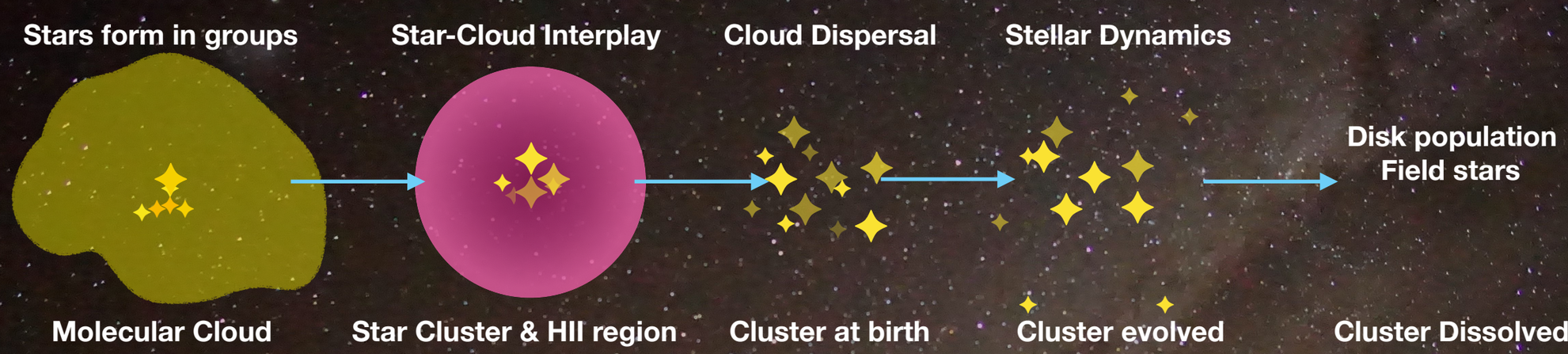
Dynamical interaction in stellar cluster — Evidence from binaries of NGC 3532

Lu Li (Shanghai Astronomical Observatory, Chinese Academy of Sciences)

Zhengyi Shao, Zhaozhou Li, Jincheng Yu, Jing Zhong, Li Chen



Why binary stars in open cluster are important?

- Constraints to **star formation** theory
  - Almost all stars form in clusters
  - The majority forms in binary or multiple systems
- D**ynamical evolution** of stellar clusters may change the binary properties
  - Heggie-Hill Law: soft binaries get disrupted efficiently in the early stage.
  - Extremely hard binaries get harder can provide gravitational fuel that prevent core collapse.

Extra advantages on constraining the binary properties in open clusters:

The stars in the open cluster have same age, metallicity, distance —> Main sequence in the Color-Magnitude Diagram (CMD)

An open cluster is a city of stars and binary stars are the lovers. What is the fate of these couples?

Modeling the unresolved binaries in the CMD

Unresolved binaries in CMD

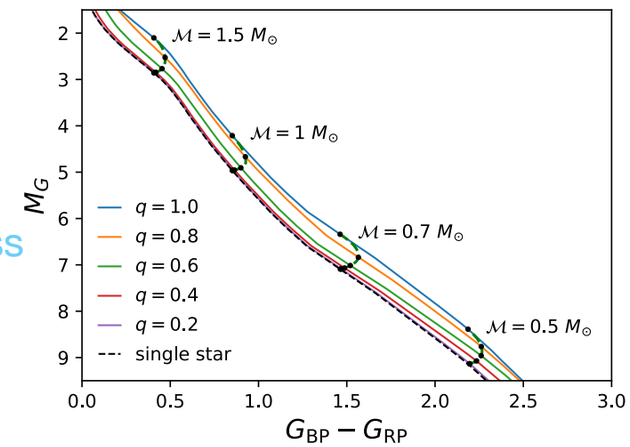
Binary fraction $f_b = \frac{N_b}{N_{tot}}$

Can be function of mass and radius!

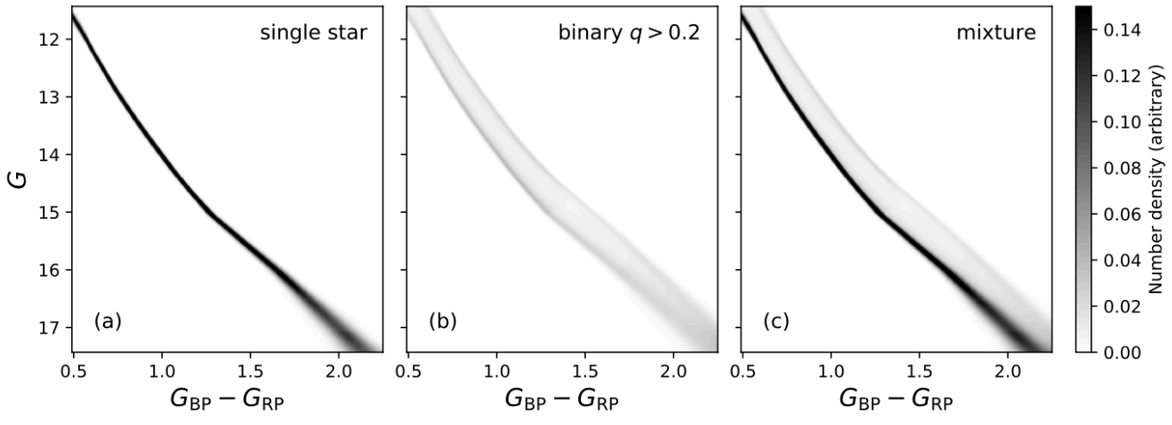
Mass ratio $q = \frac{m_2}{m_1}$ m_2: secondary mass, m_1: major mass

