug.tubitak.gov.tr`.

[5]IRAF is distributed by the National Optical Observatory, which is operated by the Association of the Universities for Research in Astronomy, inc. (AURA) under cooperative agreement with the National Science Foundation.

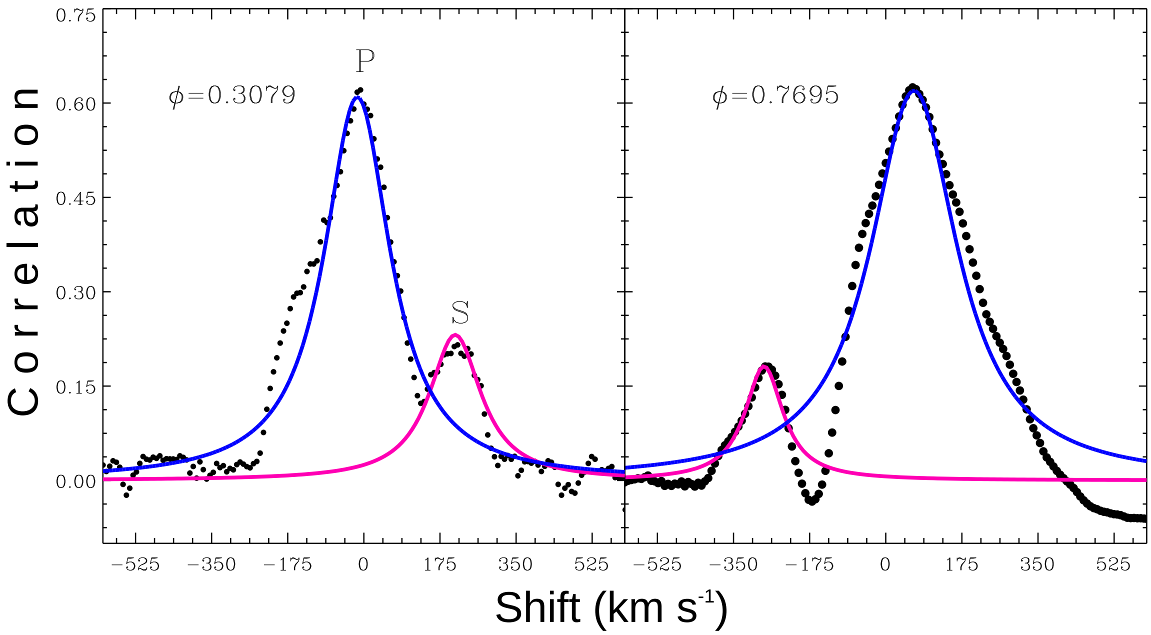

Fig. 1. Sample of Cross Correlation Functions (CCFs) between V1898 Cyg and the radial velocity template spectrum (Vega) at four different orbital phases. The color figure can be viewed online.

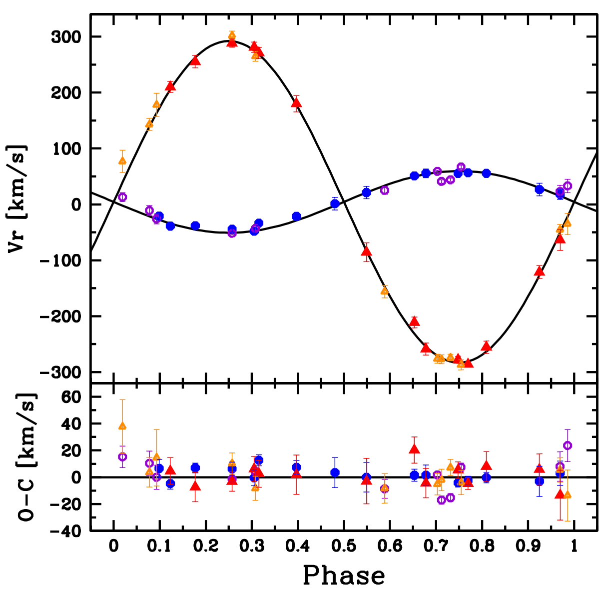

Fig. 2. Radial velocities of the primary (dots) and secondary stars (triangles) folded on an orbital period of 1.513126 days. The velocities obtained at the Catania observatory are indicated by filled symbols while those obtained at the National Observatory of Turkey by open symbols. The vertical lines show error bars of each radial velocity. The residuals between the observed and computed RVs are plotted in the lower panel. The color figure can be viewed online.

