The evolutionary status of chemically peculiar eclipsing binary star DV Boo

Filiz Kahraman Alicavuş1,2 and F. Alicavuş1

1 Çanakkale Onsekiz Mart University, Faculty of Sciences and Arts, Physics Department, 17100, Çanakkale, Turkey; filizkahraman01@gmail.com
2 Nicolaus Copernicus Astronomical Center, Bartycka 18, PL-00-716 Warsaw, Poland

Received 2019 December 16; accepted 2020 April 26

Abstract Eclipsing binary systems are unique objects to examine and understand stellar evolution and formation. Thanks to these systems, the fundamental stellar parameters (mass, radius) can be obtained very precisely. The existence of metallic-line (Am) stars in binaries is noticeably common. However, the known number of Am stars in eclipsing binaries is less. The Am stars in eclipsing binaries are extremely useful to deeply investigate the properties of Am stars, as eclipsing binaries are the only tool to directly derive the fundamental stellar parameters. Additionally, the atmospheric parameters and metallicities of such binary components could be obtained by a detailed spectroscopic study. Therefore, in this study, we present a comprehensive photometric and spectroscopic analysis of the eclipsing binary system DV Boo which has a possible Am component. The fundamental stellar parameters were determined by the analysis of radial velocity and photometric light curves. The atmospheric parameters of both binary components of DV Boo were derived considering the disentangled spectra. The chemical abundance analysis was conducted as well. As a result, we showed that the primary component exhibits a typical Am star chemical abundance distribution. The fundamental stellar parameters of the binary components were also obtained with an accuracy of <1% for masses and <3% for radii. The evolutionary status of DV Boo was examined utilizing the precisely obtained stellar parameters. The age of the system was found to be 1.00 ± 0.08 Gyr.

Key words: techniques: photometric : spectroscopic — stars: variables: binaries: eclipsing: fundamental parameters — stars: individual: DV Boo

1 INTRODUCTION

A significant amount of stars are members of binary or multiple systems (Alfonso-Garzón et al. 2014; Sana & Evans 2011). These objects, in particular the eclipsing binary systems, are unique tools to acquire information about the formation and evolution of stars. Eclipsing binary systems provide a direct measurement of the fundamental stellar parameters (e.g., mass, radii) with a good accuracy (Torres et al. 2010; Southworth 2013). These fundamental parameters are significant for a deep investigation of a star. To obtain the precise fundamental stellar parameters, both photometric and spectroscopic data are needed. Radial velocity analysis enables the determination of exact orbital parameters, while light curve analysis provides the orbital inclination and radii of the stars relative to the semi-major axis. As a result of both analyses, precise fundamental stellar parameters such as mass (M) can be obtained. M is the most important parameter which determines the life of a star. Therefore, an accurate determination of M is essential. In addition to M, metallicity also affects the life of a star. Hence, for a comprehensive investigation of the binary evolution, both parameters should be obtained. Double-lined eclipsing binary systems provide an opportunity to derive these parameters. While a precise M can be obtained from the analysis of radial velocity and light curves, the metallicity can be determined by implementing special approaches like the spectral disentangling method (Simon & Sturm 1994).

Binary systems are thought to form in the same interstellar area and hence the component stars in a binary system should have the same chemical abundance pattern. However, recent detailed studies about eclipsing binary stars indicated that components in a binary system could have different chemical structures (e.g., Paunzen et al. 2018; Jeong et al. 2017). This result is very important for understanding the binary’s evolution. The increased number of such samples will be effective. Therefore, in this s-
tudy, we present a detailed analysis of a suspected metallic-line eclipsing binary star, DV Boo.

