

Article

Fundamental Parameters and Evolutionary Scenario of HD 327083

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Abstract: In this study, we present refined orbital and fundamental parameters of the Galactic B[e] supergiant binary system HD 327083 using the Bayesian Markov Chain Monte Carlo (MCMC) method applied to the radial velocities data of HD 327083. We found that the system is well described by a circular orbital model with the mass ratio of the components of $q = 1.15 \pm 0.07$. We modeled the evolutionary history of the system using MESA code. Initially, the system was formed by a binary with the orbital period of $P_{orb} = 108$ day, which contained stars with $13.00 \pm 0.05 M_{\odot}$ and $11.50 \pm 0.05 M_{\odot}$ masses. They had a relatively slow rotation $v_{rot} = 0.40 \pm 0.13 v_{crit}$ and provided a strong stellar wind. The current system age is 13.6 ± 0.1 Myr, and the state of the system corresponds to a close filling of the high massive component's Roche lobe and a beginning of the mass transfer. The mass-transfer event will occur in a short interval of $\lesssim 0.1$ Myr only. After that, the mass of the post-primary drops to $\approx 5 M_{\odot}$, the post-secondary mass grows until $\approx 20 M_{\odot}$, and the binary will convert to a detached system with a long orbital period of ≈ 700 days.

Keywords: spectroscopy; binary stars; B[e] stars; circumstellar matter; stellar evolution



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1. Introduction

The B[e] phenomenon is characterized by prominent Balmer emission lines and forbidden emission lines accompanied by a substantial infrared excess indicative of the presence of circumstellar dust. These features strongly imply the presence of dense circumstellar environments consisting of gaseous and dusty material surrounding a star or a stellar system [1]. HD 327083 (MWC 873) is a complex binary system exhibiting the B[e] phenomenon. It was first identified during the Mount Wilson survey for stars with hydrogen emission lines [2] and initially classified as a B5-type star based on the intensity ratios of its helium and magnesium absorption lines [3]. Over subsequent decades, various photometric and spectroscopic studies have revealed the intricate nature of this system, including a high interstellar reddening of $E(B - V) \sim 1.9$ mag [4], near-infrared excess [5], and CO emission features. These findings led to diverse estimates of its fundamental parameters, including luminosity, effective temperature, and mass [6,7].

The binary nature of HD 327083 was revealed by Miroshnichenko et al. [8], who detected photospheric absorption lines from a secondary cool component. Based on a

limited dataset, they proposed two possible orbital solutions with periods of approximately 55 and 180 days. The system was classified as a binary comprising an early B-type primary and an early F-type secondary, with nearly equal masses. These findings positioned HD 327083 as a system at an advanced evolutionary stage, potentially similar to β Lyrae-type binaries. Similar challenges in detecting and analyzing binary Be stars have been discussed in [9], where phase-locked variations in emission-line profiles were used as a diagnostic tool to confirm binarity in multiple systems.

Subsequent high-resolution interferometric studies [10,11] confirmed the presence of a circumbinary Keplerian disk, which contributes to the infrared excess and further supports the system's post-main-sequence evolutionary status. Such gaseous-and-dusty envelopes are often associated with mass transfer in binary systems, as explored in [12] for FS CMA-type objects exhibiting the B[e] phenomenon.

Despite these advancements, several key aspects of HD 327083 remain uncertain. The orbital parameters derived in previous studies were based on a limited number of spectroscopic observations, leaving significant uncertainties in the system's kinematics and evolutionary history. In particular, the role of mass transfer between the components and its influence on the surrounding circumbinary disk has yet to be fully constrained. Recent high-resolution spectroscopy and long-term photometric monitoring reported by Nodyarov et al. [13] refined the system's orbital period to $P_{\text{orb}} = 107.68$ days and provided updated estimates of the component masses, radii, and effective temperatures. In that work, the authors also utilized the latest *Gaia* EDR3 parallax measurement of HD 327083, $\pi = 0.41(2)$ mas [14], which implies a distance of $d = 2.26^{+0.12}_{-0.17}$ kpc. This revised distance underpins the reliability of their new orbital and stellar parameters and was incorporated into their stellar evolution calculations for the system. However, a more detailed investigation of the system's orbital dynamics and evolutionary pathways remains essential.