Figure 1 shows examples of CCFs of V1898 Cyg near the first and second quadrature. The two non-blended peaks correspond to each component of V1898 Cyg. We applied the cross-correlation technique to five wavelength regions with well-defined absorption lines of the primary and secondary components. These regions include the following lines: Si III 4568 Å, Mg II 4481 Å, He I 5016 Å, He I 4917 Å, He I 5876 Å. The stronger CCF peak corresponds to the more massive component that also has a larger contribution to the observed spectrum. To better evaluate the centroids of the peaks (i.e. the radial velocity difference between the target and the template), we adopted two separate Gaussian fits for the case of significant peak separation.

The radial velocity measurements, listed in Table 1 together with their standard errors, are weighted means of the individual values deduced from each order. The observational points and their error bars are displayed in Figure 2 as a function of orbital phase as calculated by means of the linear part of the ephemeris given in equation (2). The radial velocities of the secondary component of V1898 Cyg are presented for the first time in this study. The simultaneous analysis of both curves shows the semi-amplitude of the more massive, more luminous component to be $K_1 = 55.2 \pm 0.8$ km s^{-1} and $K_2 = 287.6 \pm 2.1$ km s^{-1} for the secondary component, with a systemic velocity of 4.4 ± 0.8 km $^{-1}$.

TABLE 1

RADIAL VELOCITIES OF THE V1898 CYG'S COMPONENTS[1]

HJD 2400000+	Phase	Star 1 $\mathbf{V}_p$	σ	O-C	Star 2 $\mathbf{V}_s$	σ	O-C	Remarks
54327.55412	0.5489	21.1	10.9	0.0	−85.5	16.9	−3.0	a
54328.50480	0.1772	−38.1	3.6	6.9	255.3	11.1	−7.2	a
54329.46135	0.8093	55.5	3.9	−0.3	−255.5	11.1	8.0	a
54330.47685	0.4805	1.2	11.1	3.5	···	···	···	a
54331.44914	0.1231	−38.8	4.2	−4.7	210.1	9.9	4.7	a
54335.45358	0.7695	56.7	3.3	−2.5	−285.8	4.3	−4.8	a
54336.40281	0.3969	−21.5	5.1	7.3	179.9	14.6	1.9	a
54337.46485	0.0988	−21.1	6.6	6.5	···	···	···	a
54338.44704	0.7479	55.5	3.1	−4.1	−277.7	6.1	5.5	a
54360.40110	0.2571	−44.4	5.1	6.3	288.6	7.2	−3.2	a
54361.41090	0.9245	16.6	11.2	−3.0	−121.1	11.6	5.8	a
54362.55110	0.6780	55.5	7.7	1.4	−258.6	10.9	−4.3	a
54363.50010	0.3052	−47.9	5.9	−0.5	281.1	9.2	6.1	a
54364.50527	0.9695	18.0	9.1	3.1	−63.7	18.5	−13.4	a
54365.53939	0.6530	51.1	4.5	1.4	−211.1	9.8	20.3	a
54366.54137	0.3152	−33.5	4.1	12.6	270.9	10.1	2.6	a
55387.53130	0.0777	−11.0	9.0	10.4	143.0	11.0	3.6	b
55390.46920	0.0193	13.0	8.0	15.2	77.0	20.0	37.8	b
55390.58090	0.0932	−26.0	9.0	0.0	178.0	21.0	14.6	b
55391.50380	0.7031	59.0	2.0	1.8	−276.0	8.0	−5.2	b
55391.58150	0.7544	67.0	3.0	7.4	−287.0	9.0	−3.9	b
55392.41900	0.3079	−43.0	3.0	4.1	265.0	9.0	−8.3	b
55393.41980	0.9694	23.0	11.0	8.0	−45.0	9.0	5.5	b
55394.57290	0.7314	44.0	3.0	−15.2	−274.0	6.0	7.2	b
55396.47080	0.9857	33.0	12.0	23.6	−35.0	19.0	−13.6	b
55397.38320	0.5887	25.0	7.0	−8.6	−156.0	11.0	−8.3	b
55397.56950	0.7119	41.0	3.0	−17.0	−277.0	8.0	−2.0	b
55398.39480	0.2573	−52.0	2.0	−1.4	302.0	8.0	10.2	b

[1]The columns give the heliocentric Julian date, the orbital phase, the radial velocities of the two components with the corresponding errors and residuals.