DV Boo (HD 126031, \( V = 7^m.54 \)) was classified as an eclipsing binary system by Hipparcos data (ESA 1997). The star was defined as a metallic-line star by Bidelman (1988). Grenier et al. (1999) gave a spectral classification of A3kA7hF5m which signifies a chemically peculiar star. However, these spectral classifications could be suspected because the double-lined feature of DV Boo was later discovered by Carquillat et al. (2004). Carquillat et al. (2004) analyzed medium resolution (R~20000, 42 000) spectroscopic data to obtain the orbital parameters of the binary system. Additionally, they presented the analysis of the Hipparcos light curve to derive the fundamental stellar parameters. However, because of the low quality of the photometric data and less number of measured radial velocities for the secondary component (low-mass), these parameters could not be determined sensitively. DV Boo is also present in a list of candidate pulsating eclipsing binary stars (Soydugan et al. 2006). However, the pulsating nature (if it exists) of the star has not been discovered.

In this study, we introduce a detailed analysis of DV Boo which is believed to manifest chemically peculiar characteristics. The star also has enough and good spectroscopic and photometric public data to investigate the star thoroughly. A detailed analysis of the star will allow us to obtain the atmospheric chemical structure of both binary components in DV Boo.

The paper is organized as follows. Information about the considered spectroscopic and photometric data is given in Section 2. Analysis of the radial velocity measurements is presented in Section 3. We introduce a comprehensive spectral analysis in Section 4. The light curve analysis is provided in Section 5. Discussion and conclusions are presented in Section 6.

2 OBSERVATIONAL DATA

In this study, we referenced the public photometric and spectroscopic data of DV Boo. The system has photometric data in two different archives. First is the All Sky Automated Survey (ASAS) archive\(^1\) (Pojmanski 2002). ASAS is a low budget project which aims to detect and identify variable stars. The project provides data taken with \( V \)- and \( I \)-bands. However, DV Boo has only \( V \)-band data in the ASAS archive. The second archive is the Kamogata/Kiso/Kyoto Wide-field Survey (KWS) archive\(^2\) (Maehara 2014). This study provides \( B \)-, \( V \)- and \( Ic \)-band data. However, DV Boo only has usable \( V \)- and \( Ic \)-band data in the archive. These available photometric data were gathered and scattered points beyond the 3\( \sigma \) level were removed for the light curve analysis.

The spectroscopic data of DV Boo are available in ELODIE\(^3\) and European Southern Observatory (ESO)\(^4\) archives. In the ELODIE archive, there are twelve spectra of DV Boo. ELODIE is an échelle spectrograph which was mounted at the 1.93-m telescope at the Observatoire de Haute-Provence (France). The spectrograph provided spectra with a resolving power of \( \sim42 000 \) and with a wavelength range of 3850 – 6800 Å (Moultaka et al. 2004). The ELODIE spectra are served after an automatic data reduction by the dedicated pipeline. All available reduced ELODIE spectra of DV Boo were compiled for analysis in this study.

The ESO archive provides the data taken from the ESO instruments at La Silla Paranal observatory. In this archive, there are six FEROS and eight HARPS spectra of DV Boo. FEROS and HARPS are échelle spectrographs and they are attached to the 2.2-m and the 3.6-m telescopes, respectively. FEROS has a resolving power of 48 000 and its spectral range is approximately between 3500 and 9200 Å (Kaufer et al. 1999). HARPS has a higher resolving power (85 000) and it supplies spectra in a wavelength range of about 3780 – 6900 Å (Mayor et al. 2003). The spectra of FEROS and HARPS were reduced and calibrated by their dedicated pipelines. All available FEROS and HARPS spectra for DV Boo were incorporated into this study.

The collected reduced spectra were manually normalized applying the NOAO/IRAF\(^5\) continuum task. Each spectrum was normalized separately and the continuum level was controlled with a synthetic spectrum that was generated using approximate atmospheric parameters. The information for the utilized spectroscopic data is given in Table 1. The average signal-to-noise ratio (S/N) of all spectroscopic data is \( \sim95 \).