In this study, we aim to provide a more comprehensive picture of HD 327083's current state and future evolution by integrating updated orbital solutions with calculated evolutionary models. We present a revised determination of the orbital parameters of HD 327083 and, based on them, perform a detailed evolutionary analysis of the system using the stellar evolution code Modules for Experiments in Stellar Astrophysics (MESA, version 24.05.1; [15–20]).

2. RV Variations

To refine the orbital parameters of HD 327083, we analyzed the radial velocity (RV) data from Nodyarov et al. [13], which include both absorption and Fe II emission lines. We applied a Bayesian Markov Chain Monte Carlo (MCMC) approach using the *emcee* Python library [21]. Although we mainly assumed a circular orbit, we also allowed for an elliptical one by including the eccentricity (e) and the time of periastron passage (T_0) in the model. The similar MCMC-based methodology has been validated on both circular and elliptical orbital solutions in previous studies [22].

Our primary parameters of interest were the orbital period (P_{orb}), systemic velocity (γ), and the RV semi-amplitude (K). For initial guesses, we took the mean of all measured RVs as γ and half the difference between the maximum and minimum RVs as K . Assuming normally distributed errors for each measurement, we modeled the likelihood using a Gaussian centered on the predicted orbital RV curve.

These best-fit values, listed in Table 1, illustrate that the observed RV variations are well described by a circular orbital model. The eccentricity included in the fitting procedure turned out to be insignificant. From the best fit, we obtained a mass ratio of the system components¹, $q = K_2/K_1 = M_1/M_2 = 1.15 \pm 0.07$, where K_2 corresponds to the emission lines associated with the secondary component, while K_1 is derived from the absorption

lines of the primary component. The goodness of the fit is reflected in the reduced chi-square values, with $\chi^2_{\nu, \text{Abs}} = 1.3$ ($\nu_{\text{Abs}} = 14$) for the absorption lines and $\chi^2_{\nu, \text{FeII}} = 4.2$ ($\nu_{\text{FeII}} = 9$) for the Fe II emission lines, where ν_{Abs} and ν_{FeII} denote the number of degrees of freedom for each respective data set. We note that our approach to the orbital fitting allowed us to significantly improve the orbital elements' accuracy compared with that reported by Nodyarov et al. [13].

The optical spectrum of the system is dominated by absorption lines from the primary component, while no distinct features from the secondary component are detected. This suggests that the spectrum of the secondary component is heavily veiled, likely due to its high rotational velocity or the presence of circumstellar material. A visualization of the phase-dependent RV variations based on spectral line measurements is presented in Figure 1.

