



Analysis of a Double-lined Spectroscopic Binary System Using LAMOST and TESS Data

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Abstract

We present a detailed analysis of a double-lined spectroscopic binary system, Bo Gem, using data obtained from the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) and the Transiting Exoplanet Survey Satellite (TESS). By applying spectral disentangling techniques to the LAMOST Medium Resolution Spectra, we determine the orbital parameters, including the orbital period of $P = 4.0689$ days, and semimajor axis of $a = 14.90 \pm 0.04 R_{\odot}$. The mass ratio between the two components is found to be $q = 0.198 \pm 0.006$, with an inclination of $i = 82.3 \pm 0.13$. The photometric data from TESS revealed periodic light variations due to the eclipsing nature of the system, allowing for the determination of the primary star's radius as $R_1 = 1.68 \pm 0.03 R_{\odot}$ and the secondary star's radius as $R_2 = 3.68 \pm 0.04 R_{\odot}$. The effective temperatures of the primary and secondary stars are measured to be $T_{\text{eff},1} = 9705 \pm 50$ K and $T_{\text{eff},2} = 5830 \pm 22$ K, respectively. By analyzing the disentangled spectra, we determined the stellar atmospheric parameters—including surface gravity and metallicity of both stars. These results not only confirm the double-lined spectroscopic binary status of Bo Gem, but also underscore its value as an important system for testing and refining stellar evolution models.

Key words: (stars:) binaries: eclipsing – (stars:) binaries: spectroscopic – (stars:) binaries: general

1. Introduction

Stellar multiplicity is a ubiquitous outcome of star formation, with observations indicating that a significant fraction of Galactic stars reside in binary or multiple systems (Duchêne & Kraus 2013; Moe & Di Stefano 2017). Understanding these systems is fundamental to advancing stellar physics. For double-lined spectroscopic binary systems (SB2s), where both components are visible in the spectrum, the radial velocity (RV) measurements can be appended for each star throughout their orbit. When these systems are also eclipsing binaries (EBs), combining RV data with light curve analysis allows us to estimate stellar masses and radii with an accuracy of about 1% (Hilditch 2001; Torres et al. 2010; David et al. 2019). These precise measurements make double-lined eclipsing binaries (DLEBs) crucial for testing and validating models of stellar evolution, as their properties can be determined independently of theoretical models (Pols et al. 1997; Pourbaix 2000; Lastennet & Valls-Gabaud 2002; de Mink et al. 2007).

Our current project aims to expand the catalog of DLEBs with accurate mass and radius measurements, primarily using data from the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) survey. The Transiting Exoplanet Survey

Satellite (TESS) has also provided extensive observations of thousands of DLEBs, many of them have high-precision RV measurements.

Bo Gem is an Algol-type eclipsing binary system, first identified by Hoffmeister (1934). Although early studies provided initial orbital elements and light curves (Kreiner 1971; Soyduğan et al. 2011), comprehensive photometric and spectroscopic analyses have remained limited. Recent research, such as the period study by Erdem et al. (2010), highlighted the presence of a significant period increase in Bo Gem, potentially due to a combination of mass transfer and mass loss processes. Their study also indicated the possible existence of a third body with a mass of at least $4.5 M_{\odot}$, suggesting complex dynamical interactions that may involve the light-time effect. Furthermore, other studies have suggested the possibility of additional third and fourth bodies within the system, with masses estimated as $5.4 M_{\odot}$ and $2.5 M_{\odot}$, and have confirmed the presence of negligible third light (L_3) contribution (Yıldırım & Soyduğan 2023). These findings suggest that Bo Gem exhibits intricate interactions and dynamical evolution, making it an ideal candidate for further investigation.

To address the limitations in previous analyses (lack of multi-epoch spectroscopy and atmospheric parameter

determinations), our study combines LAMOST time-domain spectroscopy with TESS photometry. Recent analysis of LAMOST RV residuals reveals a 0.51 yr periodic signal (Lomb-Scargle FAP $< 10^{-4}$; Figure 5), potentially indicating a low-mass tertiary companion with $M_3 \sin i \approx 0.25 M_\odot$. While our current 5 yr data set cannot confirm the 71 yr/30 yr companions proposed by Yıldırım & Soyduğan (2023), future joint LAMOST-TESS monitoring will test this hypothesis through eclipse timing variation (ETV) analysis and Doppler tomography.

This paper is organized as follows: Section 2 describes the data from TESS and LAMOST. Section 3 outlines the analysis methods and results, including orbital and stellar parameters. Section 4 discusses our results and Section 5 provides discussion and conclusions regarding the binary system's evolutionary status.

2. Observations

2.1. Photometry Data

The observational data for this study were obtained from TESS mission, which, beyond its primary goal of exoplanet detection, has collected extensive data on a wide range of celestial bodies (Ricker 2015). Launched on 2018 April 8, TESS is equipped with four cameras that continuously image a 24° by 96° section of the sky with a pixel resolution of $21'' \times 21''$ (Ricker 2015). The satellite covers 85% of the sky in overlapping sectors, each observed for approximately 27 days. High-cadence monitoring is performed for 200,000 pre-selected stars at 120 s intervals, and full-frame images are captured every 1800 s, enabling detailed analysis of stellar and planetary phenomena (Ricker 2015).

