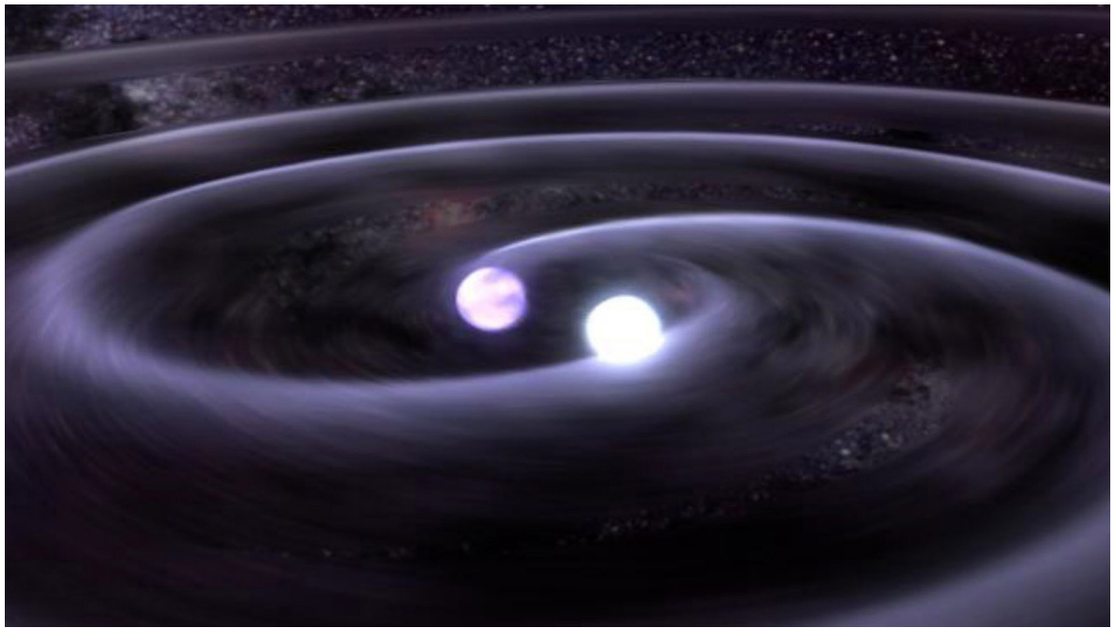
# Constrain the Unresolved Binary Distribution of Open Clusters in CMD



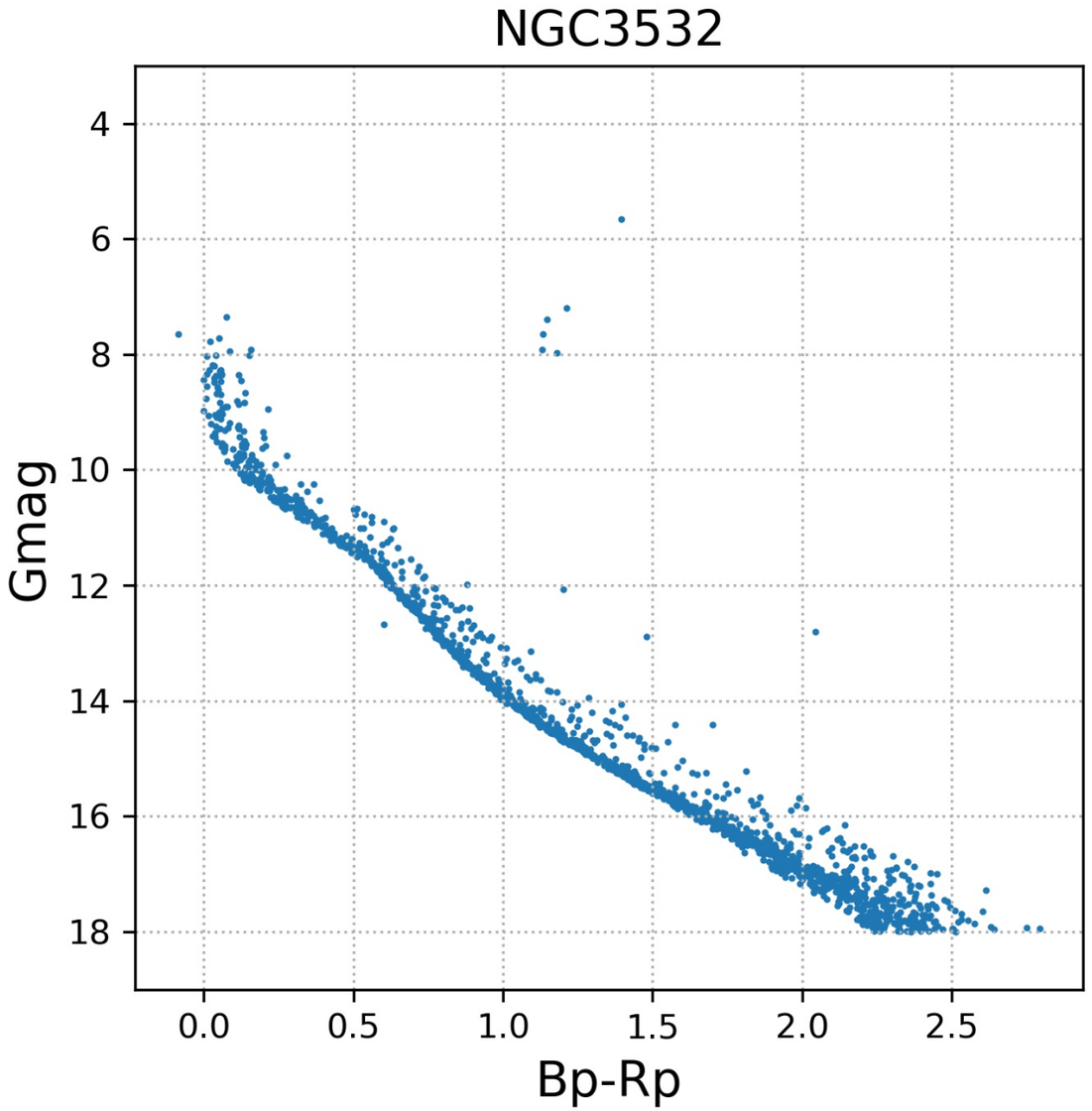

李璐

上海天文台

导师：邵正义、陈力

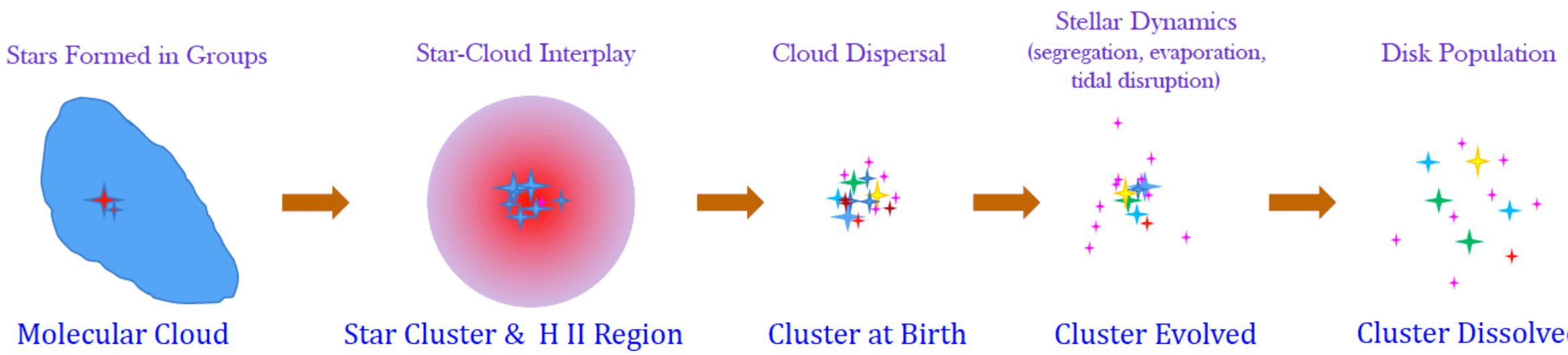

2019.11.29 Daqing

# Open cluster — NGC3532




**Age = 300 Myr**
**Distance = 485 pc**
**[Fe/H] = 0.0**
**E(B-V) = 0.022**

# Why binary stars in open cluster are important?




- Constraints to **star formation** theory
  - Most stars form in open clusters or associations
  - And majority form in binary or multiple systems
- Tracers for **dynamical evolution** of stellar clusters

- **Extra benefits**: OCs have better measurement to age, metallicity, distance than field stars.