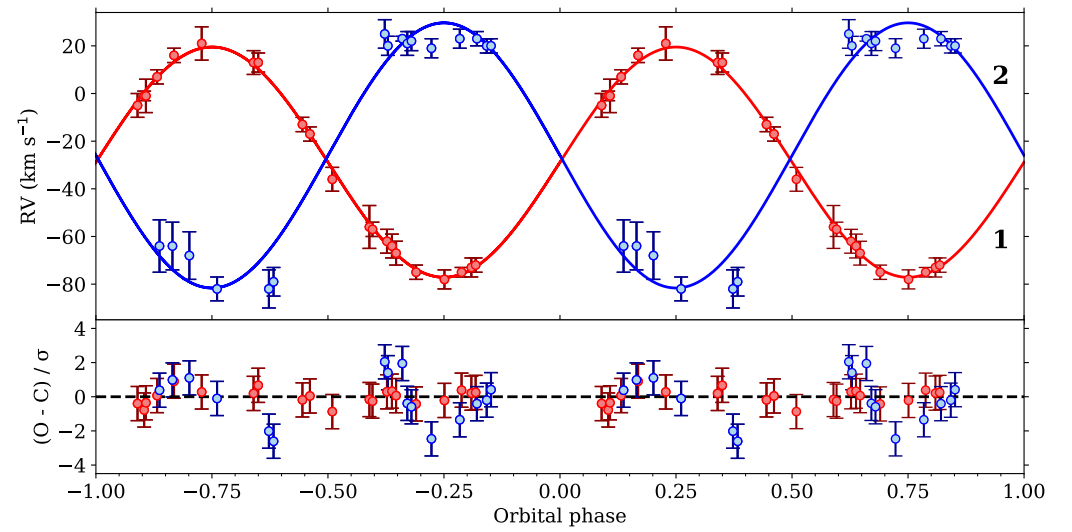


Figure 1. RV variations based on spectral line measurements. **(Top panel)** RV variations as a function of orbital phase. The red curve (labeled “1”) corresponds to the primary (donor) star, whose RV is derived from absorption lines. The blue curve (labeled “2”) corresponds to the secondary (accretor) star, traced by several Fe II emission lines. **(Bottom panel)** $(O - C)/\sigma$ diagram, where O is the observed RV, C is the fit RV value, and σ is the measurement uncertainty (standard deviation) of each RV point.

Table 1. Comparison of orbital parameters.

Parameter	RV_{abs}	$RV_{em} \text{ (Fe II)}$
P_{orb} (days)	107.76 ± 0.01	107.77 ± 0.09
T_0 (HJD—2450000)	1810.56 ± 0.35	1923.31 ± 1.89
e	0.03 ± 0.02	0.04 ± 0.03
ω (degrees)	3.2 ± 0.7	4.3 ± 0.4
γ (km s^{-1})	-28.81 ± 0.35	-25.98 ± 6.17
K (km s^{-1})	48.32 ± 0.47	55.64 ± 2.78
$f(m)$, $M_{\odot}$	1.25 ± 0.03	1.92 ± 0.28
N	20	16

P_{orb} —orbital period, T_0 —epoch of superior conjunction, γ —systemic velocity, e —eccentricity, ω —argument of periastron, K —semi-amplitude of the RV variations, $f(m)$ —mass function, N —number of spectra used in the orbit calculation.

3. System Evolution

We performed evolutionary calculations for the HD 327083 system using the stellar evolution code MESA on a multicore, multiprocessor server at the Laboratory of Astrophysics of the Al-Farabi Kazakh National University². As the input parameters, we

adopted the updated RV solution. The initial orbital period was varied from 105 to 109 days (in an increment of 0.5 day), while the masses of the donor and accretor spanned the ranges $11\text{--}15 M_{\odot}$ and $10\text{--}14 M_{\odot}$, respectively, with increments of $0.5 M_{\odot}$. The effects of stellar rotation were taken into account by specifying an initial surface rotational velocity v_{rot} as a fraction of the critical velocity, v_{crit} , computed according to Meynet and Maeder [23]:

$$v_{\text{crit}} \approx 437 \left(\frac{M_*}{R_*} \right)^{\frac{1}{2}} \text{ km s}^{-1}, \quad (1)$$

where M_* and R_* are the mass and the radius of a star given in solar units, respectively. The ratio $v_{\text{rot}}/v_{\text{crit}}$ was varied from 0.1 to 1.0.

We also adopted the solar metallicity ($Z = 0.014$), which is typical for massive Galactic stars and governs their radiative mass-loss rates. For this purpose, we employed the MESA prescription of the line-driven wind scaled by a factor α_{wind} ³ ranging from 0.1 to 1.0. For the high-temperature regime ($T_{\text{eff}} \gtrsim 10,000 \text{ K}$), the code follows the prescription by Vink et al. [24], and once the effective temperature drops below $\sim 8000 \text{ K}$, it switches to the prescription by de Jager et al. [25]. By varying α_{wind} between 0.1 and 1.0, we can thus finely tune the stellar mass-loss rate. Recent publications (e.g., [26,27]) indicate that classical mass-loss rates for massive stars, such as those predicted by the widely used prescriptions of Vink et al. [24] for hot stars and de Jager et al. [25] for cool supergiants, may be systematically overestimated in certain temperature or metallicity regimes. However, observations also suggest that some stars exhibit mass-loss rates comparable to or even stronger than the theoretical predictions (e.g., [28,29]).