TESS provided observational coverage of Bo Gem across three consecutive sectors (43, 44, and 45) from 2021 August 21 to November 5, with a 10 minutes cadence. Each sector typically spans 27 days, although there are inter- and intra-sector gaps of 1–3 days when the satellite transmits data back to the Earth or awaits command uploads.

2.2. Spectroscopy Data

The LAMOST, located at the Xinglong Observatory in Hebei Province, China, is a uniquely designed reflecting Schmidt telescope with an effective aperture of 3.6–4.9 m, a focal length of 20 m, and a field of view (FOV) of 5° (Chu & Cui 1996; Chu 1998; Su et al. 1998; Wang 1999; Zhao 1999). Equipped with 4000 fibers, LAMOST has the capability to provide millions of stellar spectra in both Medium Resolution Spectra MRS ($R \sim 7500$) or Low Resolution Spectra LRS ($R \sim 1800$) modes. In the Data Release 10 (DR10), LAMOST has released 22.29 million spectra, showcasing its significant contribution to stellar research. A notable aspect of LAMOST's observational strategy is its multiple-epoch

observations of the same targets, which greatly enhance the application of dynamical methods for identifying and studying binary systems (Liu et al. 2020, 2024; Li et al. 2023, Kovalev et al. 2024).

The effectiveness of LAMOST in binary star research is exemplified by its observations of Bo Gem. For this system, data were collected over an extended period, with 84 medium-resolution spectra (MRS) recorded from 2018 October to 2023 February. In addition, 10 low-resolution spectra (LRS) were obtained from 2014 February to 2022 November. The MRS, with a resolution of $R \sim 7500$, provides detailed insights into specific wavelength ranges, namely 495–535 nm of the blue arm and 630–680 nm of the red arm. On the other hand, the LRS, covering a broader wavelength range of 370–900 nm with a lower resolution of $R \sim 1800$, offers a comprehensive overview of the spectral characteristics of the system (Zhao et al. 2012). These data sets are essential for advancing our understanding of the Bo Gem system.

3. Data Analysis

3.1. LC Data Detrending

Utilizing the Python package LIGHTKURVE (Lightkurve Collaboration et al. 2018), we retrieve data from the Mikulski Archive for Space Telescopes (MAST) in the form of target pixel files (tpf). From these tpf, we extract the recorded fluxes, measured in electrons per second, to obtain raw light curves. For each quarter, we visually inspect the raw light curves sector-by-sector to identify any possible low-frequency trends. If such a trend is detected, we remove it by applying a flattening procedure. In the final step, we normalize the light curve of each quarter by dividing all flux values by the median flux value of the respective quarter. In practice, the removal of low-frequency trends and the normalization of light curves are performed using the `flatten` and `normalize` functions of the LIGHTKURVE package, respectively. We present the available TESS photometry in Figure 1.

3.2. RV Measurements and Spectral Disentangling

To derive the stellar atmospheric parameters of both components in the binary system, we perform a detailed spectral analysis using observed spectra from the LAMOST MRS. A key aspect of our analysis is the implementation of the Two-Dimensional Cross-Correlation (TODCOR) algorithm (Zucker & Mazeh 1994), which allows us to effectively disentangle the combined spectra of the binary components and accurately determine their individual radial velocities. By applying TODCOR to all available spectra with a signal-to-noise ratio (SNR) greater than 20 across all orbital phases, we account for the blended spectral lines resulting from the orbital motion and enhanced the robustness of our parameter extraction. The inclusion of spectra from various phases

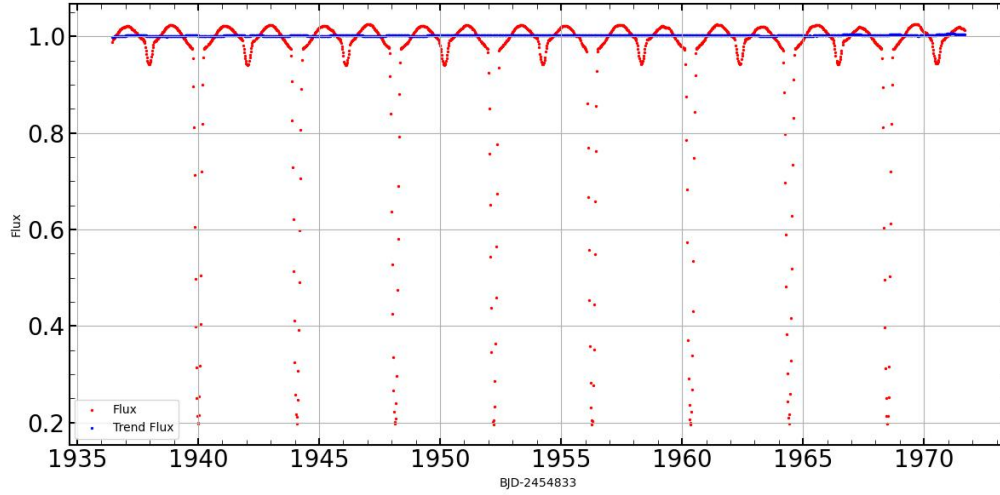


Figure 1. A portion of the light curve of Bo Gem observed by TESS. The red points represent the raw flux measurements, while the blue line shows the trend-corrected flux.