3 RADIAL VELOCITY MEASUREMENTS

A binary system is defined with its orbital parameters such as inclination \( i \), eccentricity \( e \), semi-major axis \( a \) and argument of periastron \( \varpi \). To obtain accurate orbital para-

---

\(^1\) http://www.astrow.edu.pl/asas
\(^2\) http://kws.cetus-net.org/\~{}maehara/VSdata.py
\(^3\) http://atlas.obs-hp.fr/elodie/
\(^4\) http://archive.eso.org
\(^5\) http://iraf.noao.edu/
Fig. 1 Theoretical fits (solid lines) to the radial velocity measurements of the primary (asterisks) and the secondary (squares) components are plotted in the upper panel. The red, blue, green and black symbols illustrate the ELODIE, FEROS, HARPS and literature values (Carquillat et al. 2004), respectively. The dashed line in the upper panel signifies the $V_\gamma$ level. The residuals from the fits are displayed in the lower panel. The subscripts "1" and "2" represent the primary and the secondary components, respectively.

Table 2 The Results of the Radial Velocity Analysis

| Parameters | Value |
|------------|-------|
| $P$ (d)    | 3.7826330 |
| $T_0$ (HJD) | 2450003.58014 ± 0.01523 |
| $e$        | 0.004 ± 0.001 |
| $\omega$ (deg) | 347 ± 3 |
| $v_\gamma$ (km s$^{-1}$) | -28.12 ± 0.03 |
| $K_1$ (km s$^{-1}$) | 82.08 ± 0.04 |
| $K_2$ (km s$^{-1}$) | 110.08 ± 0.07 |
| $M_1 \sin^3 i$ ($M_\odot$) | 1.593 ± 0.002 |
| $M_2 \sin^3 i$ ($M_\odot$) | 1.188 ± 0.002 |
| $q = M_2/M_1$ | 0.7457 ± 0.0007 |
| $a_1 \sin i$ (10$^6$ km) | 4.2696 ± 0.0024 |
| $a_2 \sin i$ (10$^6$ km) | 5.7256 ± 0.0039 |

* Signifies fixed parameters.

4 SPECTRAL ANALYSIS

We aim to obtain the atmospheric parameters and chemical compositions of both binary components of DV Boo to examine their chemical structure and binary evolution. Therefore, in this section, we first disentangle the compos-
4.1 Spectral Disentangling

The spectral disentangling method can be employed to acquire individual spectra of binary components in a double-lined (SB2) eclipsing binary system. To obtain the individual spectra of binary components, the composite spectra of the binary system taken in different orbital phases and the fractional light contribution of binary components are needed. To obtain initial fractional lights of the binary components, we performed a preliminary light curve analysis using the ASAS data. In the initial light curve analysis, effective temperature ($T_{\text{eff}}$) value of the primary component was fixed. This $T_{\text{eff}}$ value was estimated with the following steps. First, the $T_{\text{eff}}$ value was estimated at 4200 K. In the initial light curve analysis, effective temperature ($T_{\text{eff}}$) value of the primary component was fixed. This $T_{\text{eff}}$ value was estimated with the following steps. First, the Gaia distance (Gaia Collaboration et al. 2018) was utilized to estimate the interstellar absorption coefficient ($A_V = 0.062$, Schlafly & Finkbeiner 2011) and we calculated the $(B-V)_0$ value to be 0.31 mag. By considering the derived $(B-V)_0$ and the list given by Eker et al. (2018) (see table 7 in that article), we estimated the initial $T_{\text{eff}}$ value of the primary binary component to be 7161 K. As a result of the preliminary light curve analysis, we determined the light contributions to be around 80% and 20% for the primary and secondary components, respectively. The final light curve analysis will be provided after accurate $T_{\text{eff}}$ values are obtained.

The FDBINARY (Ilić et al. 2004) code was used to obtain the individual spectra of the binary components. FDBINARY disentangles the composite spectra based on Fourier space by taking into account some orbital parameters such as P, $T_0$, $K_{1,2}$, $e$ and $\omega$. These orbital parameters can be fixed or adjusted during the analysis. However, the fractional light contributions of the binary components should be fixed in the analysis according to the orbital phases of the binary system in the considered spectra.