Consequently, both stars lose mass through stellar winds throughout their evolution, even outside the phases of direct Roche-lobe overflow. Additionally, the models include the so-called wind Roche-lobe overflow mechanism (WRLOF) [30,31], which allows the secondary to capture part of the primary's outflow, if the wind acceleration region is comparable to the donor's Roche-lobe radius. This is implemented by introducing the parameter β_{wind} , the fraction of the primary's wind mass that is accreted by the secondary. Here, we adopt $\beta_{\text{wind}} = 0.3$, i.e., 30% of the wind is accreted, while the remaining 70% leaves the system and carries away mass and angular momentum. This moderate value is commonly used in WRLOF-based models to represent a typical, neither minimal nor fully conservative, efficiency of the wind capture within a broad 0.1–0.7 range found in the literature [30].

Convective energy transport was treated with the standard Mixing-Length Theory (MLT) [32], adopting `mixing_length_alpha` = 2.0. Core overshooting was implemented with the MESA step prescription (`overshoot_scheme` = 'step'). We adopted `overshoot_f` = 0.02, which corresponds to a low extension of the convective core. Although this value lies near the lower edge of the empirical range of 0–0.30 [33], it reproduces the observed parameters of both components without requiring excessive mixing.

The models were evolved from the zero-age main sequence (ZAMS) up to a maximum age of 10^8 years or until numerical instabilities arose. To capture rapid phases, we relied on MESA's built-in time-step adaptation with an accuracy of 10^{-3} . In addition, we employed the user hooks in `run_binary_extras` to mitigate non-physical resonances: (1) limiting abrupt changes in radius or luminosity by reducing the timestep if ΔR or ΔL exceeded certain thresholds, and (2) refining the mass-transfer calculations so that sudden spikes in $\dot{M}$ trigger a similar reduction in timestep. These custom routines effectively eliminated non-physical "resonances" without altering the main MESA infrastructure.

We computed 700 evolutionary tracks covering a wide range of initial conditions for the HD 327083 system. The best agreement between the observed data and calculated parameters was achieved for the model with the following initial ($t_0 = 0$ year) param-

ters: $P_{\text{orb}}(t_0) = 108$ days, the primary star mass of $13.00 \pm 0.05 M_{\odot}$, the secondary star mass of $11.50 \pm 0.05 M_{\odot}$, the mass ratio $q = 1.13$, the rotational velocity of both stars $v_{\text{rot}} = (0.40 \pm 0.13) v_{\text{crit}}$, and $\alpha_{\text{wind}} = 0.40 \pm 0.03$.

At an age of 13.6 ± 0.1 Myr, when mass transfer starts and the mass ratio remains within range at $q = 1.15 \pm 0.07$, our best-fitting model predicts a current orbital period of $P = 107.6 \pm 0.8$ days; a separation of $a = 280 \pm 15 R_{\odot}$; and component masses of $12.7 \pm 0.3 M_{\odot}$ and $11.4 \pm 0.2 M_{\odot}$.

These values align well with the estimates derived from spectroscopic analysis and RV measurements. Despite their nearly identical masses, the two stars exhibit significantly different radii and temperatures: the primary star has $R = 107.1 R_{\odot} \pm 5.6$, $T_{\text{eff}} = 7300 \pm 100$ K, and a luminosity $\log(L/L_{\odot}) = 4.47 \pm 0.53$, while the secondary star has $R = 8.5 R_{\odot} \pm 1.5$, $T_{\text{eff}} = 25,000 \pm 250$ K, and $\log(L/L_{\odot}) = 4.40 \pm 0.12$. Both stars rotate at $0.40 v_{\text{crit}}$; accordingly, the donor has an equatorial rotational velocity of $\sim 49 \text{ km s}^{-1}$, while the accretor rotates at $\sim 165 \text{ km s}^{-1}$.