ensures that the derived atmospheric parameters are representative of the stars' behavior throughout their orbit. The synthetic spectral models are used to the observed spectra using Markov Chain Monte Carlo (MCMC) methods, enabling us to determine stellar parameters such as effective temperature (T_{eff}), surface gravity ($\log g$), metallicity ($[\text{Fe}/\text{H}]$), and projected rotational velocity ($v \sin i$) for both the primary and secondary stars.

3.2.1. Spectral Data Selection

We utilize the available observed spectra that have an SNR greater than 20, covering a wide range of orbital phases. This comprehensive selection maximizes the amount of information extracted from the data and improves the statistical significance of our results. By including spectra from different phases, we ensure that the varying radial velocity separations between the stars are adequately sampled, enhancing the effectiveness of the TODCOR algorithm in disentangling the spectra and accurately determining the atmospheric parameters for each star.

3.2.2. Synthetic Spectra Generation

Synthetic spectra are generated using the ATLAS9 stellar atmosphere models (Castelli & Kurucz 2003), covering grids of T_{eff} , $\log g$, $[\text{Fe}/\text{H}]$, and $v \sin i$ values relevant to the expected properties of the binary components. To ensure consistency with the observed LAMOST MRS data, the synthetic spectra are convolved with the instrumental profile to match the spectral resolution of LAMOST MRS ($R \sim 7500$). The model spectra are produced for both the primary and secondary stars at the same spectral resolution as the observations.

3.2.3. Spectral Fitting Procedure

The observed spectra are normalized and corrected for radial velocity shifts using the preliminary orbital solution obtained from the RV analysis. The fitting procedure involved several key steps:

1. *Component-Specific Broadening.* Apply rotational broadening ($v \sin i$) and instrumental line profile convolution to each component's synthetic spectrum separately.
2. *Visibility-Weighted Combination.* Construct composite spectra using geometric visibility and Stefan–Boltzmann flux scaling:

$$F_{\text{composite}}(\lambda) = \frac{1}{4\pi} \left(\frac{a_1(\phi)}{R_1^2} T_1(\lambda_{\text{shift},1}) + \frac{a_2(\phi)}{R_2^2} T_2(\lambda_{\text{shift},2}) \right) \quad (1)$$

where:

- a. $\lambda_{\text{shift},k} = \lambda(1 - v_k/c)$ for Doppler shifts
- b. $a_k(\phi) = \frac{1}{2}[1 + \cos i \cdot \sin(2\pi\phi)]$ is the projected visible area at orbital phase ϕ
- c. R_1 and R_2 (primary and secondary star radii, respectively) derived from light curve fitting
3. *Post-Combination Normalization.* Apply continuum normalization to the merged spectrum, critical for systems with $|\Delta T_{\text{eff}}| > 4000$ K.
4. *Radial Velocity Calculation with TODCOR.* The radial velocities of both stars are computed using the TODCOR algorithm (Zucker & Mazeh 1994). TODCOR extends the traditional cross-correlation technique by simultaneously considering both stellar components, allowing us to disentangle their individual contributions even when

