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Spectroscopic and photometric study of a possible multiple system: V684 Mon

E. Kıran[1], **V. Bakış**[2] **and Ö.L. Değirmenci**[3]

[1] *Department of Astronomy and Space Sciences, Faculty of Science, Atatürk University, 25240, Erzurum, Türkiye (E-mail: evrim.kiran@atauni.edu.tr)*

[2] *Department of Space Sciences and Technologies, Faculty of Science, Akdeniz University, 07058, Antalya, Türkiye*

[3] *Department of Astronomy and Space Sciences, Faculty of Science, Ege University, 35100, Bornova - İzmir, Türkiye*

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Abstract. Binary and multiple systems (MSs) are important objects since the fundamental physical parameters of those systems allow us to test stellar evolution models. Thanks to increasing satellite observations and advanced technology light measuring instruments in recent years, precise position and light measurements of double star systems can be made. With these highly sensitive data, new multiple systems are found and their natures are examined. In this study, we present spectroscopic and photometric solutions of V684 Mon.

Key words: stars – multiple systems – eclipsing binary systems

1. Introduction

Using precise satellite data, many candidates of binary or multiple systems are being discovered and their properties determined (e.g. Kervella et al. (2022); Gaia Collaboration et al. (2023); Kostov et al. (2024)). Formation and evolution of these systems are also interesting. Jiménez-Esteban et al. (2019) likened the wide multiple systems to mini star clusters with components born at the same time and with the same chemical composition. They indicated that wide multiple systems are excellent candidates for testing stellar models and for age indicators, as the component stars in these systems are separated wide enough to evolve independently. Star cluster and associations are suitable environments for testing the formation and evolution models of binary and MSs. Open star clusters are the most studied objects among stellar groups due to the young and middle-aged stars they contain and the fact that these stars can be in different stages of evolution. Kounkel et al. (2019) emphasized the importance of close binary fraction and properties of young stars, that provides an invaluable insight into the mechanisms behind the formation and evolution of multiples.

V684 Mon (HD 47755, TIC 220314428, GaiaDR3 3326715714242517248) was discovered by Koch et al. (1986) as a binary system with a period of $P =$

$1^d.8514195$ (Kim et al., 2018). The UBV colors of the system are given by Ducati (2002), V684 Mon system is a member of open cluster NGC 2264 (Tarricq et al., 2021). The system was also cataloged as WDS J06406+0947-A in Washington Visual Double Star Catalogue (Mason et al., 2001). WDS J06406+0947B and WDS J06406+0947C were listed as the visual components of V684 Mon, with an angular separation of $21''.0$ and $26''.0$ respectively. Apsidal motion of the system was studied by Zasche (2012). Spectroscopic and photometric solutions of V684 Mon were presented by Bradstreet et al. (2007).

2. Photometric and spectroscopic data

V684 Mon was observed by The Transiting Exoplanet Survey Satellite (TESS) (Ricker et al., 2015) in Sector 6 and Sector 33. The QuickLook Pipeline (QLP) light curves (LCs) produced by the MIT QuickLook Pipeline (QLP) (Huang et al., 2020) were used to improve the linear ephemerides and for the LCs solutions. Spectroscopic observations of V684 Mon stars were carried out on Turkish-Russian 150cm telescope (RTT150). TFOSC (TUG Faint Object Spectrograph and Camera) spectrograph with $R = 5099$ was used in the observations. The wavelength range of the obtained spectra is between 3350-9400 Å. Spectroscopic observations were made between January and March 2013. IRAF (Tody, 1986) was used to reduce the obtained spectra and measure of radial velocities (RVs).

3. Analysis

3.1. Improved ephemerides

Times of minimum data of V684 Mon obtained in this study from the TESS observations given in Figure 1 were used to improve the linear ephemerides of the system. The minimum times obtained by using Kwee van Worden method (Kwee & van Woerden, 1956) are shown in Figure 1 and used in the O-C analysis. We applied an unweighted least-squares fit to the primary and secondary eclipse times separately to obtain the following linear light elements in Eq (1) for primary minima:

$$MinI(HJD) = 2444617.789(3) + 1.851419(1) \times E, \tag{1}$$

3.2. Determination of orbital parameters

The RVs of the components were measured from the absorption line of HI (6562.8 Å) element. The wavelength shifts were measured by applying Gaussian fit to the reduced spectra and RVs were calculated. The RVs of V684 Mon system were plotted by using the improved ephemerids given in Eq. 1 and the radial velocity curve (RVC) of the system and O-C of RVs are given in Figure 2. The orbital parameters of the system are listed in Table 1.

