# Dynamical interaction in the stellar cluster – Evidence from binaries of NGC3532

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**Abstract**

The binary properties of open clusters impose important restrictions on star formation theories and clusters' dynamical evolution. We establish a comprehensive method for modeling the cluster members' color-magnitude diagram (CMD) as a mix of single stars and photometric unresolved binaries. Using this method, we can infer the binary fraction $f_{\rm b}$ and the binary mass-ratio distribution index $\gamma_q$ when a power-law is assumed, with high precision and accuracy. We employ a modified Gaussian process to determine the main sequence ridge line and its scatter from the observed CMD as model input. We apply the method to the open cluster NGC3532 with the *Gaia* DR2 photometry. For the cluster members within a magnitude range corresponding to FGK dwarfs, we obtain $f_{\rm b} = 0.267 \pm 0.019$ and $\gamma_q = -0.10 \pm 0.22$ for binaries with mass ratio $q > 0.2$. The $f_{\rm b}$ value is consistent with the previous work on NGC3532 and smaller than that of field stars. The near-zero $\gamma_q$ implies a nearly uniform distribution of binary mass ratios. For the first time, we unveil that the stars with smaller mass or in the inner region tend to have lower $f_{\rm b}$ and more positive value of $\gamma_q$ due to the lack of low mass-ratio binaries. The clear dependences of binary properties on mass and radius are most likely caused by the internal dynamics.

**Key Words:** Mixture model, Astrophysics, Open cluster, Binary stars

## 1. Introduction

Characterization of the binary fractions and mass ratio function in star clusters is of fundamental importance. It is generally accepted that the majority of stars formed in clusters and most of them formed in binary or multiplicity systems. The properties of binaries in open clusters can provide essential constraints on the star formation theory. Moreover, binaries are deeply involved in the dynamical evolution of stellar clusters. For example, close encounters involving binary systems can disrupt soft binaries. This process occurs more frequently in the central region of clusters due to the higher stellar number density. Therefore, binaries can serve as a probe of cluster dynamical interaction.

Most binaries are unresolvable in images. Here we develop a new method which models the single stars and unresolved binaries as a mixture in color magnitude diagram. As we will show, this new method can determine the binary fraction and the index of mass ratio distribution of open clusters with unprecedented precision.

## 2. Mixture Model Method

The members of an open cluster formed in the same molecular cloud simultaneously as a single stellar population (SSP). Single stars lie on an isochrone in CMD, where the location

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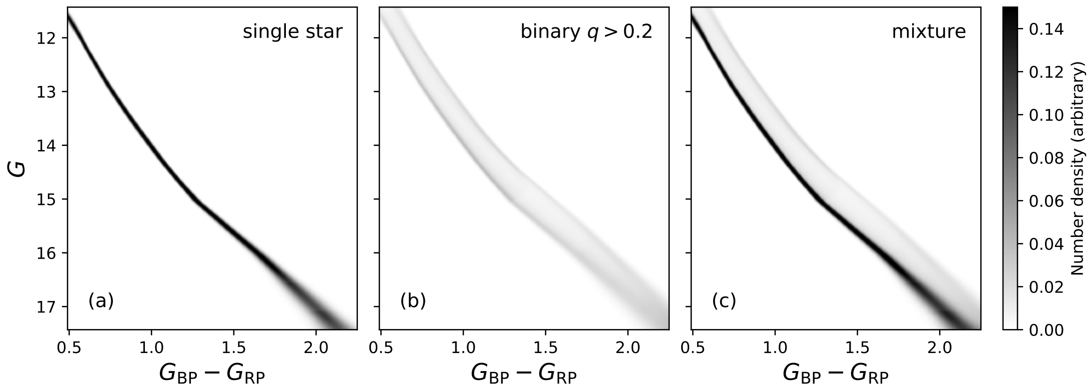


**Figure 1**: The model number density distribution of single stars (a), unresolved binaries (b) and their mixture (c). For illustration, we use a SSP at age = 400 Myr with solar metallicity and adopt a mass function with power index $-2.35$. For binaries, we adopt $f_{\rm b} = 0.27$, $\gamma_q = 0.0$ and $q_{\rm min} = 0.2$. The scatters, $\sigma_m$ is 0.01 magnitude and $\sigma_c$ is a function of $G$.

of a star is solely determined by its mass. An unresolved binary contains two stars that are too close to be resolved in image. Its composite color and magnitude are determined by the masses of the two stars, $m_1$ and $m_2$, or equivalently, the mass of the major star, $m_1$, and the binary mass ratio, $q \equiv m_2/m_1$. Assuming that the distribution of $q$ follows a power-law $q^{\gamma_q}$, the task is to measure the binary fraction $f_{\rm b}$ and the index $\gamma_q$ from observation.