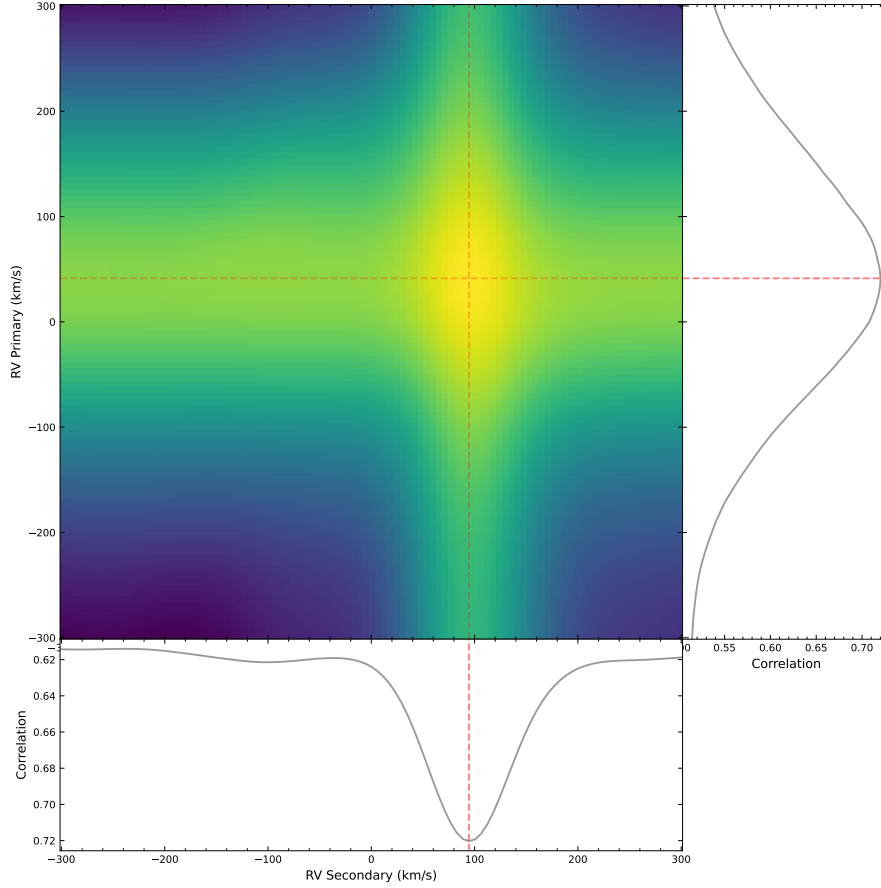


Figure 2. An example of radial velocity calculations using the TODCOR algorithm. The 2D correlation map shows the correlation intensity for different radial velocities of the primary and secondary stars. The y-axis represents the radial velocity of the primary star, while the x-axis represents the radial velocity of the secondary star. Color intensity indicates the strength of the correlation, with the brightest point corresponding to the optimal radial velocity pair. The right and bottom panels display the correlation projections for the primary and secondary stars, respectively.

spectral lines are blended due to orbital motion. Figure 2 shows an example of the 2D correlation map generated by TODCOR. This approach enables a precise determination of the radial velocities for both stars, even in cases where spectral line blending presents challenges.

3.2.4. Parameter Estimation

The MCMC simulations are run with a sufficient number of iterations to ensure convergence and adequate exploration of the parameter space. The median values of the posterior distributions are taken as the best estimates, and the 16th and 84th percentiles provided the uncertainties. The results of these fitting procedures for a specific orbital phase (around 0.75) are shown in Figure 4, illustrating the comparison between the observed spectra and the final combined synthetic models for both components of the system. Although this figure presents the results at one particular phase, it is representative of the fitting quality and parameter accuracy obtained across the full set of observations.

3.3. RV Fitting

To model the RV curves, we develop a custom class, `BinaryStarFitter`, to perform nonlinear least-squares fitting of the spectroscopic data for a binary star system. The RV data, derived from spectral disentangling, are input into `BinaryStarFitter` for parameter optimization.

We initialize the fitting process by defining initial guesses for key orbital parameters, including the eccentricity e , argument of periastron ω , orbital period P , and semi-amplitudes k_1 and k_2 for the primary and secondary stars. Based on the chosen fitting method, we apply either the Levenberg–Marquardt least-squares algorithm, basinhopping for global optimization, or the MCMC method with the `emcee` sampler.

For the MCMC approach, we set 500 steps with 12 walkers to explore the parameter space and use Gaussian priors where applicable. The posterior distributions generated by MCMC provided robust uncertainty estimates for each parameter, effectively capturing potential correlations between parameters. We also incorporate options to lock certain parameters,

