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REFINED PHYSICAL PROPERTIES OF THE HD 327083 BINARY SYSTEM

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ABSTRACT. HD 327083 is a member of a small group of supergiants exhibiting the B[e] phenomenon. It was found to be a binary system with an early-B and an early-F supergiant components. However the fundamental and orbital parameters of the system were not accurately known. We determined a new set of the system parameters that include the orbital period and the components' masses using a combination of photometric and spectroscopic data. A new orbital period of 107.7 days was found from both the spectral line positional variations and the visual light curve. Absorption lines of the cool component show a radial velocity semi-amplitude of 48.3 km s^{-1}, similar to that of emission lines that originate around the hot component. The system shows partial eclipses. We estimated the components' masses to be nearly equal and close to 6-8 M$_\odot$. The masses turned out to be smaller then the evolutionary masses that may be a consequence of a recent mass-transfer.

Keywords: circumstellar matter — stars: early-type — stars: emission-line, B[e] — stars, stars — individual: HD 327083.

АНОТАЦІЯ. HD 327083 є членом невеликої групи надгігантів, які демонструють явище B[e]. Було виявлено, що це подвійна система з компонентами надгіганта раннього B і раннього F. Однак фундаментальні та орбітальні параметри системи не були точно відомі. Ми визначили новий набір параметрів системи, які включають орбітальний період і маси компонентів, використовуючи комбінацію фотометричних і спектроскопічних даних. Новий орбітальний період 107.7 днів було знайдено як за змінами положення спектральних ліній, так і за кривою візуального блиску. Лінії поглинання холодного компонента демонструють напівамплітуду променевої швидкості 48.3 км с$^{-1}$, подібну до ліній випромінювання, які виникають навколо гарячого компонента. Система показує часткові затемнення. Ми оцінили маси компонентів як майже рівні та близькі до 6-8 M$_\odot$. Маси виявилися меншими за еволюційні маси, що може бути наслідком недавнього масопереносу.

Ключові слова: навколозоряна речовина, зорі раннього типу, зорі: емісійна лінія, B[e] зорі, зорі окремі: HD327083.

1. Introduction

The B[e] phenomenon is defined as the presence of permitted and forbidden low-excitation emission lines, such as H I, Fe II, [Fe II], N II and [O I], and a strong IR excess due to circumstellar dust in the spectra of B?type stars (Allen & Swings 1976) and first systematically analyzed Lamers et al. (1998), who suggested to call them objects with the B[e] phenomenon. These properties are observed in stars with a wide range of masses and evolutionary states. Despite a strong

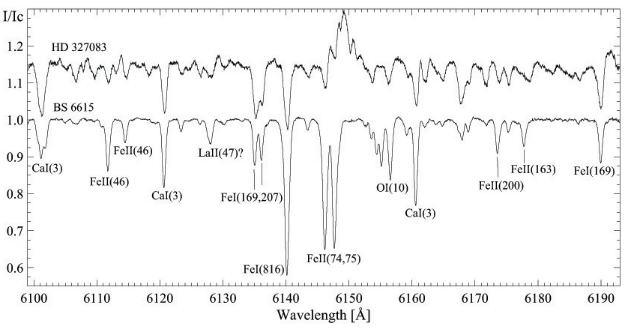

Figure 1: Absorption-line spectra of HD 327083 and BS 6615 (T_{eff}=7,000 K, log g = 1.5). The hot component (spectral type B1) and circumstellar matter contribute ∼10% to the continuum of HD 327083 in this wavelength region.