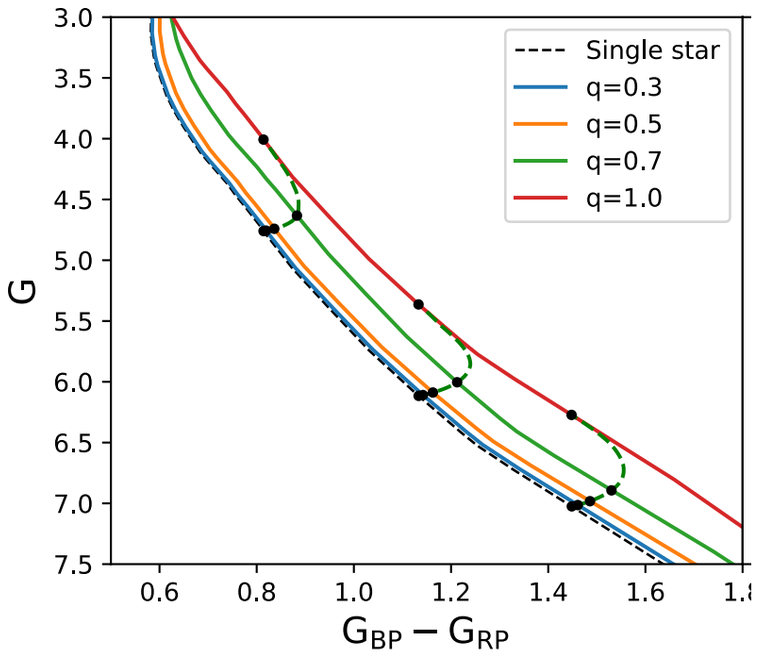
# Unresolved Binary — Non co-evolution binary star

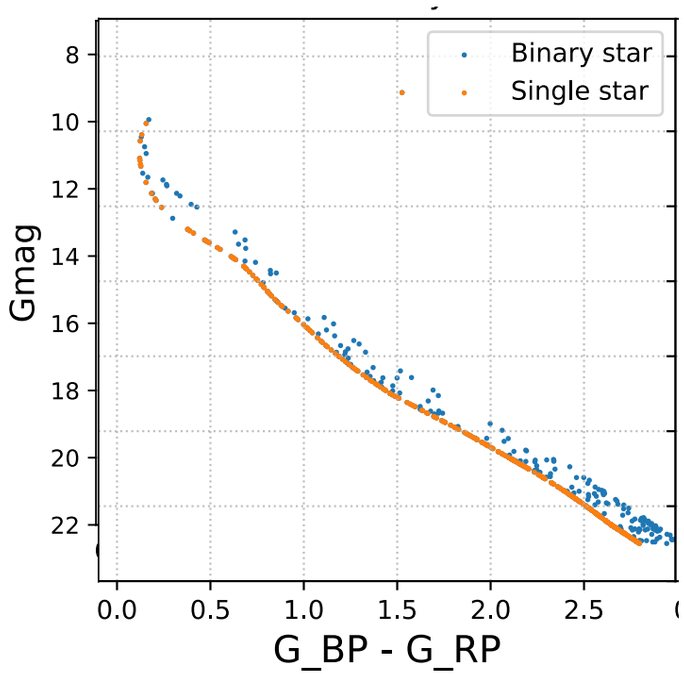
**Binary fraction** $f_{bin} = \frac{N_{bin}}{N_{tot}}$ Can be function of mass and radius!

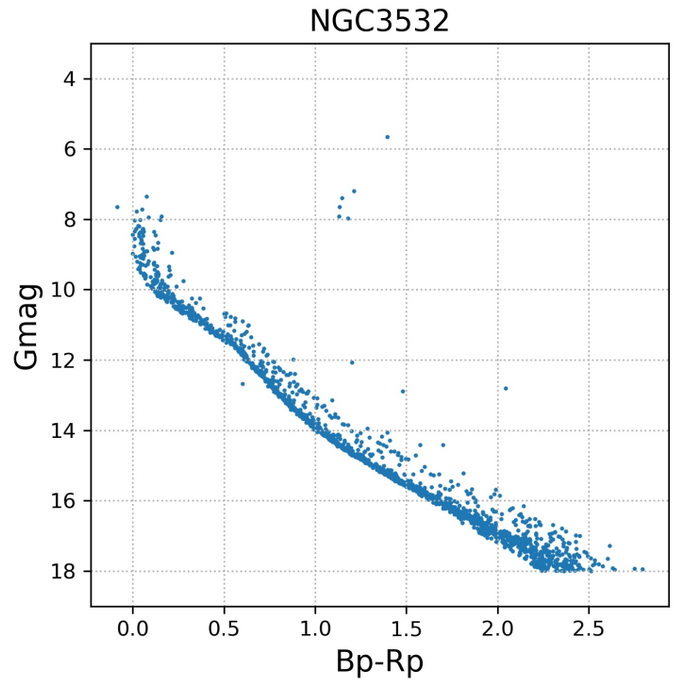
**Mass ratio** $q = \frac{m_2}{m_1}$ $m_2$: secondary mass; $m_1$: major mass

**Mass ratio distribution** $\frac{dN}{dq} = q^{\gamma_q}$ Large $\gamma_q$ ⇨ more high $q$ binaries

$$m_b = -2.5\log(10^{-0.4m_1} + 10^{-0.4m_2})$$



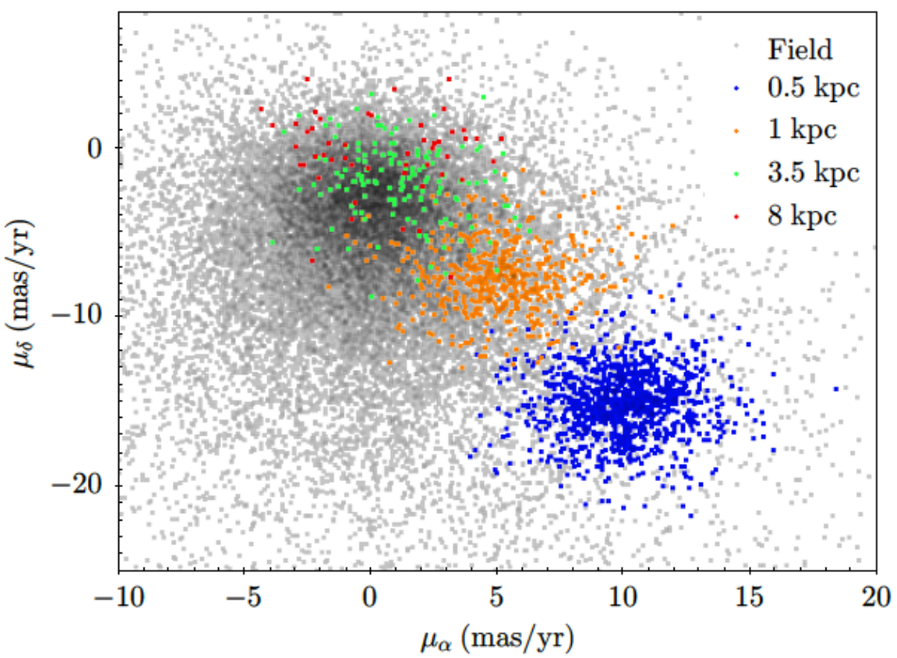



# Challenges

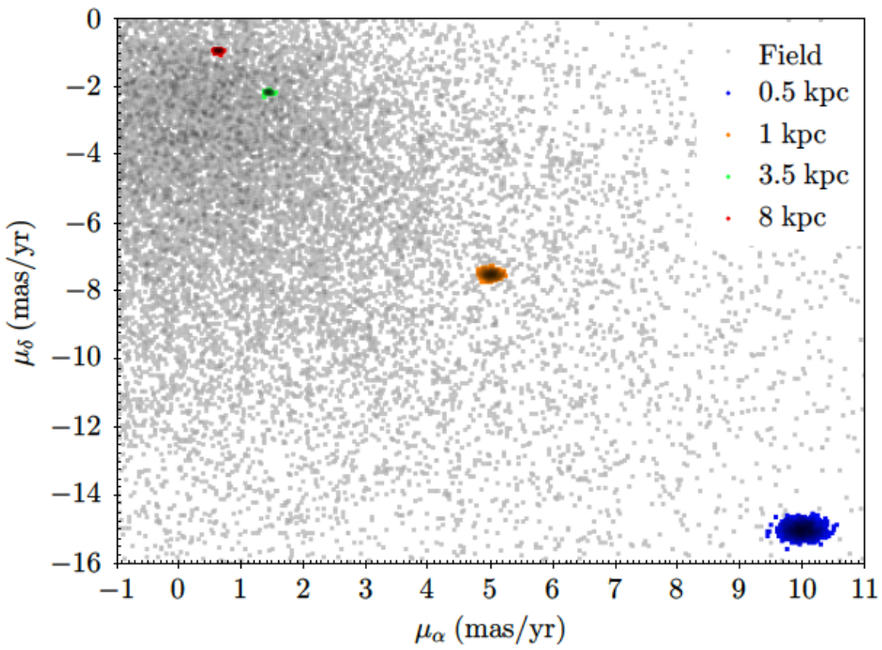
Previous attempts are limited by small sample size

- Poor membership determination ⇒ solution: Gaia

HSOY uncertainties
(Altmann et al, 2017, A&A 60, 4)




Gaia end-of-mission uncertainties
from Gaia web-site




- Lack of rigorous statistics ⇒ here we are!