Remarks: (a) Based on Catania and (b) on TUG observations.

3.1. *Spectral classification*

The spectral types of the stars can be found either from photometry or from spectroscopy or from both. The apparent visual magnitude and colors of V1898 Cyg were estimated by Hiltner (1956) as $V = 7^m.81$, $B-V = 0^m.01$, $U-B = -0^m.82$. However the apparent magnitudes are given by Reed (2003) as $7^m.0$, $7^m.80$ and $7^m.82$ in the U, B and V passbands, respectively. On the other hand, the $B-V$ color of the system out of eclipse was determined as $0^m.01$ by Halbedel (1985). We computed the $B-V$ color of the system at the maxima as $0^m.036$ using the data given by Dallaporta & Munari (2006). The combined spectral types are given as B1 IVp by Abt et al. (1972) and B2 III by Kennedy & Buscombe (1974). The infrared magnitudes of the system are given by Cutri et al. (2003) as $J = 7^m.697$, $H = 7^m.718$ and $K = 7^m.757$. Unfortunately, intermediate- and narrow-band photometric measurements are not available. Bessell, Castelli, & Plez (1998) derive reddening-independent Q-parameter from theoretical colors as $Q = (U-B) - 0.71\ (B-V)$. They also predict an interstellar reddening for the main-sequence OB stars as $E(B-V) = (B-V) - ((U-B) - 0.71(B-V))/3$. Using the observed $(U-B)$ and $(B-V)$ colors by Hiltner (1956) we find $E(B-V) = 0^m.28$, while Dallaporta & Munari (2006) estimate the reddening as $0^m.31$.

We computed the intrinsic colors of the primary component using the JHK magnitudes as $J-H = -0^m.021 \pm 0^m.044$ and $H-K = -0^m.039 \pm 0^m.033$. V1898 Cyg is located between supergiants and dwarfs in the infrared $(J-H)-(H-K)$ diagram (Tokunaga 2000). Using the the equations given by Straižys, Corbally, & Laugalys (2008) we estimated the interstellar reddening as $E(J-H) = 0^m.106 \pm 0^m.060$ and $E(H-K) = 0^m.052 \pm 0^m.060$. Using the transformation equation given by Bessell et al. (1998) we find $E(B-V) = 0^m.286$, in very good agreement with that found from the UBV colors. Since the observed common color index is $0^m.036$ one obtains an intrinsic $B-V$ color of $-0^m.25$ which corresponds to a B1V star in the calibrations of Papaj, Krelowski, & Wegner (1993).

We used our spectra to determine the spectral type of the primary component of V1898 Cyg. We followed the procedures of Hernández et al. (2004), choosing helium lines in the blue-wavelength region, where the contribution of the secondary component to the observed spectrum is almost negligible. From several spectra we measured EWs of HeI $\lambda\, 4026, 4144, 4387, 4922$ as 0.867 ± 0.044, 0554 ± 0.062, 0.497 ± 0.090, 0.768 ± 0.028 Å, respectively. Then we used the EW-spectral type diagrams given by Hernández et al. (2004). The EWs of the helium lines indicate that the spectral type of the primary component is $B1.8 \pm 0.6$ which is in a agreement with that obtained from infrared photometry. The calibration of Papaj et al. (1993) gives an effective temperature of 18700 K and $B-V$ of $-0^m.21$ for a B2V star, 16800 K and $-0^m.19$ for the same spectral type but for a giant star. Therefore, we estimated an effective temperature of 18000 ± 600 K for the primary component of V1898 Cyg.

3.2. *Reddening*

The measurement of reddening is a key step in determining the distance of stars. V1898 Cyg is located in the direction of the NAP, where reddening varies from one place to other. We estimated the reddening in the $B-V$ color as $0^m.29$ using the infrared colors. On the other hand we find $E(B-V) = 0^m.25$ for a star of type B2V and $E(B-V) = 0^m.23$ for a B2III star. The photometric and spectroscopic determinations of the interstellar reddening seem to be in a good agreement within a 3σ error. Our spectra cover the interstellar Na I (5890 and 5896 Å) doublet, which is an excellent estimator of the reddening as demonstrated by Munari & Zwitter (1997). They calibrated a tight relation linking the Na I D1 (5890 Å) equivalent widths with the $E(B-V)$ reddening. On spectra obtained at quadratures, lines from both components are un-blended with the interstellar ones, and they can therefore be accurately measured. We derive an equivalent width of 0.52 ± 0.06 Å for the Na I D1 line, which corresponds to $E(B-V) = 0^m.33 \pm 0.09$. Since the star is located nearly on the galactic plane ($l = 87°.60$, $b = -0°.34$) and near the edge of North America nebula (NAN) such a reddening at optical wavelengths is expected.