Mass ratio distribution $\frac{dN}{dq} = q^{\gamma_q}$

Large γ_q ⇨ more high q binaries



Mixture model



The model number density distribution of single stars (a), unresolved binaries (b) and their mixture (c). For illustration, we use a single stellar population at age = 400 Myr with solar metallicity and adopt a mass function with power index -2.35. For binaries, we adopt f_b = 0.27, γ_q = 0.0, and q_{min} = 0.2. The scatters, σ_m is 0.01 magnitude and σ_c is a function of G.

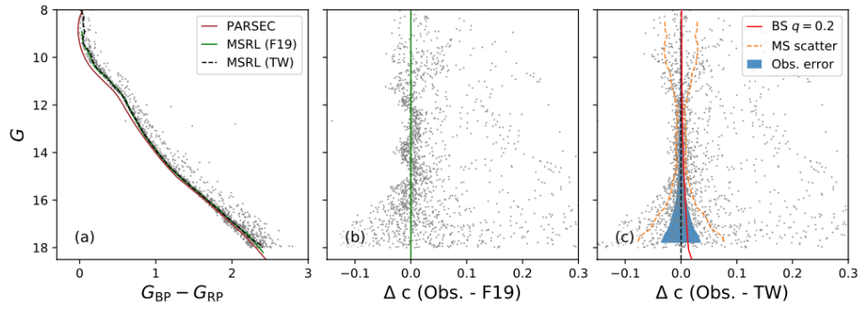
- **Single stars**: Isochrone (age, [Fe/H], distance, extinction), Mass function
- **Binaries** (Fitting parameters): Binary fraction f_b, mass ratio distribution γ_q.
- Convolve observational error -> Probability density distribution

Identifying the main sequence and its scatter

Why important:
- The inferred binary properties are sensitive to isochrone model.
- Stellar models can not match the Gaia data perfectly.
- The scatter of the main sequence is larger than observational error.

Solution: using main sequence ridge line from data itself
- Draw the ridge line by hand manually (Fritzewski, 2019, hereafter F19)
- Robust Gaussian process based on iterative trimming: objectively, fast, automatic (this work)

https://github.com/syrte/robustgp



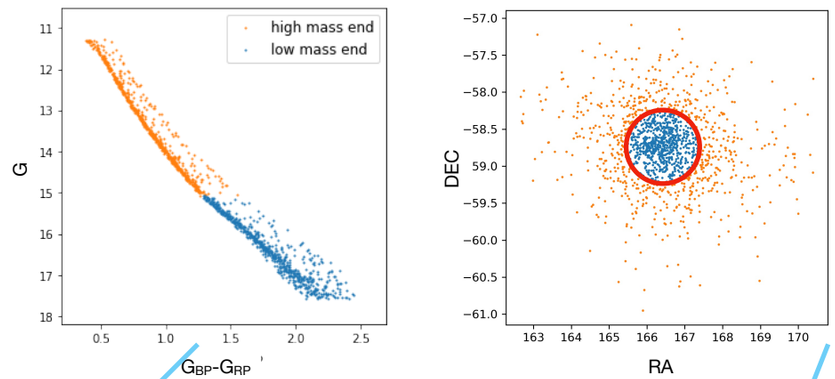
Comparison of the main sequence ridgelines and the scatters of NGC3532. (a) The color-magnitude diagram of the cluster. Member stars are shown as gray dots. The brown curve shows the PARSEC isochrone provided by G18, the green curve, and the black dash line show the MSRLs from F19 and the Gaussian process (this work, TW), respectively. (b) The residual color with MSRL by F19. (c) The residual color with MSRL by this work. Orange curves show the 1σ interval of residual color for single stars as a function of magnitude. The Blue shaded region shows the typical color uncertainties of Gaia measurement for comparison. The red curve shows the BS of q=0.2.

Binary properties of NGC 3532 — Evidence of dynamics

Inferred binary fraction $f_{\rm b}$ and mass-ratio index γ_q for NGC3532.

