

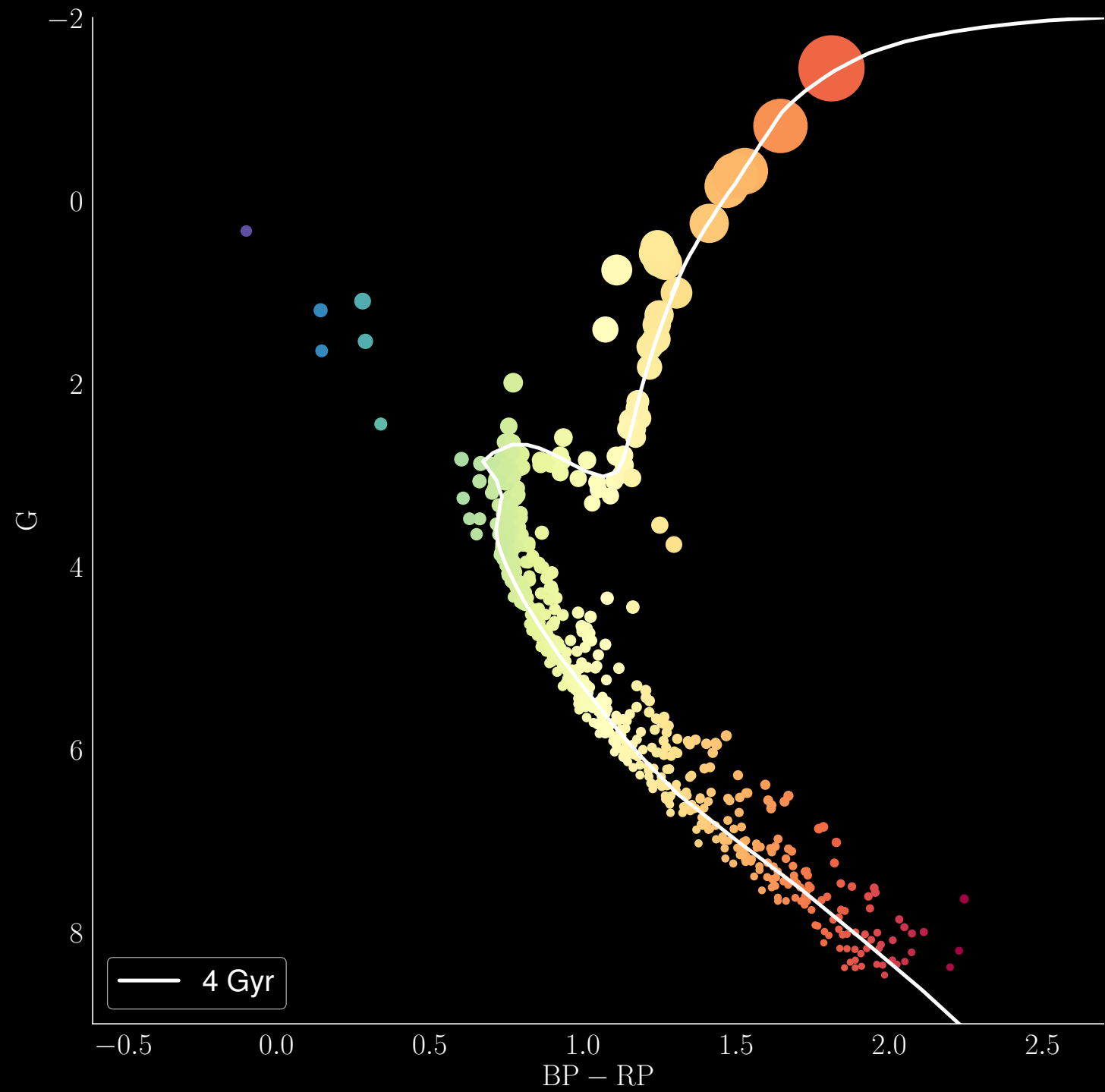


Blue straggler stars in Galactic open clusters

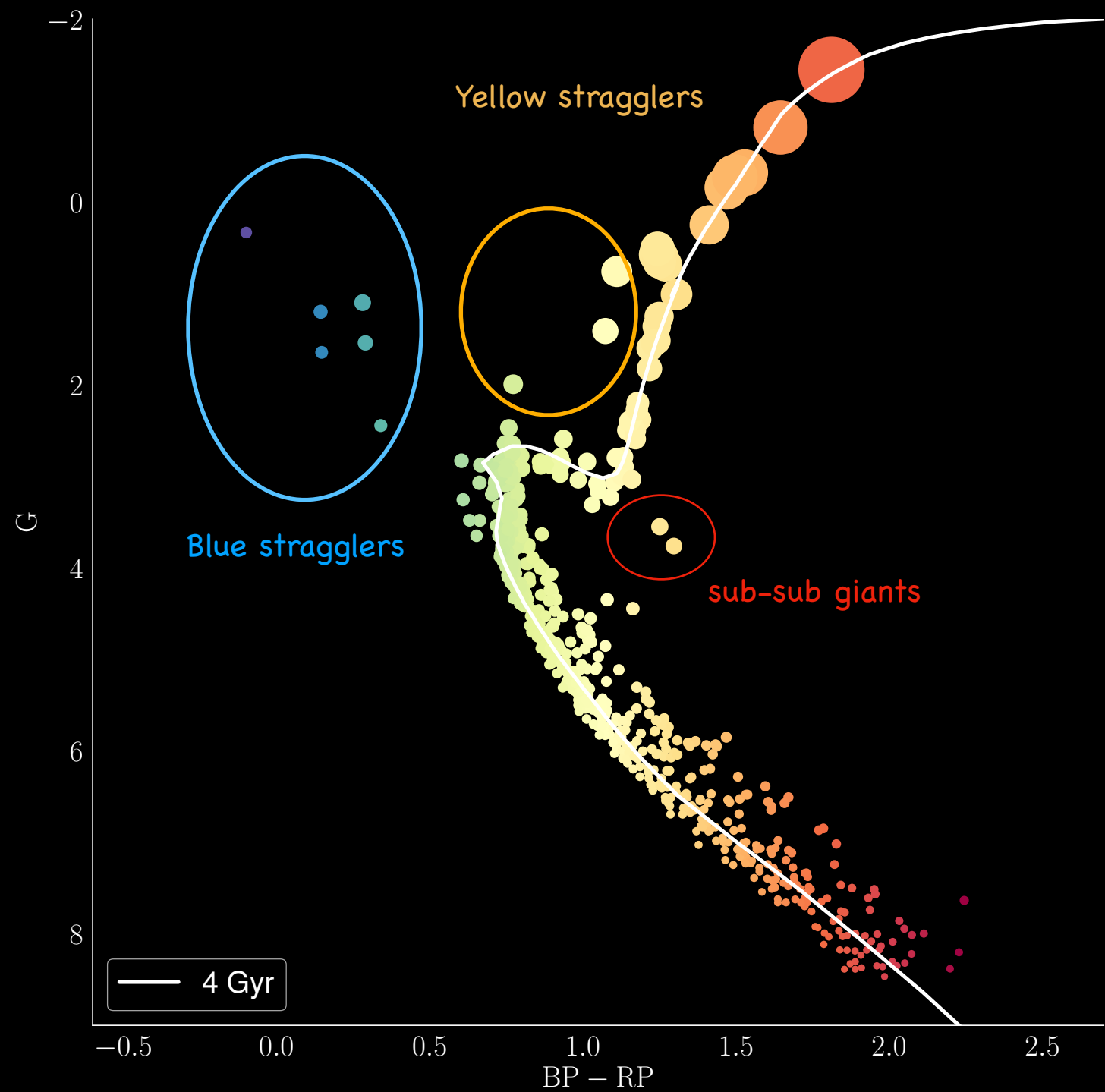
María José Rain (ESO-Chile)



Oddities in OCs



Oddities in OCs



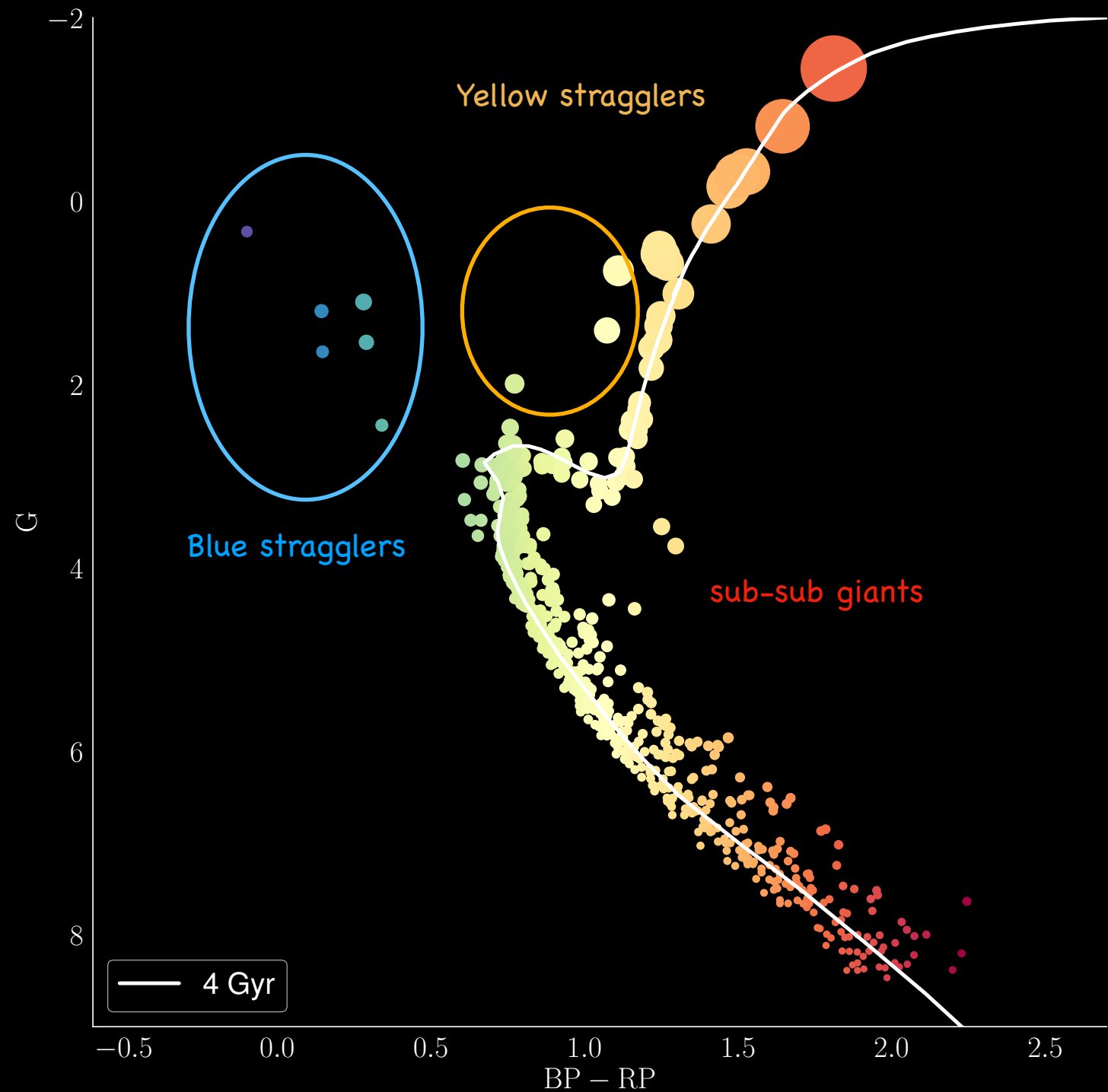
What are Blue straggler stars?



Brighter and bluer than main sequence Turnoff (MSTO)

MBSS > MMS

Formations mechanisms; binary evolution, stellar collisions and multiple interactions (e.g, hierarchical triple systems)

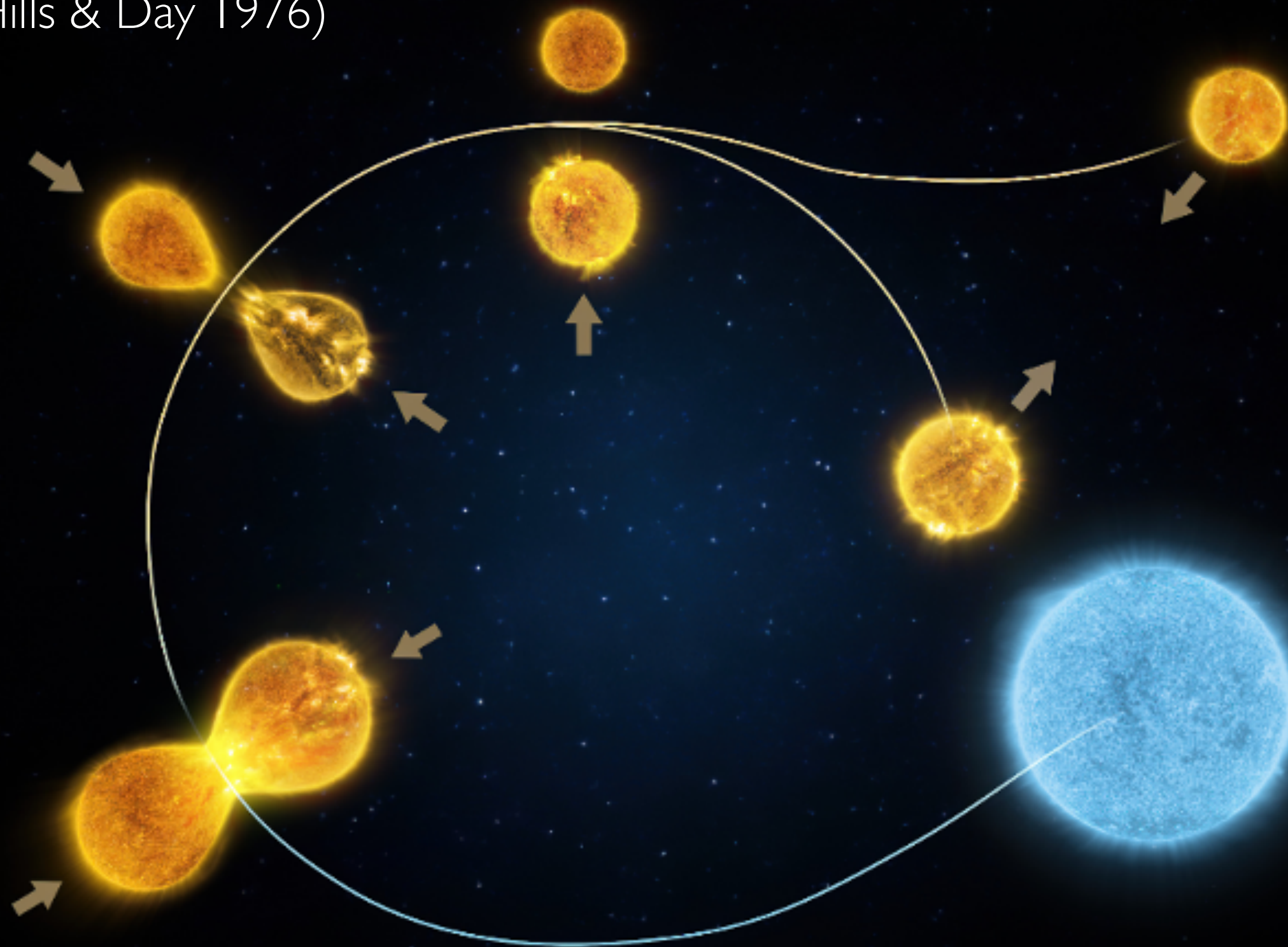


The elixir of youth of BSS

Stellar collisions (Hills & Day 1976)



More relevant in
the core of GCs!



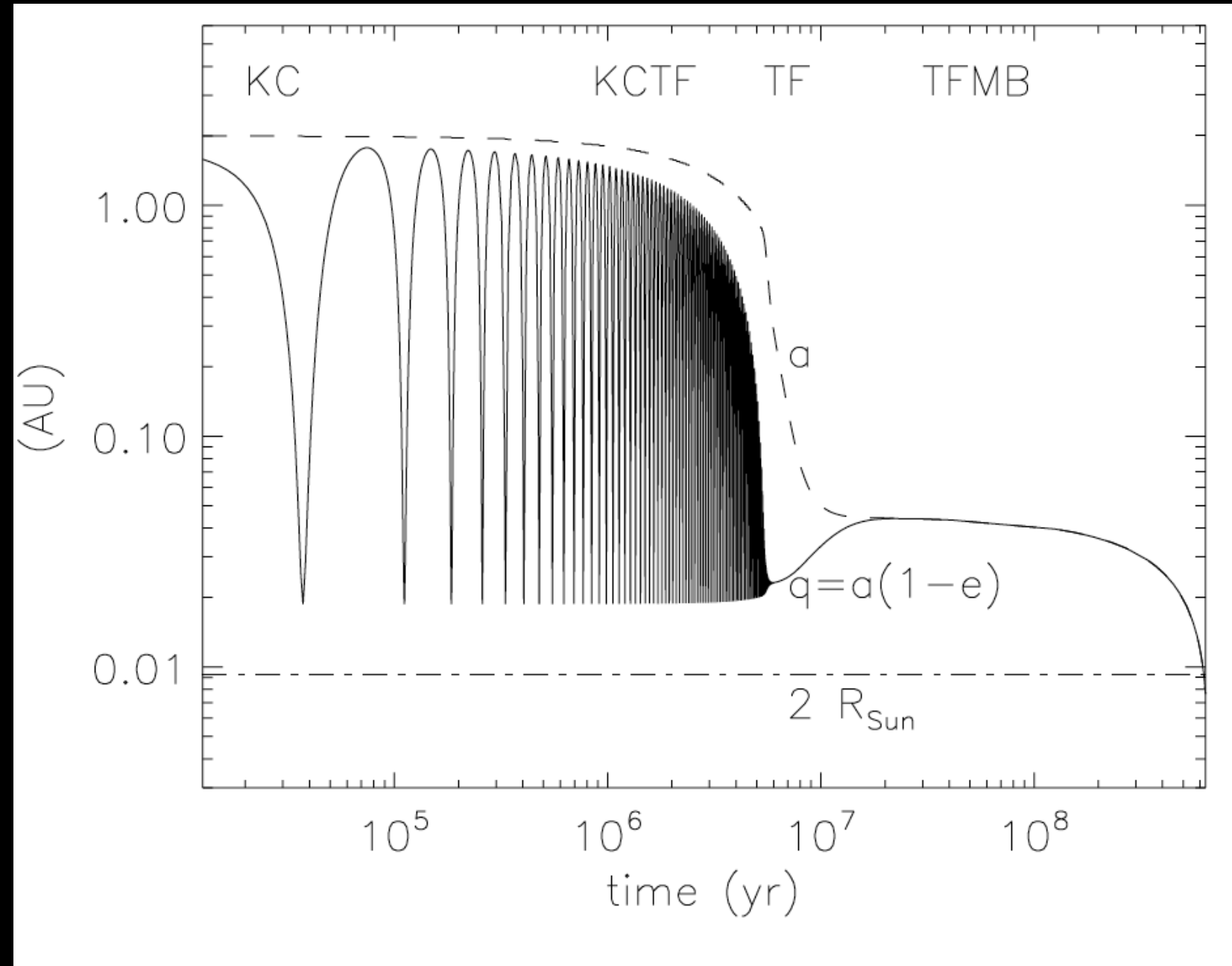
The elixir of youth of BSS



(Hierarchical) Triple systems Perets & Fabrycky (2009)