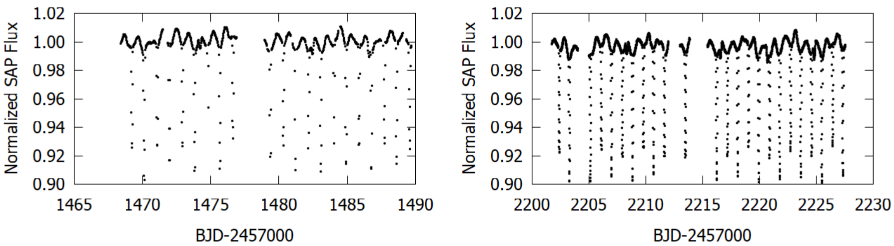

Figure 1. TESS light variation of V684 Mon system from Sector 6 (left) and 33 (right).

Table 1. The orbital parameters obtained from the radial velocity curve solution of V684 Mon.

Parameter	Value
e	0.027 ± 0.040
V_γ (kms^{-1})	6.0 ± 4.0
ω ($^\circ$)	336.9 ± 0.0
K_1 (kms^{-1})	193.2 ± 13.0
K_2 (kms^{-1})	164.3 ± 11.0
$a\sin i$ (R$_\odot$)	12.8 ± 0.4
q	1.19 ± 0.1

3.3. Photometric solutions

The PHOEBE 1 program developed by Prša & Zwitter (2005), which is the implementation of the Wilson-Devinney code (Wilson & Devinney, 1971), was used to analyze photometric data. Ducati (2002) gives the B-V color and V magnitude of the system as $-0^m.13$ and $8^m.44$ respectively. The temperature for V684 Mon was estimated from the given color value by using the relation given by Eker et al. (2020) as $T_{\rm eff}$= 15300K. The orbital parameters of the system given in Table 1 were used as initial parameters for the light curve (LC) solution. The gravitational darkening coefficients $g_{1,2}$ and albedo $A_{1,2}$ for both components with radiative atmosphere are taken as 1.0. van Hamme (1993) tables were used to calculate the edge darkening coefficients of the components. The observed data and the model of the initial solution and the residuals are shown Figure 3.

In Figure 3 (left panel), apart from two dominant eclipses (primary and secondary) eclipse-like light loss stand out. Those light losses are also seen as the dips at 248470, 248474, 248482 together with the pulsation variations in the