In the analysis, we used FEROS spectra because these data have significantly higher S/N on average relative to HARPS and ELODIE data. Additionally, available FEROS spectra are also distributed well over the orbital phases of DV Boo for the disentangling analysis.

In the analysis, the spectral range of around 4200 – 5600 Å was taken into account. This spectral window was divided into several spectral subsets with 150 – 250 Å steps. These spectral subsets were analyzed separately. In the analysis, the input parameters were taken from the results of the radial velocity analysis and they were fixed. Only the $T_0$ parameter was adjusted during the spectral disentangling process. After the individual spectra of binary components were obtained, these spectra were normalized considering each component star’s light fraction (Pavlovski & Hensberge 2005).

The S/N of the resulting individual spectra of the binary components can be calculated applying the equation given by Pavlovski & Southworth (2009). When we calculated the S/N, we found that the spectra of the primary and secondary binary components have S/N around 290 and 38 S/N, respectively. The S/N for the secondary component is low because of its less light contribution in total. Therefore, we are only able to determine the atmospheric parameters and metallicity value for the secondary star with this low S/N. A detailed abundance analysis will not be carried out for the secondary star.
4.2 Determination of the Atmospheric Parameters and Abundance Analysis

To determine the atmospheric parameters ($T_{\text{eff}}$, surface gravity $\log g$, microturbulence $\xi$) and projected rotational velocity ($v \sin i$) of both binary components, we followed two different approaches. First, the $H_\alpha$ line was taken into account to derive the $T_{\text{eff}}$ parameter because hydrogen lines are very sensitive to $T_{\text{eff}}$. It is also known that for cool stars ($T_{\text{eff}} < 8000$ K) hydrogen lines are not sensitive to $\log g$ (Smalley et al. 2002; Smalley 2005). Hence, in the hydrogen line analysis, we took $\log g$ to be 4.0 cgs and additionally we assumed solar metallicity, as metallicity does not change the profile of hydrogen lines. The $H_\alpha$, $T_{\text{eff}}$ values were derived considering the minimum difference between the synthetic and observed spectra. During this and future spectral analyses, the hydrostatic, plane-parallel and line-blanketed local thermodynamic equilibrium (LTE) ATLAS9 model atmospheres (Kurucz 1993) were used. The synthetic spectra were generated by SYNTHE code (Kurucz & Avrett 1981). The errors in the $H_\alpha$, $T_{\text{eff}}$ values were estimated considering the $1\sigma$ difference in $\chi^2$ and also taking into account possible uncertainties that come from normalization ($\sim 100$ K, Kahraman Aliçavuş in preparation). The resulting $H_\alpha$, $T_{\text{eff}}$ values are expressed in Table 3 and the theoretical fits to the $H_\alpha$ lines are depicted in Figure 2.

All atmospheric parameters were determined following another approach. In this approach, the excitation and ionization potential balances of iron (Fe) lines were taken into account. In this method, some small spectral parts ($1 - 5$ Å) were analyzed separately based on the spectral synthesis method. The final $T_{\text{eff}}$, $\log g$ and $\xi$ parameters were searched in the range of $6000 - 7600$ K, $3.8 - 4.5$ cgs and $1 - 4$ km s$^{-1}$ with 100 K, 0.1 cgs and 0.1 km s$^{-1}$ steps, respectively. By employing the given input parameter(s), we adjusted Fe abundances and $v \sin i$ parameters considering the minimum difference between the theoretical and observed spectra. The final $T_{\text{eff}}$ and $\log g$ parameters were derived considering the relationships between Fe abundance and excitation/ionization potentials. For the correct atmospheric parameters, these relationships should be flat because the abundance of the individual elements obtained from different lines should be the same for different excitation potentials. Additionally, the $\xi$ value was obtained utilizing the same abundance – excitation potential relationship as explained by Sousa (2014). For a detailed explanation of the employed method, check the studies of Kahraman Aliçavuş et al. (2016) and Niemczura et al. (2015).