	N	$f_{\rm b}^{0.2}$	γ_q	$f_{\rm b}^{0.5}$	$f_{\rm b}^{0.7}$
main sample	1403	0.267 ± 0.019	-0.10 ± 0.22	0.162 ± 0.009	0.096 ± 0.007
$G < 15.06$ mag	701	0.337 ± 0.030	-0.44 ± 0.25	0.182 ± 0.014	0.103 ± 0.010
$G > 15.06$ mag	702	0.194 ± 0.022	0.71 ± 0.44	0.143 ± 0.012	0.094 ± 0.010
$r < r_{\rm h}$	701	0.201 ± 0.019	0.75 ± 0.35	0.149 ± 0.013	0.099 ± 0.010
$r > r_{\rm h}$	702	0.374 ± 0.037	-0.82 ± 0.26	0.174 ± 0.013	0.092 ± 0.010

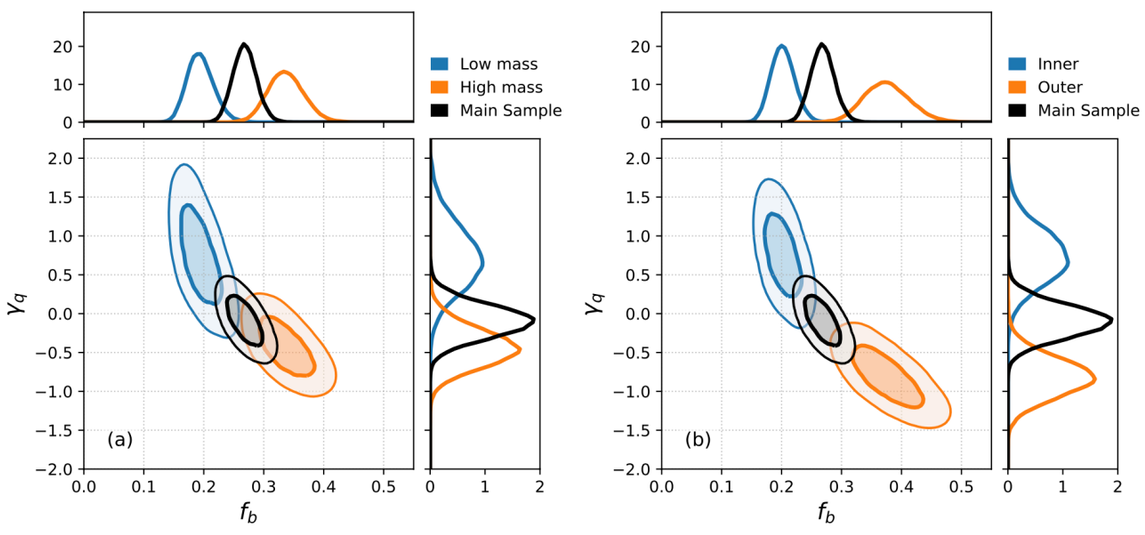
The main sample adopted for NGC 3532 have the flux limitation of [11.32, 17.62] mag, corresponding to the single star mass between [0.5, 1.5] $M_\odot$. We fit $f_b^{0.2}$ (fraction with q > 0.2) and γ_q , Then derive $f_b^{0.5}$ and $f_b^{0.7}$ from the original fitting parameters, represent the fraction of the binaries with q > 0.5 and q > 0.7.



Dividing the stars by mass (left) or distance to center (right). Red circle represents the half number radius r_h.

Results:

- Main Sample: $f_{\rm b}^{0.2} = 0.27 \pm 0.02,\ \gamma_q = -0.01 \pm 0.22$
  - Mass ratio distribution is significantly more flatten than the shape of random paring, might be dynamical hint.
- Mass/Radius dependence — **for the first time!**
  lower $f_b^{0.2}$ and **higher** γ_q for stars with smaller mass or in the inner region.
  - Smaller binding energy for small M or low q: $E_b \propto m_1^2 q$.
  - More encounters in the inner cluster.
- Difference comes from low *q* binaries. The fraction of high *q* binaries is nearly constant.
  - Larger primary mass are less affected by dynamical processing.



The PDFs of parameters f_b and γ_q based on the emcee sampling of NGC 3532 for different sample stars. Each set of contours show the 1σ and 2σ confidence regions for f_b and γ_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.

Sociology in the CITY OF STARS

- Many stars (30%) in open cluster are in marriage (binary system).
- The most stable style of marriage is monogamy, open relations (higher order systems) would be destroyed by dynamics efficiently.
- The marriage is fragile when (massive ~ wealth)



1. You are both poor (less massive)
2. You are much poorer than your partner (low q)
3. You live in the downtown (inner region) where there are too many temptations (dynamical encounter)!

- Exceptions: the Heggie-Hill law: very loved ones (hard binary stars) tend to harden.

Email: lilu@shao.ac.cn
http://arxiv.org/abs/2008.04684
This paper is accepted in ApJ.