3.3. *Rotational velocity*

The width of the cross-correlation profile is a good tool for the measurement of $v \sin i$ (see, e.g., Queloz et al. 1998). The rotational velocities ($v \sin i$) of the two components were obtained by measuring the FWHM of the CCF peaks in nine high-S/N spectra of V1898 Cyg acquired close to the quadratures, where the spectral lines have the largest Doppler-shifts. In order to construct a calibration curve FWHM-$v \sin i$, we have used an average spectrum of HD 27962, acquired with the same instrumentation. Since the rotational velocity of HD 27962 is very low but not zero ($v \sin i \simeq 11$ km s^{-1}, e.g., Royer et al. (2002) and references therein), it could be considered as a useful template for A-type stars rotating faster than $v \sin i \simeq 10$ km s^{-1}. The spectrum of HD 27962 was synthetically broadened by convolution with rotational profiles of increasing $v \sin i$ in steps of 5 km s^{-1} and the cross-correlation with the original one was performed at each step. The FWHM of the CCF peak was measured and the FWHM-$v \sin i$ calibration was established. The $v \sin i$ values of the two components of V1898 Cyg were derived from the FWHM of their CCF peak and the aforementioned calibration relations, for a few wavelength regions and for the best spectra. This gave values of 110 ± 5 km s^{-1} for the primary star and 90 ± 9 km s^{-1} for the secondary star.

4. TIMES OF MINIMA AND THE ORBITAL PERIOD

Times of mid-eclipses were published by Halbedal (1985), CS, DM and Brát et al. (2008). These times of eclipses are presented in Table 2. The O-C(I) residuals are computed using the light curve elements given below,

$$\mathrm{MinI(HJD)} = 2\,450\,690.6948 + 1^d.51311 \times E\,, \quad (1)$$

where the orbital period is adopted from DM. The behavior of the deviations from the linear light curve

TABLE 2

TIMES OF MID-ECLIPSES FOR V1898 CYG AND THE O-C RESIDUALS (SEE TEXT)

Minimum time (HJD-2400000)	Epoch	O-C(I)	O-C(II)	O-C(III)	Ref.
45960.6758	−3126	−0.0371	0 .0139	0.0004	1
45963.6986	−3124	−0.0406	0.0105	−0.0030	1
46010.6101	−3093	−0.0355	0.0151	0.0018	1
46013.6351	−3091	−0.0367	0.0138	0.0006	1
50690.6948	0	0.0000	0.0010	0.0010	3
52169.7772	977.5	0.0174	0.0027	0.0014	3
52185.6636	988	0.0161	0.0013	0.0000	3
52895.3220	1457	0.0259	0.0036	0.0007	2
52901.3740	1461	0.0255	0.0031	0.0002	2
52928.6107	1479	0.0262	0.0035	0.0005	3
53207.7802	1663.5	0.0269	0.0013	−0.0025	3
53226.6966	1676	0.0294	0.0036	−0.0003	3
53246.3663	1689	0.0287	0.0027	−0.0013	2
53270.5757	1705	0.0284	0.0021	−0.0020	3
54443.2559	2480	0.0483	0.0096	0.0011	4
54443.2565	2480	0.0489	0.0102	0.0017	4
54691.4070	2644	0.0494	0.0080	−0.0016	4
54691.4089	2644	0.0513	0.0099	0.0003	4
54691.4097	2644	0.0521	0.0107	0.0011	4

References: (1) Halbedel (1985), (2) Dallaporta & Munari (2006), (3) Caton & Smith (2005), (4) Brát et al. (2008).

elements O-C(II) with respect to the epoch numbers suggests an upward curved parabola. Therefore, a parabolic fit to the data was adopted, which gives,

$$\mathrm{MinI(HJD)} = 2\,450\,690.6938(8) + 1^d.5131260(2) \times E + 1.38(13)10^{-9} \times E^2\,. \quad (2)$$