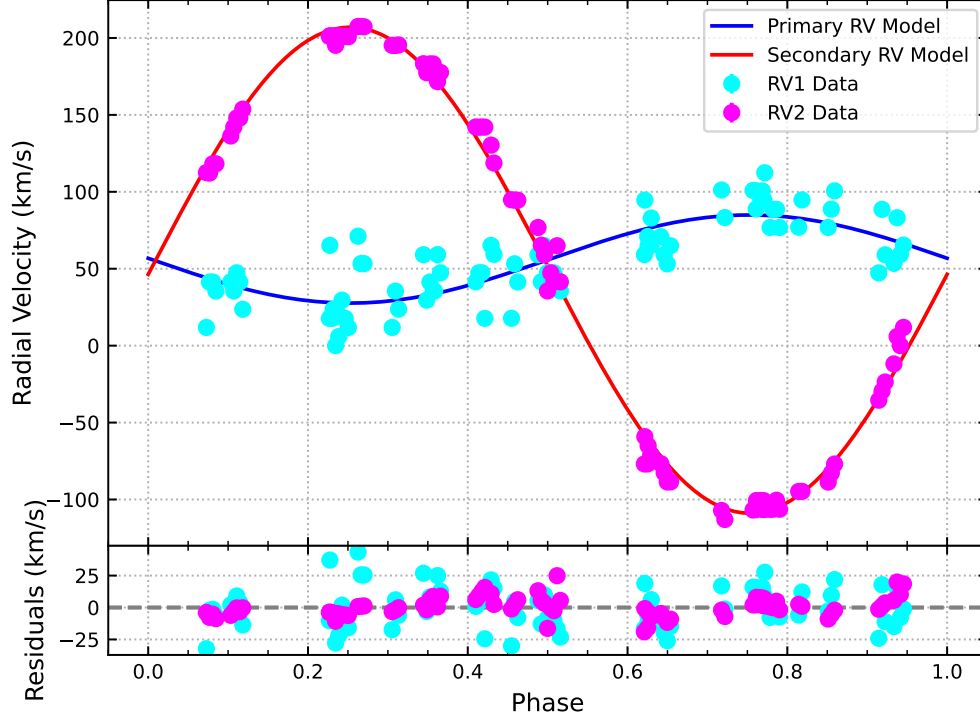


Figure 3. Phase-folded radial velocity (RV) curves of the binary system, with observed data points (dots) and the best-fitting model (dashed lines). The top panel shows the RV curves for the two components of the binary, while the bottom panel displays the residuals between the observed RVs and the model fit, indicating the accuracy of the fitting process.

such as linking γ_2 to γ_1 (systemic velocity) or constraining $k_2 = k_1/q$, based on physical constraints of the system.

The final model yielded the following parameters: the mass ratio $q = 0.198 \pm 0.006$, the eccentricity $e = 0.027 \pm 0.011$, the systemic velocity $\gamma = 55.52 \pm 1.15 \text{ km s}^{-1}$, and the argument of periastron $\omega = 276.5 \pm 5^\circ$. To validate the robustness of these uncertainties, we perform a Monte Carlo simulation using 100 synthetic data sets, each incorporating random Gaussian noise. The results confirm the stability and consistency of the derived parameter uncertainties, demonstrating the reliability of the final estimates.

Figure 3 shows the observed and modeled RV curves, with residuals indicating a good fit. The consistency between the results from spectral disentangling and RV fitting confirms the reliability of our analysis. To further explore potential additional components in the system, we analyzed the radial velocity residuals after subtracting the best-fitting binary orbit. Figure 5 presents a comprehensive analysis of radial velocity anomalies. After fitting the primary Keplerian orbit using MCMC methods (fixed $P = 4.0687722$ days; $q = 0.198$), we calculated the systemic centroid velocity as:

$$\gamma = \frac{q \cdot \text{RV}_{\text{primary}} + \text{RV}_{\text{secondary}}}{1 + q} \quad (2)$$

The Lomb–Scargle periodogram of radial velocity residuals reveals a significant peak at 0.515 yr (FAP = 0.03) following

VanderPlas (2018), distinct from the 71 yr modulation proposed in literature. Phase-folding these residuals at 0.5145 yr shows coherent sinusoidal variation with amplitude $3.17 \pm 0.31 \text{ km s}^{-1}$. Bootstrap analysis confirms the signal significance (FAP = 0.03) against stochastic noise. The lower panel demonstrates the phase-folded centroid velocity perturbations, supporting the hypothesis of a low-mass tertiary companion ($M_3 \sin i \approx 0.25 M_\odot$) gravitationally perturbing the binary system’s barycenter.

3.4. Stellar Parameters

To determine the absolute stellar parameters of the binary system, we employ PHOEBE 2.4, using the parameters obtained from our RV analysis and spectral disentangling (see Section 3.3) as initial estimates. Key parameters such as the mass ratio, semimajor axis, eccentricity, orbital period, and effective temperature are fixed in our model. We also adopt a metallicity of $[\text{Fe}/\text{H}] = -1.11$ based on our spectral analysis.

Initially, we utilize PHOEBE’s built-in estimators to compute theoretical values for parameters such as the flux ratio between the primary and secondary components. This flux ratio is incorporated into the RV measurements, refining the radial velocities of both stars and enhancing their precision. With the updated RV results from Section 3.2, we repeat the