# How to constrain $f_{bin}$?

**Conventional method:**

**Main Sequence ridge line**

↓

**Distinguish two groups**

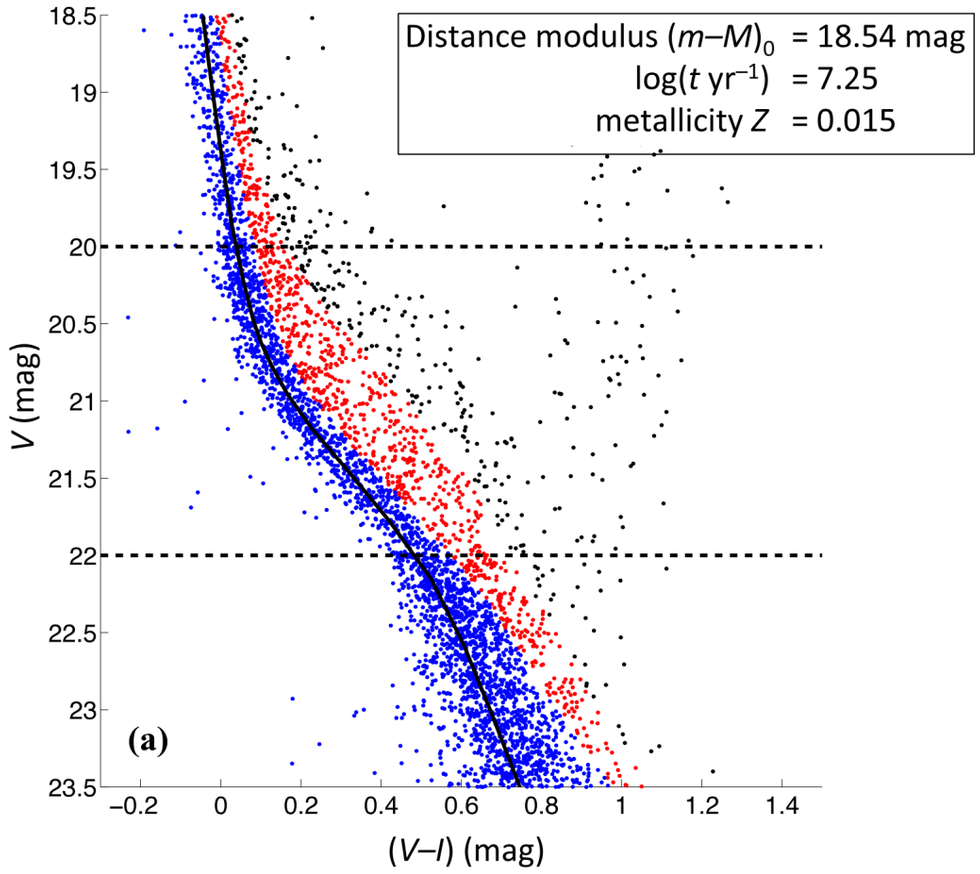
↓

**Single star** | **Binary**

↓

**Just Count**

## Globular cluster



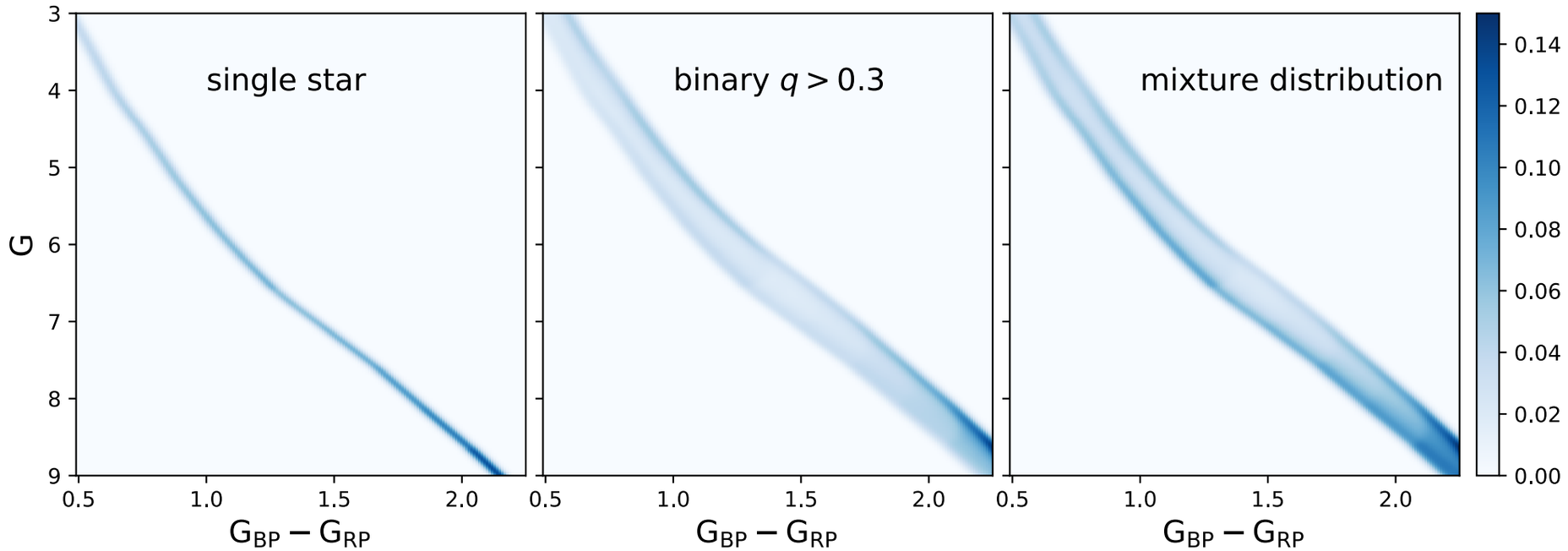

**Li et al. 2015**

**Open clusters**
limited member stars

We have better solution!

# Mixture model

## combine multiple components into a single probability density distribution




$$\Phi(\Theta) = (1 - f_{bin})\Phi_s + f_{bin}\Phi_b(\gamma_q)$$

1. **Single stellar population + Binary population**
   **SSP: isochrone(Age, [Fe/H], Distance, Extiction) + MF**
   **BP: Binary fraction, Mass ratio distribution**

2. **Convolve observational error -> Probability density distribution**

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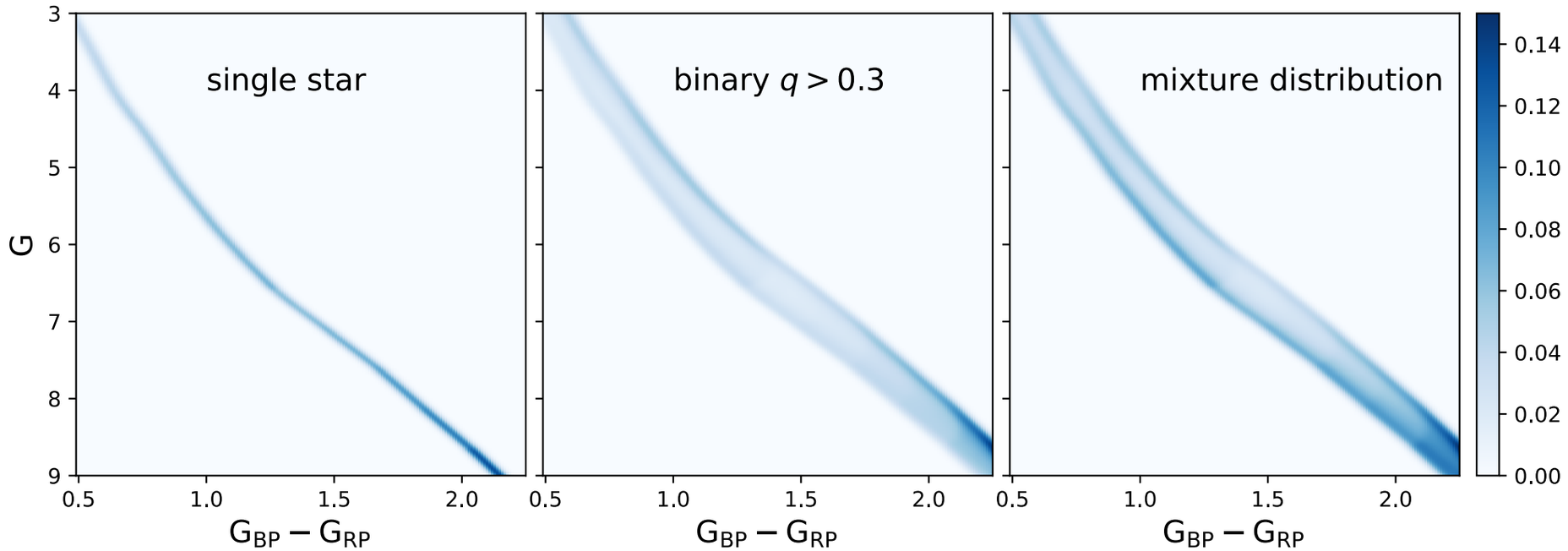


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# NGC3532

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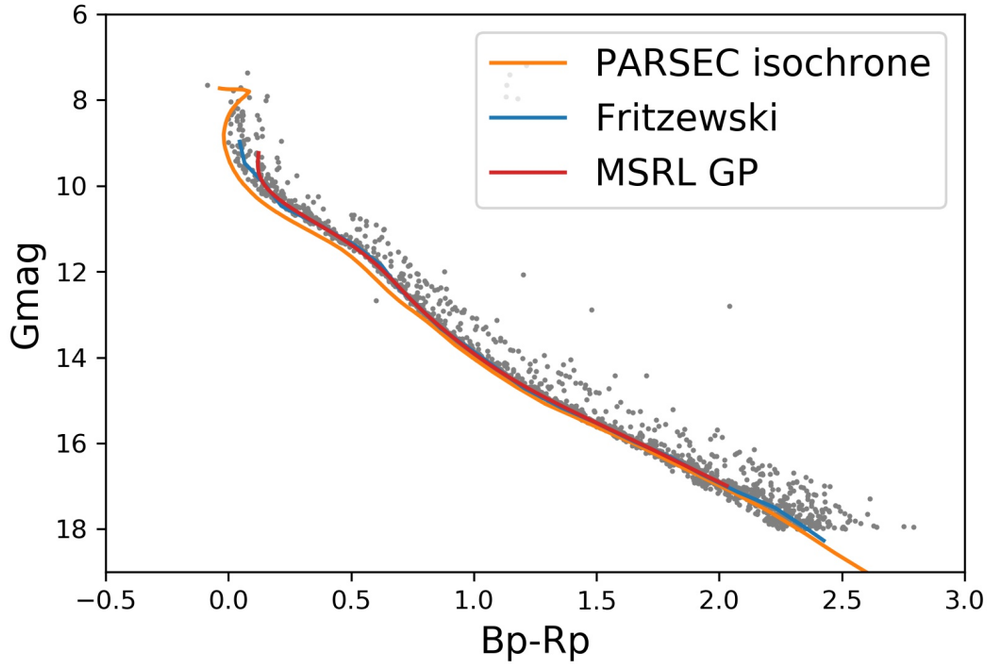
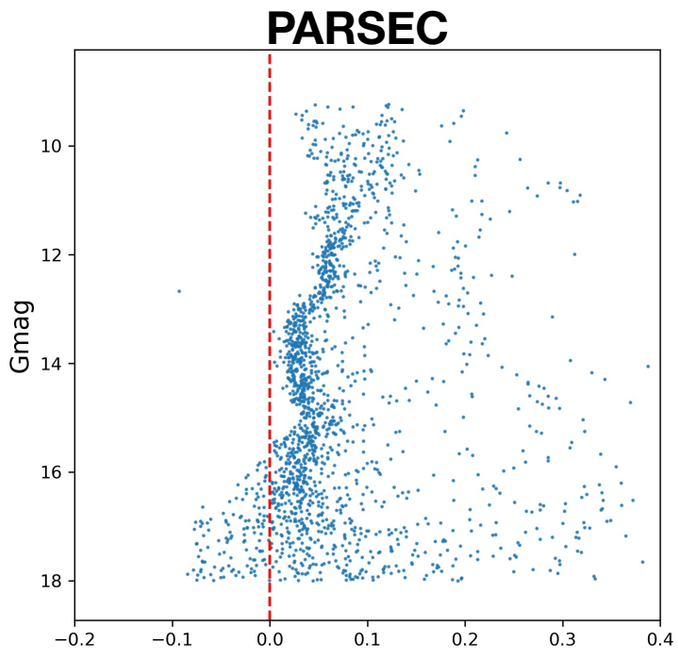
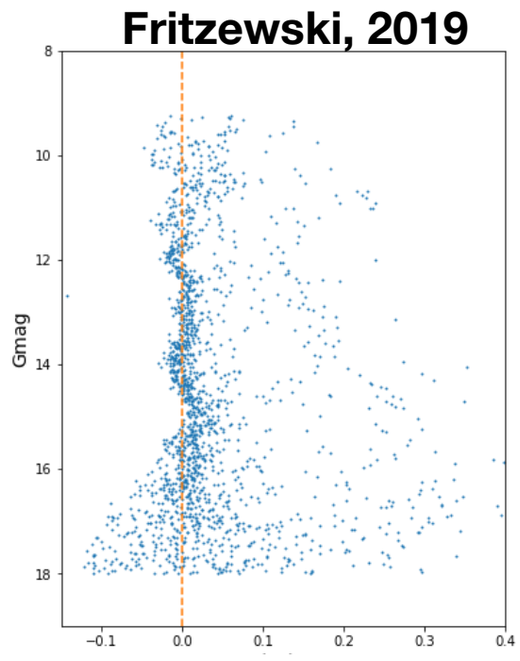
# Better Main Sequence Ridge Line by Gaussian Process