The standard mean errors in the last digits are given in parentheses. The coefficient of the quadratic term is positive, which indicates that the orbital period of the system is increasing with the epoch number. Such a quadratic ephemeris appears to a very good representation of the orbital period change of V1898 Cyg, as well as other interacting Algols. This quadratic behaviour of the O-C(II) residuals, plotted in the upper panel of Figure 3, is an indication of the secular period increase for the system. In the bottom panel of Figure 3 the O-C(III) residuals with respect to ephemeris (2) are plotted, which illustrates a good agreement between the timings and the new ephemeris. It is known that the classical Algols have an evolved less massive component which fills its Roche lobe and transfers its mass to the more massive primary star through the Lagrangian L_1 point of the system. The orbital period of the system is increasing at an average rate of $\dot{P}/P = 6.68(\pm 0.63) \times 10^{-7}$ yr^{-1} which means that the orbital period has increased by about 0.38(±0.04) seconds in the last 24 years. The sum of the squares of residuals for the parabolic fit is 3.672×10^{-5} d^2. We limited times of mid-eclipses covering about 24 yrs. The time span of the observations is too short to reveal any abrupt period change caused by the fast mass transfer phenomenon. Of course, observations to be obtained in the coming years could indicate some hints about the nature of the orbital period change. Assuming a conservative mass transfer from the less massive component to the more massive primary star we estimate a transfer of $1.88(\pm 0.17) \times 10^{-7}$ $M_\odot$ in a year.

5. ANALYSIS OF THE LIGHT CURVES

Three light curves V1898 Cyg have been obtained and published. The first photometric observations were obtained by Halbedel (1985) between July and November, 1985. The second photometric observations were made by CS from August 22, 2001 to Oc-

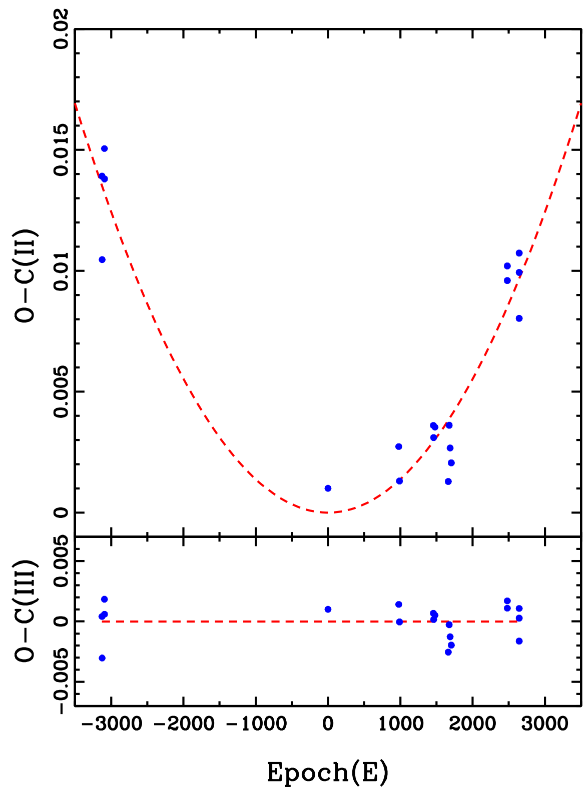

Fig. 3. The O-C(II) residuals plotted versus the epoch number for V1898 Cyg. A least-squares quadratic fit to the residuals is shown by the dashed line (upper panel). In the lower panel the O-C(III) residuals, the deviations from the quadratic fit, are also plotted. The color figure can be viewed online.

tober 26, 2004. The star was observed by DM from July 22, 2003 to September 17, 2004. Only the V-band light curve and observational data of CS were published. However, DM published the B and V light curves. The V light curves obtained in these studies are asymmetric in shape, and they differ from each other. The brightness of the system shows a fast decrease from phase 0.75 up to external contact. However, the increase in brightness following the primary eclipse is no steeper. The distortion of the light curve preceding the primary eclipse is larger in the CS light curve. A remarkable change in the light curve is seen at the phase interval between 0.09 and 0.42. The total brightness of the system in the V-bandpass at this phase interval is greater by about $0^m.03$ in the CS light curve than in DM's. However, CS report that the brightness of their primary comparison star showed light variations during the observations. Moreover the depth of the secondary eclipse is larger by about $0^m.007$ in the light curve of CS than in that of DM. We should note that there is also a slight asymmetry in both the DM's B- and V-passband light curves. This feature is attributed to the transfer of material from the cool secondary to the high temperature primary star which occults a small area of the primary star just before the deeper eclipse.