In analysis of the primary component, 59 neutral and 24 ionized suitable Fe lines were used, while these numbers are 36 (FeI) and 15 (FeII) for the secondary component. The uncertainties in the determined final atmospheric parameters were obtained by the $1\sigma$ change in the associated relationships. We calculated how much the atmospheric parameters alter with the $1\sigma$ difference in the considered relationships. The final atmospheric parameters and their uncertainties are given in Table 3.

After the final atmospheric parameters were determined, abundance analysis was carried out taking these parameters as input. However, we only performed this analysis for the primary component, because the secondary component has a low S/N for an abundance analysis. We only obtained $\log \epsilon$ (Fe) for the secondary component using the Fe lines because Fe lines are abundant and dominate in the secondary star’s $T_{\text{eff}}$ range. For abundance analysis of the primary component, first a line identification was done for each spectral part using the Kurucz line list\footnote{kurucz.harvard.edu/linelists.html} and then all parts were analyzed separately. The chemical abundances determined from the different spectral parts were taken into account to obtain the average individual chemical abundances. The list of final chemical abundances for the primary component is provided in Table 4. The uncertainties in the chemical abundances were estimated considering the effects of quality of the spectrum (S/N, resolution), errors in the atmospheric parameters and assumptions in the model atmosphere calculations. The effect of the LTE model assumption on chemical abundance calculations was searched by Mashonkina (2011) and it turned out that these assumptions introduce around a 0.1 dex error. The effects of S/N and resolution were examined by Kahraman Aliçavuş et al. (2016) in detail. We took into account the errors caused by these sources from this study. Additionally, we calculated the errors caused by uncertainties in the determined atmospheric parameters.

Table 4 Abundances of Individual Elements of the Primary Star and Sun (Asplund et al. 2009)

| Elements | Star abundance | Solar abundance |
|----------|----------------|-----------------|
| $^6$C    | 8.78 ± 0.44 (1) | 8.43 ± 0.05     |
| $^{11}$Na| 6.68 ± 0.44 (1) | 6.24 ± 0.04     |
| $^{12}$Mg| 7.90 ± 0.40 (4) | 7.60 ± 0.04     |
| $^{14}$Si| 7.94 ± 0.39 (5) | 7.51 ± 0.03     |
| $^{20}$Ca | 5.85 ± 0.41 (3) | 6.34 ± 0.04     |
| $^{23}$Sc | 1.57 ± 0.41 (3) | 3.15 ± 0.04     |
| $^{22}$Ti | 5.01 ± 0.37 (15) | 4.95 ± 0.05   |
| $^{23}$V  | 4.51 ± 0.42 (2) | 3.93 ± 0.08     |
| $^{24}$Cr | 6.00 ± 0.37 (15) | 5.64 ± 0.04     |
| $^{25}$Mn | 5.80 ± 0.39 (5) | 5.43 ± 0.05     |
| $^{26}$Fe | 7.79 ± 0.25 (83) | 7.50 ± 0.04     |
| $^{28}$Ni | 6.82 ± 0.37 (19) | 6.22 ± 0.04     |
| $^{30}$Zn | 5.06 ± 0.44 (1) | 4.56 ± 0.05     |
| $^{38}$Sr | 4.14 ± 0.45 (1) | 2.87 ± 0.07     |
| $^{39}$Y  | 4.14 ± 0.44 (1) | 2.58 ± 0.07     |
| $^{40}$Zr | 4.62 ± 0.43 (2) | 2.58 ± 0.04     |
| $^{56}$Ba | 3.59 ± 0.44 (1) | 2.18 ± 0.07     |

Number of analyzed spectral parts is expressed in the Brackets.
Fig. 3 Chemical abundance distribution of the primary binary component relative to solar abundance (Asplund et al. 2009).

Fig. 4 Theoretical fits (dashed lines) to the disentangled spectrum (solid lines) of the primary binary component (upper panels) and the residuals ($O - C$) (lower panels).