Model calculations suggest that the primary star is on the verge of the Roche-lobe overflow (RLOF), with a filling factor of about 99.2%. We employ the “Kolb” mass-transfer scheme [34] in MESA, so once the stellar radius slightly exceeds its Roche-lobe radius, the system transitions into an active RLOF phase. This near-100% filling factor does not signify a prolonged equilibrium at that level; rather, it reflects the onset of significant mass exchange. As the star crosses the Roche boundary, the mass-transfer rate rapidly increases, producing substantial but numerically stable changes in both the orbital configuration and the stellar properties.

Upon completion of the main mass-transfer episode, the same model predicts a significant orbital expansion. By the end of this phase (13.7 ± 0.1 Myr), the orbital period rises to $P_{\text{orb}} = 711 \pm 11$ days, while the binary separation grows to $a = 971 \pm 22 R_{\odot}$. Despite this considerable increase in P_{orb} and a , our calculations indicate that the orbit remains effectively circular ($e \lesssim 0.05$), owing to strong tidal coupling in the system (e.g., [35,36]). The RLOF mechanism further suppresses eccentricity growth by ensuring a relatively symmetric mass transfer [34], so we do not expect any significant deviation from a near-zero e , even as the system evolves toward a detached configuration.

At this stage, the initially more massive donor has been stripped down to $M_{\text{donor}} = 3.7 \pm 0.1 M_{\odot}$ while the former accretor has gained mass, reaching $M_{\text{accretor}} = 19.6 \pm 0.3 M_{\odot}$. The stripped donor now has a reduced radius of $R = 240 \pm 20 R_{\odot}$, an effective temperature of $T_{\text{eff}} = 4430 \pm 130$ K, and a luminosity of $\log(L/L_{\odot}) = 4.30 \pm 0.13$. The former accretor exhibits a contracted radius of $R = 7 \pm 1 R_{\odot}$, an effective temperature of $T_{\text{eff}} = 37,300 \pm 900$ K, and a luminosity of $\log(L/L_{\odot}) = 4.93 \pm 0.10$.

Further details of both stars’ evolution are illustrated in Figure 2, where we plot their luminosity–temperature tracks. The thick color-coded lines correspond to our best-fit for systems components. Meanwhile, the thinner and/or dashed lines show how varying the wind intensity parameter α_{wind} (from 0.1 to 1.0) shifts the evolutionary paths. We keep the initial masses, orbital period, and rotation fraction fixed, so any differences arise solely from changing α_{wind} .

Figure 3 displays the orbital period as a function of stellar age for a suite of models that share identical initial masses and orbital periods, but differ in their wind intensities (see legend). The thick red line denotes our best-fitting model, converging to an orbital period of approximately 107.6 days at the system’s current age. Even modest variations in the wind parameters—governed by scaling factors for the hot [24] and cool [25] phases—lead to appreciable differences in the rate of orbital evolution.