“We suggest that this scenario has a major (possibly dominant) role in the formation of BSSs in open clusters”

“BSSs could have long-period main-sequence binary companions”



The elixir of youth of BSS



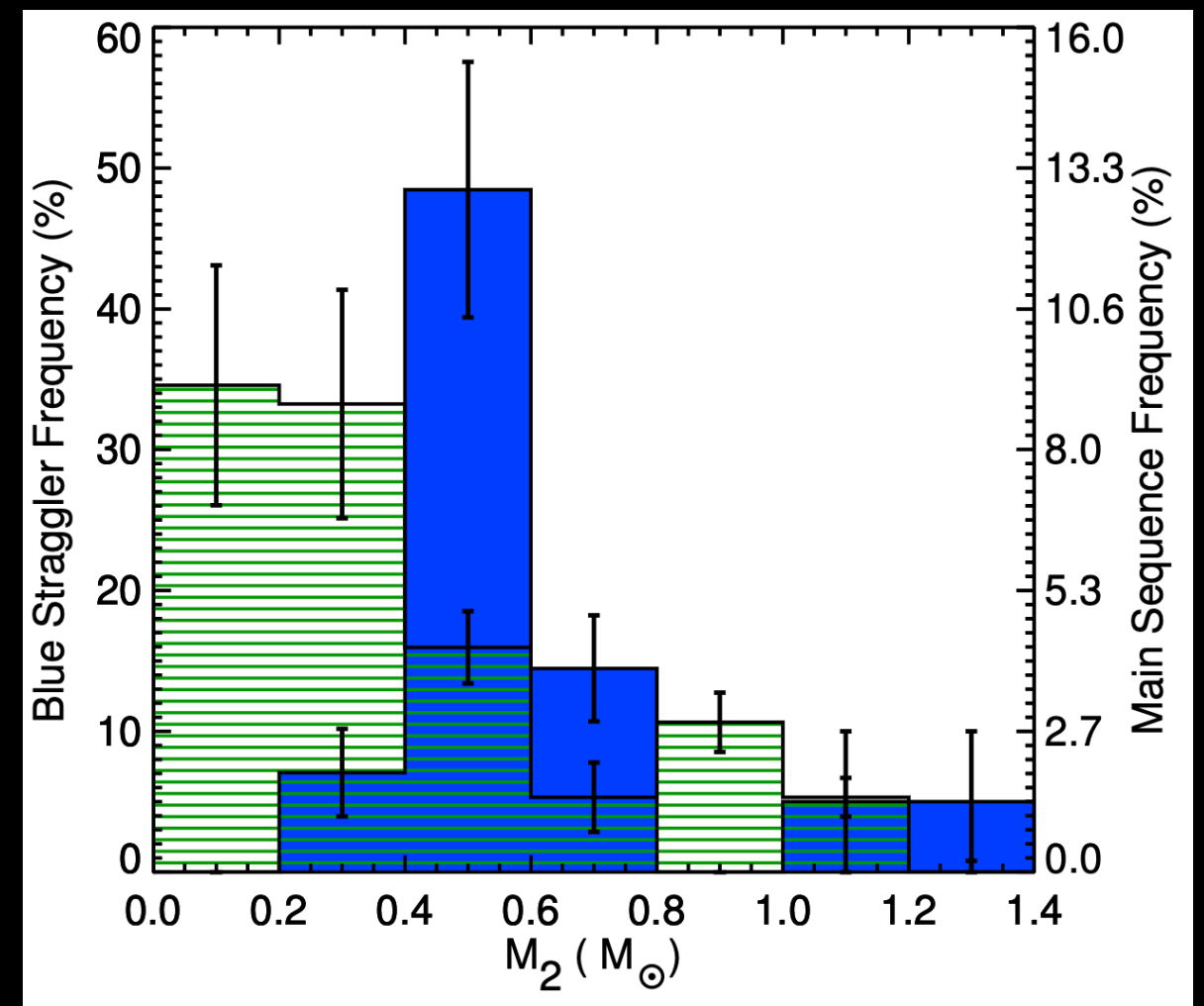
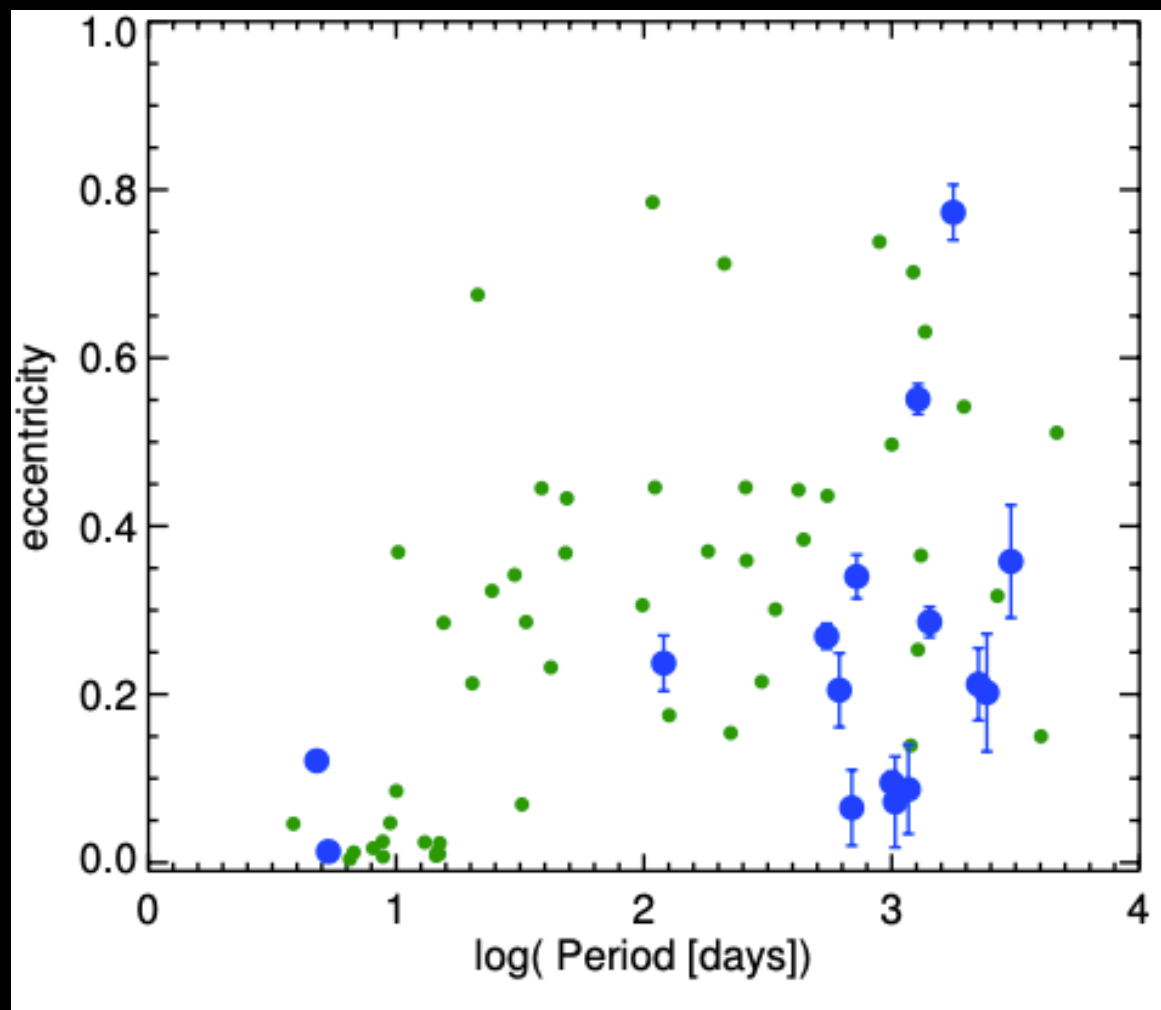
Mass Transfer (McCrea 1965)

The elixir of youth of BSS



Observed **MS** and **BSS**, $\log(P)$ vs. e distribution and mass distribution

Geller et al. 2008: Binary Frequency of BSS ($76\% \pm 21\%$) vs. Main Sequence ($29\% \pm 3\%$)



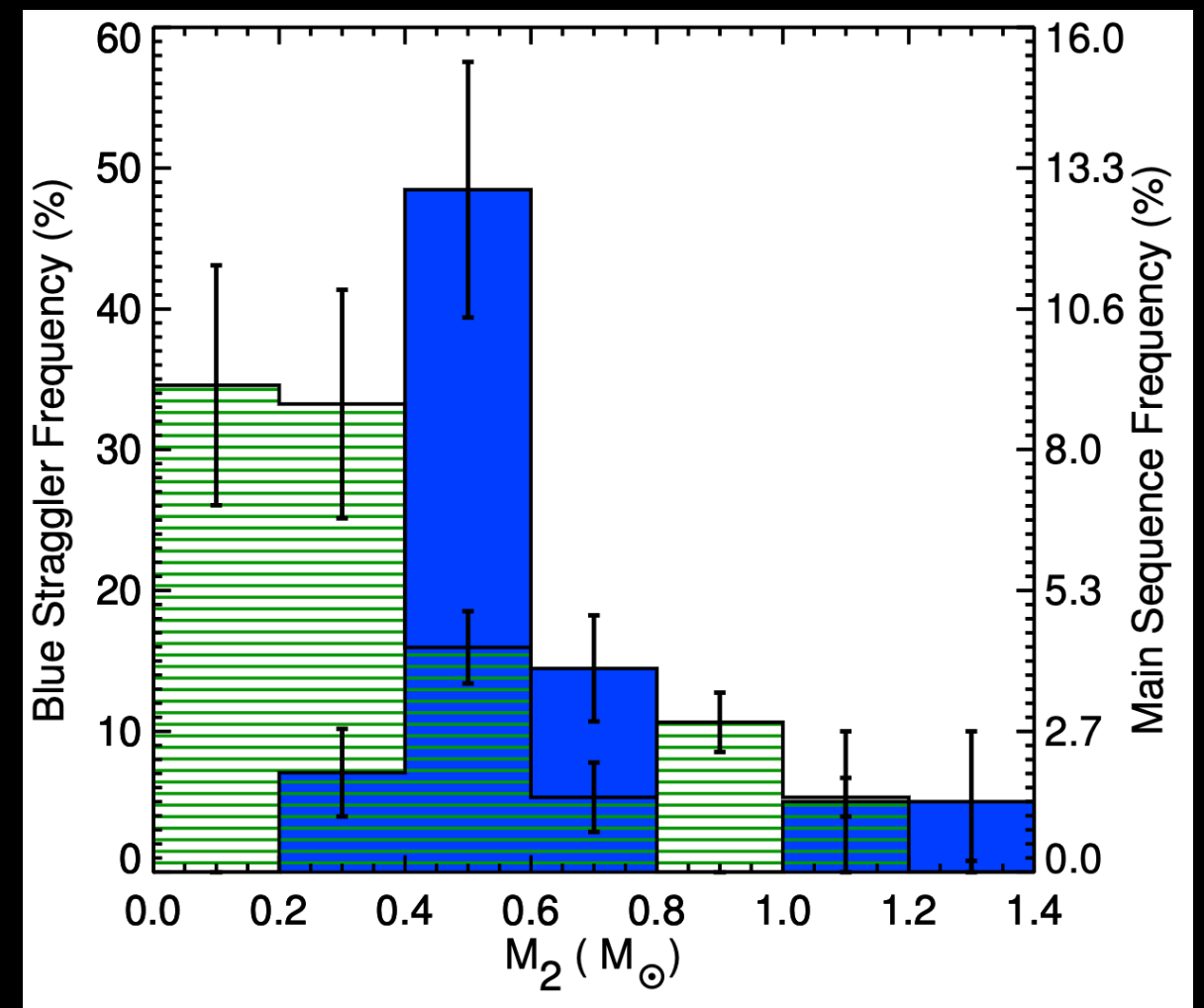
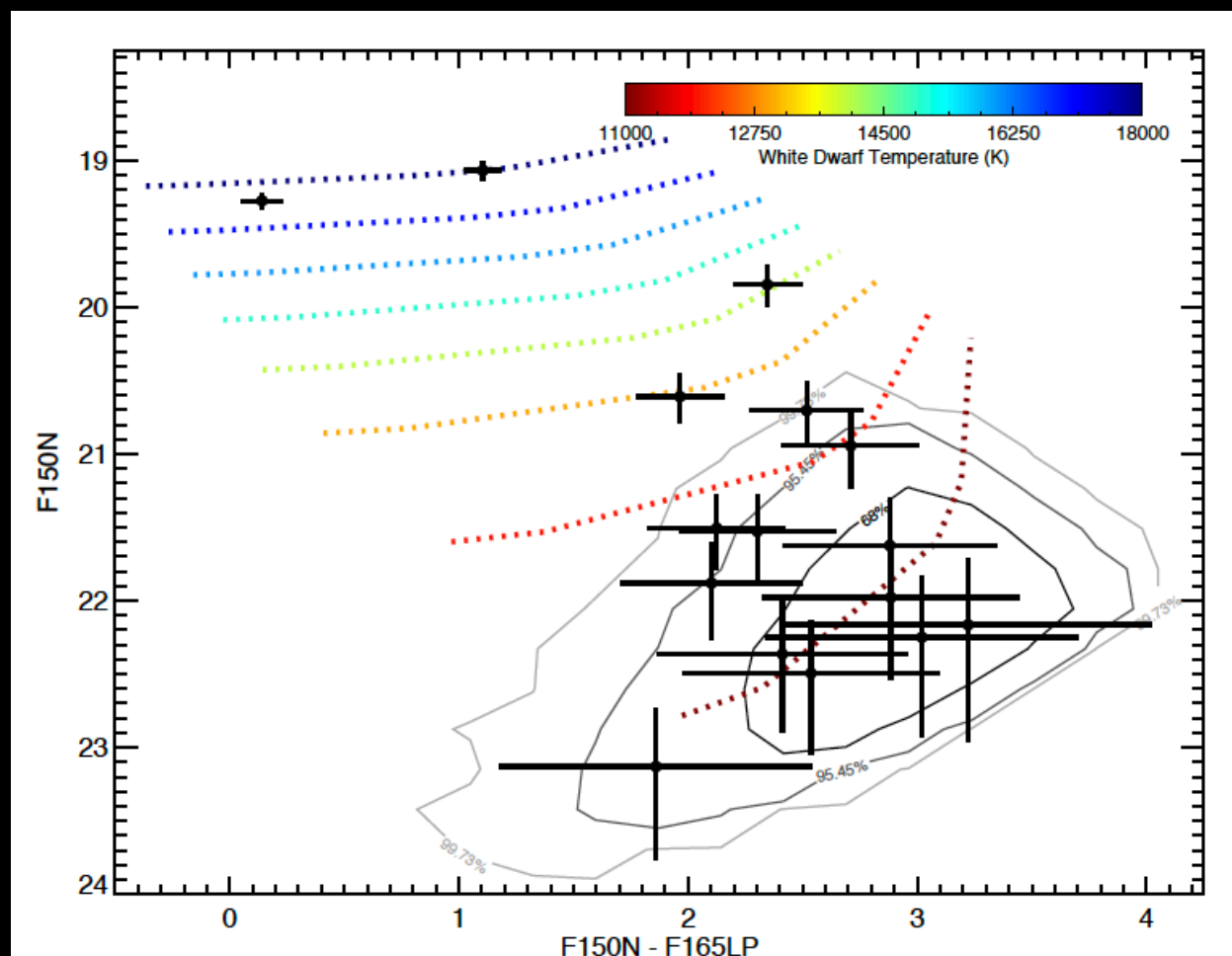
The elixir of youth of BSS



Observed **MS** and **BSS**, log(P) vs. e distribution and mass distribution

White Dwarf companions.

Case B mass transfer (Gosnell et al. 2014, 2015)



Geller et al. 2008

New catalog of oddities in Open clusters in the Gaia era



First catalog of evolved-BSS (YSS)!



**Based on
homogeneous data**

**Field contamination
accounted**

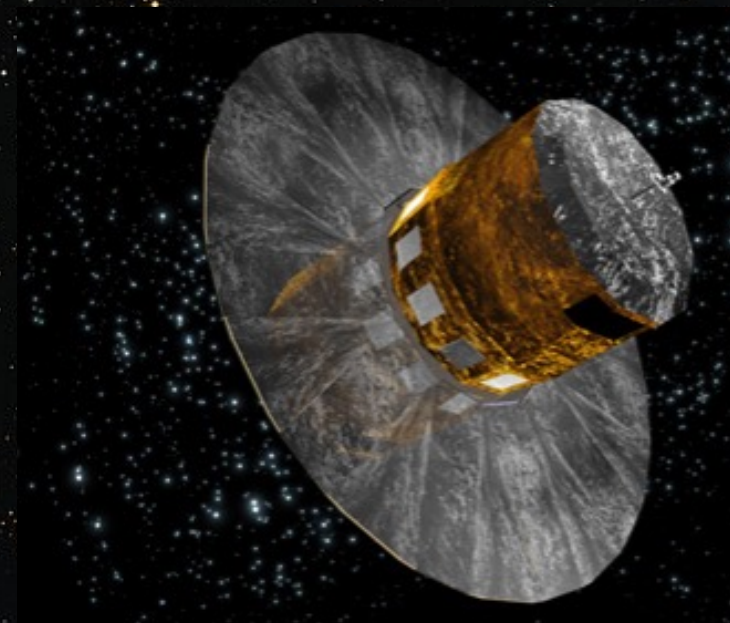
**Membership information
(e.g, RVs, proper motions)**



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How do we create color-magnitude diagrams in the Gaia era and find BSS?