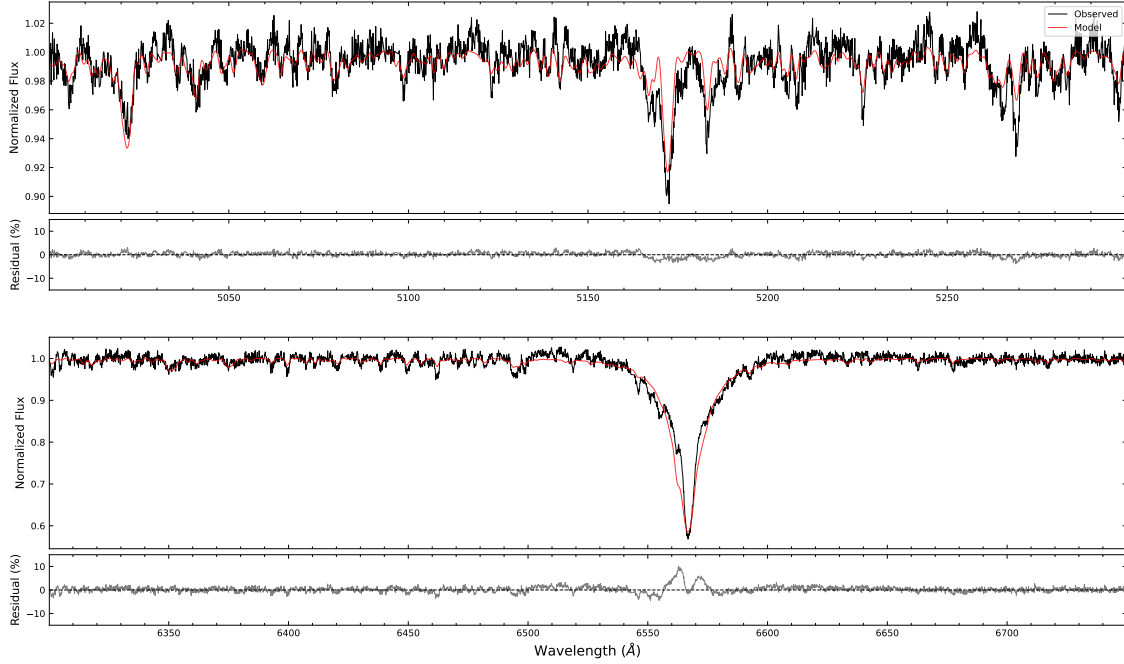


Figure 4. Comparison between the observed and modeled spectra of the binary system at an orbital phase around 0.75. The observed spectrum is represented by the black line, while the red line denotes the best-fit combined model. The residuals (percentage differences between observed and modeled spectra) are shown below each spectral region, highlighting the fit quality. Prominent spectral features, such as the H- α absorption line near 6563 Å, are well-reproduced by the model.

determination of the absolute stellar parameters using PHOEBE.

To refine the model further, we adjust the remaining free parameters, including the argument of periastron ω , the temperature ratio between the secondary and primary stars $r_{\text{eff}} = T_{\text{eff},2}/T_{\text{eff},1}$, and the stellar radii R_1 and R_2 . We apply a gravitational darkening coefficient of 1.0 for the primary star, indicative of a radiative atmosphere, and 0.32 for the secondary star (Ruciński 1969; Lucy 1967), consistent with a convective atmosphere, ensuring accurate representation of the stellar atmospheres.

We optimize these parameters using MCMC simulations with the `emcee` sampler to thoroughly explore the parameter space. Gaussian priors based on observational data are applied to obtain robust and reliable estimates.

After several iterations of recalculating the RVs and re-optimizing the PHOEBE model, we derive the final stellar parameters. The best-fit values for the stellar masses, radii, temperatures, and orbital elements are summarized in Table 1, confirming the accuracy and consistency of our analysis. The phase-folded light curve of the binary system is shown in Figure 6, where the residuals exhibit non-random structures around phases 0 and 0.5. This suggests that certain physical effects may not be fully captured by our current model. A possible source is the adoption of fixed gravitational darkening coefficients (1.0 for the radiative primary and 0.32 for the

Table 1
Best-fit Atmospheric Parameters for the Primary and Secondary Stars

Parameter	Primary Star	Secondary Star
Effective Temperature, T_{eff} (K)	$9705.85^{+54.79}_{-49.55}$	$5820.88^{+55.10}_{-54.93}$
Surface Gravity, $\log g$ (cgs)	$4.33^{+0.09}_{-0.10}$	$2.91^{+0.11}_{-0.11}$
Metallicity, [Fe/H]	$-1.12^{+0.09}_{-0.09}$	$-1.11^{+0.08}_{-0.10}$
Projected Rotational Velocity, $v \sin i$ (km s $^{-1}$)	$154.86^{+15.94}_{-18.57}$	$47.38^{+17.17}_{-22.63}$

convective secondary), which may be inadequate in the presence of surface inhomogeneities, irradiation, or ongoing mass transfer. Alternatively, these features could arise from incomplete treatment of reflection effects, simplified limb-darkening laws, or circumstellar material. Further refinement of the model will be pursued in future. The best-fit atmospheric parameters for the primary and secondary stars are summarized in Table 2. The results are consistent across the spectra from different orbital phases, indicating the robustness of the fitting procedure.

4. Results

We present a comprehensive analysis of the binary system by integrating photometric data from TESS with spectroscopic data from LAMOST, incorporating RV measurements via the TODCOR algorithm. This methodology, which contrasts with the light-curve-focused approach used by Yıldırım & Soydugan (2023), enhances the precision and reliability of the orbital