Acerbi & Barani (2007) analysed the DM's light curves. Since the spectroscopic mass-ratio was not available at that time, they started the analysis by deriving the photometric mass-ratio. Their preliminary analysis indicated that the mass-ratio for the system was about 0.30. Assuming an effective temperature of 20183 K for the primary component and that the secondary, less massive, star fills its corresponding Roche-lobe, i.e. a semi-detached configuration, they arrived at preliminary elements for the system. Their orbital parameters were: $i = 70°$, $r_1 = 0.3196$ and $r_2 = 0.2795$ and $T_2 = 7500$ K. Since the light curves were asymmetric they reported that the agreement between the computed and observed light curves was not very satisfactory: the sum of the squares of the residuals was about 0.814.

In order to analyse the light curves we choose the Wilson-Devinney (W-D) code implemented into the PHOEBE package tool by Prsa & Zwitter (2005). A preliminary analysis indicates that the system is a classical Algol, the secondary component filling its corresponding Roche lobe. Therefore Mode-5 is applied. The WD code is based on Roche geometry which is sensitive to the mass ratio which is taken from RV analysis as 0.192±0.002. Gravity-darkening exponents $g_1 = 1$, $g_2 = 0.32$ and bolometric albedos $\mathrm{Alb}_1 = 1$, $\mathrm{Alb}_2 = 0.5$ were set, i.e. the more massive star has a radiative envelope while the less massive secondary has a convective atmosphere. We used the non-linear square-root limb-darkening and the bolometric limb-darkening coefficients from the tables of Díaz-Cordovés, Claret, & Giménez (1995) and van Hamme (1993).

The orbital inclination (i), effective temperature of the secondary star (T_2), surface potential of the primary (Ω_1), phase shift ($\Delta\phi$), and fractional luminosity of the primary (L_1) were taken as adjustable parameters. The other parameters were fixed. The iterations were carried out automatically until convergence was achieved, and a solution was defined as the set of parameters for which the differential corrections were smaller than the probable errors. The final results obtained by separate analysis of three light curves are listed in Table 3 and the computed light curves are shown as continuous lines in Figure 4. The uncertainties assigned to the adjusted parameters are the internal errors provided directly

TABLE 3

RESULTS OF INDIVIDUAL LIGHT CURVE ANALYSES FOR V1898 CYG

Parameter	CS V	DM B	DM V
$i(^\circ)$	74.20±0.02	73.05±0.03	73.03±0.03
T_1 (K)		18000[Fix]	
T_2 (K)	6582±65	6205±76	6109±50
Ω_1	3.0887±0.0085	3.2885±0.0116	3.2784±0.0103
Ω_2		2.2122[Fix]	
$q_{\rm spec}$		0.1918[Fix]	
$L_1/(L_{1+2})$	0.9563±0.0013	0.9801±0.0017	0.9490±0.0016
r_1	0.3513±0.0013	0.3296±0.0013	0.3286±0.0012
r_2	0.2464±0.0012	0.2464±0.0012	0.2464±0.0012
$\Delta\phi$	0.0022±0.0001	0.0008±0.0001	0.0008±0.0001
$\Sigma(\rm res)^2$	0.1196	0.0109	0.0123

Ref: r_1, r_2: Relative volume radii, CS V: Caton & Smith's (2005) V-band light curve, DM B and DM V: The B- and V-band light curves of Dallaporta & Munari (2006). The errors quoted for the adjustable parameters are the formal errors determined by the WD-code.