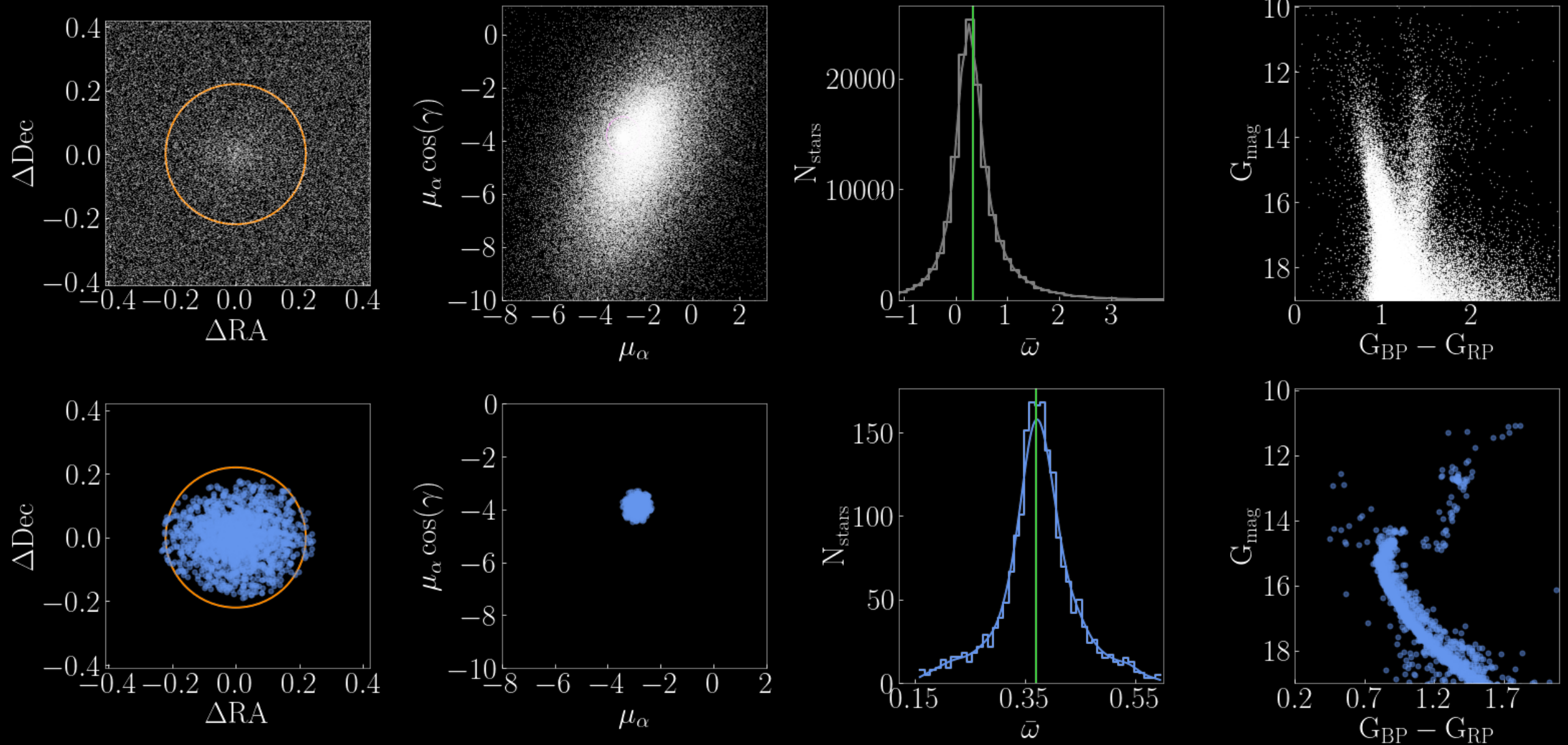
In collaboration with Giovanni Carraro (UNIPD) and Javier Ahumada (UNC)



One by one on each cluster

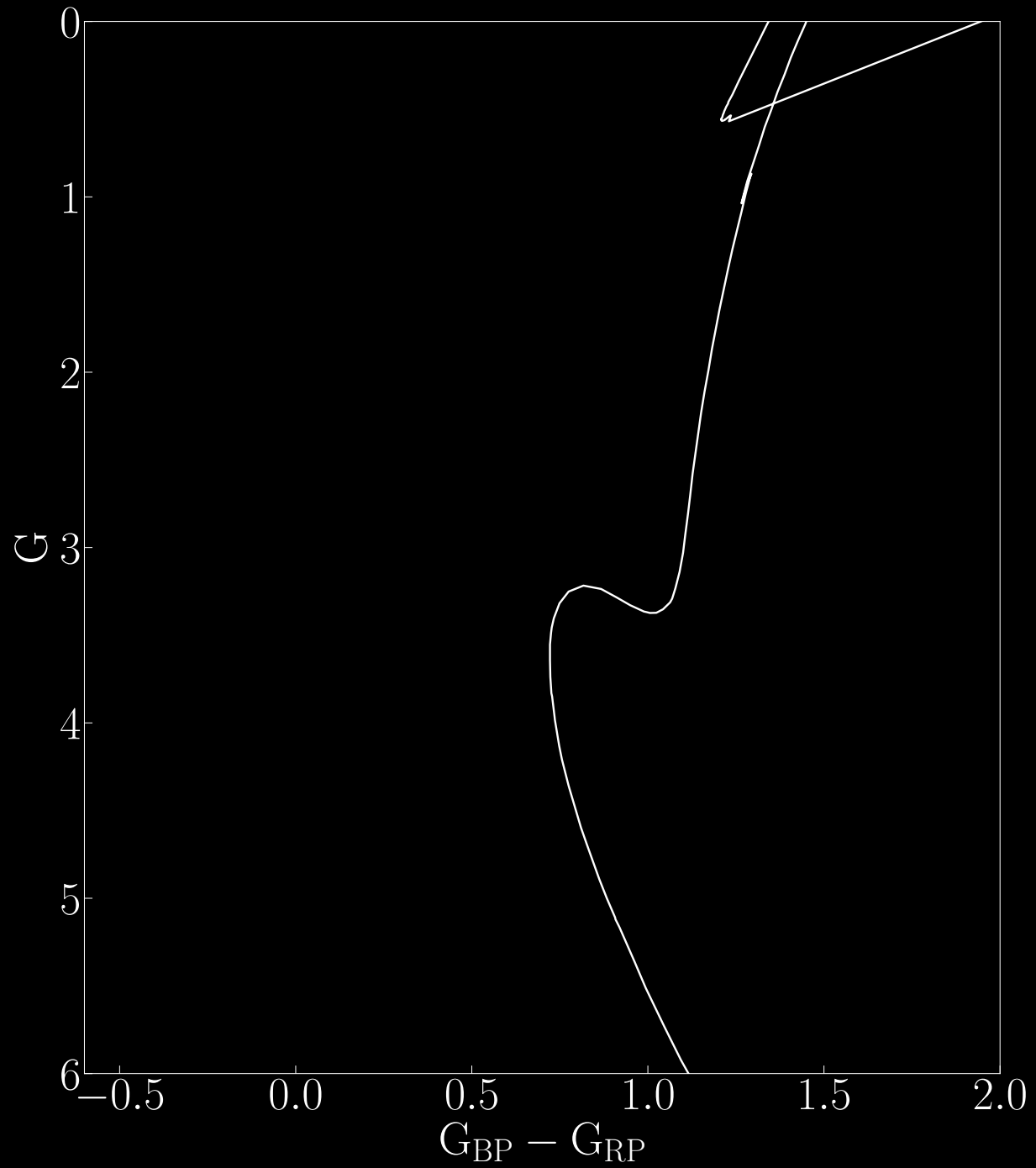


```
SELECT *  
FROM gaiaedr3.gaia_source  
WHERE 1=CONTAINS (POINT ('ICRS', 295.32700, 40.1900) ,  
CIRCLE ('ICRS', ra, dec, 1))
```



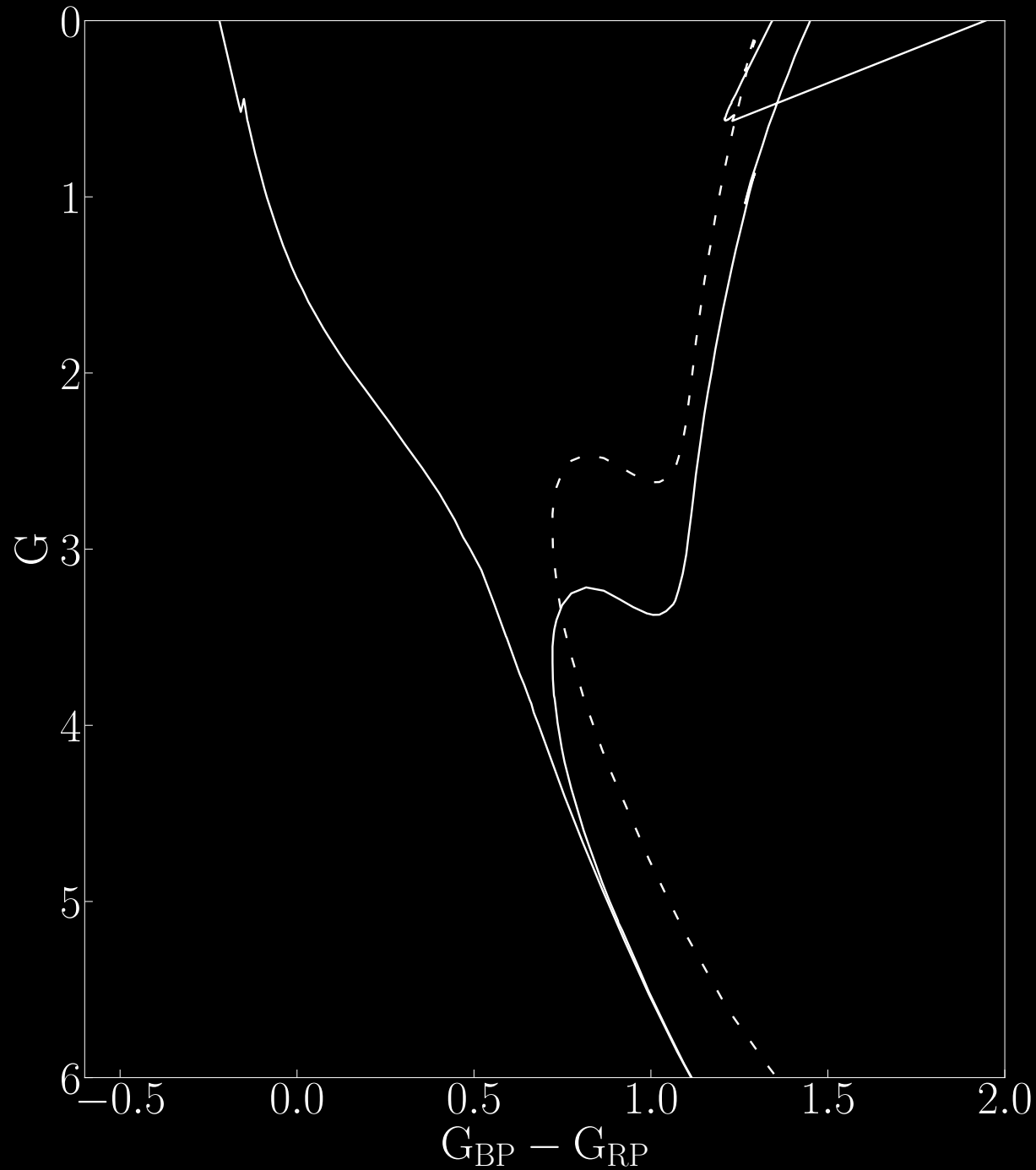
Membership probabilities: **pyUpmask** (Pera et al. 2021)

One by one on each cluster



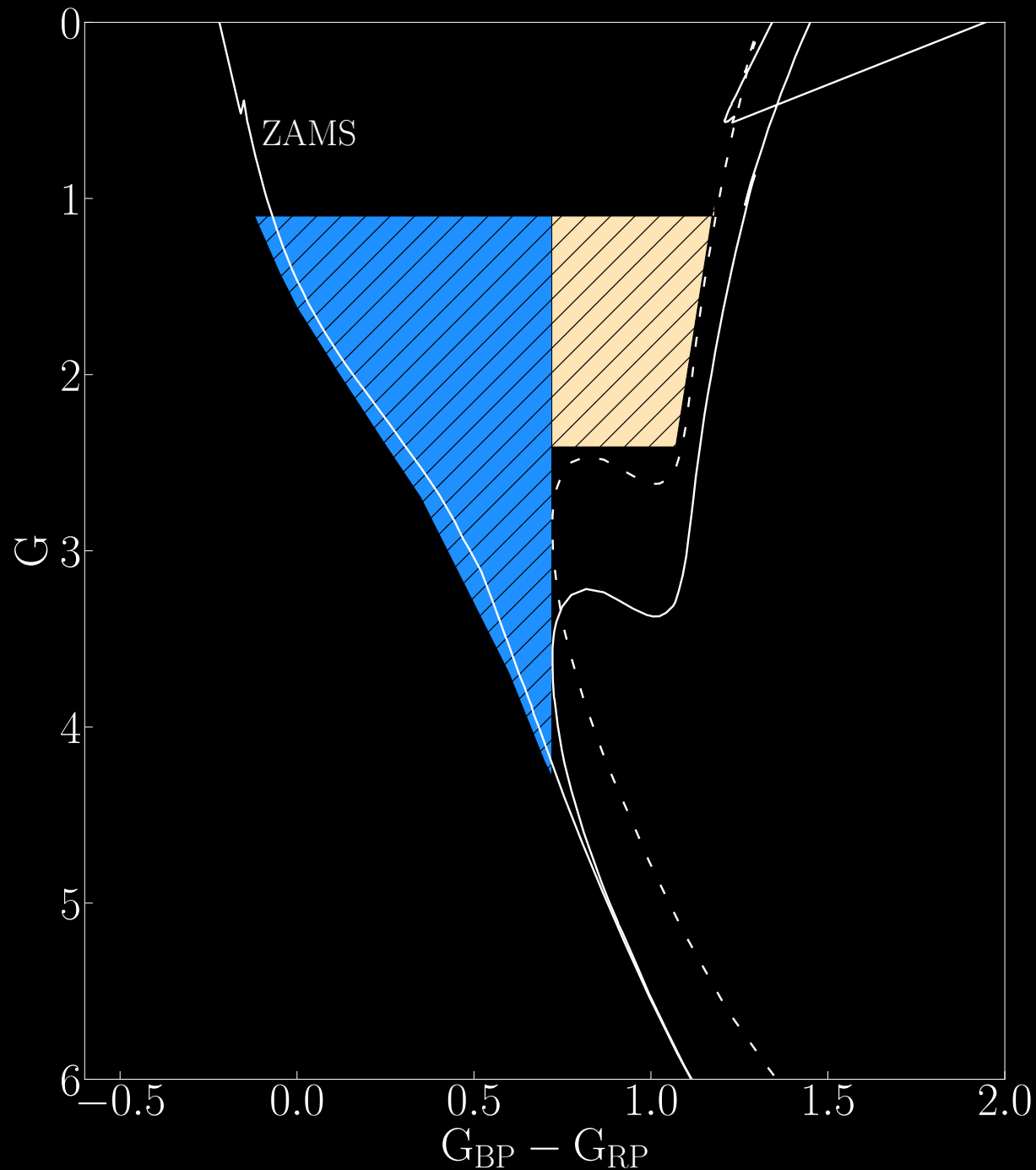
Fit isochrones with cluster parameters

One by one on each cluster



Fit isochrones with cluster parameters
Plotted the Zero age main sequence
(ZAMS) and binary sequence

One by one on each cluster



Fit isochrones with cluster parameters

Plotted the Zero age main sequence (ZAMS) and binary sequence

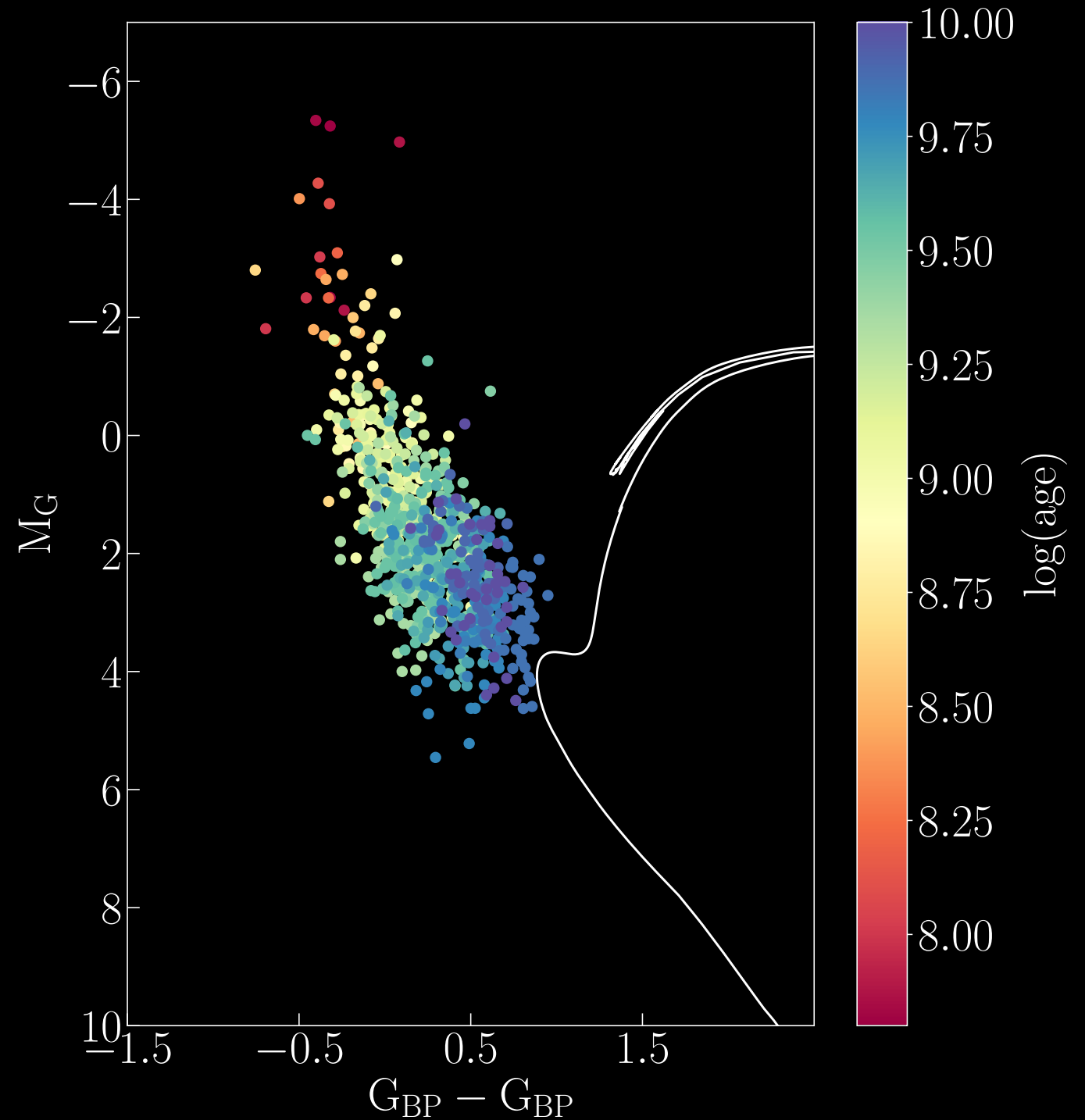
Isolated the blue stragglers population, only those with $P_{\text{memb}} > 50\%$