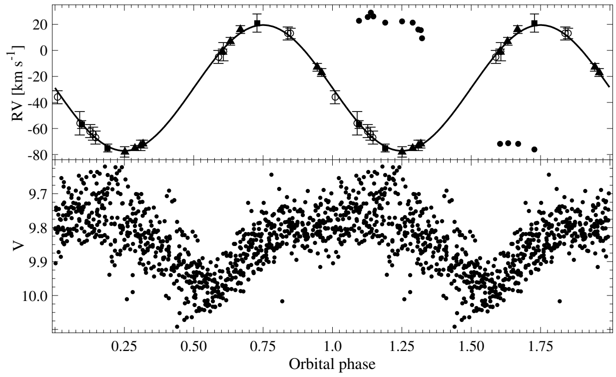

Figure 2: The RV curve (top panel) and the light curve (bottom panel) for HD 327083. RV of the photospheric lines are shown by open circles (data from Miroshnichenko et al. 2003), squares (CFHT), and triangles (ESO). The Fe II 6456Å emission line RVs are shown by filled circles with no error bars. The optical light curve was retrieved from the ASAS SN catalog and folded with the orbital period.

progress in understanding of these complex objects, nature of many of them was not revealed. This prompted Miroshnichenko (2007) to introduce a subgroup named FS CMa type objects that included nearly a half of the original list of 65 Galactic objects with the B[e] phenomenon, which were not associated with any known stellar group with a known evolutionary state, and suggest that they were binary systems with an ongoing or finished mass-exchange. B[e] supergiants and FS CMa objects need more observations to constrain their physical parameters and evolutionary status.

HD 327083 is a highly reddened object with optical color indices of a hot star. Miroshnichenko et al.(2003) concluded that it is a binary system with an early B-type and an early F-type supergiants and suggested two possible orbital periods of 55 and 180 days from only 8 spectra. Machado et al.(2003) studied optical high-resolution (R∼50,000) spectra and suggested that HD 327083 is a superluminous 60 $M_\odot$ single star with the following parameters: $\log(L/L_\odot)$=6.0, T_{eff}=11,500 K, and a mass loss rate of $8\cdot10^{-5}$ $M_\odot$ yr^{-1}. IR interferometry by Wheelwright et al.(2012) suggested that the system is surrounded by a circumbinary disk. Studying some emission-line profiles, Maravelias et al.(2018) suggested that the disk consists of several rings and reported 10 peaks in the Fourier power spectrum of the ASAS survey photometry with no further analysis.

All the mentioned studies did not determine the orbital period and fundamental parameters of the system with a reasonable accuracy. In this study we report new data and addressed these problems.

2. Observations

For this study we used 8 optical high-resolution spectra reported by Miroshnichenko et al. (2003) that were taken at the 2.1 m Otto Struve telescope of the McDonald Observatory (Texas, USA, R=60,000, 1 spectrum) in 2002 with the Sandiford spectrograph (McCarthy et al. 1993) and at the 2.1 m telescope of the Complejo Astronomico El Leoncito (Argentina, R∼15,000, 7 spectra) in 2000–2002 with the échelle-spectrograph REOSC, mounted in the Nasmyth-2 focus and equipped with a 2K × 2K CCD-chip.

This data set was enlarged by 3 spectra taken at the 3.6 m Canada-France-Hawaii Telescope (CFHT, Mauna Kea, HI, USA, R=65,000) in 2006–2008 with the ESPaDOnS spectropolarimeter (Manset & Donati 2003) and 9 spectra taken in 2009–2017 at the 2.2 m telescope of the European Southern Observatory (ESO, Chile, $R = 40,000 - 50,000$) with spectrographs FEROS and UVES retrieved from the ESO data archive. Observations obtained at CFHT were reduced with the Upena and Libre-ESpRIT software packages (Donati et al. 1997). Spectra from the other observatories were processed using the *echelle* package in IRAF.

Photometric observations in the $V-$ and $g-$band that we analyse here were taken from the ASAS–3 (2003–2010, Wozniak et al. 2004) and ASAS SN (2014–2022, Kochanek et al. 2017) surveys.