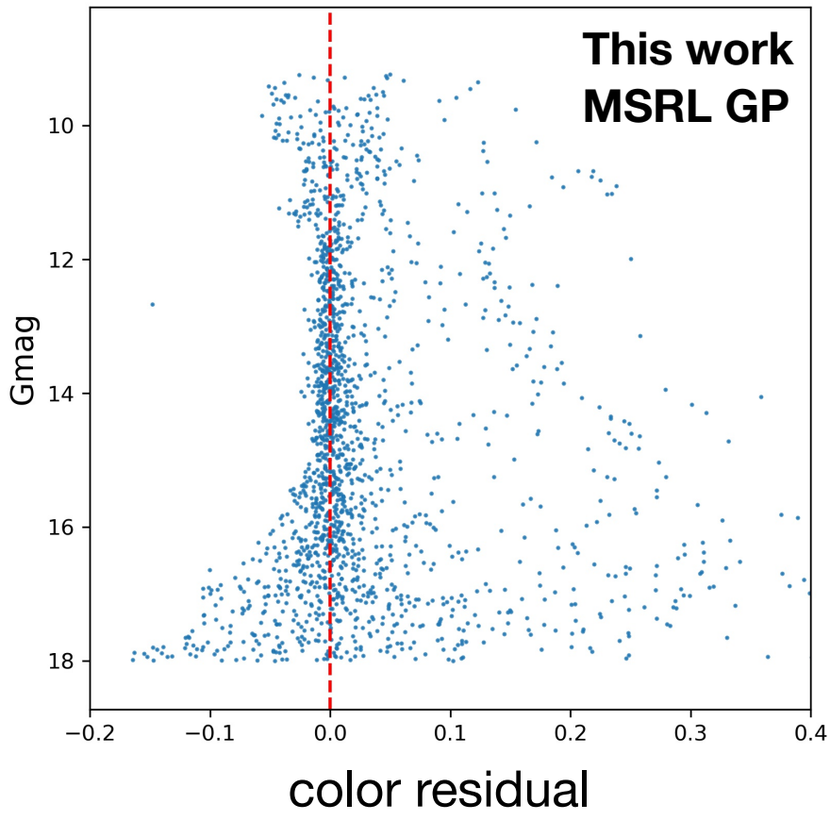




The inferred binary properties are sensitive to isochrone model.

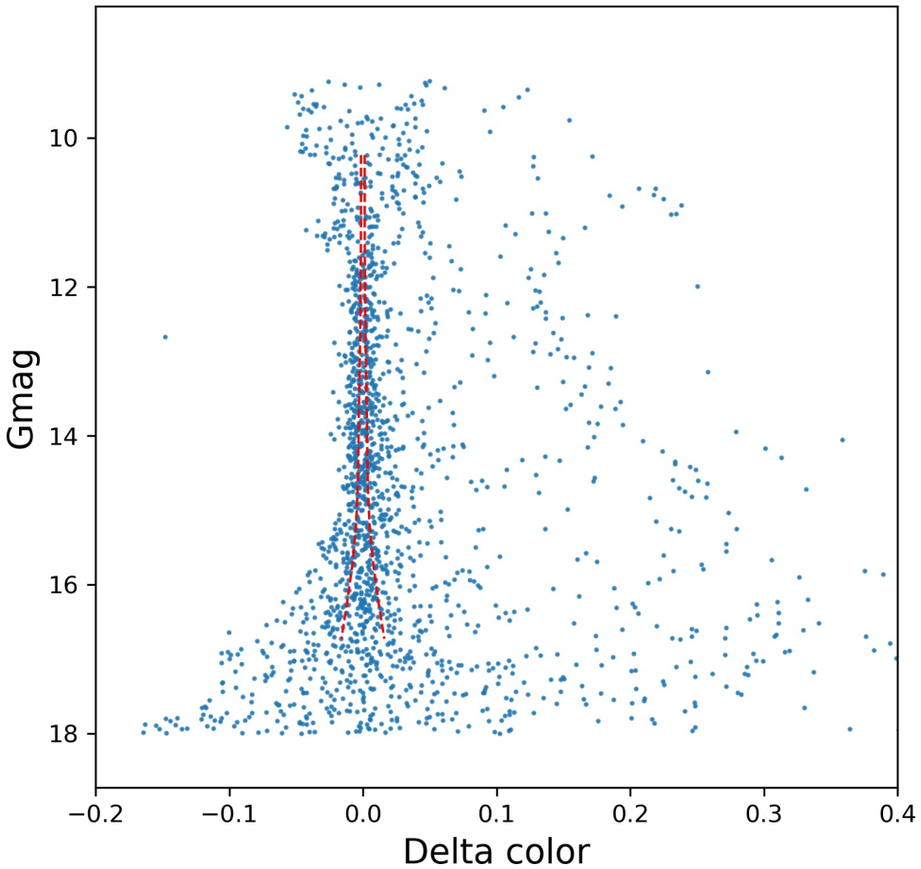
Inconstancy between PARSEC and Gaia
Solution: using main sequence ridge line from data itself

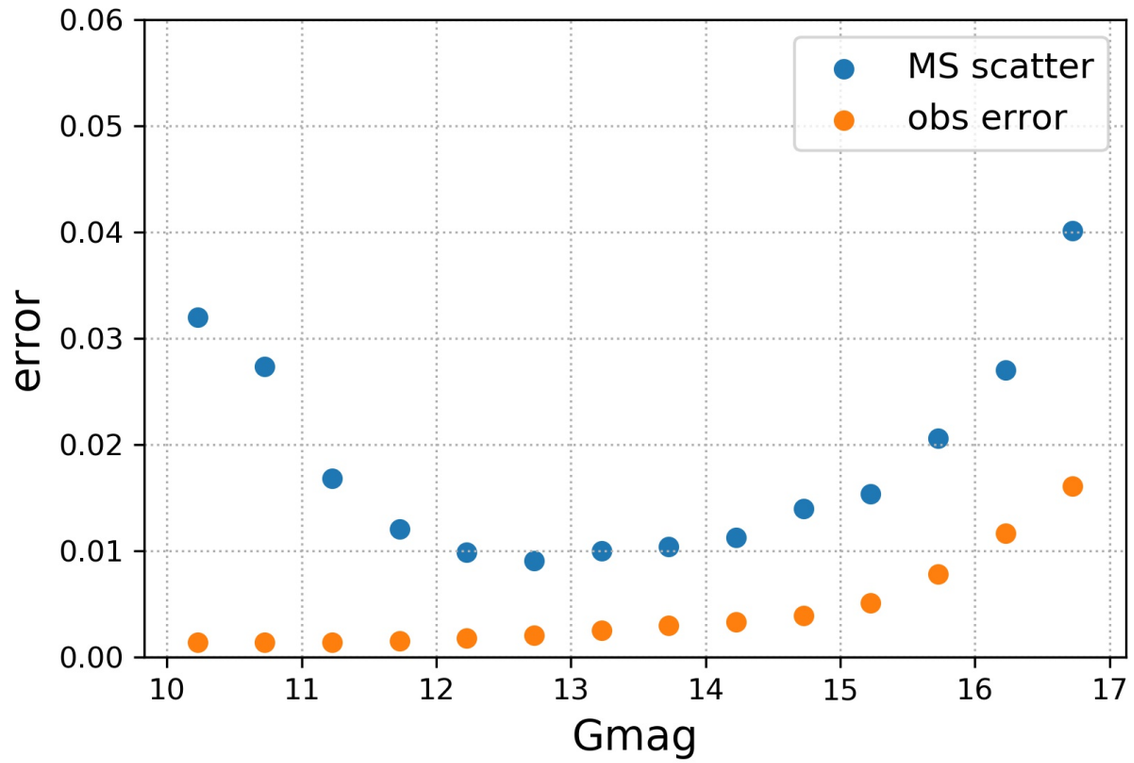
- Draw the ridge line by hand manually
- Gaussian process: objectively, fast, automatic (this work)

Algorithm: Robust Gaussian process based on iterative trimming ➔
(Li, **Li** et al. 2019, in prep.)