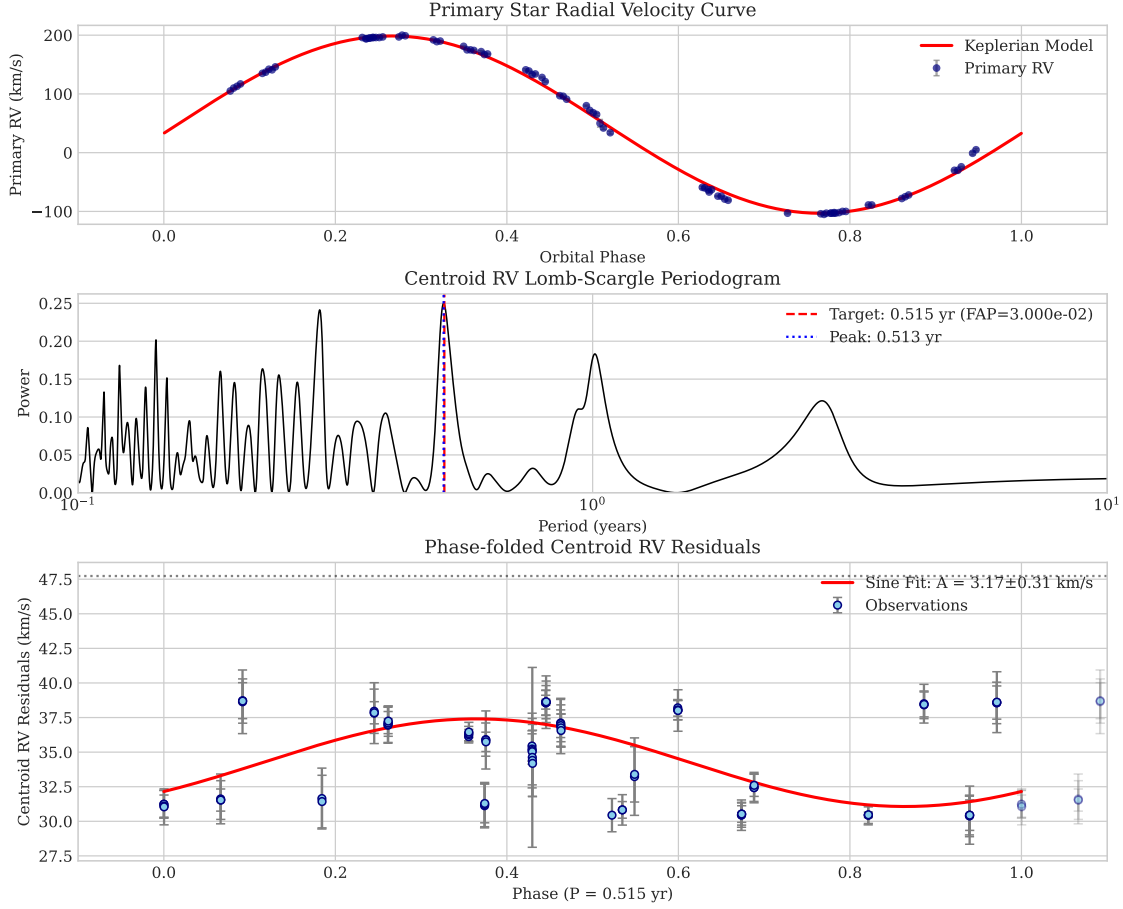


Figure 5. Top panel: Primary star radial velocity measurements (blue points) phase-folded at the orbital period $P = 4.0687722$ days, with the best-fitting Keplerian model (red curve). Middle panel: The Lomb–Scargle periodogram of radial velocity residuals, showing a significant peak at 0.515 yr (FAP = 0.03) distinct from the literature-reported 71 yr period (blue dashed). Bottom panel: Centroid RV residuals phase-folded at 0.5145 yr with best-fit sinusoid (solid red line, amplitude = $3.17 \pm 0.31 \text{ km s}^{-1}$), indicating gravitational perturbations from a tertiary companion ($M_3 \sin i \approx 0.25 M_\odot$).

Table 2
Comparison of Stellar Parameters for Bo Gem from Yıldırım & Soyduğan (2023) and this Study

Parameter	Yıldırım & Soyduğan (2023)	This Study	Unit
Mass ratio, q	0.210 (8)	0.198 (Fixed)	...
Primary RV semi-amplitude, K_1	...	29.81(90)	km s^{-1}
Secondary RV semi-amplitude, K_2	...	150.57(9)	km s^{-1}
Semimajor axis, a	14.90 (6)	14.90 (4)	$R_\odot$
Primary mass, M_1	2.22(22)	2.24(20)	$M_\odot$
Secondary mass, M_2	0.47(4)	0.44(3)	$M_\odot$
Primary temperature, $T_{\text{eff},1}$	9700 (45)	9708.1 (Fixed)	K
Secondary temperature, $T_{\text{eff},2}$	4740 (45)	5830 (22)	K
Metallicity, [Fe/H]	-1.10 (0.05)	-1.11 (Fixed)	...
Orbital inclination, i	80.03(32)	82.3 (1.3)	degrees
Primary radius, R_1	2.21 (3)	1.68 (3)	$R_\odot$
Secondary radius, R_2	3.90 (2)	3.68 (4)	$R_\odot$