3. Data analysis

The optical spectrum of HD 327083 exhibits absorption and emission lines, which were identified using a catalog by Coluzzi (1999). Their radial velocities (RVs) were determined by fitting the line profiles to a Gaussian, and the equivalent widths (EW) were measured by integration in the continuum normalized

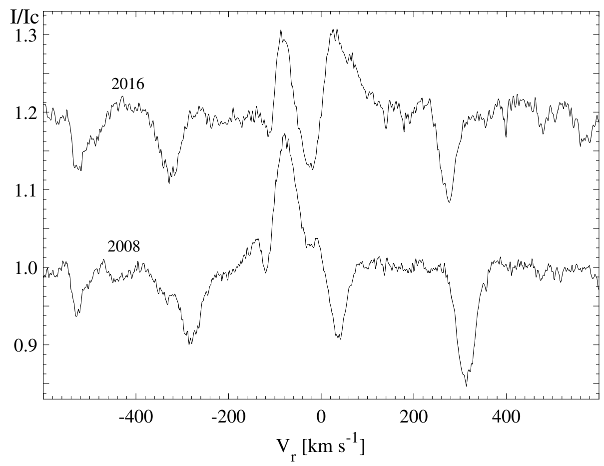

Figure 3: Comparison of high-resolution spectra taken at CFHT on 2008/07/19 (orbital phase 0.76) and at ESO on 2016/04/13 (phase 0.96). The cool component is located behind the hot one at the phase 0. The radial velocity (RV) scale is shown relative to that of the emission line Fe II (λ6456.38 Å). The intensity is normalized to the continuum.

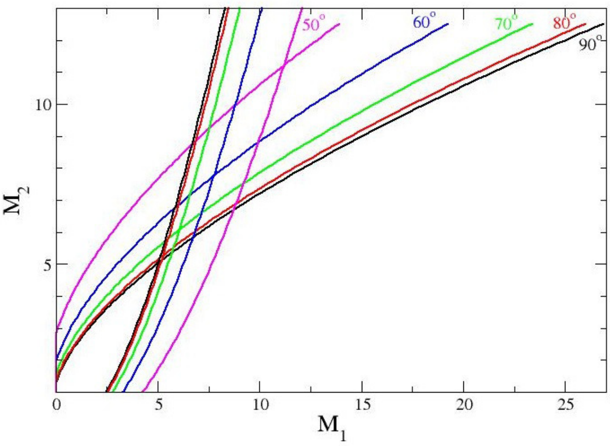

Figure 4: Mass function for the system components. Inclination angles of the system rotational axis are shown by different colors. Masses are shown in $M_\odot$.

spectra. The discovery of absorption lines of neutral metals in the spectrum of HD 327083 reported by Miroshnichenko et al. (2003) unambiguously indicates the presence of a secondary component, which is cooler than the primary component responsible for the emission-line spectrum. In Fig. 1 we compare a part of a high-resolution spectrum of HD 327083 with that of the yellow supergiant BS 6615. The absorption lines of BS 6615 are stronger than those of HD 327083 that suggests a noticeable contribution of the system's hot component.

The absorption lines of HD 327083 were also compared with model atmosphere spectra calculated with the code *SPECTRUM* by Gray & Corbally (1994). Parameters of the cool component ($T_{\rm eff}$ = 7000 K and $v\,sin\,i = 30$ km s^{-1}, log g=2.0) were estimated from the detected absorption lines and their widths. The contributions of the hot and cool components to a wavelength range within the V-band were estimated by comparing the observed and calculated absorption-line strengths and found to be 40% and 60%, respectively.

Fourier analysis of the absorption lines RVs and subsequent fitting them with an orbital solution implies a circular orbit with a period of 107.68±0.02 days. The same period is detected in the photometric variations (see Fig. 2). Near the orbital phases 0.0 (the cool component is behind the hot one) and 0.5, some absorption lines are superimposed on emission lines that makes it impossible to measure the position of the latter (Fig. 3). Overall we confirm the result of Miroshnichenko et al. (2003) that the positions of the emission and absorption lines vary in anti-phase.