Some results



900 BSS candidates

27% of the open clusters host at least one blue straggler





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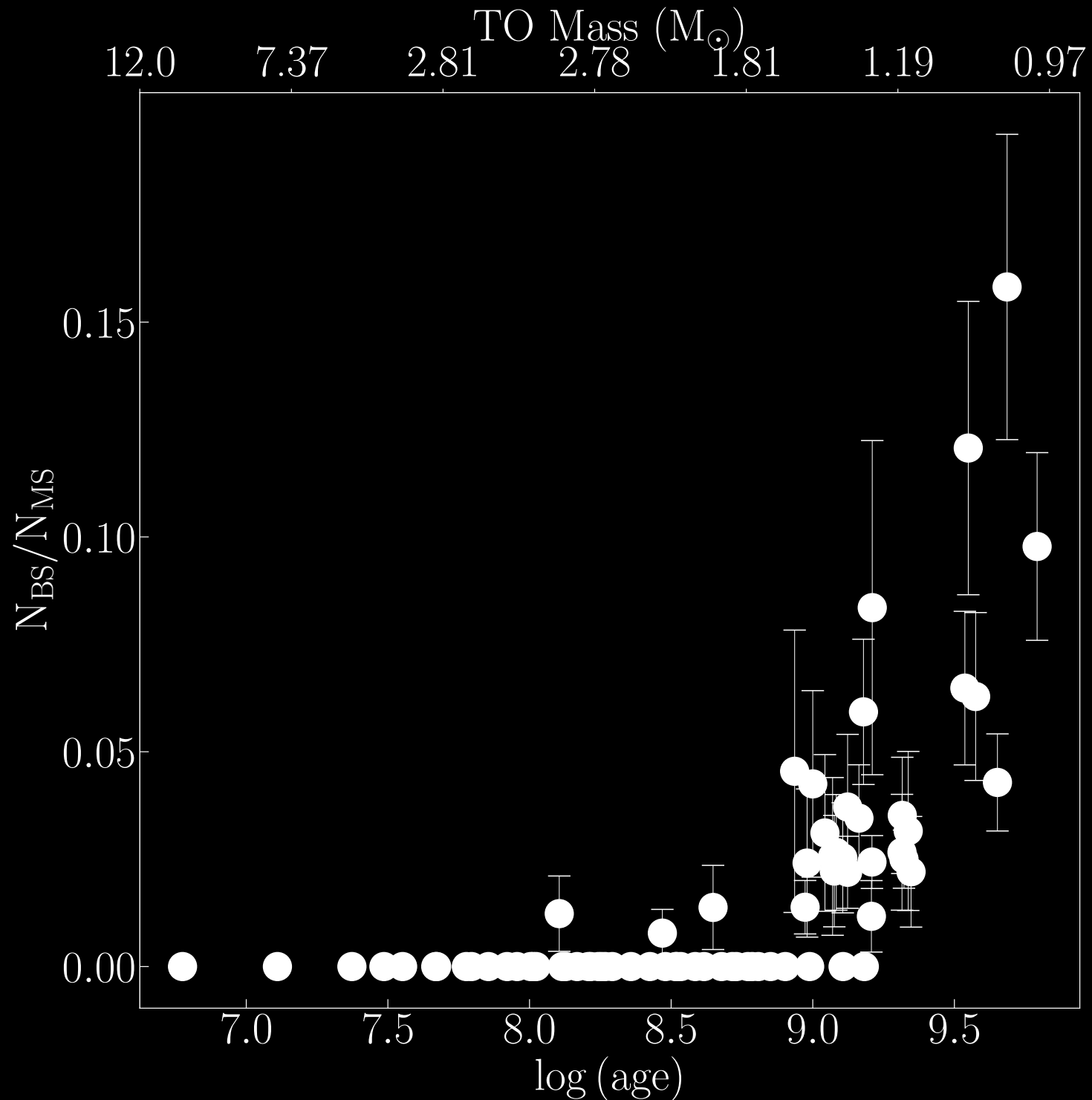
Can we provide hints on BSS formation mechanisms?

Giovanni Carraro (UNIPD), Gabriel Perren (IFIR-UNR), Omar Benvenuto (IALP-UNLP), Jorge Panei (IALP-UNLP), Alejandra de Vito (IALP-UNLP) and Sandro Villanova (UdeC)



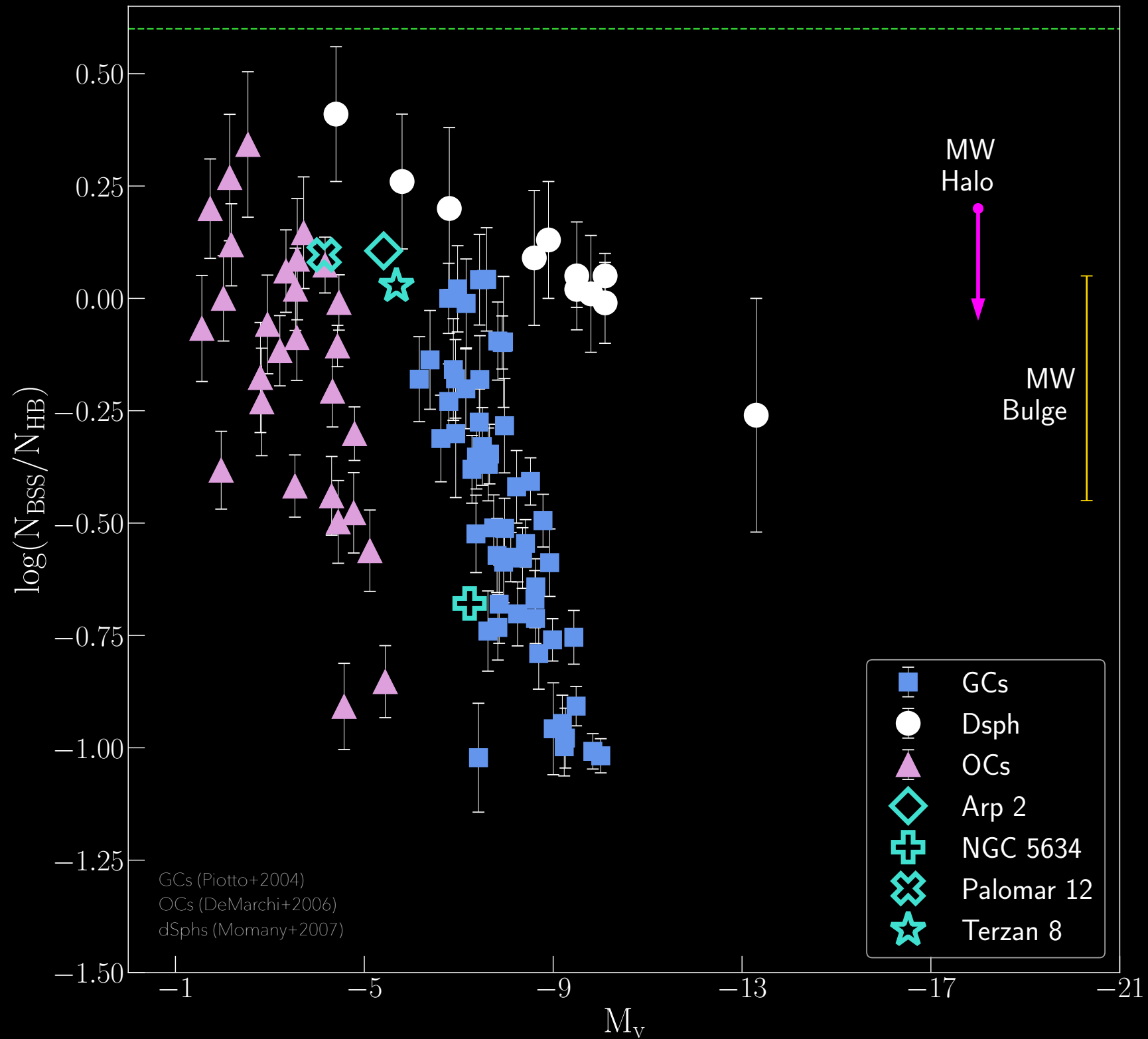
N_{BSS} vs age

70% of the straggler candidates in clusters with age >2 Gyrs





N_{BSS} vs M_V



N_{BSS} vs f_{bin}

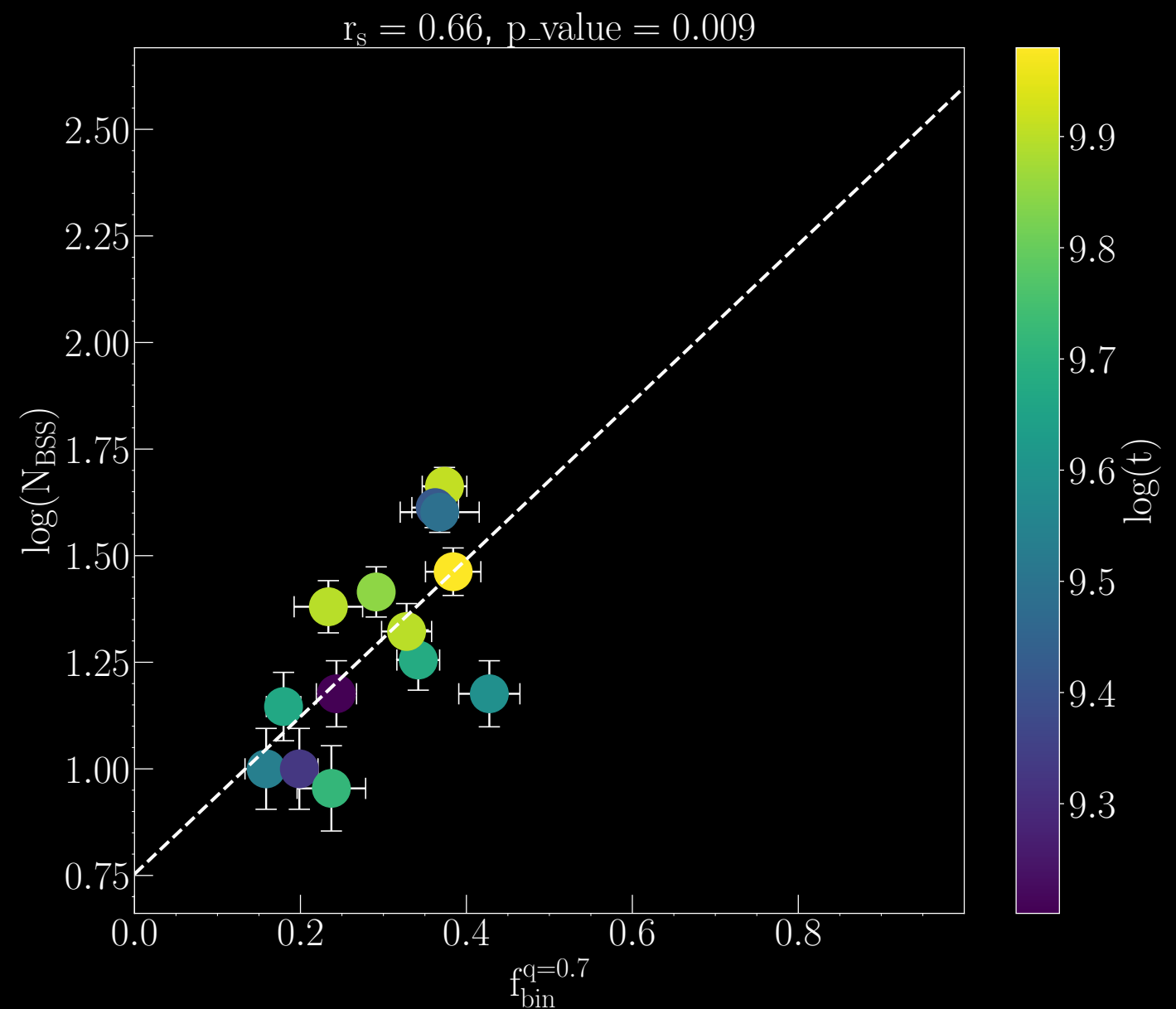


ASteCa (Perren et al. 2015) for
mass and binary fraction

First time this relation is
explored in OCs.

Analogous to Sollima et al. 2008,

Milone et al. 2012 in GCs



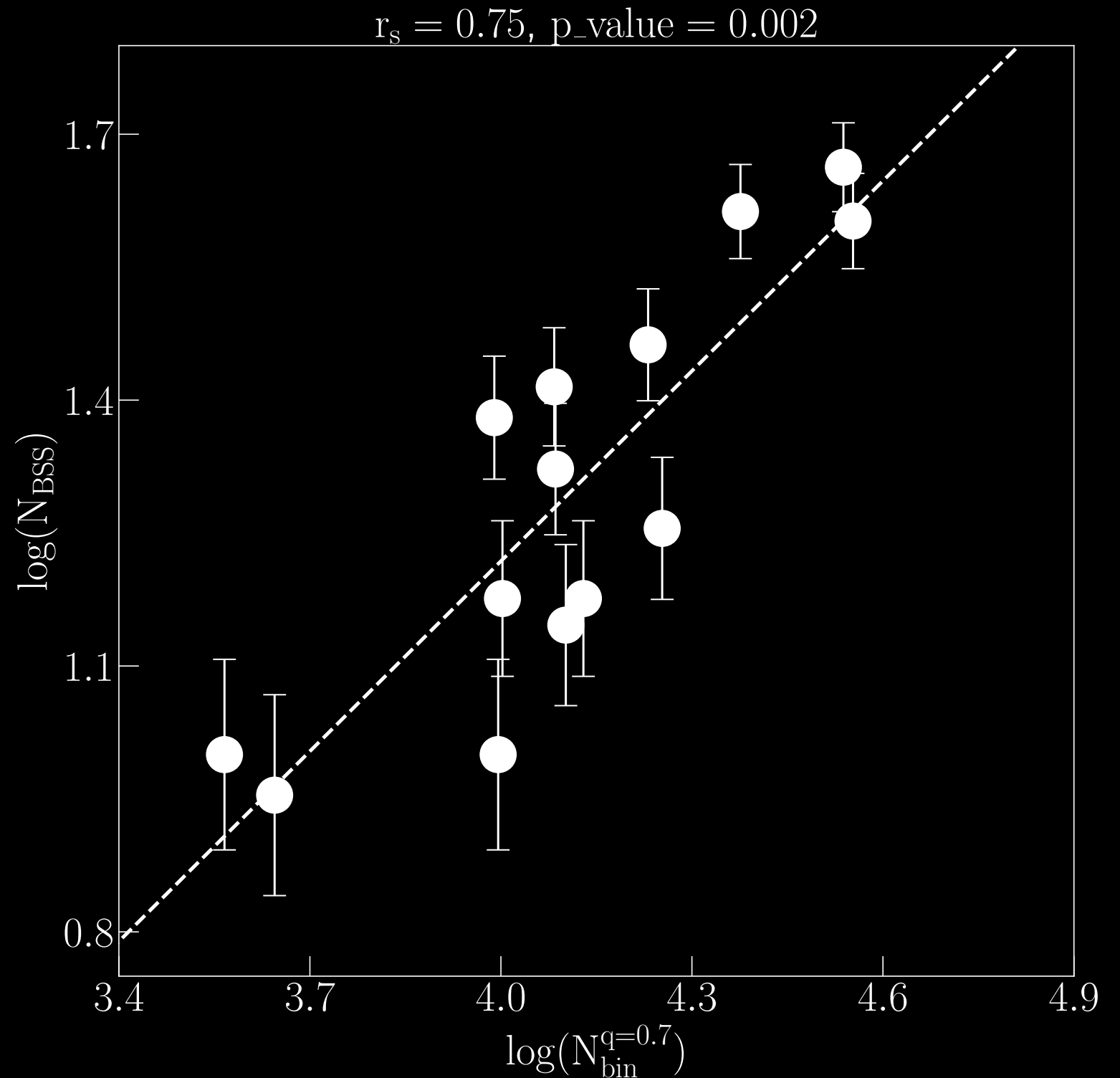
Rain et al. 2024

N_{BSS} VS N_{bin}



$$N_{\text{BSS}} \propto N_{\text{bin}} \sim \frac{f_{\text{bin}} M_{\text{tot}}}{\bar{m}}$$

Direct evidence that supports the binary escenario!!