Fig. 5 Theoretical light curve fits (solid lines) to the observed public photometric data (points) of DV Boo.
Table 5 Results of the Light Curve Analysis and the Astrophysical Parameters

| Parameter                          | Value     |
|------------------------------------|-----------|
| $i$ (deg)                          | 82.995 ± 0.251 |
| $T_1$ (K)                          | 7400 ± 100  |
| $T_2$ (K)                          | 6398 ± 174  |
| $V_0$ (km s$^{-1}$)                | −28.11 ± 0.03 |
| $a$ ($R_\odot$)                    | 14.469 ± 0.010 |
| $e^a$                              | 0.0004 ± 0.0001 |
| $\Omega_1$                         | 8.100 ± 0.223 |
| $\Omega_2$                         | 9.499 ± 0.277 |
| Phase shift                        | 0.0004 ± 0.0001 |
| $q^a$                              | 0.746 ± 0.001 |
| $r_1$ (mean)                       | 0.1359 ± 0.0036 |
| $r_2$ (mean)                       | 0.0889 ± 0.0026 |
| $L_1$ ($L_\odot$)                  | 0.797 ± 0.016 |
| $L_2$ ($L_\odot$)                  | 0.797 ± 0.016 |
| $L_1$ ($L_\odot$)                  | 0.778 ± 0.016 |
| $L_2$ ($L_\odot$)                  | 0.203 ± 0.016 |
| $L_1$ ($L_\odot$)                  | 0.203 ± 0.016 |
| $L_2$ ($L_\odot$)                  | 0.222 ± 0.016 |
| $l_3$                              | 0.0         |

Derived Quantities

| $M_1$ ($M_\odot$)                  | 1.629 ± 0.004 |
| $M_2$ ($M_\odot$)                  | 1.215 ± 0.003 |
| $R_1$ ($R_\odot$)                  | 1.966 ± 0.052 |
| $R_2$ ($R_\odot$)                  | 1.286 ± 0.038 |
| $log (L_1/L_\odot)$                | 1.020 ± 0.033 |
| $log (L_2/L_\odot)$                | 0.398 ± 0.054 |
| $log q_1$ (cgs)                    | 4.063 ± 0.023 |
| $log q_2$ (cgs)                    | 4.304 ± 0.025 |
| $M_{bolometric1}$ (mag)            | 2.201 ± 0.082 |
| $M_{bolometric2}$ (mag)            | 3.755 ± 0.134 |
| Distance (pc)                      | 130 ± 5      |

The subscripts 1, 2 and 3 represent the primary, secondary and third binary components, respectively.

In this study, we present a detailed photometric and spectroscopic study of an eclipsing binary system DV Boo. The fundamental atmospheric parameters of binary components were obtained by using the disentangled spectra of each component. DV Boo was classified as a metallic-line (Am) star. According to our chemical abundance analysis, we found that the primary component exhibits typical Am star properties (see, Fig. 4). The primary star has mostly overabundant iron-peak elements and manifests deficiency in Ca and Sc elements. This is a typical chemical abundance behavior of Am stars. It is known that many (~70%) Am stars are members of binary systems (Carquillat & Prieur 2007). However, eclipsing binary Am stars are rare (Smalley et al. 2014). Therefore, the current detailed analysis of DV Boo is important to thoroughly understand Am stars’ behavior. Additionally, we found that the secondary binary component also has a similar Fe abundance with the primary star.

When the obtained atmospheric parameters were examined, we noticed that the secondary binary component has a higher $\xi$ value compared to the $\xi$ range for a star with similar $T_{eff}$ value (Gebran et al. 2014; Landstreet et al. 2009). However, we keep in mind that our star is a member of a binary system and there are interactions between the two binary components. Therefore, the reason for the resulting $\xi$ value could be the effect of binarity. This should be investigated in further studies.

A light curve analysis was performed utilizing the ASAS V-band and KWS V- and Ic-band data. As a result, we derived the orbital and fundamental stellar parameters. The $M$ values of the binary components were obtained with an accuracy of less than 1%, while the accuracy in $R$ values is less than 3%. These precise $M$ and $R$ values allow us to examine the evo-
The positions of the primary and secondary (smaller symbol) binary components of DV Boo in the H-R diagram. Solid black and grey lines represent the evolutionary tracks for primary and secondary components, respectively. The dashed line illustrates the ZAMS.