# Main Sequence Scatter



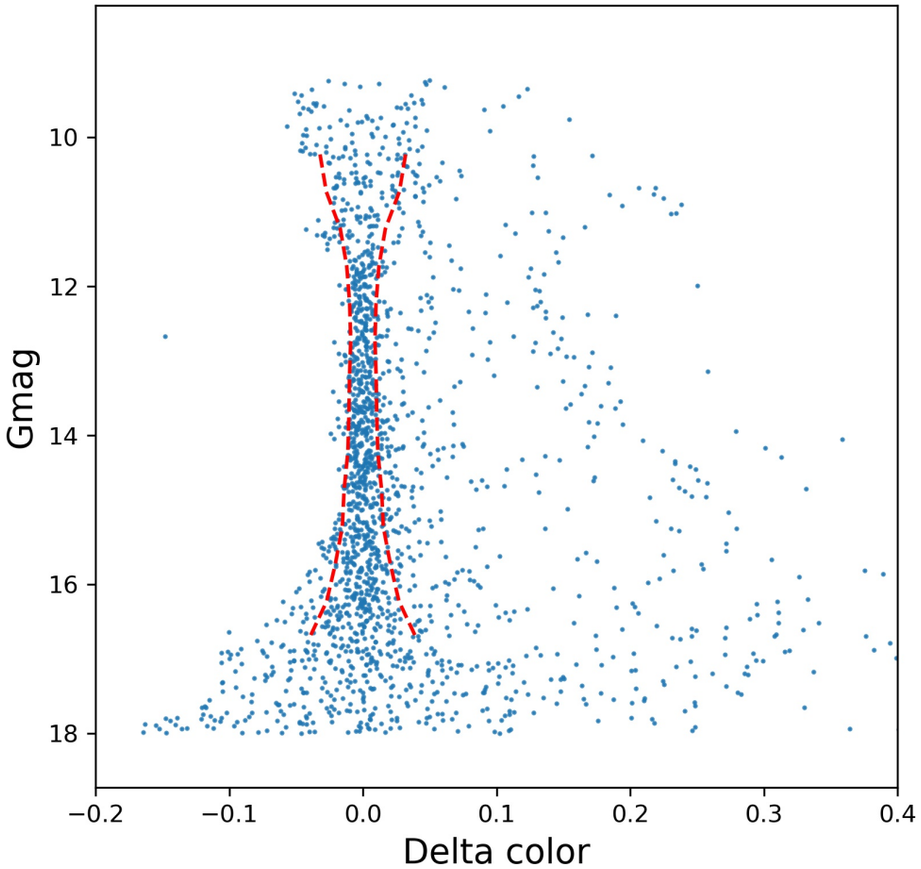

Degeneracy between scatter in main sequence and low mass-ratio binary fraction

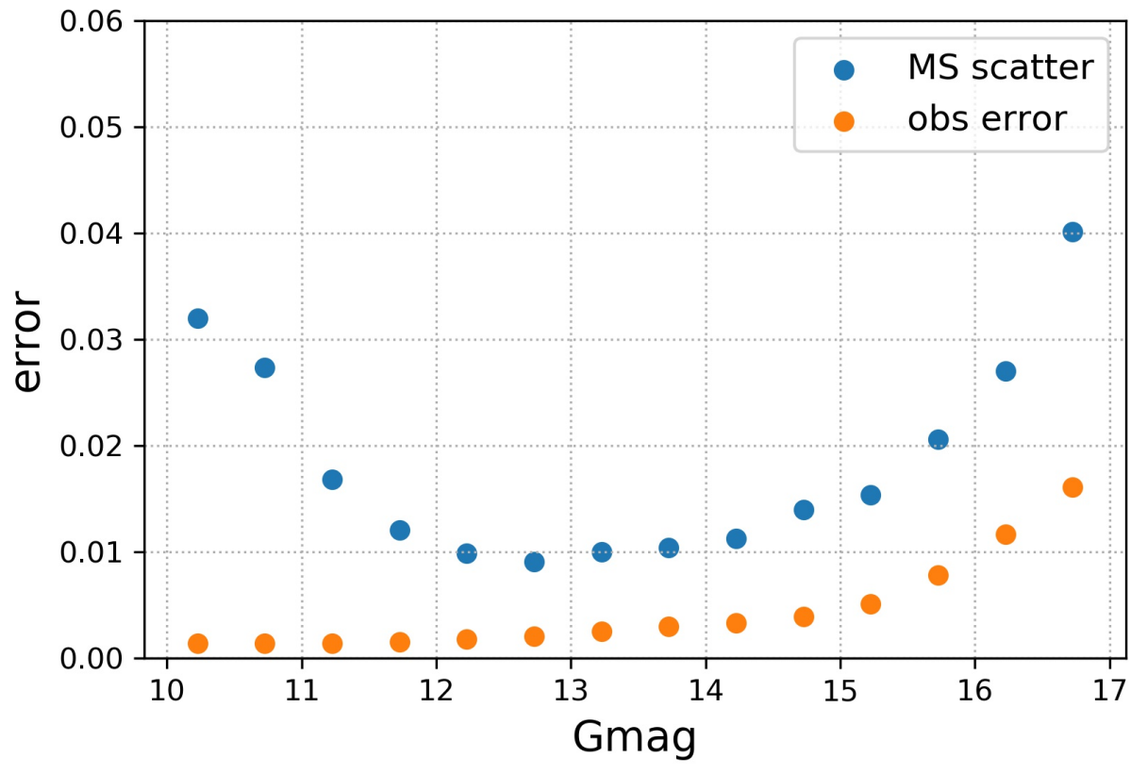
The actual scatter is much larger than measurement error reported by Gaia due to

- Non-negligible intrinsic scatter
- Underestimated error by Gaia

Solution: fit scatter from data directly, and the model with $q>0.3$

# Main Sequence Scatter

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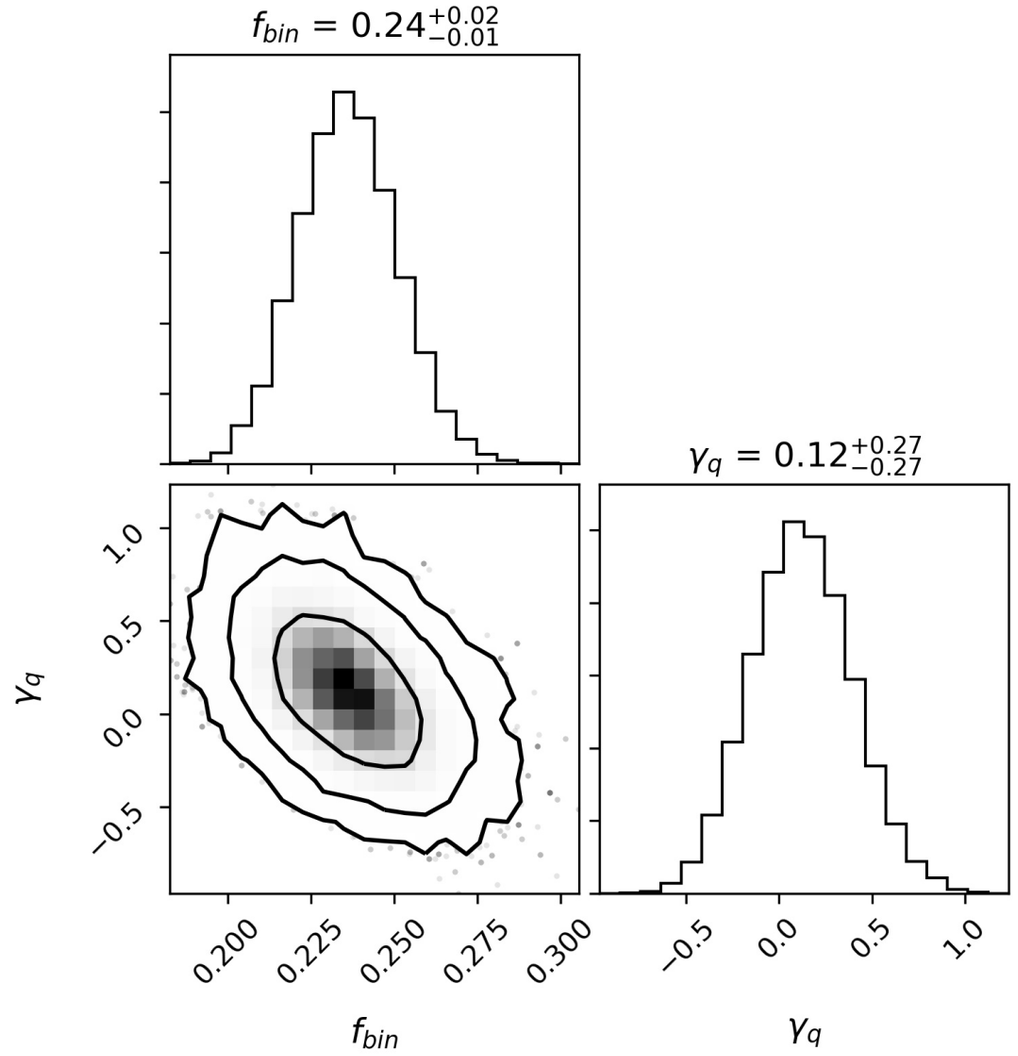
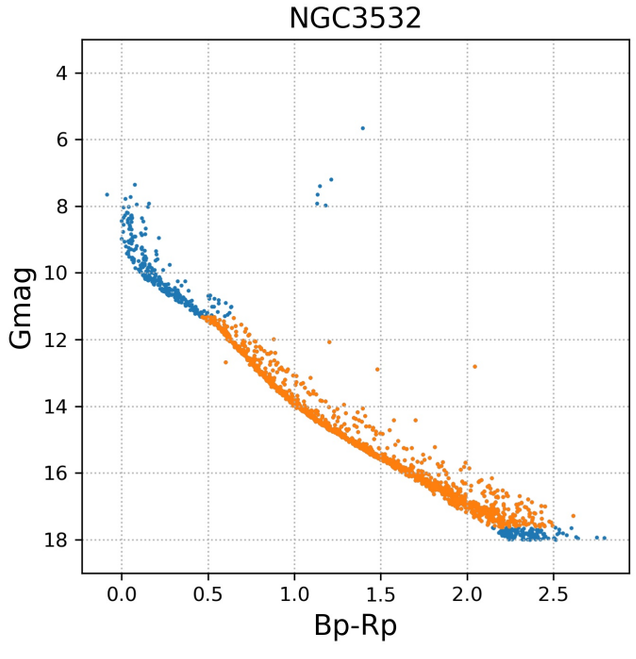
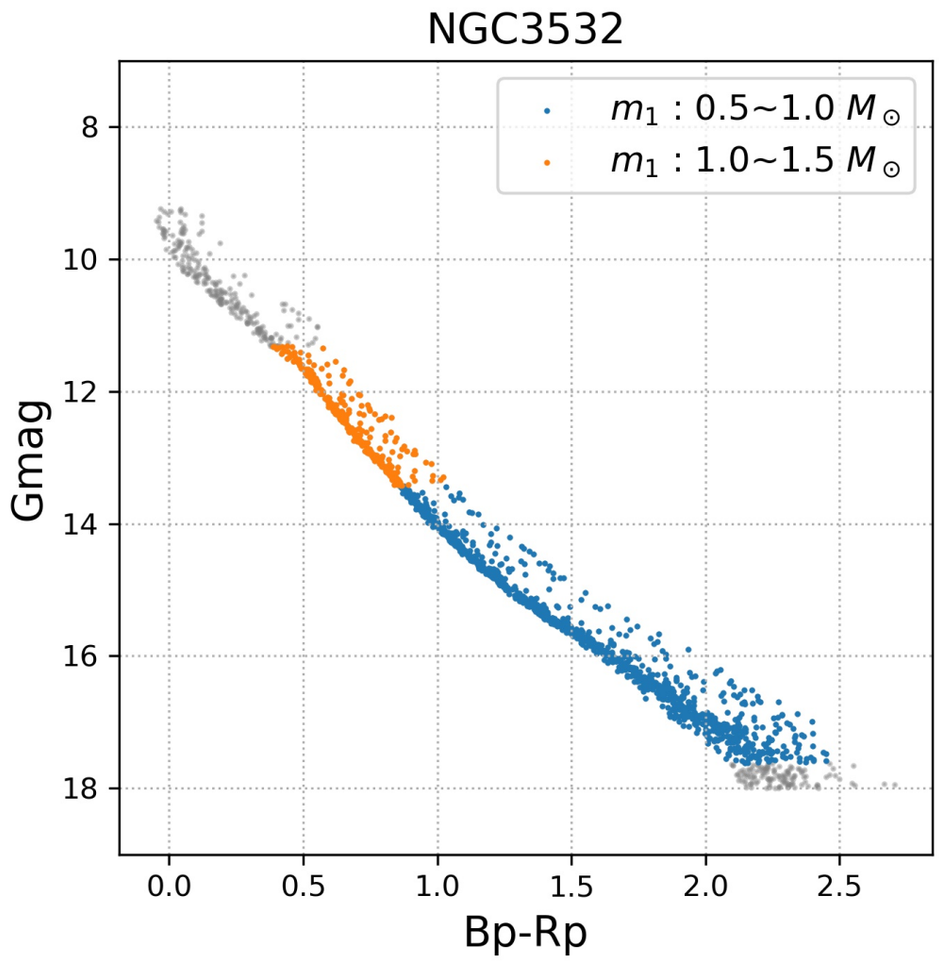
# NGC3532