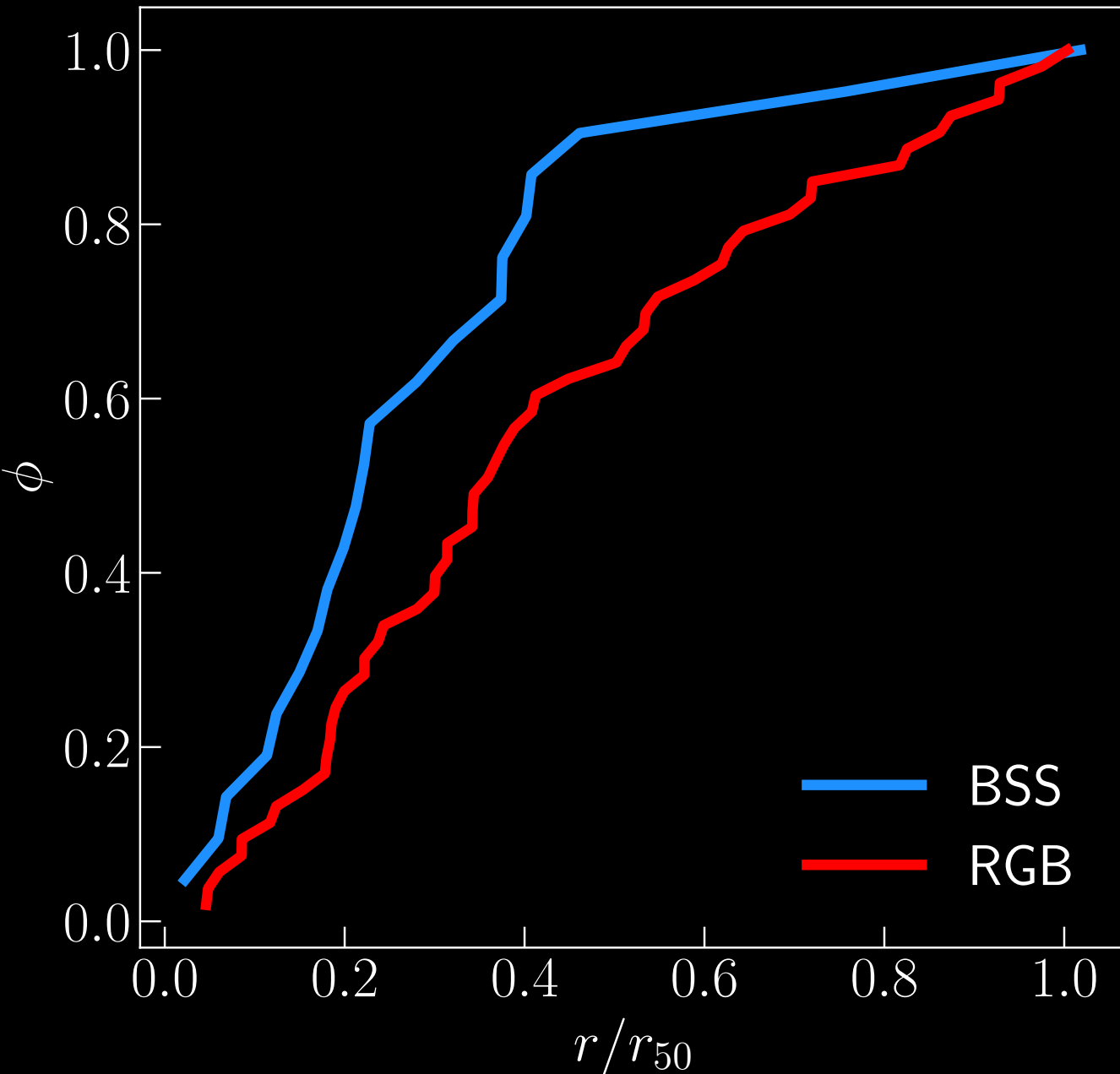


Rain et al. 2024

Dynamical clock: mass segregation



NGC 188

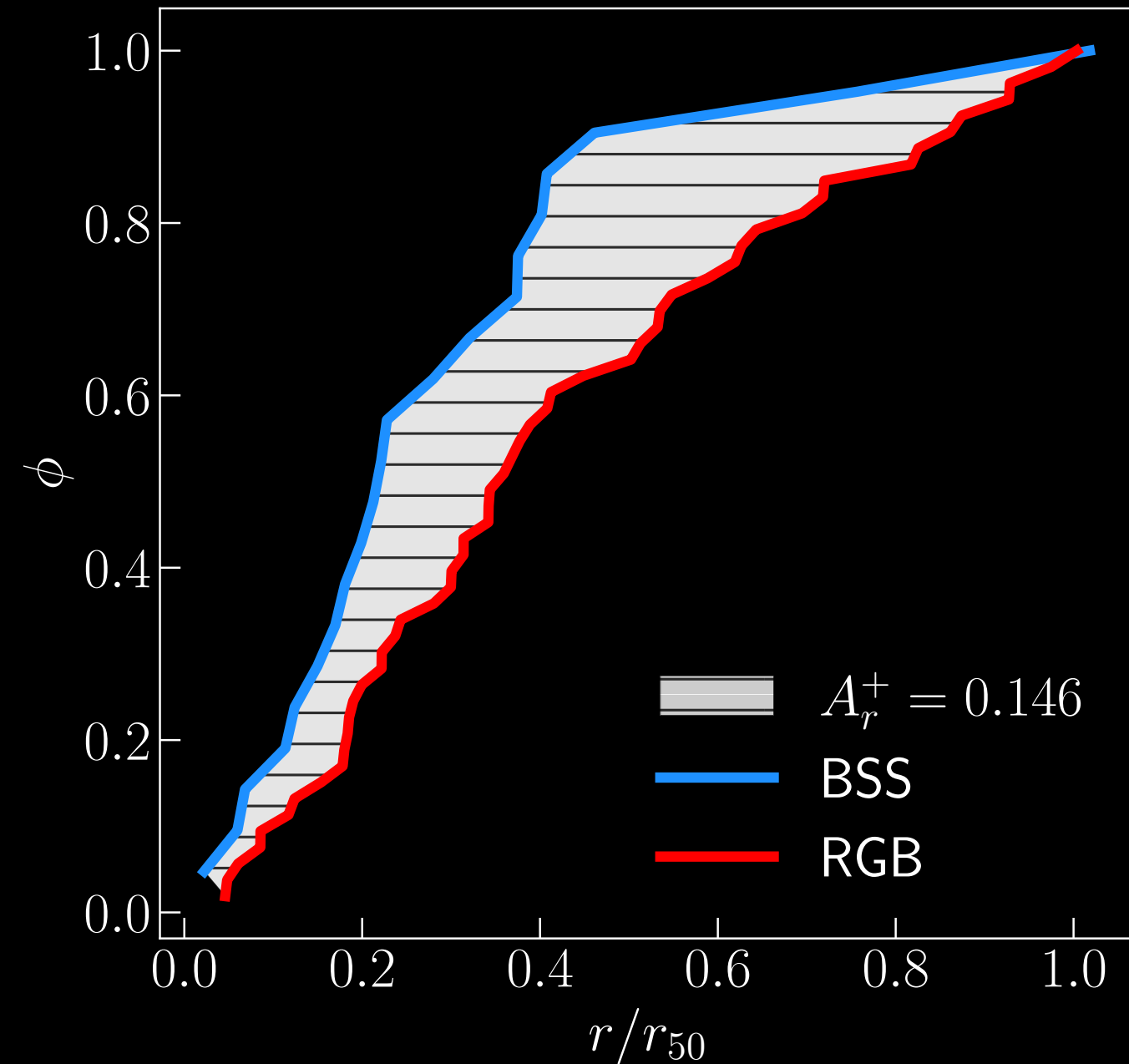


Are BSS more segregated than normal cluster stars?

Dynamical clock: mass segregation



NGC 188



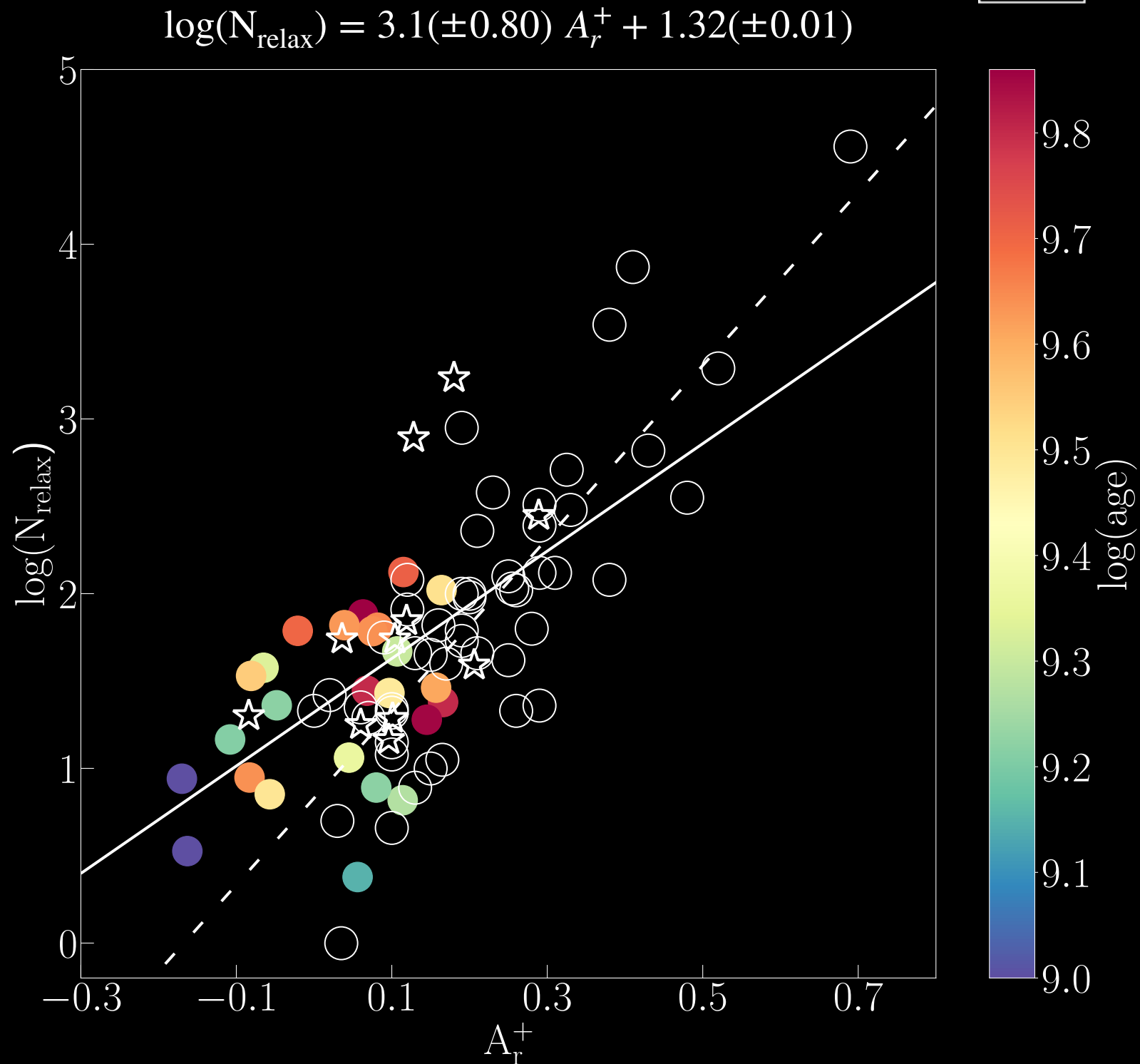
$$A_r^+ = \int_{x_{min}}^x \phi_{BSS}(x') - \phi_{ref}(x') dx'$$

$x=r/r_{50}$ and x_{min} are the outermost and innermost radii from the cluster center

Extension of the sample from 10 to 40. We got;

$$N_{\text{relax}} = \frac{\text{age}}{T_{\text{relax}}}$$

Correlations of less evolved GCs and OCs are similar according to Fisher and Zou test



Rain+unpublished



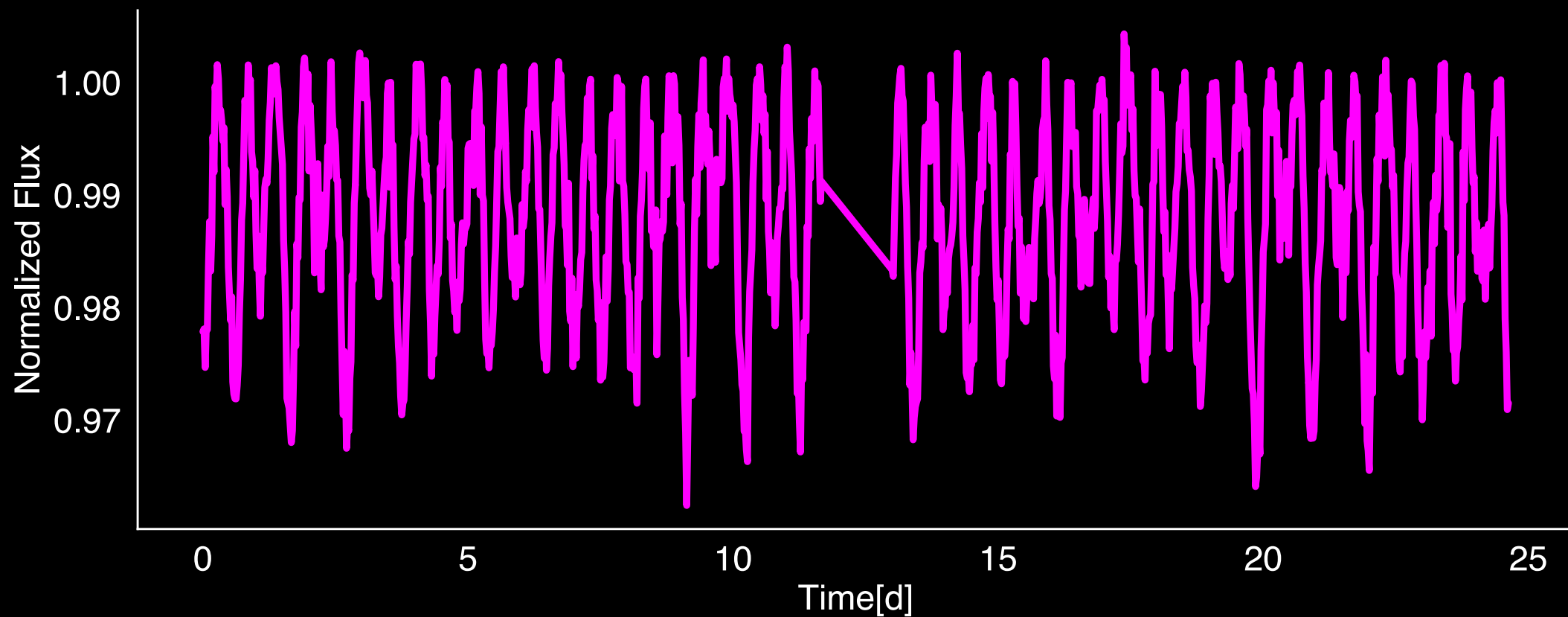
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How to find binaries among BSS?

In collaboration with Henri M.J. Boffin (ESO)



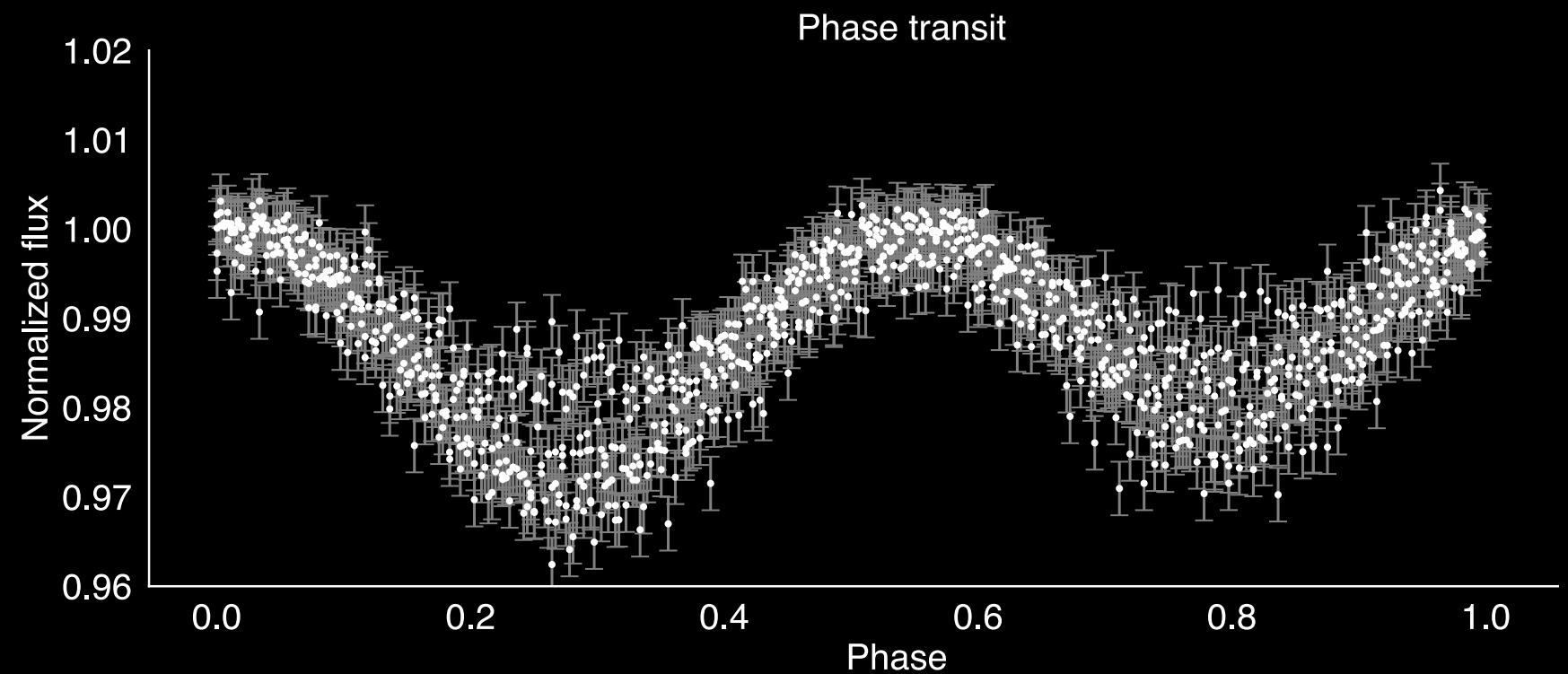
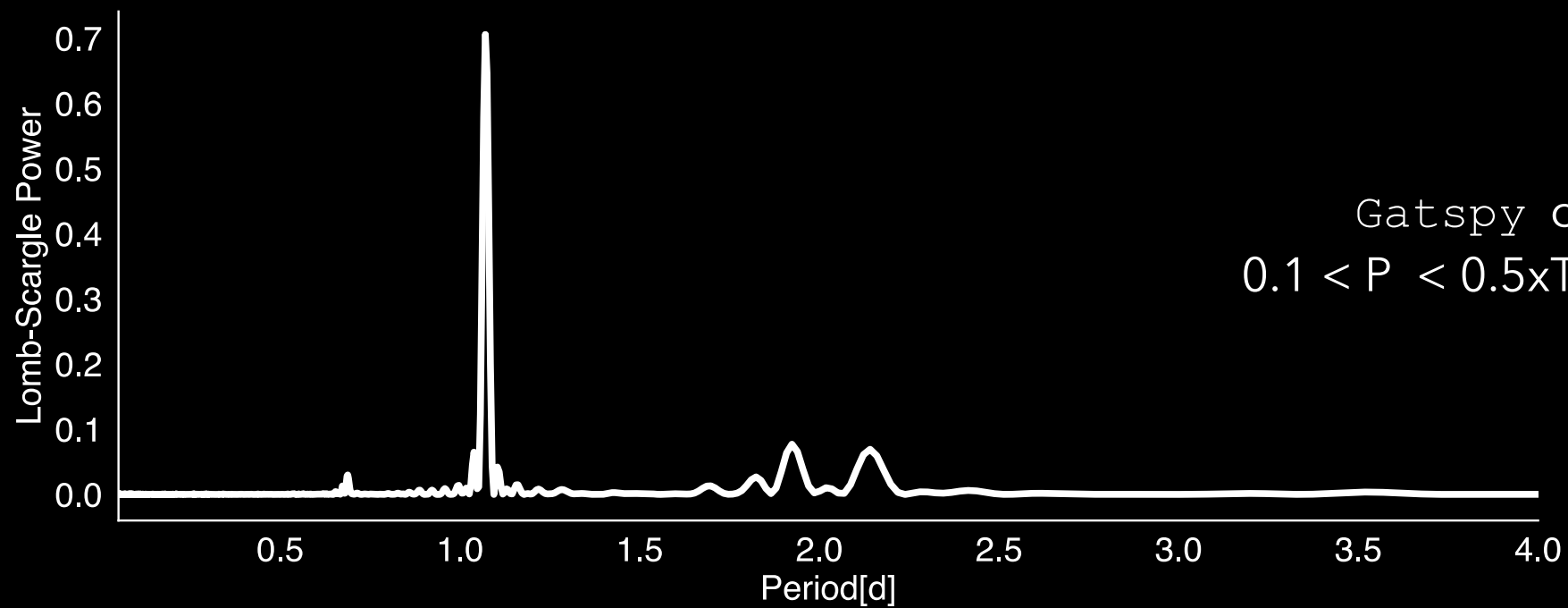
BSS in the Transiting exoplanet satellite survey (TESS)