A widely adopted method to study binaries in the CMD is simply dividing the CMD into single and binary regions and counting cluster members in each region (see, e.g., Sollima et al. (2010); Milone et al. (2012); Li et al. (2013) and references therein for applications in star clusters). However, it is intractable to infer the mass-ratio distribution using this method. Moreover, most previous work only focus on the binaries with high mass ration (e.g., $q > 0.4$). It is because low mass ratio binaries (e.g., $q < 0.2$) are very close to the main sequence, which makes the classification of low mass ratio binaries and single stars particularly difficult. The observational errors may blend the single stars and low mass ratio binaries, and the theoretical isochrones do not always match the observed main sequence of a real cluster to a satisfactory level, both of which can severely bias the parameter estimates.

Instead of explicitly classifying each cluster member as a single star or a binary, we show that a better approach is to model the CMD as a mixture of the two components where the mass function and observational error can be naturally considered in a Bayesian framework (see Li et al. (2020) for details). The basic idea is illustrated in Figure 1, which shows the number distribution of single stars, binaries, and their mixture for an example cluster.

Moreover, we propose a novel algorithm, a robust Gaussian process regression based on iterative trimming, which can pinpoint the main sequence ridge line precisely in the CMD and allows us to measure the low mass-ratio binaries (Li et al., 2021). This is a particular advantage, because the lower mass ratio binaries are more sensitive to the dynamic interaction.

## 3. NGC 3532 as an example

By using the Gaia DR2 photometric data and the astrometric members, the open cluster NGC3532 is found to have $f_{\rm b} = 0.267 \pm 0.019$ and $\gamma_q = -0.10 \pm 0.22$, with the sample of $m_1$ between 0.5 to 1.5 $M_\odot$. These results imply that NGC3532 is not a binary-rich cluster,

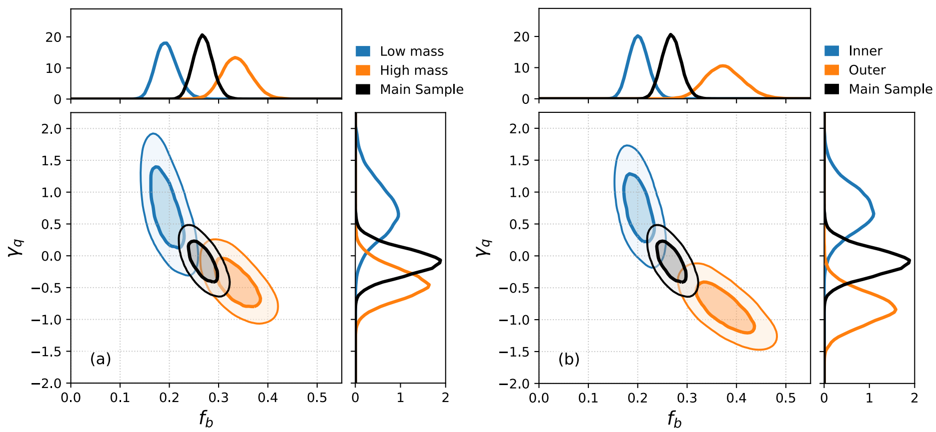


**Figure 2**: Probability density functions (PDFs) of parameters $f_{\rm b}$ and $\gamma_q$ based on the EMCEE sampling of NGC3532 for different sample stars. Each set of contours show the $1\sigma$ and $2\sigma$ confidence regions for $f_{\rm b}$ and $\gamma_q$ inferred from the relevant sample. The black contours are the same for two panels and show the distribution for the whole sample, whereas the blue (orange) contours show the distributions for the fainter (brighter) half of this sample in panel (a), and the inner (outer) part in panel (b). The corresponding marginalized PDFs for each sample are also shown as the colored curves in the top and right side panels.

and its binary mass ratio follows a nearly uniform distribution.

We further unveil the mass and radius dependences of binary properties. As show in Figure 2, the lower mass and the inner region stars have few low mass ratio binaries. Such correlations are evidence of internal dynamical interaction, consistent with the argument that binaries with smaller primary mass or lower mass-ratio get disrupted by interactions more efficiently due to their lower binding energy.

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