The interstellar absorption features in the spectrum of HD 327083 include diffuse interstellar bands (DIBs) as 5780, 5796, 6613, and 8620 Å as well as the lines of Na I at 5889 and 5895 Å. Using relationships between the EW of the DIB at 5780 Å and the color excess E($B-V$) found by Herbig (1993) and Kos & Zwitter (2013), we derived E($B-V$) $\approx$ 1.8 mag.

The optical light curve of HD 327083 shows a deep around the phase 0.5 (the cool component in front of the hot one). It may be due to a partial eclipse of the hot component or to a hot spot on the surface of the cool component created by the radiation from the hot one. Preliminary modeling of both processes suggest an inclination of the system's rotational axis to the line of sight of ~55–60 degrees. This result along with the mass functions for the components (see Fig. 4) lead to their masses of ~6–8 $M_\odot$. The scatter of data points on the photometric phase curve is related to the inhomogeneity of the circumstellar medium (Figure 2).

The spectral energy distribution (SED) data of HD 327083 were taken from different sources, which included both ground- and space-based photometric data. It was modeled with as a sum of a hot and a cool star model atmospheres taken from Kurucz (1994) with effective temperatures of $T_{\rm eff} = 20,000$ K and $T_{\rm eff} = 7,000$ K, respectively (see Fig. **??**). The best fit was found for the 60% contribution of the cool component and 40% contribution of the hot component. The theoretical SED of the sum of the two models is in good agreement with the observed one corrected for the interstellar extinction of E($B-V$) = 1.8 mag. Considering that in the direction of the object A_V/E($B-V$) = 2.95, we get A_V = 5.3 mag.

Using two alternative distances, D_1 = 1.5±0.5 kpc (Miroshnichenko et al. 2003) and D_2 = 2.26±0.15 kpc from (Gaia EDR3, Bailer-Jones et al. 2021), we calculated the luminosity of the system components

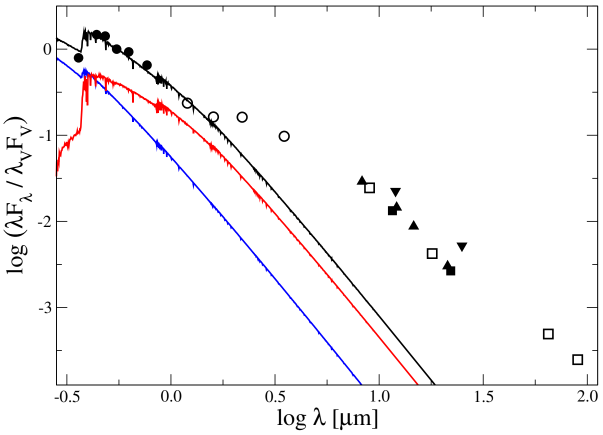

Figure 5: Spectral Energy Distribution of HD 327083 corrected for the interstellar reddening. Symbols: filled circles – optical photometry, open circles – near-IR photometry (*JHKL*), filled squares – WISE data, filled upward triangles – MSX data, open squares – AKARI data, and downward filled triangles – IRAS data. The model atmospheres from Kurucz (1994) for the system components are shown by the blue (hot component) and red (cool component) lines, while the sum of the models is shown by the black line.

and analyzed their positions in the HR diagram (Figure **??**). The hot component has log $L/L_\odot = 4.9 \pm 0.4$ at D_1 and log $L/L_\odot = 5.3 \pm 0.2$ at D_2, while the cool component has log $L/L_\odot = 4.3 \pm 0.4$ at D_1 and log $L/L_\odot = 4.6 \pm 0.2$ at D_2. The luminosity for both distances imply an evolutionary mass of $\sim$20 $M_\odot$ for the hot component and $\sim$12 $M_\odot$ for the cool component that is inconsistent with the masses derived from spectroscopy.