TABLE 4

FUNDAMENTAL PARAMETERS OF V1898 CYG

Parameter	Primary	Secondary
Mass ($M_\odot$)	6.054±0.037	1.162±0.011
Radius ($R_\odot$)	3.526±0.009	2.640±0.010
$T_{\rm eff}$ (K)	18 000± 600	6 200±200
log ($L/L_\odot$)	3.071±0.029	0.957±0.085
log g (cgs)	4.125±0.002	3.660±0.004
Spectral type	B2IV±1	G2III±1
a ($R_\odot$)	10.714±0.022	
i ($^\circ$)	73.05±0.03	
d (pc)	501±5	
$(v \sin\, i)_{\rm obs}$ (km s^{-1})	110±5	90±9
$(v \sin\, i)_{\rm calc}$ (km s^{-1})	112.8±0.3	84.5±0.4
J, H, K_s (mag)*	7.697±0.035, 7.718±0.026, 7.757±0.020	
$\mu_\alpha \cos\delta$, μ_δ (mas yr^{-1})**	2.07±0.62, 0.81±0.53	

*2MASS All-Sky Point Source Catalogue (Cutri et al. 2003).

**Newly Reduced Hipparcos Catalogue (van Leeuwen 2007).

by the WD code. As seen in Table 3 the sum of the squares of the residuals is 0.0109 and 0.0123 for the B- and V-bandpass light curves, being 75-times smaller than those of the analysis made by Acerbi & Barani (2007) of the same data. In the bottom panel of Figure 4 the residuals between observed and computed intensities are also plotted. The residuals reveal that the binary model may represent the observed DM's light curves successfully. However, the computed light curve differs mostly from fourth contact to beginning of secondary eclipse in the CS light curve.

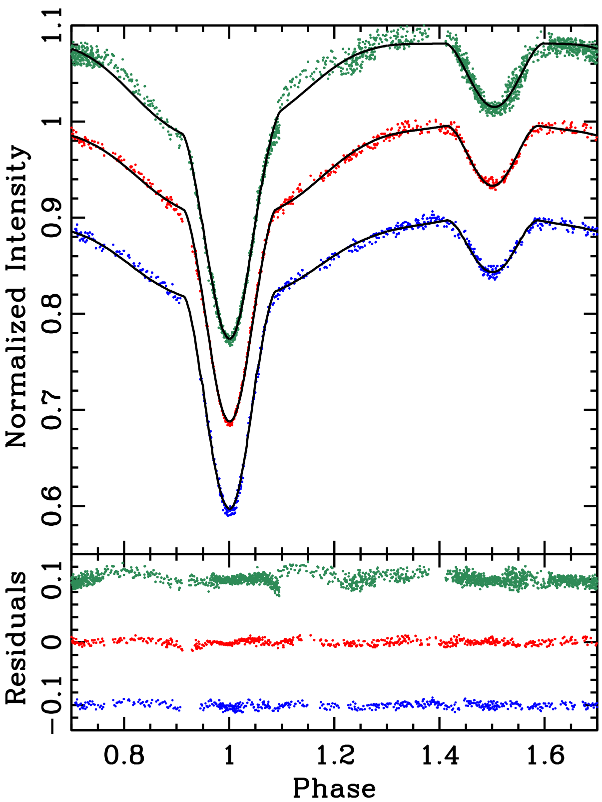

Fig. 4. Comparison of the observed and computed light curves of V1898 Cyg. From top to bottom the CS-V, DM-B and DM-V light curves, respectively. In the lower panel residuals have been plotted to show the goodness of the fits. The color figure can be viewed online.

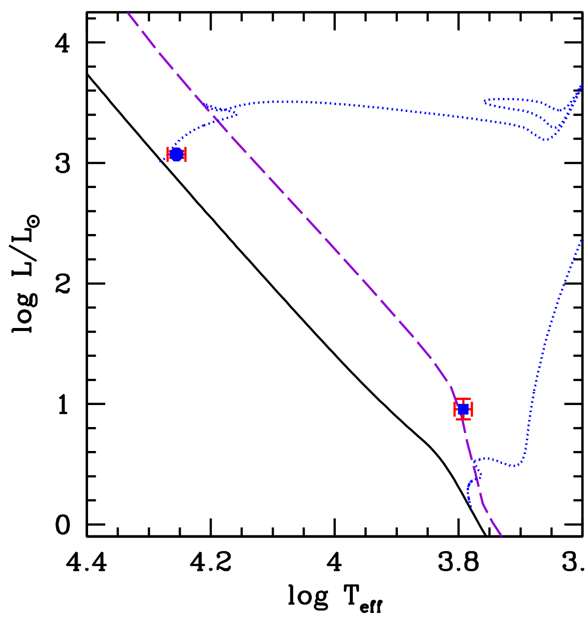

Fig. 5. Location of the two stellar components of V1898 Cyg in the log $T_{\rm eff}$ − log L diagram, together with evolutionary models for 1.15 and 6.0 $M_{\odot}$. The solid circle corresponds to the primary and the solid square to the secondary with error bars. The zero-age main-sequence (continuous line) and terminal-age MS (long-dashed-dotted line) are also plotted. The evolutionary tracks are shown by dotted lines. The color figure can be viewed online.