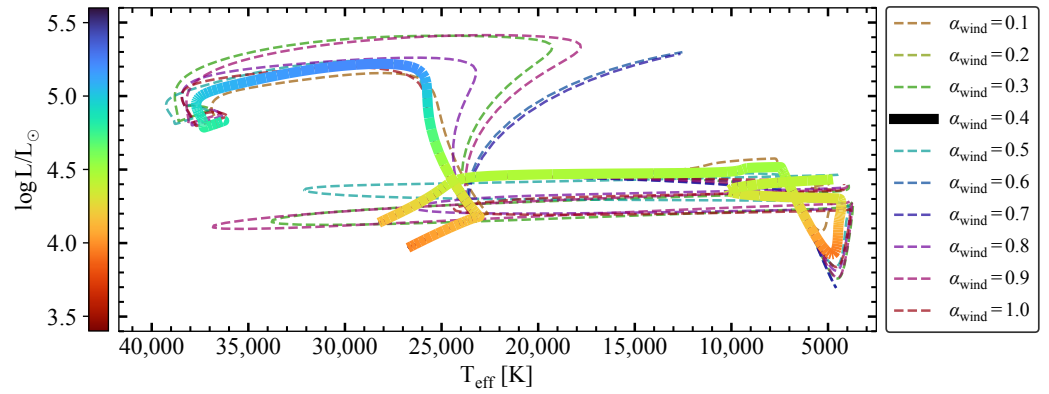


Figure 2. Luminosity vs. effective temperature for the evolutionary tracks of both stars (labeled “1” for the primary/donor and “2” for the secondary/accretor), calculated under fixed initial parameters but with varying wind strength α_{wind} . The solid lines show the evolutionary tracks for each star, with a color scale indicating luminosity. The dashed lines illustrate the range of models calculated by varying α_{wind} . The color bar on the right indicates the value of α_{wind} for each track. The green points correspond to the beginning of the evolution, while the cross marks the end.

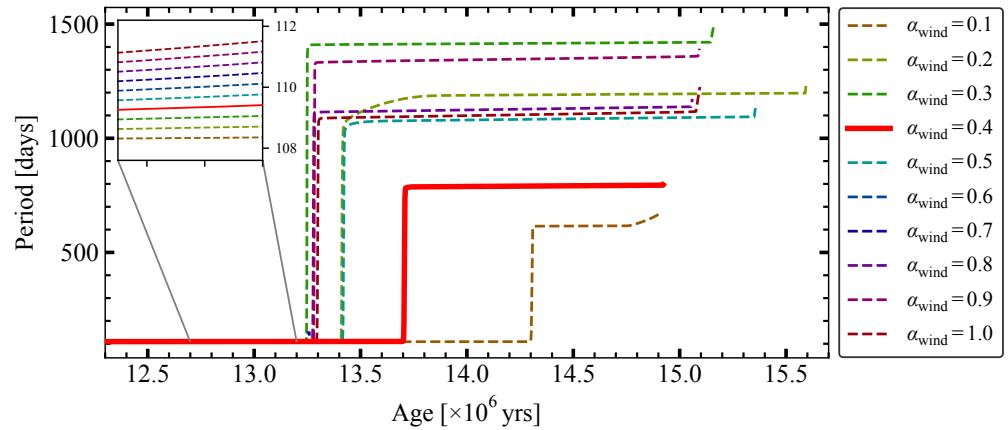


Figure 3. Orbital period vs. system age for models with fixed initial masses and orbital period but different wind coefficients α_{wind} . The color bar indicates the value of α_{wind} . The thick red solid line provides the best fit to the current orbital parameters.

In particular, a stronger early mass-loss can delay or even preempt the Roche-lobe overflow (RLOF), altering both the mass distribution and subsequent evolution of the system. Conversely, weaker winds enable the stars to retain more mass, accelerating RLOF and resulting in a markedly different evolutionary pathway. Because these processes exhibit strong nonlinear feedbacks, the evolutionary tracks do not follow a single monotonic trend, but instead “branch out” into separate evolutionary routes, underscoring the high sensitivity of massive close binaries to initial conditions and wind-driven mass-loss physics (e.g., [37–39]).

Figure 4 shows the mass-transfer rate, $\dot{M}_{\text{transfer}}$, as a function of time for the same suite of models. Once the initially more massive star expands sufficiently to fill its Roche lobe, the mass-transfer rate climbs toward a peak level of $\sim 3 \times 10^{-4} M_{\odot} \text{ yr}^{-1}$. Comparing this plot with Figure 3 reveals that the onset of Roche-lobe overflow (RLOF) coincides with a rapid rise in $\dot{M}_{\text{transfer}}$, which subsequently drives a notable increase in the orbital period. Physically, once mass begins to flow from the donor, its mass decreases, and depending on the internal structure and evolutionary stage, its radius may increase, while the accretor’s mass increases, potentially reversing the initial mass ratio and prompting orbital expansion. In our models, the first mass-transfer episode spans from 13.68 to 13.75 Myr, lasting only

about 0.07 Myr. A subsequent, secondary mass-transfer phase is triggered around 14.92 Myr, but is not explored in detail here.