Outliers with $DQUALITY > 0$ | Flux $> 2.5 \sigma_{FLUX}$ | Sky $> 3.5 \sigma_{sky}$



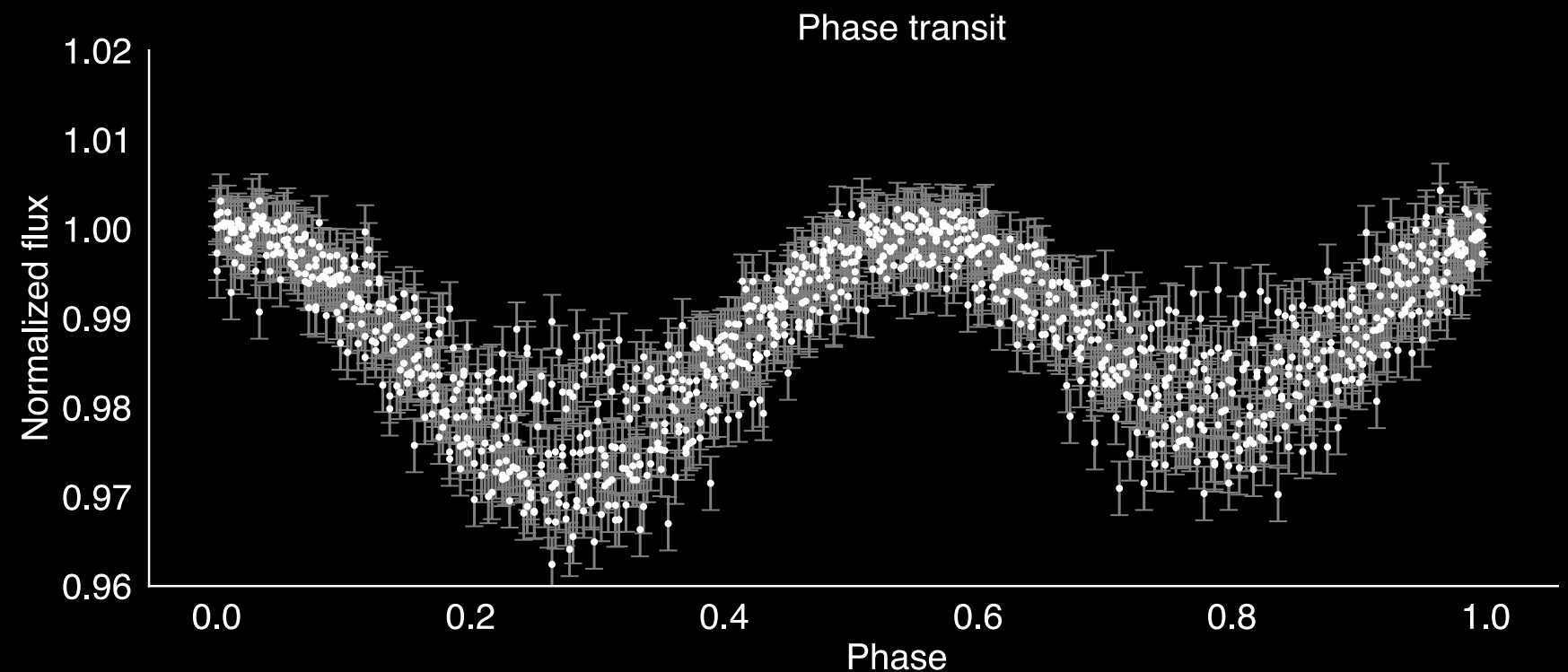
$P \sim 1.074^d$





60 short-period BSS and 90% are
"new discoveries"

7 clusters with a high rate $>10\%$





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And what about radial velocities (RVs)?

In collaboration with Sandro Villanova (UDEEC)

Multi epoch observations



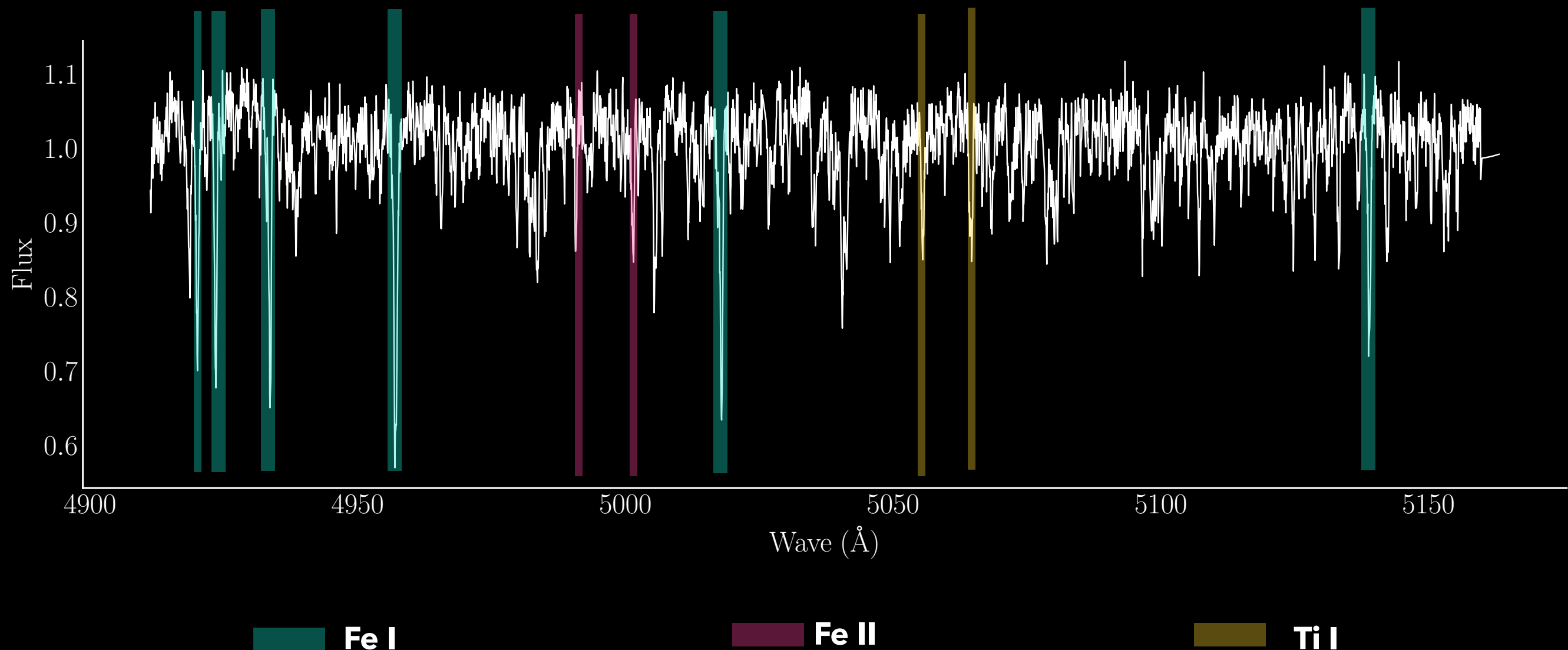
>700 FLAMES/GIRAFFE observed with HR8 grating (490-520nm) and S/N ~15-80

Multi epoch observations

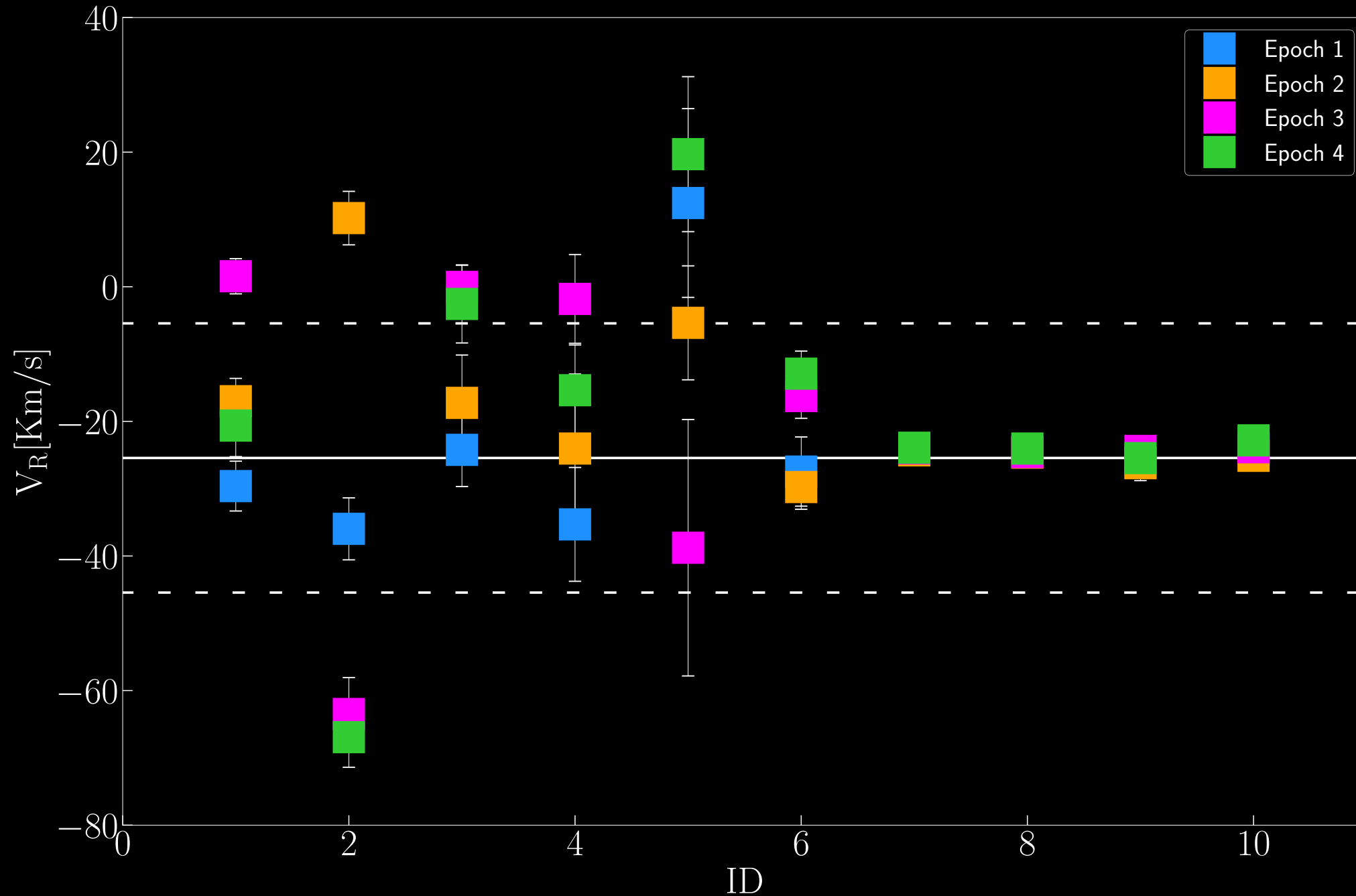


>700 FLAMES/GIRAFFE observed with HR8 grating (490-520nm) and S/N ~15-80

RVS (CCF) + V_{sin}i (comparison with synth. Template)



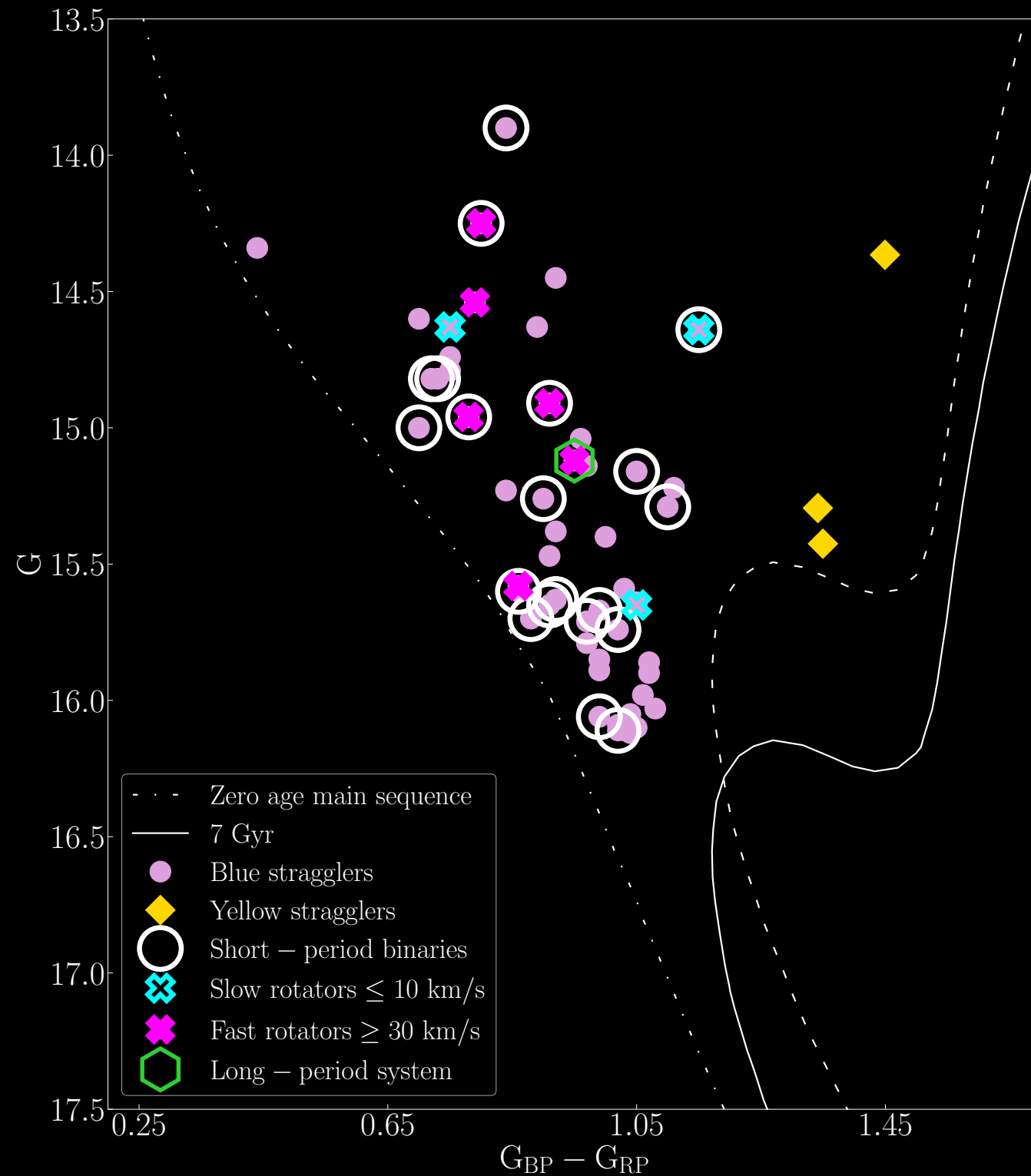
The case of Collinder 26 I



Short ($< 100^d$) long binaries ($> 700^d$) and non-variable stars

The case of Collinder 26 I

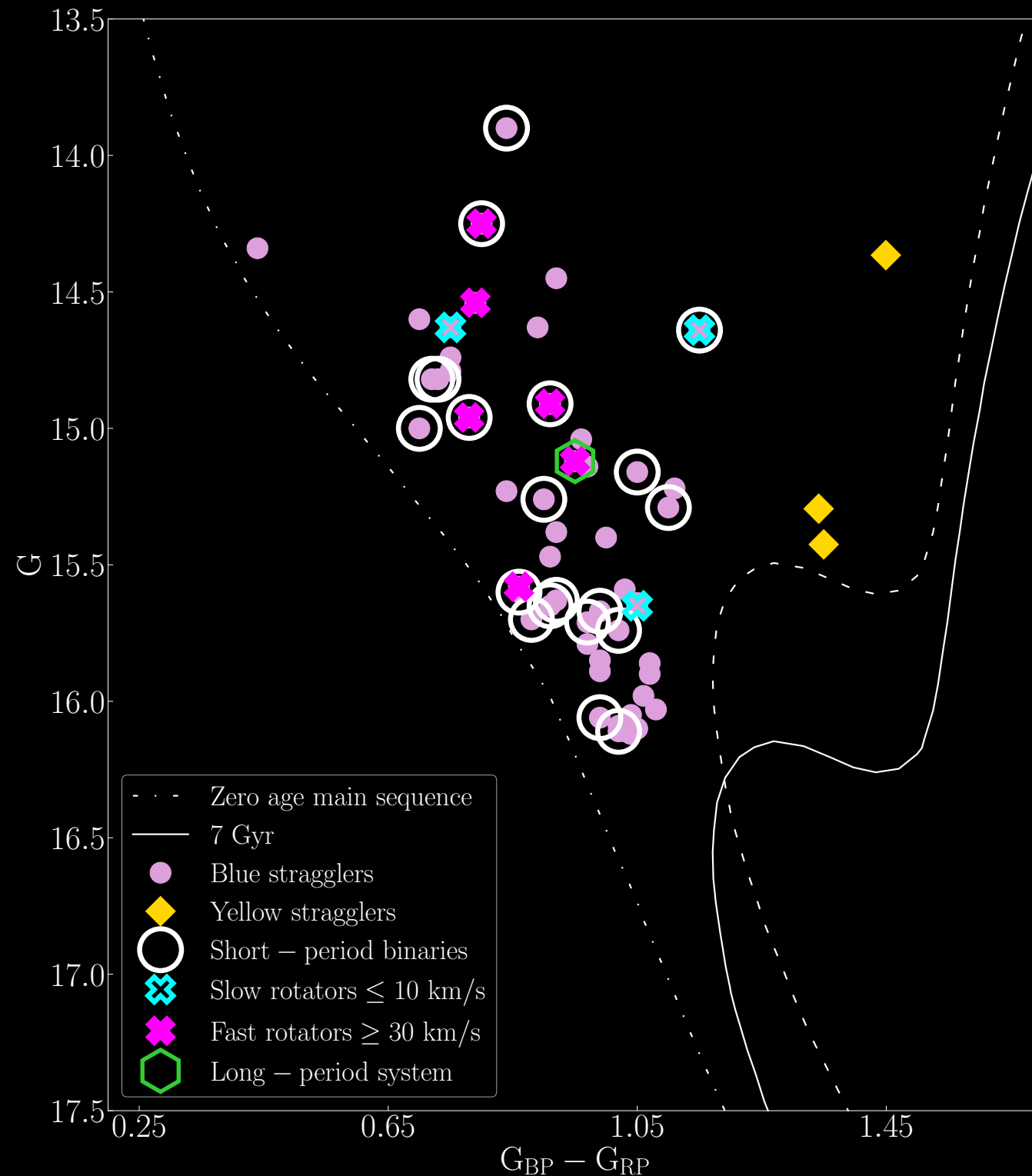
> 50 candidates



Rain, M.J & Boffin H. in prep.