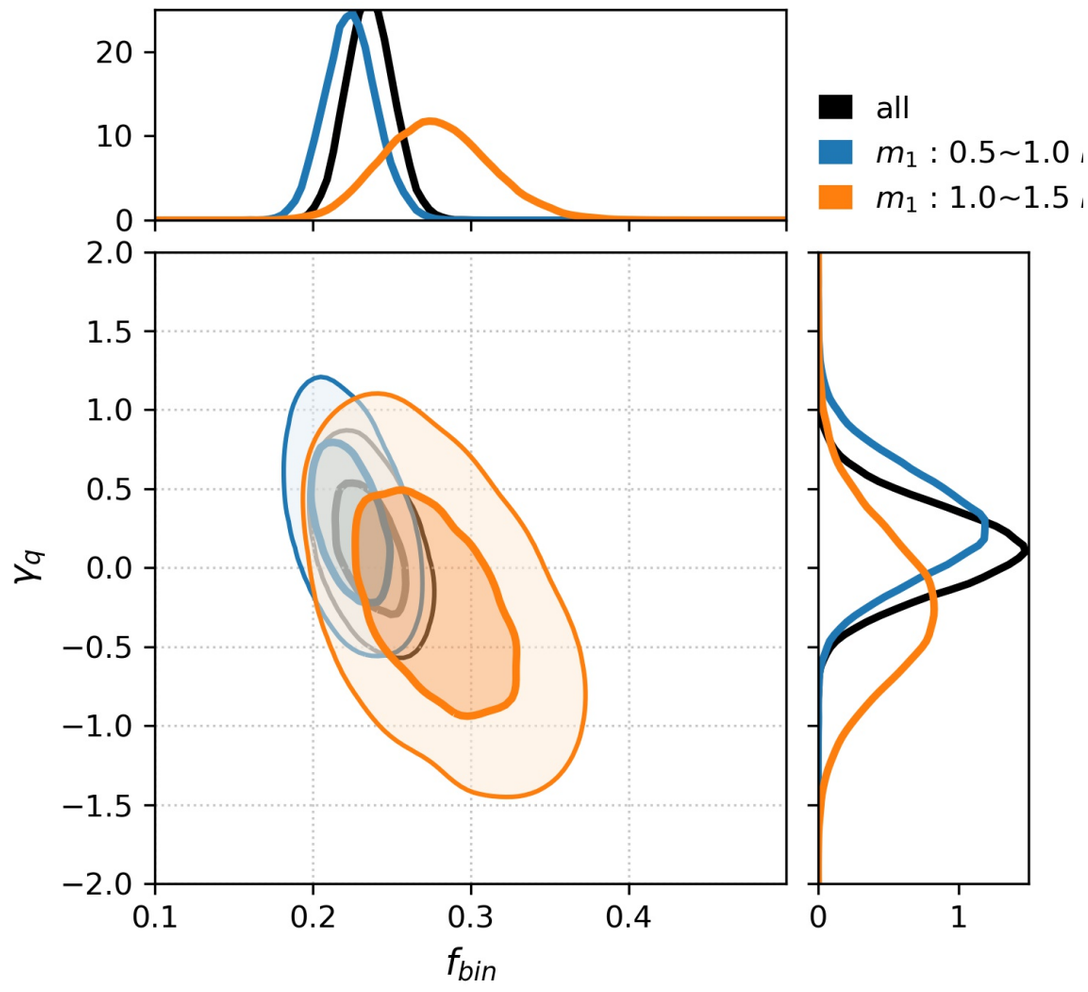



**0.5 ~1.5 solar mass**

# NGC3532 - Mass dependence



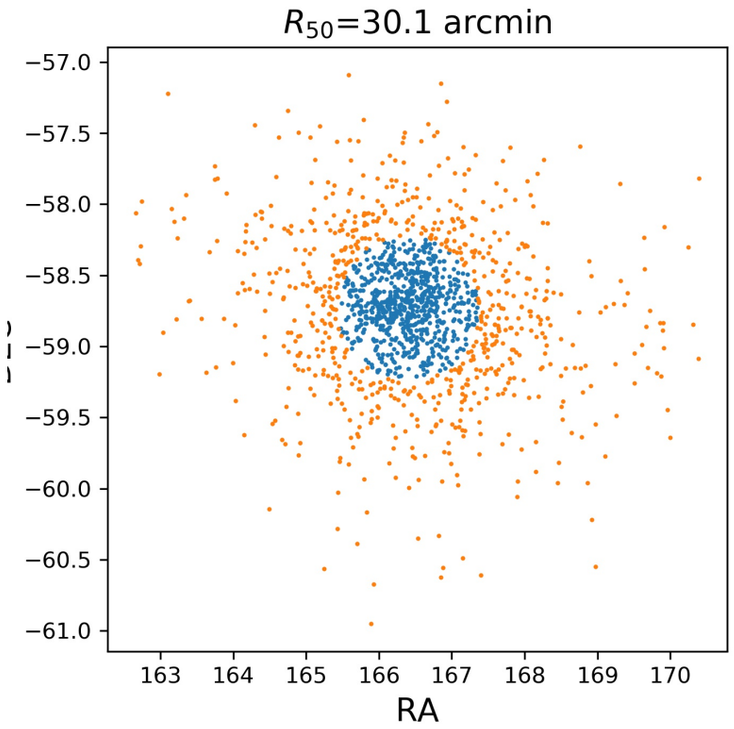



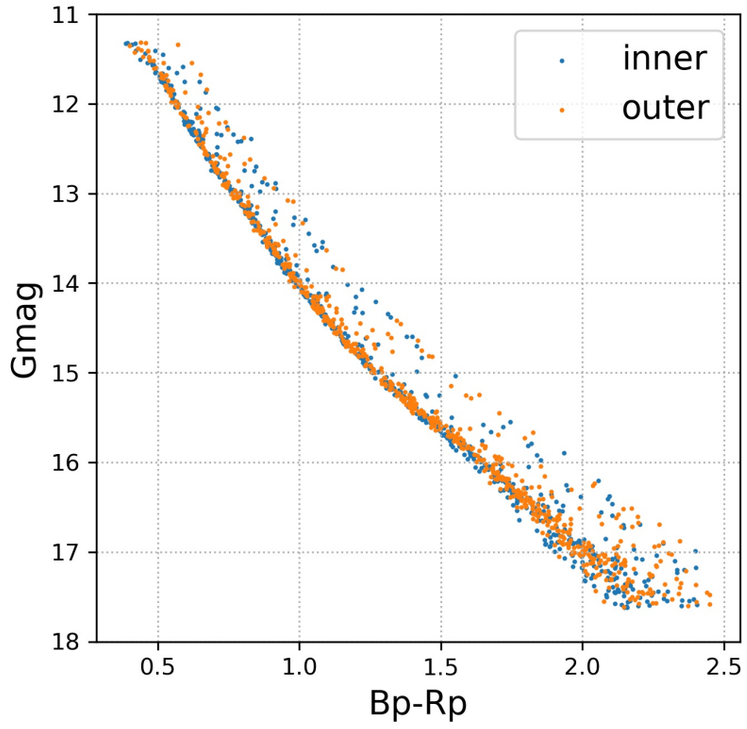

Larger mass end: higher binary fraction, more low mass-ratio binaries

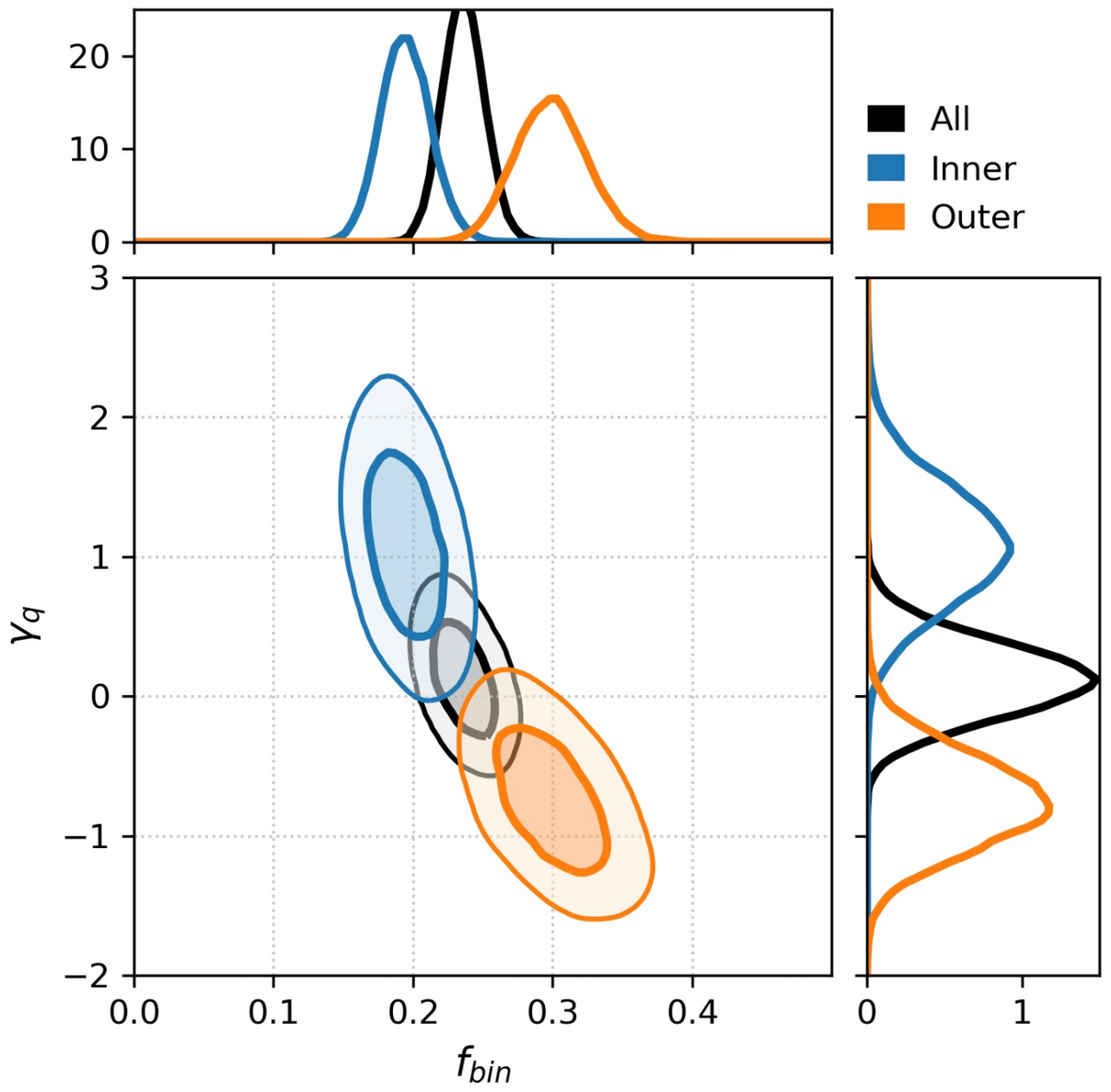
Binding energy of a binary system: $E_b \propto \frac{m_1^2 q}{a}$

→ larger primary mass will less affected by dynamical processing.