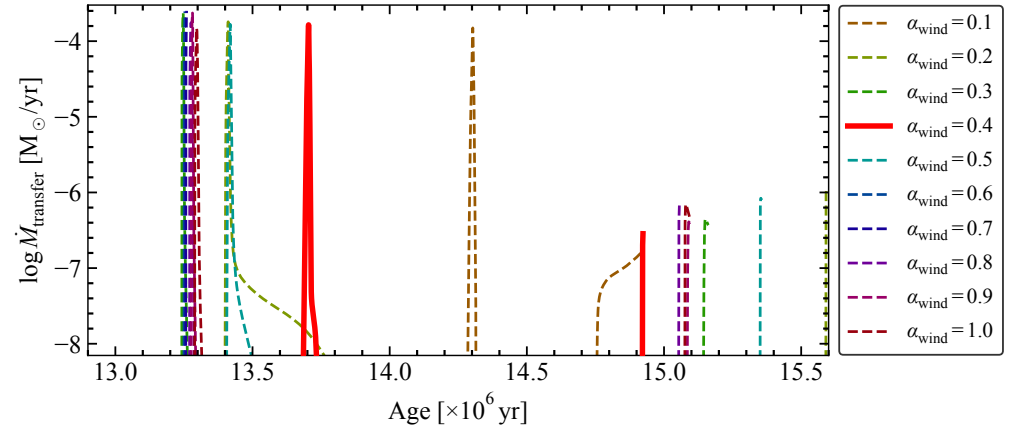


Figure 4. The mass-transfer rate in the binary as a function of time depending on the α_{wind} parameter. The thick red solid lines correspond to the best model.

Figure 5 compares the evolutionary tracks of both components of the best model. The upper panel plots stellar radius vs. temperature (color-coded by luminosity) for each star, revealing how the donor expands and cools during mass loss, while the accreting component maintains a more compact structure. The lower panel plots stellar mass vs. temperature, using the same luminosity color scale, illustrating the decline of the donor's mass and the corresponding luminosity variations. Such a configuration supports the conclusion that HD 327083 currently undergoes an active mass-exchange stage, where the nearly Roche-lobe-filling the primary star transfers matter at a rate of $\dot{M} \sim 3 \times 10^{-4} M_{\odot} \text{ yr}^{-1}$, thereby explaining the observed B[e] phenomenon and the likely presence of a dense circumbinary environment.