6. DISCUSSION AND CONCLUSION

Since the sum-of-squares in the analysis of CS light curve is too large when compared to the DM's light curves, and there is doubt about the light constancy of their primary comparison star, we take weighted mean orbital parameters obtained by the analysis of the DM's B and V light curves. The mean parameters obtained from the light curve analysis are: $i = 73°.05 \pm 0.02$, $r_1 = 0.3291 \pm 0.0013$, $r_2 = 0.2464 \pm 0.0012$, $T_2 = 6200 \pm 200$ K. The fractional radius of the secondary component exceeds its corresponding Roche lobe radius by about 4%. Combining the results obtained from RVs analysis we have derived the astrophysical parameters of the components and other properties listed in Table 4. The mass and radius of the massive primary star are derived with an accuracy of 0.6 and 1.4 percent, while for the less massive donor star we obtain 0.4 and 0.5 percent. The observed and computed rotational velocities of the components are in good agreement, showing nearly synchronized rotation. In Figure 5, we plot the location of the V1898 Cyg stellar components in a log $T_{\rm eff}$ − log $L/L_{\odot}$ diagram. The evolutionary tracks for masses 6 and 1.16 $M_{\odot}$ are also shown in this figure. For constructing the solar metallicity evolutionary tracks, we used the Cambridge version of the STARS CODE which was originally developed by Eggleton (1971) and substantially updated by Eldridge & Tout (2004). The continuous and dashed lines from left to right show the zero-age and terminal-age main-sequences, respectively. While the primary star is located very close to the ZAMS the secondary, less massive star appears to have evolved up to the giant branch as is common in semi-detached Algol-type binaries. The appearance of the components in the HR diagram is common for the classical Algol-type binaries. The donor seems to have higher temperature and luminosity, and most of its atmospheric material has been transferred to its companion. Since the secondary component fills its Roche lobe it transfers its mass to the more massive component. Therefore the orbital period change is attributed to the mass transfer. However, the gainer has climbed up to higher effective temperature and luminosity. In addition, V1898 Cyg is located in the diagram between the specific angular momentum and mass-ratio where angular momentum decreases faster (see İbanoğlu et al. 2006). The average distance to the system was calculated to be 501 ± 5 pc. However, the average distance to the system is estimated to be 621^{+443}_{-182} pc from the trigonometric parallax measured by the Hipparcos mission. The distance derived in this study is smaller by about 20 percent, but, most importantly, it has a very small uncertainty when compared with that measured by the Hipparcos mission.

The North America (NGC 7000) and Pelican (IC 5070) nebulae (NAP) are known to be the most nearby huge, extended HII regions where star formation with intermediate mass is still ongoing. The distance to this extended star-forming region has been estimated from 200 to 2000 pc (see for example, Bally & Reipurth 2003). While Herbig (1958) estimates a distance of 500 pc, Laugalys & Straižys (2002) derived a distance to NAP 600 ± 50 pc. If the star is a member of NAP complex, the distance to the star derived by us is in better agreement with that of Herbig, but also agrees with that proposed by Laugalys & Straižys (2002) within 2σ. Recently, Straižys et al. (2008) listed several OB stars in the vicinity of NAP, one of which is V1898 Cyg. The distance to the star estimated by us appears to confirm its membership to NAN. Proper motions for V1898 Cyg are given in the SIMBAD database as $\mu_\alpha \cos\delta = 2.07 \pm 0.62$ mas yr^{-1} and $\mu_\delta = 0.81 \pm 0.53$ mas yr^{-1}, with a space velocity of 45.3 km s^{-1}. We selected about 20 stars in the vicinity of V1898 Cyg listed by Laugalys & Straižys (2002) for comparing their mean proper motions with that of the variable. The velocities of the stars vary from 45 to -97 km s^{-1}, and the mean proper motions are: $\mu_\alpha \cos\delta = 0.48$, $\mu_\delta = -2.85$ mas yr^{-1}. It seems that one cannot definitely classify which stars actually belong to the NAP and which do not.

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