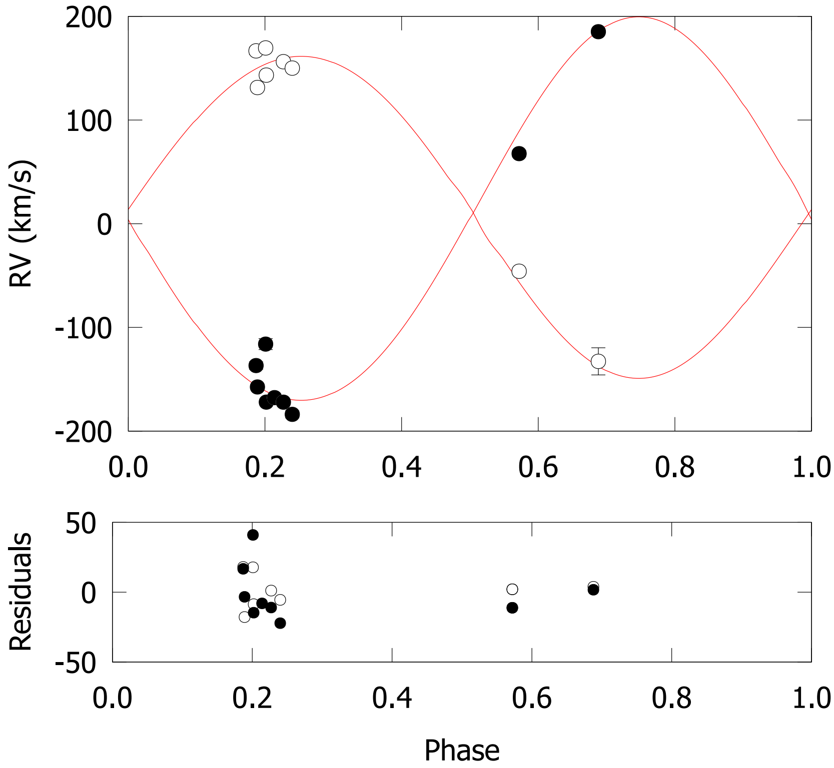

Figure 2. The radial velocities (upper panel) and corresponding residuals (right panel) of V684 Mon. The black filled and empty circles represent the primary and the secondary components, respectively. The red line represents the best-fit theoretical model.

residuals of the LC solution shown in the right panel clearly. LC analysis without removing these light changes from the LC would clearly cause systematic errors. Therefore, it was decided to characterize and remove the out-of-eclipse variations.

We checked for contamination within the TESS aperture from nearby sources. Figure 4 shows a 7x7 pixels TESS cutout centered on the target star. Two field stars are within 2 pixels of the target, WDS J06406+0947-B and C, both contaminating the extracted light curve. WDS J06406+0947-C is cataloged as an eclipsing binary system (V780 Mon) by Avvakumova et al. (2013) and the period of the system was given as 4.12 days by Kearns et al. (1997). However, we checked if there is any contamination within the TESS aperture.

Hence, we also take into account the visual components' WDS J06406+0947-B: is denoted as WDS-B and V780 Mon light contributions to the total light.

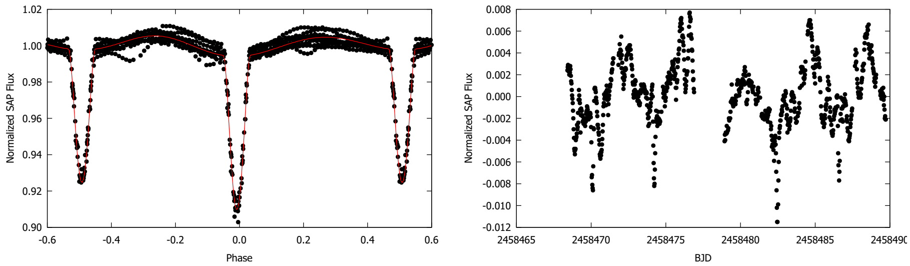

Figure 3. Left panel: TESS lightcurve (black symbols) and corresponding best-fit model (red) for V684 Mon. Right panel: shows the residuals of the solution.

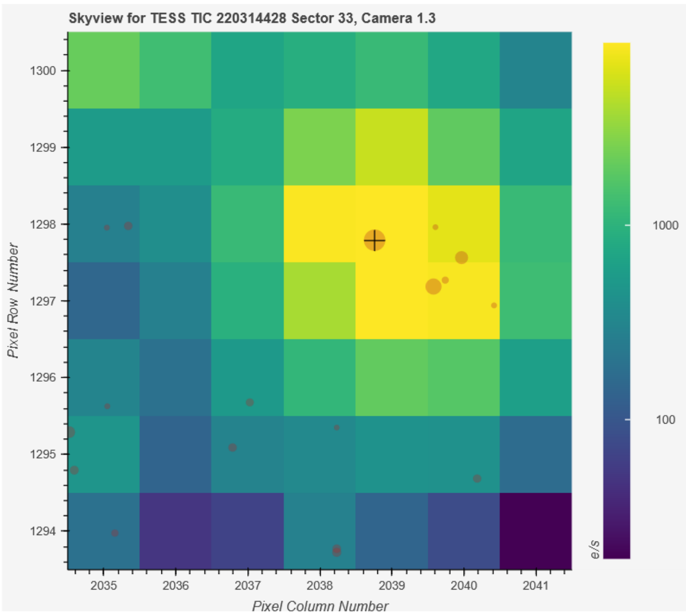

Figure 4. The pixel position of V684 Mon in TESS area.