# NGC3532 - Radial dependence




Inner region: lower binary fraction,
but more high mass-ratio binaries

Consistent with dynamical evolution
  Three body interaction
  → replace light star in binary by more massive star

# Larger sample: 30 Open clusters from Gaia

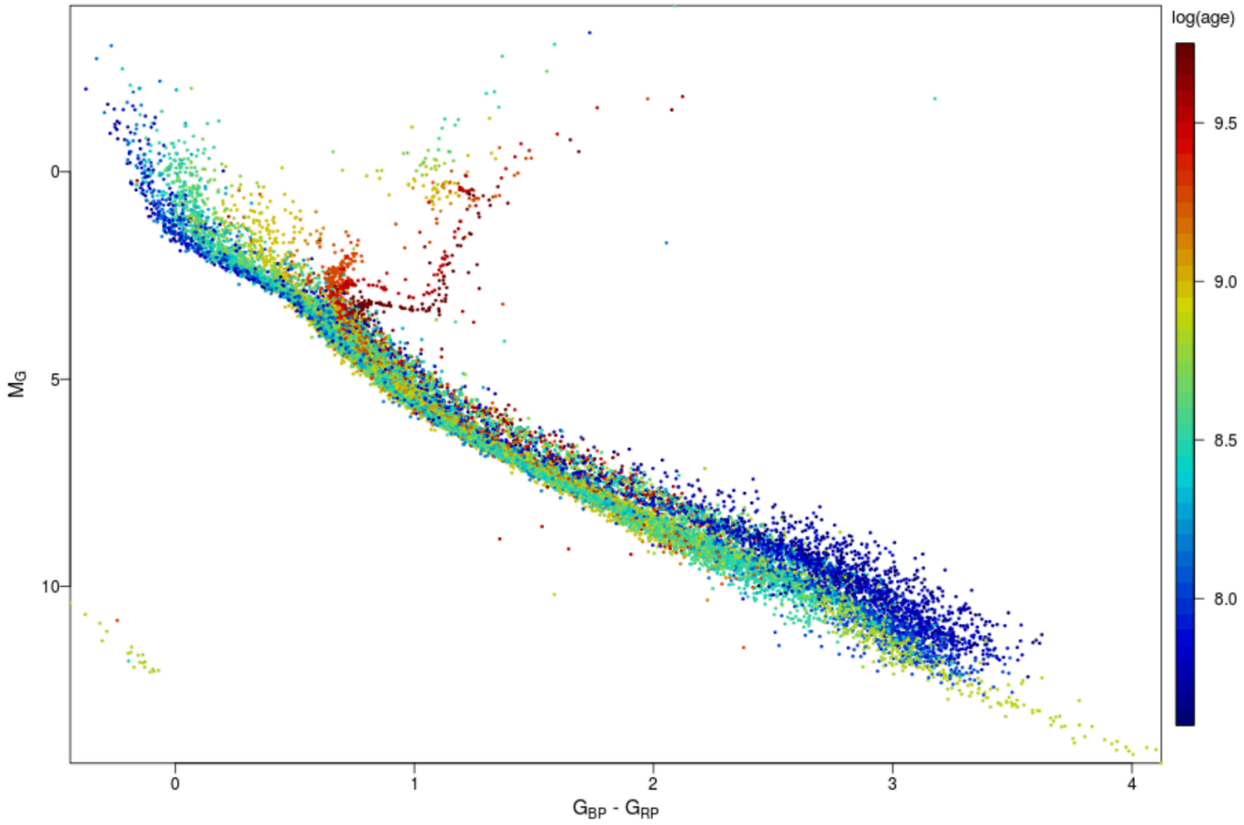



**Fig. 2.** Composite HRD for 32 open clusters, coloured according to log(age), using the extinction and distance moduli as determined from the *Gaia* data (Table 2).