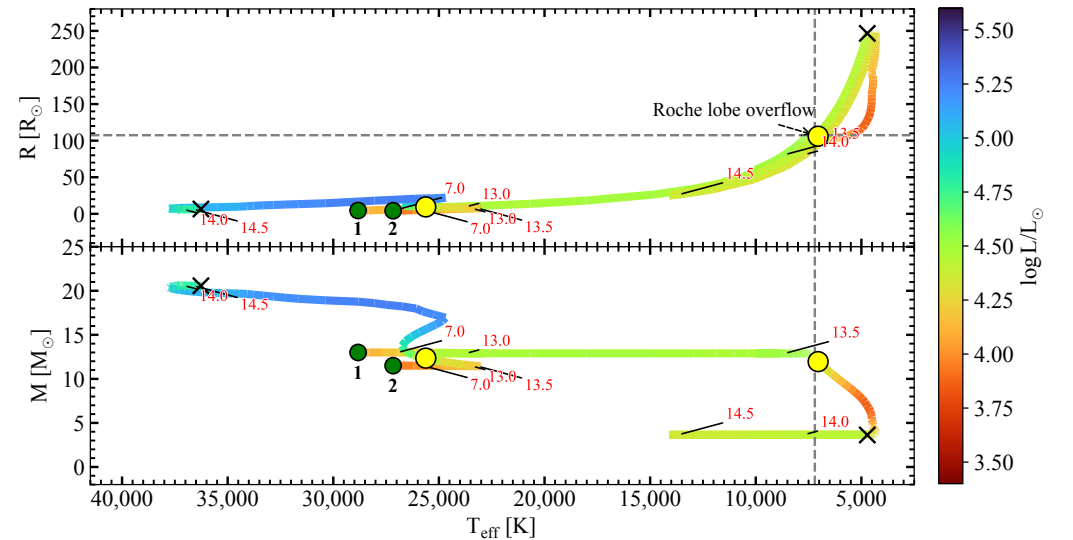


Figure 5. Evolutionary tracks of both components of the best model (labeled “1” for the primary/donor and “2” for the secondary/accretor). (**Top panel**) Stellar radius R vs. effective temperature T_{eff} . (**Bottom panel**) Stellar mass M vs. effective temperature T_{eff} . The color scale indicates luminosity. The yellow point marks the phase where the mass ratio $q = 1.15 \pm 0.07$. The green point corresponds to the beginning of the evolution, while the cross marks the end.

4. Conclusions

In this study, we have presented a detailed analysis of the Galactic B[e] supergiant binary system HD 327083, refining its fundamental and orbital parameters using high-resolution spectroscopy and evolutionary modeling with the MESA code. Our main findings are summarized as follows:

- We recalculated the orbital parameters of HD 327083 (Table 1) by applying a Bayesian Markov Chain Monte Carlo (MCMC) method to the RV data from Nodyarov et al. [13]. We found that the data described by circular orbital model with a mass ratio of the components of $q = K_2/K_1 = M_1/M_2 = 1.15 \pm 0.07$.
- We ascertained that the system evolved from a binary with an initial orbital period of $P_{orb}(t_0) = 108$ days, in which the primary component's mass was $13.00 \pm 0.05 M_\odot$ and the secondary component's mass was $11.50 \pm 0.05 M_\odot$. The initial rotational velocity of both stars were found to be $v_{rot} = 0.40 \pm 0.13 v_{crit}$, and $\alpha_{wind} = 0.40 \pm 0.03$.
- Currently, the system's age is 13.6 ± 0.1 Myr, when the more massive cold component closes to fill or fills its Roche lobe and begins a mass-transfer stage. The mass-transfer event occurred in a very short time of $\lesssim 0.1$ Myr. After that, the mass of the post-primary drops to $\approx 5 M_\odot$ and that of the post-secondary grows to $\approx 20 M_\odot$, and the binary evolves into a detached system with a long orbital period of ≈ 700 days.

We note that the emission lines predominantly formed near the accreting component exhibit larger RV uncertainties than the absorptions originating in the donor's atmosphere. Therefore, further high-resolution spectroscopic monitoring of HD 327083 is essential to shed more light on the physical mechanisms responsible for these emissions. These observations will also help clarify the relative roles of the mass transfer, disk formation, and wind interactions in shaping the observed line profiles, ultimately leading to a more comprehensive understanding of massive binary systems at the beginning of the mass transfer state.

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Data Availability Statement: The spectra are available on request via email at a_mirosh@uncg.edu.

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Abbreviations

The following abbreviations are used in this manuscript: RV—radial velocity, MCMC—Bayesian Markov Chain Monte Carlo, MESA—Modules for Experiments in Stellar Astrophysics, MLT—mixing length theory, RLOF—Roche-lobe overflow, PMS—pre-main sequence, ZAMS—zero-age main sequence, WRLOF—wind Roche-lobe overflow mechanism.

Notes

- 1 Hereafter, we consider mass transfer from the initially more massive or “primary” component onto the initially less massive or “secondary” component. Hence, we use subscript “1” for the primary and subscript “2” for the secondary component. Equivalently, the primary (secondary) and donor (accretor) references are used.
- 2 Research Center “Data Science in Astrophysics” <https://astro.kaznu.info/Computingcluster.html> (accessed on 21 April 2025).
- 3 α_{wind} corresponds to the `Vink_scaling_factor` and `de_Jager_scaling_factor` in MESA, which control the strength of stellar winds. See MESA documentation <https://docs.mesastar.org> (accessed on 21 April 2025).

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