Moreover, before the LC solutions of the EBs, we need to be sure if the light losses seen as the dips in Fig 3 are caused by one of visual components or not. The light contribution of the visual components, WDS-B and V780 Mon to the total light is approximately 0.15 and 0.04, respectively, according to the magnitudes given by Ducati (2002). The light contribution of the secondary EB system that seen in the TESS LC is about 0.01 (see Figure 3). If we take into account of this contribution and the magnitudes of V684 Mon (Ducati, 2002) and its visual components (Sung et al., 1997), we can assume that V780 Mon can provide such light loss. The third light contribution was estimated as $l_{\mathrm{V684Mon+WDS-B}}$=0.806 and $l_{\mathrm{WDS-C+V780Mon}}$=0.113 for TESS LC solutions of V780 Mon and V684 Mon systems, individually.

V780 Mon system is listed as a member of relatively young open cluster NGC 2264. The system is considered as a detached with two main sequence star. We estimated the temperature of the system given by (Ducati, 2002) and attributed to the primary component. Assuming a circular orbit, the period was calculated as 4.14725 days by frequency analysis using the Period04 (Lenz & Breger, 2005) program. The LC of the system was analyzed under these assumptions and the results are presented in Table 2 and Figure 5.

Table 2. The PHOEBE solution of V780 Mon.

Parameter	Unit	Value
T_0	(days)	2458473.1839 ± 0.002
P	(days)	4.14725 (fixed)
i	(∘)	71.8 ± 0.2
q		0.2 (fixed)
$\Delta\ T\ (T_1/T_2)$	(K)	2.98 ± 0.07
$\Omega_{1,2}$		$6.39 \pm 0.1,\ 2.47 \pm 0.01$
l_{V780Mona}		0.185
l_{V780Monb}		0.007
$l_{\mathrm{(V684Mon+WDS-B)}}$		0.807 ± 0.001
$r_{1,2}$		$0.162 \pm 0.003,\ 0.193 \pm 0.002$

Table 3. The PHOEBE solution of V684 Mon.

Parameter	Unit	Value
T_0	(days)	$2444617.80476 \pm 0.00005$
P	(days)	1.85142 (fixed)
i	(∘)	76.51 ± 0.01
ω	(∘)	5.883 ± 0.006
$T_{\mathrm{eff}_{1,2}}$	(K)	15300(fixed), 13080 ± 11
$\Omega_{1,2}$		$6.731 \pm 0.003,\ 8.697 \pm 0.005$
$l_{\mathrm{v684\ Mona}}$		0.562
$l_{\mathrm{v684\ Monb}}$		0.311
$l_{\mathrm{(WDS-B+V780\ Mon)}}$		0.127 ± 0.001
$r_{1,2}$		$0.1826 \pm 0.0001,\ 0.1540 \pm 0.0001$

The residuals of the V780 Mon LC solution were analyzed by using the Period04 program. The sinusoidal wave function with different frequency and amplitude values were applied to the residual data. Then, by subtracting the si-