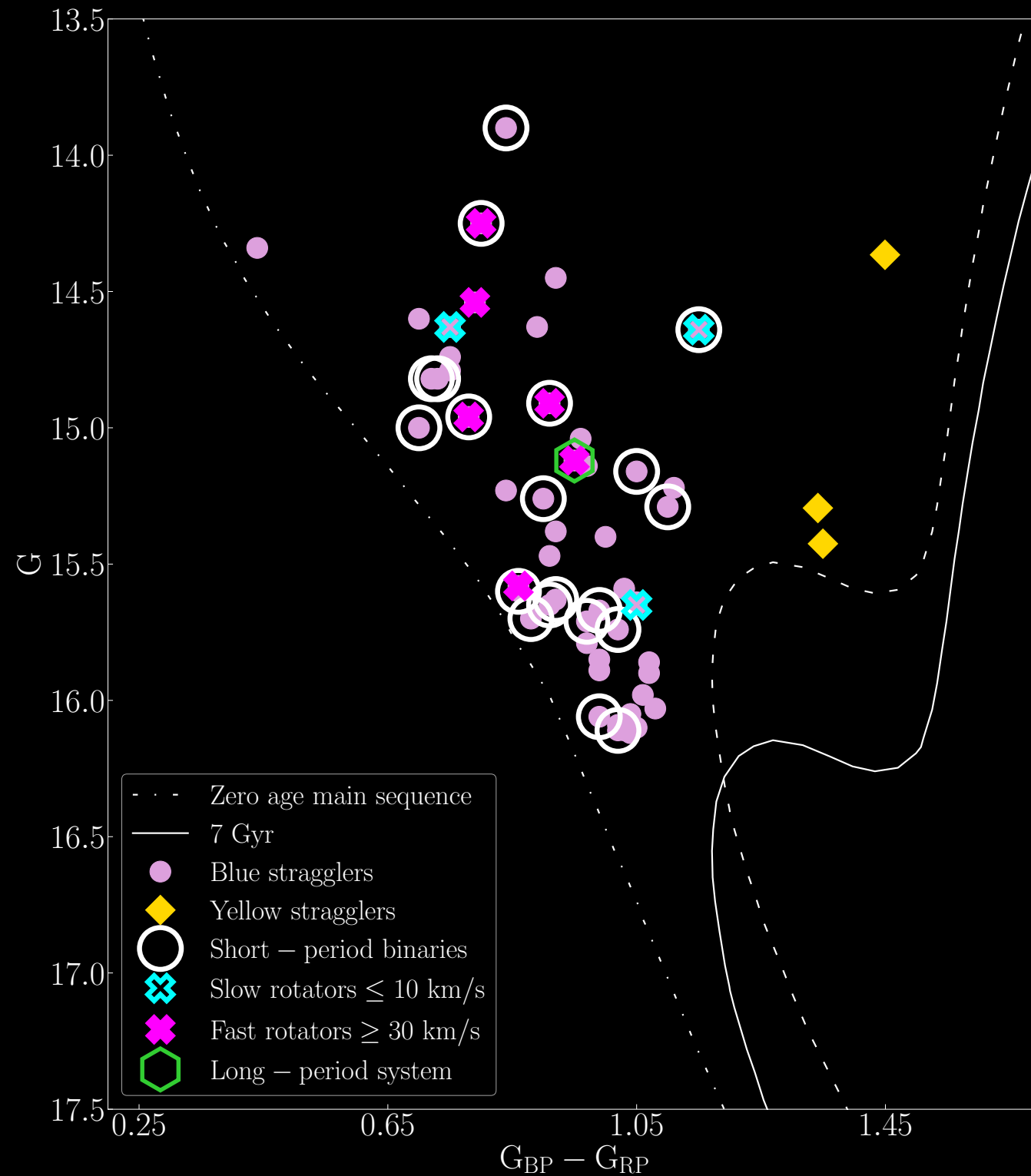
The case of Collinder 26 I

>50 % candidates of population are in binary systems



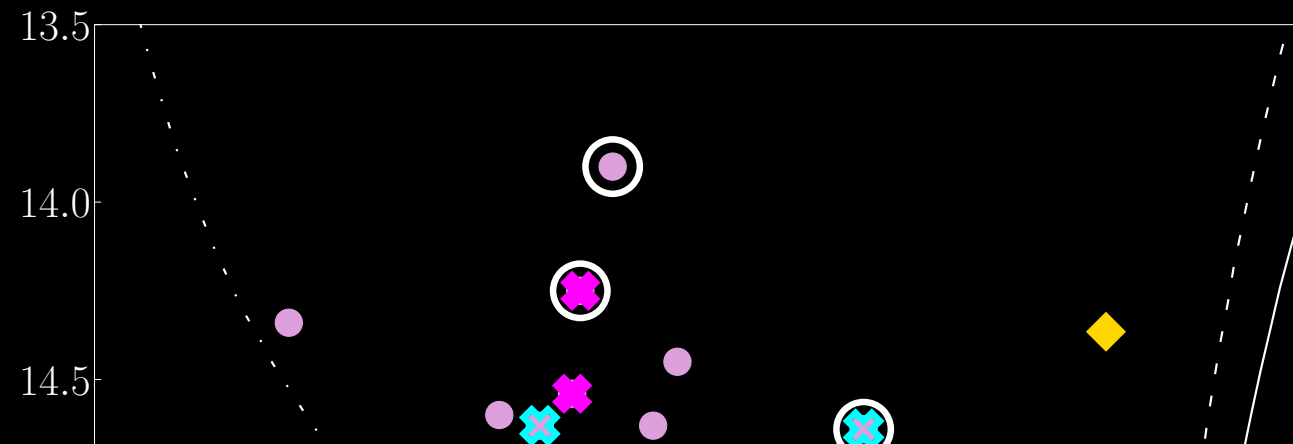
The case of Collinder 26 I

No special position in the CMD



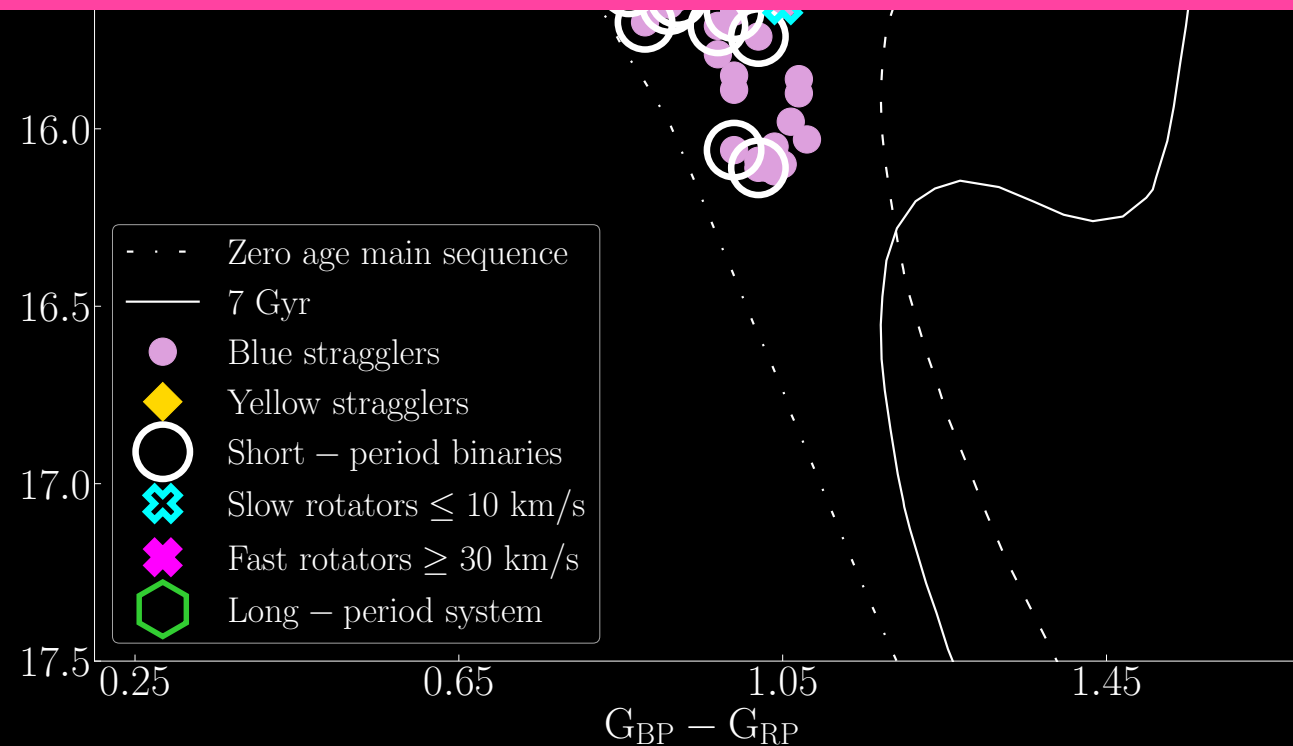
The case of Collinder 26 I

No special position in the CMD



MODELING!

Phd Thesis Maitte Echeveste



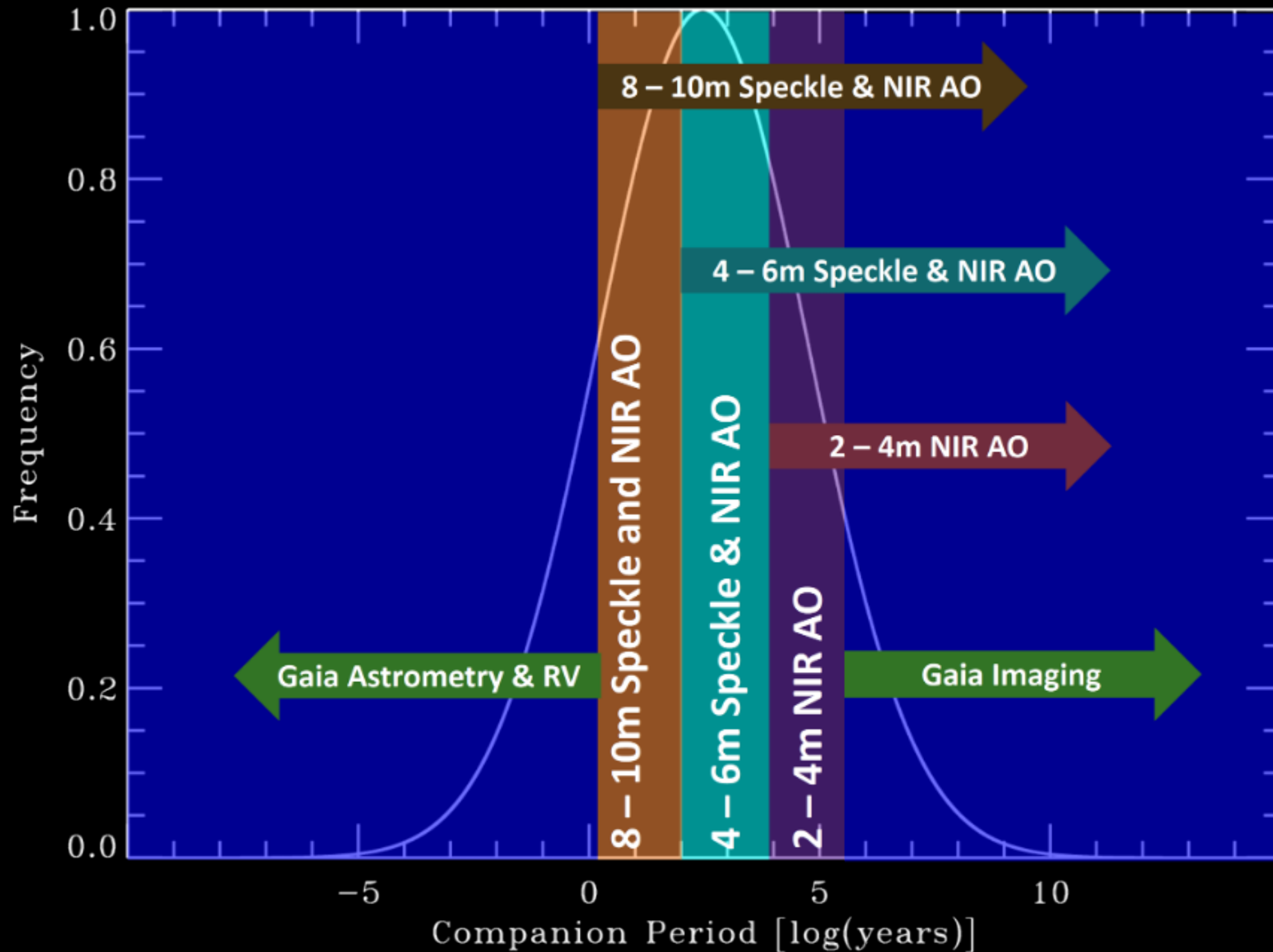


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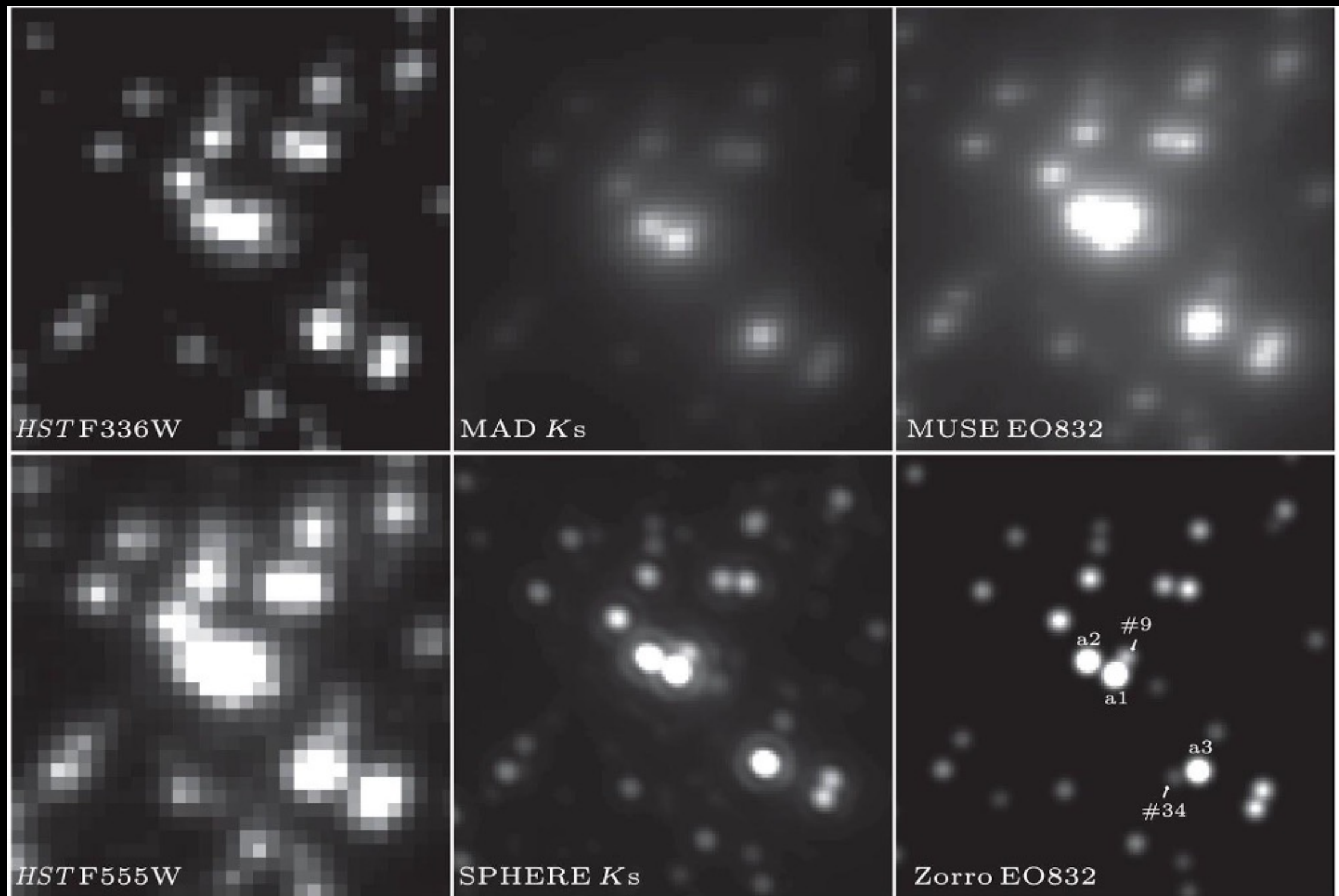
Constraining a multiple stellar origin of blue stragglers

In collaboration with R. Salinas, N. Leigh, M.J. Rain, R. Mathieu, S.B. Howell & V. Kalari

