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The multiplicity properties of early-type stars from LAMOST DR8

Y. Guo[1], **C. Liu**[2], **L. Wang**[1], **J. Wang**[1], **B. Zhang**[2], **K. Ji**[1], **Z. Han**[1] **and X. Chen**[1]

[1] *Yunnan observatories, Chinese Academy of Sciences, P.O. Box 110, Kunming, 650011, China (E-mail: cxf@ynao.ac.cn)*

[2] *School of Astronomy and Space Science, University of Chinese Academy of Sciences, Beijing, 100049, China*

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Abstract. Massive binary stars are key to understanding stellar formation and evolution. To explore the intrinsic binary fraction ($f_{\rm b}^{\rm in}$), mass ratio distribution ($f(q)$), and orbital period distribution ($f(P)$) of early-type stars (O/B/A-types), we analyze a homogeneous spectroscopic sample of 886 stars from LAMOST DR8, each with more than six observations. These stars are classified based on effective temperature ($T_{\rm eff}$), metallicity ([M/H]), and projected rotational velocity ($v \sin i$). Monte Carlo simulations were applied to correct for observational biases. Results show that the intrinsic binary fraction increases with $T_{\rm eff}$ and metallicity, while remaining relatively constant across $v \sin i$. For stars in groups of B8-A, B4-B7, O-B3, the binary fractions are $f_{\rm b}^{\rm in} = 48\% \pm 10\%$, $60\% \pm 10\%$, and $76\% \pm 10\%$, respectively.

Key words: Statistical-catalogs-surveys-early-type-binaries-rotation

1. Introduction

Most stars are part of binary systems, with early-type stars showing particularly high binary fractions (Heintz, 1969; Abt & Levy, 1976; Duquennoy & Mayor, 1991). Statistical analyses of binary systems, including the binary fraction, orbital period, and mass ratio distributions, are crucial for understanding stellar formation and compact object evolution (Sana et al., 2012; Liu, 2019; Han et al., 2020). These properties help explain the formation of double black holes, neutron stars, and other gravitational wave sources (Chen et al., 2018; Han et al., 2020; Langer et al., 2020). Among the statistical properties, the binary fraction, f_b, is one of the most critical parameters and has been widely explored over the past few decades. However, previous studies on massive binaries have reported binary fractions ranging from 51% to 69% for O-type stars, and there are ongoing debates over whether metallicity correlates with the binary fraction (Raghavan et al., 2010; Kobulnicky et al., 2014; Guo et al., 2022; Liu, 2019).

Many of these studies have been based on small or heterogeneous samples. Large spectroscopic surveys like LAMOST offer a chance to improve this analysis with more homogeneous data. Recent LAMOST studies have reported binary fractions of early-type stars, though some aspects, such as the impact of metallicity, remain unexplored due to limited observations. With the release of LAMOST DR8, we aim to improve upon previous work by analyzing a larger sample of 886 early-type stars with higher observational cadence, focusing on the binary fraction's dependency on metallicity and other stellar parameters.

2. Data

In this study, we adopt the 9,382 early-type stars from Guo et al. (2022) to investigate their statistical properties, in which the atmospheric parameters from Guo et al. (2021) and the radial velocity from Zhang et al. (2021). We then selected 886 stars from the LAMOST MRS database with more than six observations to minimize uncertainties in binary fraction, mass ratio, and orbital period distributions. The sample is divided into groups based on effective temperature ($T_{\rm eff}$), metallicity ([M/H]), and projected rotational velocity ($v \sin i$). The stars were classified into three spectral type groups: B8-A, B4-B7, and O-B3. For metallicity ([M/H]), the stars were divided into three categories: [M/H] $<$ -0.55, -0.55 $\leq$ [M/H] $<$ -0.1, and [M/H] $\geq$ -0.1. Additionally, based on projected rotational velocity ($v \sin i$), we classified the stars into three groups: $v \sin i$ $<$ 35 km/s, 35 $\leq v \sin i <$ 70 km/s, and $v \sin i \geq$ 70 km/s.

3. Method

We adopt the Monte-Carlo (MC) simulation approach from Sana (2013) to estimate the intrinsic binary fraction ($f_{\rm b}^{\rm in}$) based on the observed binary fraction ($f_{\rm b}^{\rm obs}$). Two synthetic cumulative distribution functions (CDFs) are constructed for the radial velocity variation (ΔRV) and the minimum time interval between exposures (ΔMJD), assuming orbital configurations. The distributions for the orbital period (P) and mass ratio (q) are modeled using power laws, $f(P) \propto P^{\pi}$ and $f(q) \propto q^{\gamma}$. Using the assumptions of two-body Keplerian systems, we simulate radial velocity (RV) variations and construct cumulative distribution functions (CDFs) for both ΔRV and ΔMJD. The simulated CDFs are compared to the observed data using the Kolmogorov-Smirnov (KS) test, and the simulated binary fraction ($f_{\rm b}^{\rm sim}$) is compared to the observed binary fraction ($f_{\rm b}^{\rm obs}$) using a Binomial distribution. The final results are obtained by optimizing a global merit function (GMF), which combines KS probabilities for ΔRV and ΔMJD distributions, as well as the Binomial probability.

4. Results

We found that $f_{\rm b}^{\rm in}$ increases with increasing $T_{\rm eff}$. For stars in groups of B8-A, B4-B7, O-B3, the binary fractions are $f_{\rm b}^{\rm in}$ = 48%$\pm$10%, 60%$\pm$10%, and 76%$\pm$10%, respectively. The binary fraction is positively correlated with metallicity for spectra in the sample, with derived values of $f_b^{in} = 44\% \pm 10\%$, $60\% \pm 10\%$ and $72\% \pm 10\%$ for spectra with metallicity spanning from [M/H]<-0.55, -0.55 $\leq$ [M/H]¡-0.1, to [M/H] $\geq$ -0.1. Over all the $v \sin i$ values we have considered, the f_b^{in} have constant values as $\sim$50%. It seems that the binary population is relatively evenly distributed over a wide range of $v \sin i$ values, while the whole sample shows that most of the stars are concentrated in low values of $v \sin i$ (probably from strong wind and magnetic braking of single massive stars), and in high values of $v \sin i$ (likely from the merge of binary stars) in cases. Stellar evolution and binary interaction may be partly responsible for this. In case of observations with more than six observations, we have derived $\pi = -0.9 \pm 0.35$, -0.9 ± 0.35, and -0.9 ± 0.35, and $\gamma = -1.9 \pm 0.9$, -1.1 ± 0.9 and -2 ± 0.9 for O-B3, B4-B7, B8-A type stars, respectively. There are no correlations being found between $\pi(\gamma)$ and $T_{\rm eff}$, and neither for $\pi(\gamma)$ and [M/H]. The uncertainties of the distribution decrease towards a larger sample size with higher observational cadence.

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