The position of the primary and secondary (smaller symbol) binary components of DV Boo in the Age − log $R$ diagram.

Table 6 Evolutionary Model Parameters Obtained from MESA

| Parameter  | Value               |
|------------|---------------------|
| $P_{\text{initial}}$ (d) | 3.895 ± 0.020 |
| $e_{\text{initial}}$   | 0.023 ± 0.003   |
| $Z$              | 0.015 ± 0.002    |
| Age (Gyr)        | 1.00 ± 0.08      |

The evolutionary status of DV Boo was examined by employing the 8845 version of the Modules for Experiments in Stellar Astrophysics (MESA) evolutionary program (Paxton et al. 2011, 2013). The binary module of MESA (Paxton et al. 2015) was used to estimate the initial evolutionary parameters of the binary system and to model its orbital evolution. Many evolutionary models were generated with different input parameters. During the analysis, the metallicity ($Z$) value was searched between 0.01 and 0.02 with steps of 0.001. As a result, $Z = 0.015 ± 0.002$ was found. According to current spectroscopic analysis, the binary components of DV Boo have $Z$ value around solar ($Z = 0.0143$, Asplund et al. 2009) within error bars. This $Z$ value is consistent with the $Z$ value obtained from evolutionary models. Additionally, we estimated the initial orbital period and $e$ value by comparing the models calculated with different input orbital parameters and $e$.

The resulting evolutionary models for primary and secondary binary components were estimated taking into account the best fit to the calculated Age − log $R$ diagram. As a result, we defined the age of components to be $1.00 ± 0.08$ Gyr and examined the orbital evolution of the binary system. The first Roche lobe overflow (RLOF) time...
for the primary component of DV Boo is predicted to start at the age of 1.61 Gyr (0.61 Gyr after the current age). The system is expected to become a semi-detached binary after this age with the beginning of rapid mass transfer. In this stage, the secondary component will gain mass and it will evolve parallel to the zero age main sequence (ZAMS) by its increasing radius and luminosity due to the mass transfer. The best fit evolutionary models for the binary components of DV Boo and the position of the components in the Hertzsprung-Russell (H-R) diagram are plotted in Figure 6. Furthermore, the location of the components in the Age – log R diagram is illustrated in Figure 7. In these figures, the binary components’ evolutionary models are shown from zero-age to the early stage of the beginning of mass transfer. The estimated initial evolutionary parameters are given in Table 6.

In the light curve analysis, a synchronous rotation was assumed. If the binary components are synchronized, their \( v \sin i \) values should be 26.3 \( \pm \) 0.7 and 17.2 \( \pm \) 0.5 km s\(^{-1}\) for the primary and secondary components, respectively. These values are very similar to the spectroscopic ones. This shows us the binary components are already synchronized. In addition to this, applying the resulting parameters of the light curve analysis, we estimated the distance of DV Boo to be 130 \( \pm \) 5 pc which is consistent with the \textit{Gaia} distance (\( \sim \)125 pc, \textit{Gaia Collaboration et al. 2018}).

DV Boo is included in the list of candidate \( \delta \) Scuti-type variables in eclipsing binaries (Soydugan et al. 2006). Therefore, we carried out a frequency analysis of the photometric data after removing the binary light variation. The \textit{Period04} code (Lenz & Breger 2005) was employed in the analysis. We found some frequency peaks at \( \delta \) Scuti stars’ pulsation frequency regime. However, the data are not good enough to classify the primary star to be a \( \delta \) Scuti variable. Better quality data are needed.

The present detailed study of DV Boo offers good input data to examine the evolution of binary systems and to understand the characteristic of Am stars in binaries. This kind of spectroscopic analysis of eclipsing binary systems is required for a comprehensive investigation of binary evolution.