**Gaia 2018b**

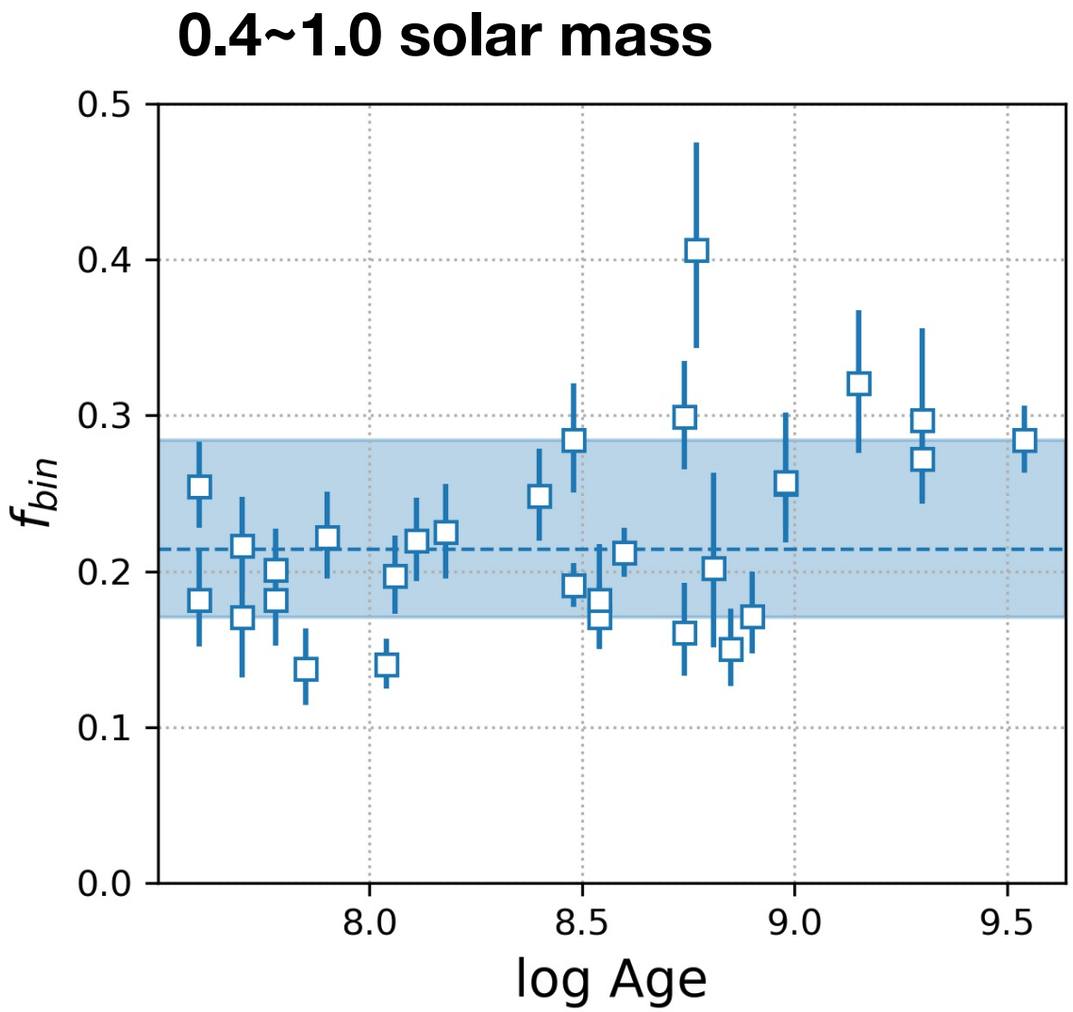
Current largest sample in similar studies
⇒ better statistics

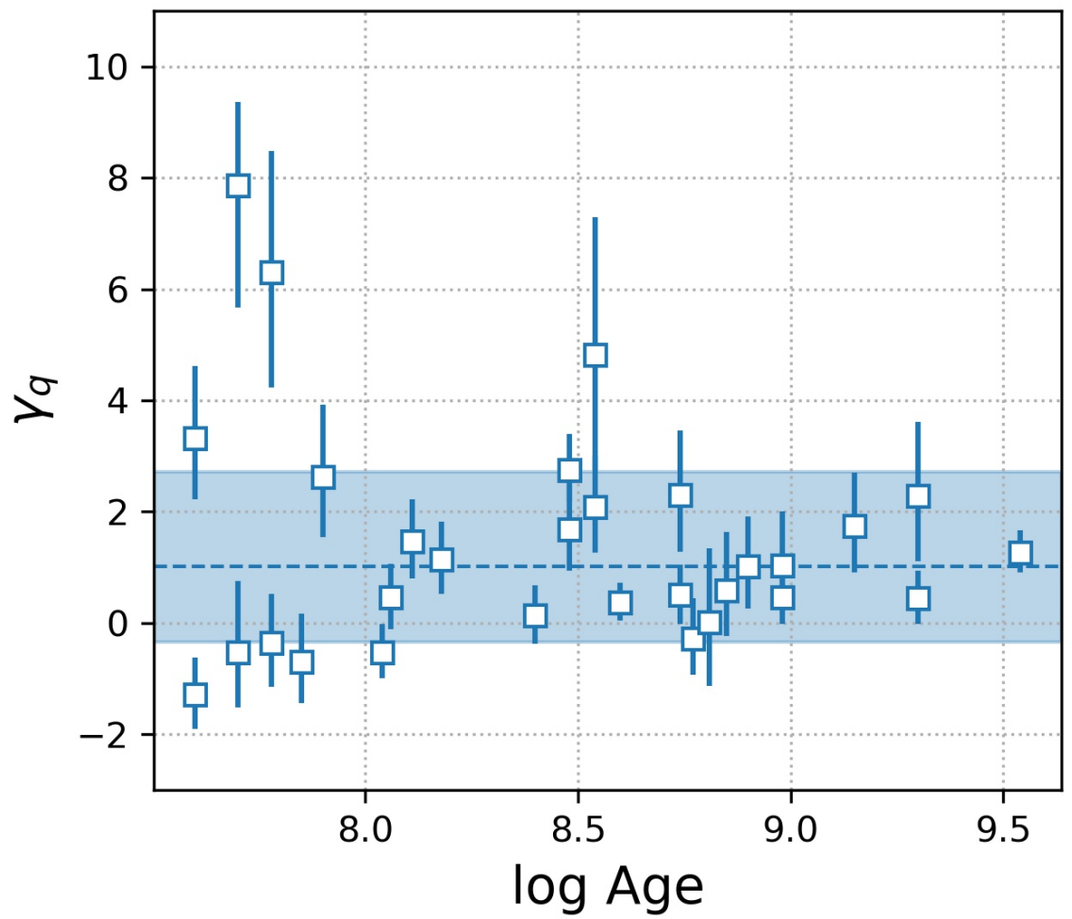
**Table 2.** Overview of reference values used in constructing the composite HRD for open clusters (Figure 2).

*Gaia* Collaboration, 2018

| Cluster | DM | log(age) | [Fe/H] | E(B−V) | Memb |
|---|---|---|---|---|---|
| Hyades | 3.389 | 8.90 | 0.13 | 0.001 | 518 |
| Coma Ber | 4.669 | 8.81 | 0.00 | 0.000 | 142 |
| Pleiades | 5.667 | 8.04 | -0.01 | 0.045 | 1323 |
| IC 2391 | 5.908 | 7.70 | -0.01 | 0.030 | 328 |
| IC 2602 | 5.914 | 7.60 | -0.02 | 0.031 | 490 |
| $\alpha$ Per | 6.214 | 7.85 | 0.14 | 0.090 | 745 |
| Praesepe | 6.350 | 8.85 | 0.16 | 0.027 | 949 |
| NGC 2451A | 6.433 | 7.78 | -0.08 | 0.000 | 397 |
| Blanco 1 | 6.876 | 8.06 | 0.03 | 0.010 | 493 |
| NGC 6475 | 7.234 | 8.54 | 0.02 | 0.049 | 952 |
| NGC 7092 | 7.390 | 8.54 | 0.00 | 0.010 | 255 |
| NGC 6774 | 7.455 | 9.30 | 0.16 | 0.080 | 154 |
| NGC 2232 | 7.575 | 7.70 | 0.11 | 0.031 | 242 |
| NGC 2547 | 7.980 | 7.60 | -0.14 | 0.040 | 318 |
| NGC 2516 | 8.091 | 8.48 | 0.05 | 0.071 | 1591 |
| Trumpler 10 | 8.223 | 7.78 | -0.12 | 0.056 | 400 |
| NGC 752 | 8.264 | 9.15 | -0.03 | 0.040 | 337 |
| NGC 6405 | 8.320 | 7.90 | 0.07 | 0.139 | 538 |
| IC 4756 | 8.401 | 8.98 | 0.02 | 0.128 | 508 |
| NGC 3532 | 8.430 | 8.60 | 0.00 | 0.022 | 1702 |
| NGC 2422 | 8.436 | 8.11 | 0.09 | 0.090 | 564 |
| NGC 1039 | 8.552 | 8.40 | 0.02 | 0.077 | 501 |
| NGC 6281 | 8.638 | 8.48 | 0.06 | 0.130 | 584 |
| NGC 6793 | 8.894 | 8.78 | | 0.272 | 266 |
| NGC 2548 | 9.451 | 8.74 | 0.08 | 0.020 | 366 |
| NGC 6025 | 9.513 | 8.18 | | 0.170 | 443 |
| NGC 2682 | 9.726 | 9.54 | 0.03 | 0.037 | 1324 |
| IC 4651 | 9.889 | 9.30 | 0.12 | 0.040 | 885 |
| ~~NGC 2323~~ | ~~10.010~~ | ~~8.30~~ | | ~~0.105~~ | ~~679~~ |
| NGC 2447 | 10.088 | 8.74 | -0.05 | 0.034 | 995 |
| NGC 2360 | 10.229 | 8.98 | -0.03 | 0.090 | 813 |
| ~~NGC 188~~ | ~~11.490~~ | ~~9.74~~ | ~~0.11~~ | ~~0.085~~ | ~~898~~ |

# Results—30 OC




**mag>18**
**q>0.3**

**median $f_{bin}$ = 0.21 ± 0.05**
**median $\gamma_q$ = 1.01 ± 1.51**

**It is the homogeneous determinations of $f_{bin}$ and $\gamma_q$ of unsolved solar-type binaries in CMD, with the largest OC sample up to now.**

# Take home message

The mixture model is strict and accurate to infer the OC binary properties.

- NGC 3532: inner region and lower primary mass end shows smaller $f_{bin}$ and higher $\gamma_q$
  - Indication of more fierce dynamical encounters.
  - Larger primary mass less affected by dynamical processing.
- *Largest* sample up to now: 30 OCs of age from 30 Myr to 5 Gyr
  - Binary fraction (q>0.3) $f_{bin}$ : 0.21 ± 0.05
    - weak age dependence, requires further investigation
  - Mass ratio power-law index $\gamma_q$ : 1.01 ± 1.51

- **Byproducts**:
  - Main sequence ridge line:
    - Calibration to star model or Gaia photometry?
  - Scatter in main sequence
    - Intrinsic or underestimated Gaia photometric error.

Thank you!

# 疏散星团中的双星

$$E_b \propto \frac{m_1^2 q}{a}$$

在恒星社区里，有伴侣的恒星（双星）占 20%，单身率 80%。
动力学的扰动－星团中心星数更密集（诱惑更多）：

1. 胖子的婚姻更加稳定
2. 质量相差的大的婚姻：
   胖-瘦 －> 容易有第三者－>胖-胖