4. Conclusions

Our study of spectroscopic and photometric data of the southern emission-line object HD 327083 resulted in the following findings. We derived a new orbital period of the system 107.68±0.02 days and a semi-amplitude of the RV variations of 48.3±1.7 km s^{-1} for the cool component (nearly the same as that of the emission lines, which represent the motion of the hot component). We confirmed $T_{\rm eff}$ of the system components determined by Miroshnichenko et al. (2003): $\sim$7,000 K for the cool component and $\sim$20,000 K for the hot component. We found the components' masses from the mass function and the system inclination to be $M_{hot} \approx M_{cool} \approx$ 6–8 $M_\odot$ and 55–60°, respectively. This result still needs further refinement using a more accurate modeling of the object's light curve. The evolutionary masses are inconsistent with the spectroscopic ones. This discrepancy may be due to the ongoing interaction between the components.

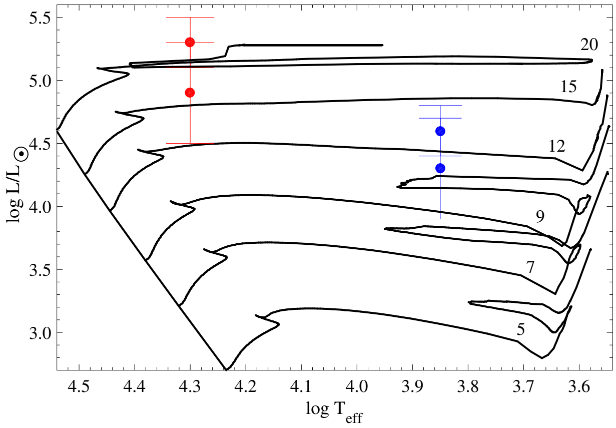

Figure 6: HR diagram with positions of the HD 327083 components for the distances D_1 (lower) and D_2 (upper). Evolutionary tracks for single rotating stars with indicated initial masses in $M_\odot$ (Ekström et al. 2012) are shown by solid lines.

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References

Allen D.A., & Swings J.P.: 1976, *A&A*, **47**, 293-302.
Bailer-Jones C.A.L., et al.: 2021, *AJ*, **161**, id. 147.
Coluzzi R.: 1999, *VizieR Online Data, Catalog*, VI-71A.
Donati J.-F. et al.: 1997, *MNRAS*, **291**, 658-682.
Ekström S., et al.: 2012, *A&A*, **537**, A146.
Gray R.O., & Corbally C.J.: 1994, *AJ*, **107**, 742-746.
Herbig G.H.: 1993, *ApJ*, **407**, 142-156.
Kochanek C.S., Shappee B.J., Stanek K.Z., et al.: 2017, *PASP*, **129**, 104502.

Kos J., & Zwitter T.: 2013, *ApJ*, **774**, id. 72.
Kurucz R.L.: 1994, *Kurucz CD ROM No. 19*, Smithsonian Astroph. Obs.
Lamers H.J.G.L.M., et al.: 1998, *A&A*, **340**, 117-128.
Machado M.A.D., & de Araújo F. X.: 2003, *A&A*, **409**, 665-675.
Manset N., & Donati J.-F.: 2003, *Proc. SPIE*, **4843**, 425-436.
Maravelias G., et al.: 2018, *MNRAS*, **480**, 320-344.
McCarthy J.K., Sandiford B.A., Boyd D., Booth J.: 1993, *PASP*, **105**, 881-893.
Miroshnichenko A.S.: 2007, *ApJ*, **667**, 497-504.
Miroshnichenko A.S., et al.: 2003, *A&A*, **406**, 673-683.
Wheelwright H.E., et al.: 2012, *A&A*, **538**, A6.
Woźniak P.R., Vestrand W.T., Akerlof C.W., et al.: 2004, *AJ*, **127**, 2436–2449.