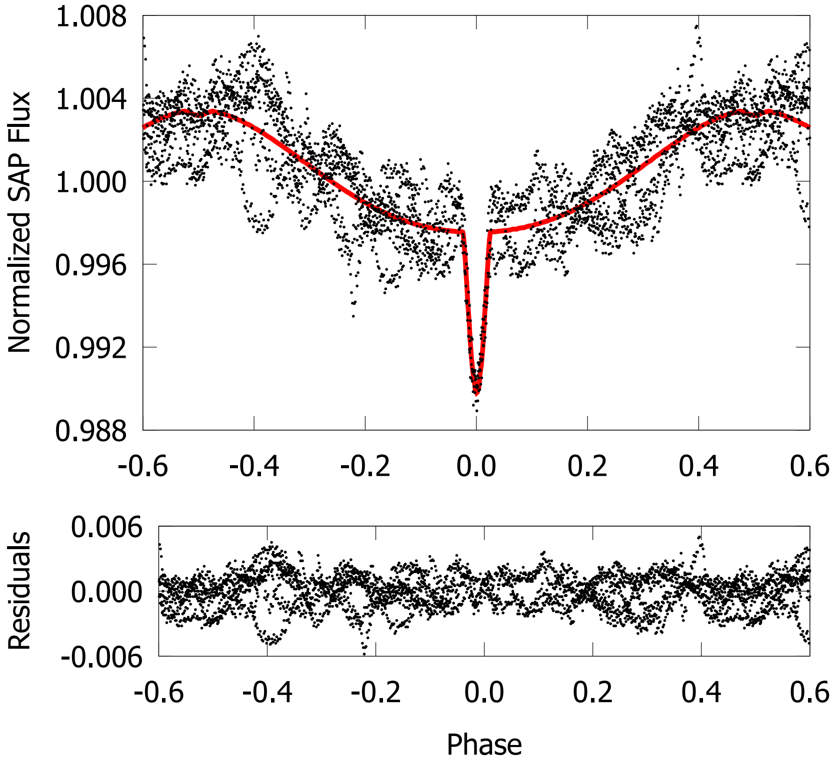

Figure 5. The TESS LC and residuals of the solutions of V780 Mon.

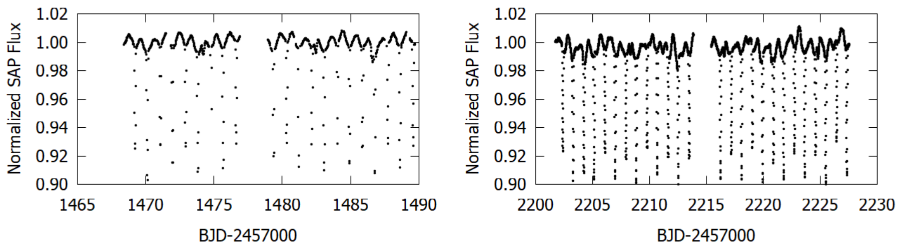

Figure 6. The pulsating-free LC of V684 Mon.

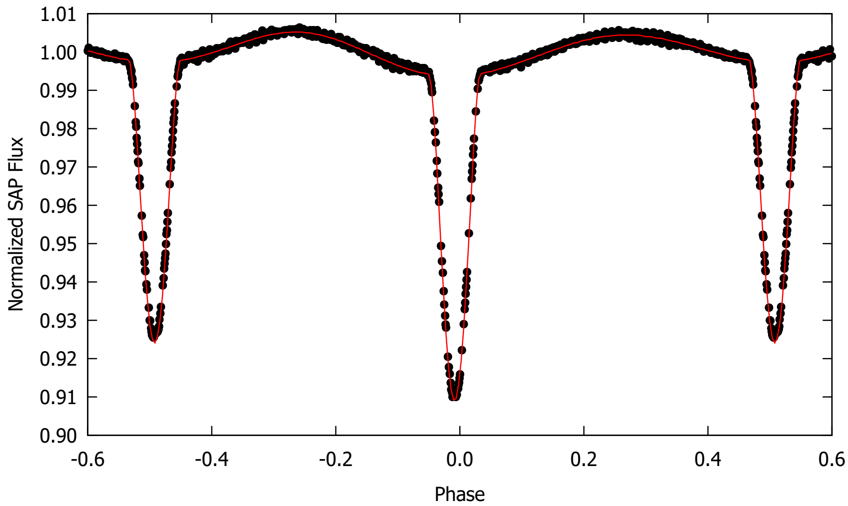

Figure 7. The LC solutions of V684 Mon.

nusoidal wave function from all the observational data (including the minima), a pulsating-free LC was obtained (see Figure 6). Finally, the LC of V684 Mon were analyzed. The results of the photometric solution are presented in Table 3.The fitting of the model of the observed data can be seen in Figure 7.

4. Conclusion

In this study, the spectroscopic and photometric solutions of the known eclipsing binary system V684 Mon system were presented. The photometric and spectroscopic solutions obtained in this study are consistent with those of the literature. We also investigated the photometric variation of V780 Mon which is near the V680 Mon. Although the TESS data are sufficient to roughly estimate the photometric parameters, ground-based spectroscopy is necessary to obtain full astrophysical data of this system. With the new spectroscopic observations that will be made in the future, more precise orbital parameters can be obtained to reach the astrophysical parameters of those systems and the evolution status can be discussed.

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