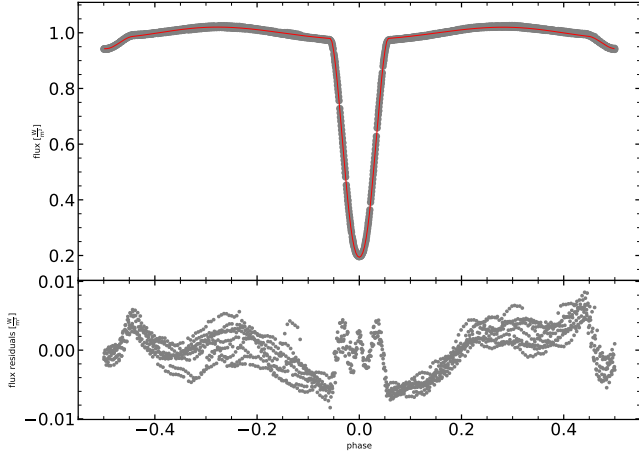


Figure 6. Phase-folded light curve of the binary system, showing flux variations due to eclipses. The upper panel displays the normalized flux over phase, indicating primary and secondary eclipses. The lower panel shows residuals of the flux fit.

and stellar parameters derived, providing a robust and in-depth picture of the system’s dynamics and structure.

The inclusion of RV data allowed us to precisely determine the binary system’s orbital parameters, including the semi-major axis, eccentricity, and mass ratio. Specifically, we obtained values of $a = 14.90 \pm 0.04 R_{\odot}$ for the semi-major axis, $e = 0.017 \pm 0.002$ for eccentricity, and $q = 0.198 \pm 0.006$ for the mass ratio. These results not only align well with previous studies but offer significantly improved precision. The integration of RV measurements reduces the biases typically associated with photometry-only methods, leading to more robust and accurate parameter estimations.

Our analysis also determines the effective temperatures of the primary and secondary stars as $T_{\text{eff},1} = 9708.1 \pm 50$ K and $T_{\text{eff},2} = 5830 \pm 22$ K, highlighting a substantial temperature contrast characteristic of a semi-detached Algol-type binary. Additionally, we obtain precise measurements of the stellar radii, with $R_1 = 1.68 \pm 0.03 R_{\odot}$ for the primary and $R_2 = 3.68 \pm 0.04 R_{\odot}$ for the secondary, which reflect the distinct evolutionary stages of each component.

The use of TODCOR-based spectral disentangling provided detailed insight into the RV variations of each component, allowing for an independent and reliable determination of the systemic velocity. This advancement in method, absent from previous studies that solely relied on light curves, enabled a precise calculation of spectral parameters for both the primary and secondary stars. Our approach underscores the advantages of combining RV data with photometric analysis, as it enhances both the precision and robustness of the orbital model and yields a more complete representation of the binary system’s dynamical behavior.

5. Discussion and Conclusions

Compared to the results of Yıldırım & Soyduğan (2023), which primarily rely on photometric data for parameter estimation, our incorporation of RV measurements and spectral disentangling yields parameters that are more physically consistent and less prone to biases inherent in photometric-only analyses. For instance, we determine the secondary star’s effective temperature to be $T_{\text{eff},2} = 5830 \pm 22$ K, which is significantly higher than $T_{\text{eff},2} = 4740 \pm 45$ K reported by Yıldırım & Soyduğan (2023). As a result, the derived radii for both the primary star ($R_1 = 1.68 \pm 0.03 R_{\odot}$) and the secondary star ($R_2 = 3.68 \pm 0.04 R_{\odot}$) in our analysis are smaller compared to the values reported by Yıldırım & Soyduğan (2023) ($R_1 = 2.21 \pm 0.03 R_{\odot}$, $R_2 = 3.90 \pm 0.02 R_{\odot}$), reflecting the impact of the different temperature estimates. These discrepancies likely arise from the inclusion of additional spectroscopic data in our study, which, combined with RV measurements, allows us to disentangle the contributions from both stellar components and achieve a more reliable determination of their intrinsic properties. Furthermore, the updated mass ratio ($q = 0.198$) and semimajor axis ($a = 14.90 \pm 0.04 R_{\odot}$) align closely with previous studies, confirming the general structure of Bo Gem as a semi-detached binary with a primary component that is significantly hotter and more compact than the secondary.

The combination of RV fitting, spectral disentangling, and light curve modeling highlights the advantages of integrating spectroscopic and photometric data for binary system analyses. Our detection of a 0.51 yr periodic signal in the RV residuals (Figure 5) suggests potential third-body perturbations, with $M_3 \sin i \approx 0.25 M_{\odot}$, though longer baseline observations are needed to confirm this candidate companion. This multi-disciplinary approach provides a more comprehensive and accurate representation of the system’s dynamics and stellar properties, revealing unexpected complexity in this supposedly well-characterized binary.

We perform a detailed spectroscopic and photometric analysis of the double-lined eclipsing binary system Bo Gem using data from LAMOST and TESS. The RV-derived mass ratio ($q = 0.198 \pm 0.006$) combined with TESS light curve modeling resolves previous discrepancies in radius determinations, while systematic residuals in $H\alpha$ line profiles (Figure 4) hint at circumstellar material potentially linked to ongoing mass transfer. Future high-cadence spectroscopic monitoring will enable Doppler tomography to map accretion structures, while continued LAMOST observations will test the proposed hierarchical architecture through eclipse timing variations.

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