The roles of speckle, radial velocities and Gaia



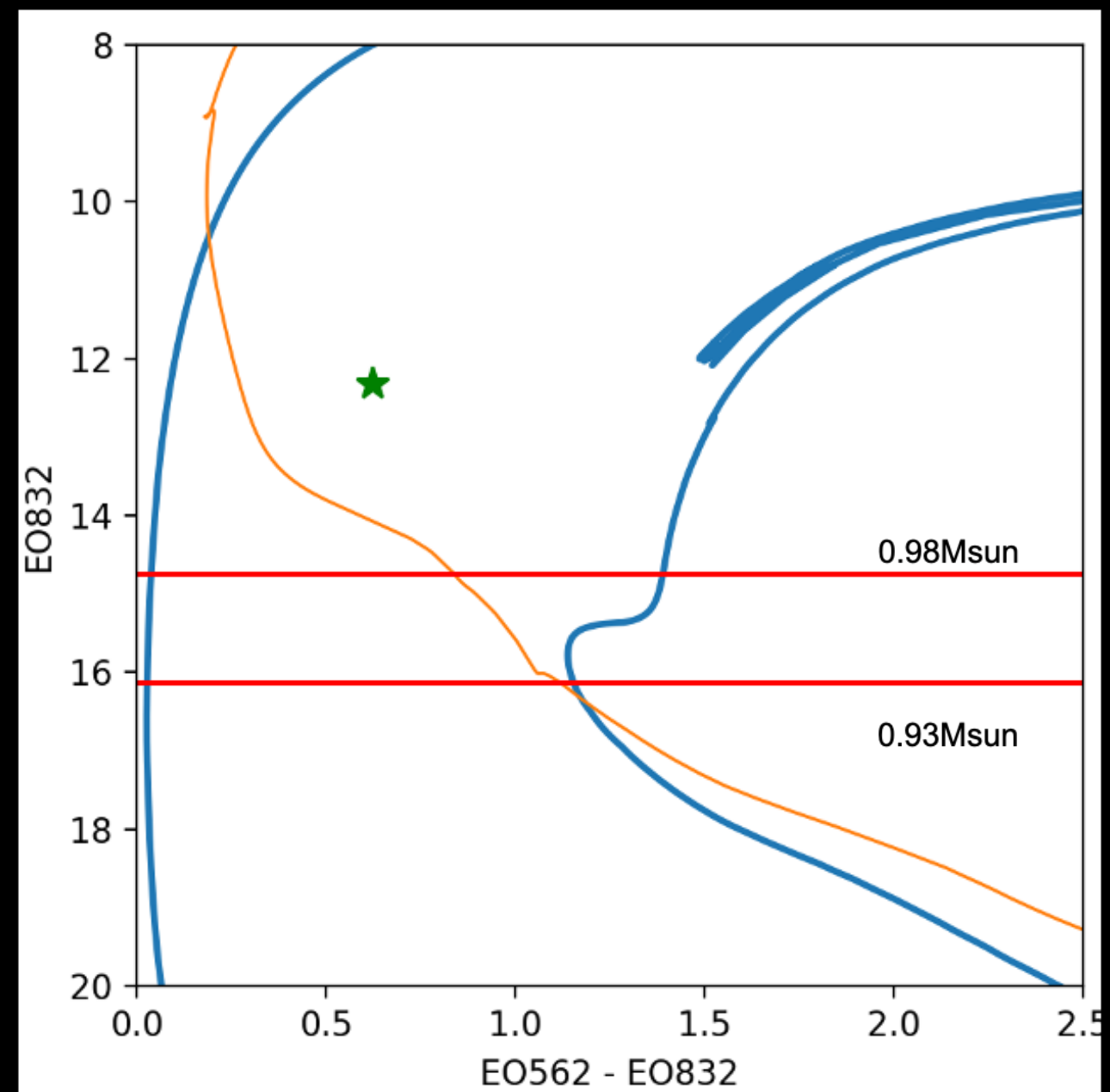
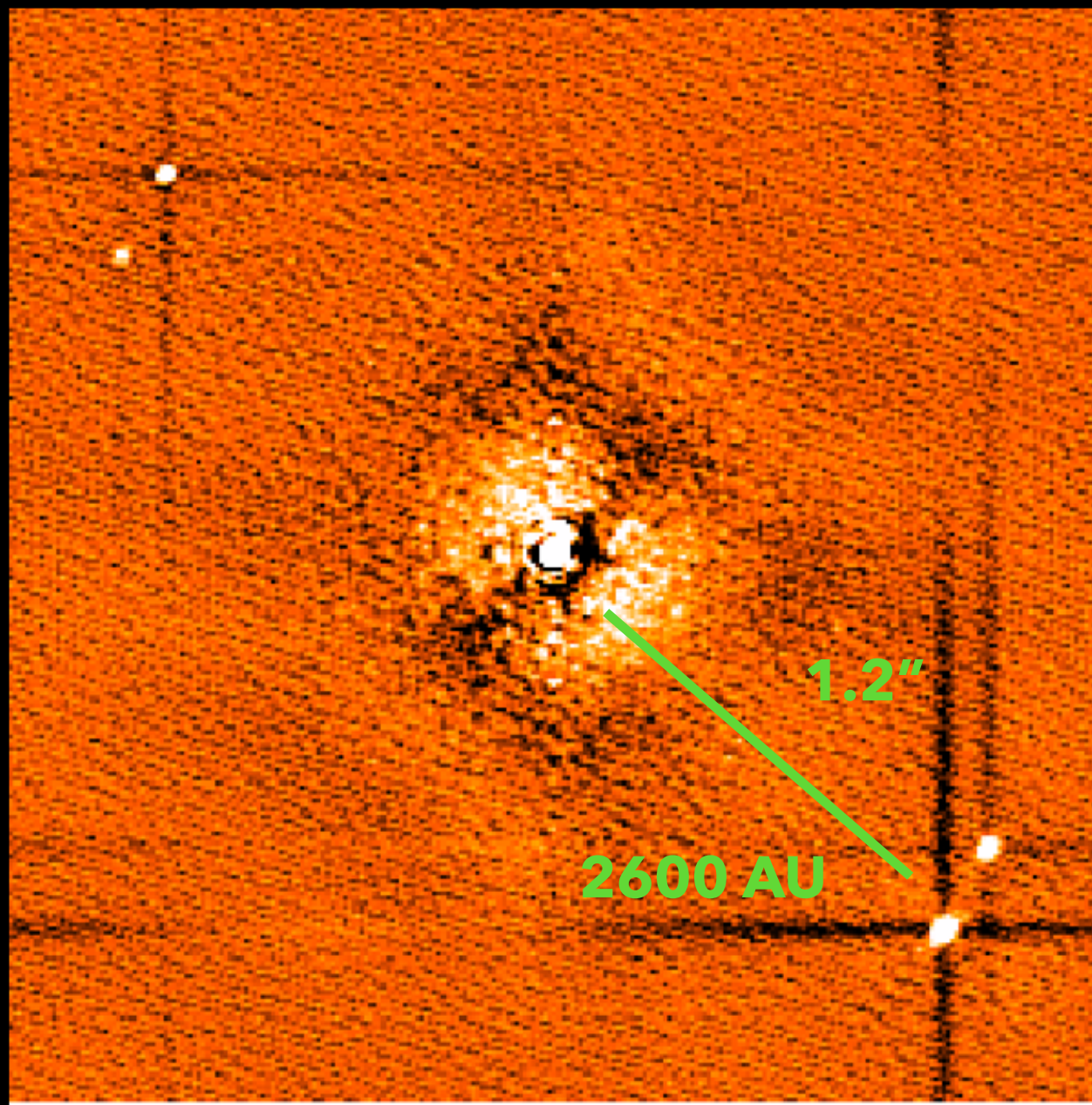
An example of speckle Interferometry



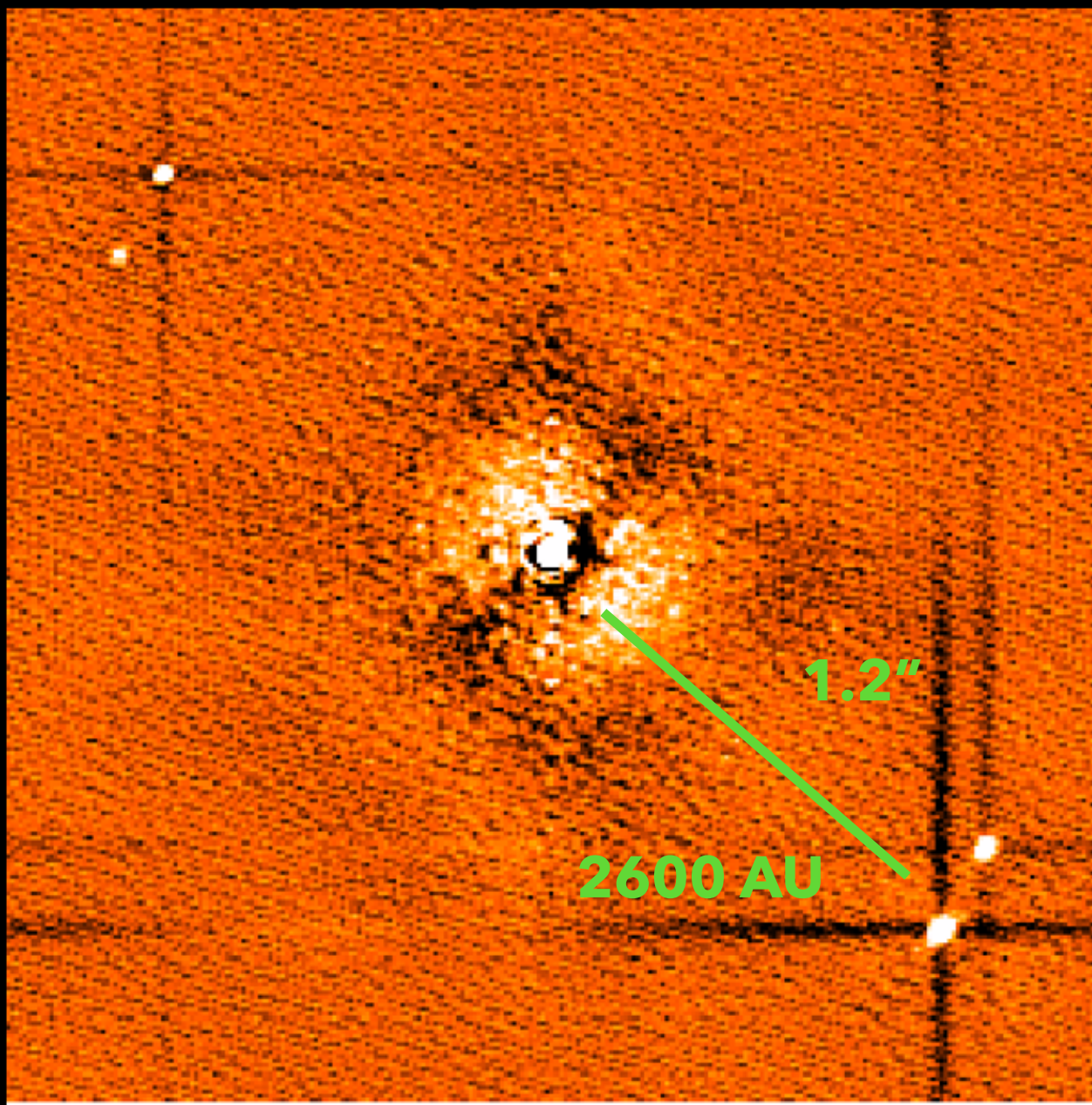
R136@24mas

Kalari et al. 2022

Some results: Case of NGC 7789



BSS masses from the isochrones



Detected companions to 6 blue stragglers on a total sample of 51 BSs, distributed in 11 open clusters

This detection rate (11%) goes in line with the expectation of BSs formed via Kozai-Lidov (up to 10% in GCs, Antonioni+16; up to ~25% in OCs, Geller et al.13)

Main takeaways

- Homogeneous and internally consistent catalog of Blue straggler stars but also the **first one of yellow stragglers**
- **Updated** previous relations with age and M_v . **Confirmed** the relation between N_{BSS} and $f_{\text{bin}}, N_{\text{bin}}$
- **Dynamical state of >36 OCs.** BSS are more segregated in clusters with ages >1 Gyr
- Reported the period of **>60 close-straggler binaries.** Collinder 261 $>50\%$ in short-period binaries
- Carried out the **first spectroscopic analysis** on the straggler population of a handful OCs. We identify long/short-period systems and non-variable stars.
- Confirmed KZ expectations in OCs
- Catalog is opening new opportunities to study the BSS formation pathways and nature.. Stay tuned!

The image features a dark, star-filled night sky as a background. The stars vary in brightness and color, with some appearing as bright white or yellow points and others as smaller, dimmer specks. A few prominent stars have a distinct blue or cyan hue. The overall effect is a serene and vast cosmic scene. Centered in the lower-middle portion of the frame is the text "Thank you!" in a clean, white, sans-serif font. The text is bold and clearly legible against the dark background.

Thank you!

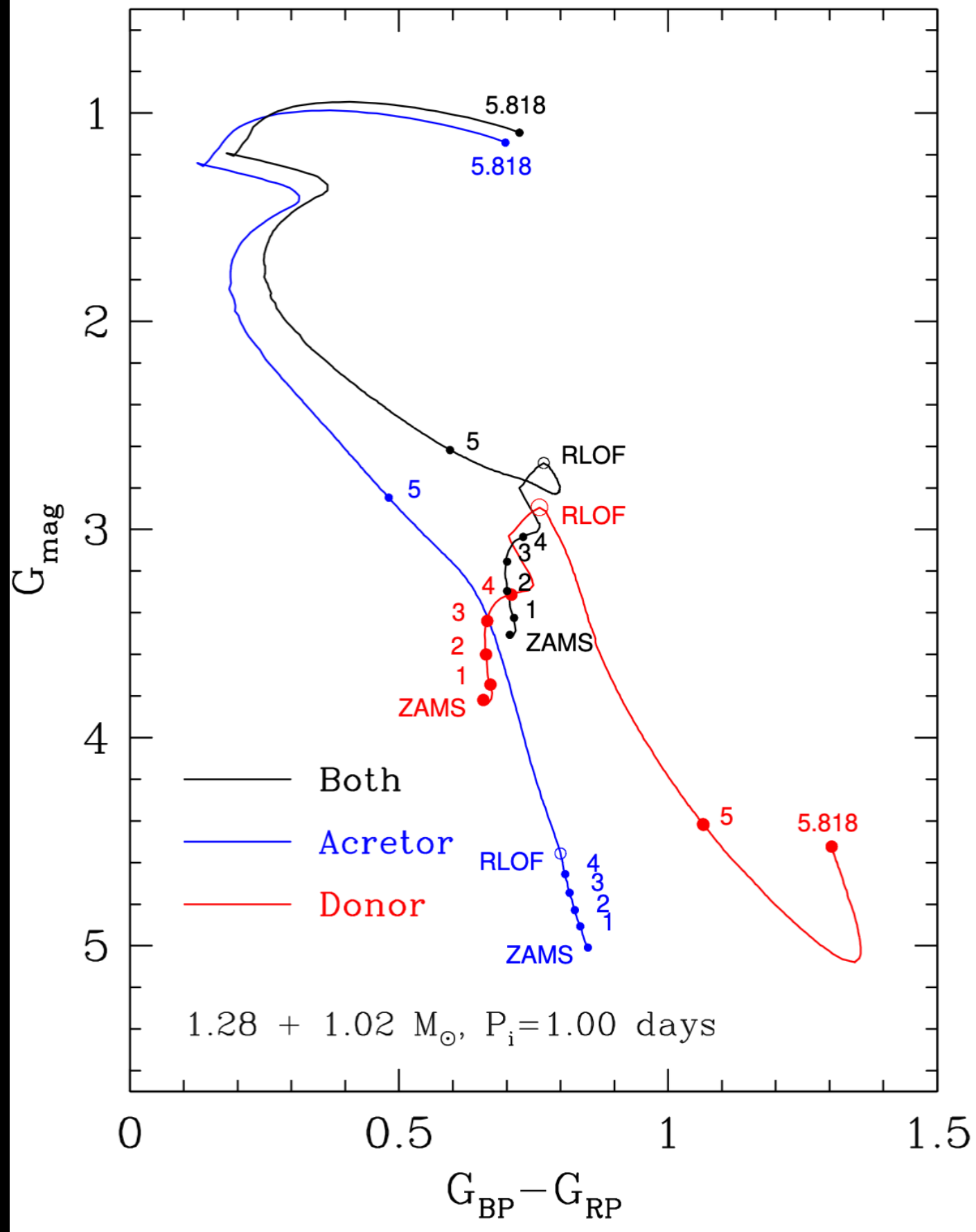


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Binary evolution and modeling

In collaboration with Echeveste, M.

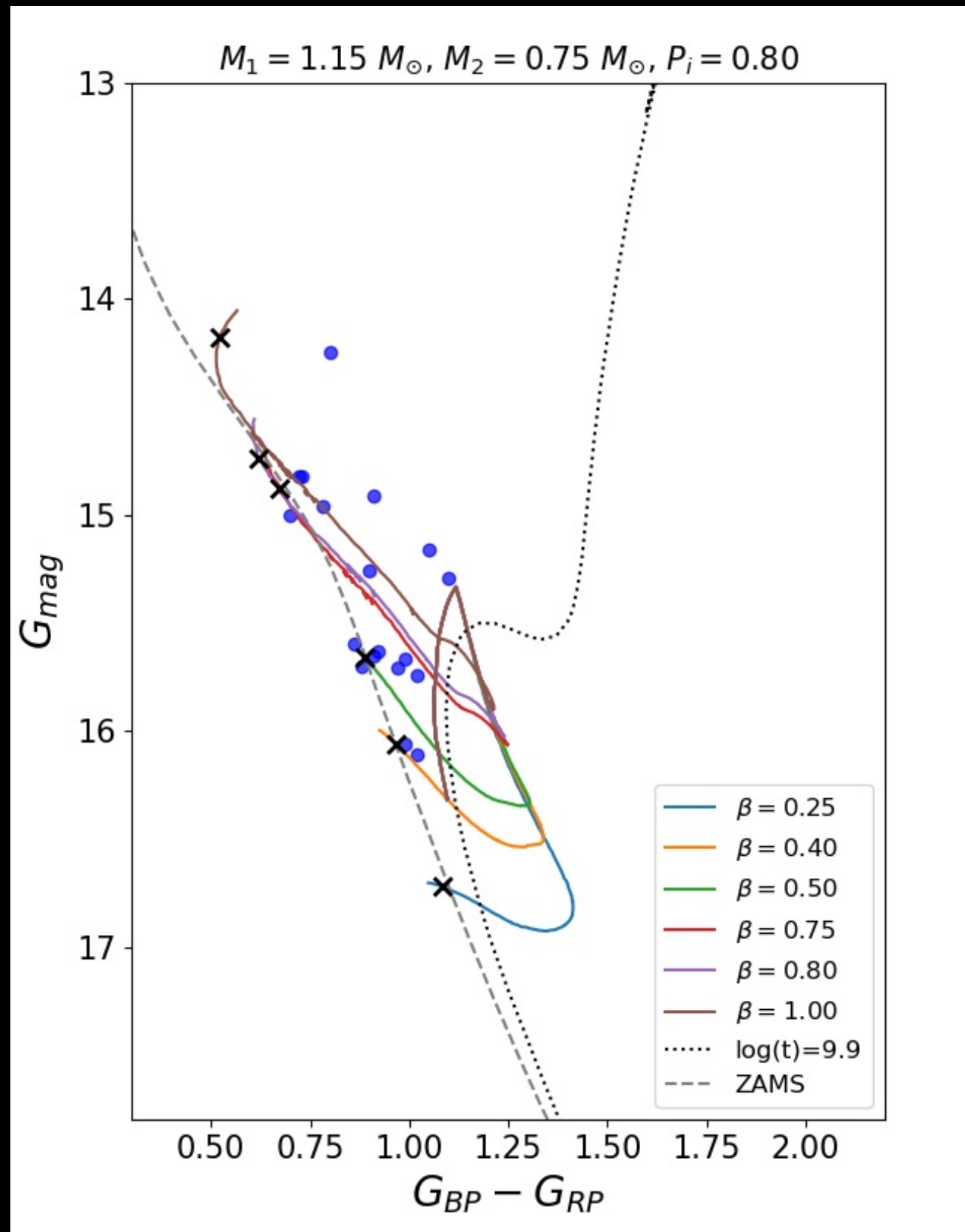
What our simulations show?



Binary evolution and BSS formation: Updated version of *Benvenuto & De Vito (2003)*

To Gaia pass-bands: updated version of *Rohrmann (2001)*

Let's go back to the case of Collinder 26 I



Parameter β : Key importance of mass transfer efficiency to reach high Gmag