**Acknowledgements** The authors would like to thank the reviewer for his/her useful comments and suggestions. FKA thanks the Polish National Center for Science (NCN) for supporting the study through grant 2015/18/A/ST9/00578. We thank Prof. G. Handler for his helpful comments. The calculations were carried out at the Wroclaw Centre for Networking and Supercomputing (http://www.wcss.pl), grant No.214. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. This study is based on data obtained from the ESO Science Archive Facility under request number 524778 by Filiz Kahraman Alicavus and based on spectral data retrieved from the ELODIE archive at Observatoire de Haute-Provence (OHP, http://atlas.obs-hp.fr/elodie/). This work has made use of data from the European Space Agency (ESA) mission \textit{Gaia} (https://www.cosmos.esa.int/gaia), processed by the \textit{Gaia} Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the \textit{Gaia} Multilateral Agreement.

**Appendix A:**

Table A.1 The \( v_r \) Measurements

| HJD     | \( v_{r,1} \) (km s\(^{-1}\)) | \( v_{r,2} \) (km s\(^{-1}\)) | Instrument |
|---------|-----------------|-----------------|------------|
| +2450000 | 1931.6262       | 23.28 \( \pm \) 0.76   | ELODIE     |
|         | 2039.4253       | 77.80 \( \pm \) 0.86   | ELODIE     |
|         | 2040.5722       | 80.82 \( \pm \) 0.66   | ELODIE     |
|         | 2041.4968       | 82.58 \( \pm \) 0.98   | ELODIE     |
|         | 2042.4086       | 7.24 \( \pm \) 1.20    | ELODIE     |
|         | 2042.5900       | 136.04 \( \pm \) 0.91  | ELODIE     |
|         | 2043.4398       | 137.16 \( \pm \) 1.02  | ELODIE     |
|         | 2297.6622       | 75.21 \( \pm \) 0.94   | ELODIE     |
|         | 2299.7025       | 133.68 \( \pm \) 0.71  | ELODIE     |
|         | 2303.7271       | 133.06 \( \pm \) 1.17  | ELODIE     |
|         | 2489.3476       | 107.19 \( \pm \) 0.84  | ELODIE     |
|         | 6473.5455       | 66.98 \( \pm \) 0.96   | FEROS      |
|         | 6473.6190       | 75.00 \( \pm \) 0.46   | FEROS      |
|         | 6474.5781       | 25.91 \( \pm \) 0.91   | FEROS      |
|         | 6474.6475       | 10.29 \( \pm \) 0.92   | FEROS      |
|         | 6475.5470       | 122.94 \( \pm \) 0.53  | FEROS      |
|         | 6475.6228       | 128.43 \( \pm \) 0.84  | FEROS      |
|         | 4887.8319       | 63.65 \( \pm \) 0.60   | HARPS      |
|         | 4887.8897       | 51.76 \( \pm \) 0.45   | HARPS      |
|         | 4889.7976       | 4.16 \( \pm \) 0.61    | HARPS      |
|         | 4890.8627       | 139.19 \( \pm \) 0.57  | HARPS      |
|         | 5431.4800       | 123.75 \( \pm \) 0.66  | HARPS      |
|         | 5432.4855       | 19.47 \( \pm \) 0.87   | HARPS      |
|         | 6449.5334       | 131.41 \( \pm \) 0.66  | HARPS      |
|         | 6450.5559       | 23.39 \( \pm \) 0.49   | HARPS      |

The subscripts “1” and “2” represent the primary and the secondary components, respectively.

**References**

Asplund, M., Grevesse, N., Sauval, A. J., et al. 2009, ARA&A, 47, 481

Alfonso-Garzón, J., Montesinos, B., Moya, A., et al. 2014, MNRAS, 443, 3022

Bidelman, W. P. 1988, PASP, 100, 1084

Carquillat, J.-M., Prieur, J.-L., Ginestet, N., et al. 2004, MNRAS, 352, 708

Carquillat, J.-M., & Prieur, J.-L. 2007, MNRAS, 380, 1064
