Blue stragglers as Tracers of the Dynamical State of Two Clusters in the Small Magellanic Cloud: NGC 339 and NGC 419

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1. Introduction

- **Globular Clusters (GCs):** gravitational interactions will alter the internal structure.
- **Timescale of a cluster dynamical evolution** depends on **internal** (total mass, density, fraction of binaries) and **external** (tidal interaction and local density).
- **Blue Straggler stars (BSSs):** brighter and bluer than the MSTO stars in the CMDs; more massive than the normal stars.
- Small Magellanic Cloud (SMC) is an ideal environment because it is populated by several young ($t < 2\ Gyr$) and intermediate-age clusters ($t = 3 - 7\ Gyr$).
- NGC 339 (6 Gyr); NGC 419 (1.5 Gyr).

2. Data analysis

- **Multi-epoch observations** with HST: 10.75 yr for NGC 339 and 12.67 yr for NGC 419.

- **photometric reduction: followed Bellini et al. (2017b, 2018).**

➢ Performed a single-pass photometry to measure bright stars in each exposure.

➢ Performed a multi-pass photometry with *KS2* program after correcting the instrumental positions for geometric distortions with the solutions provided by Anderson & King (2006).

➢ Calibrated instrumental magnitudes into *VEGAMAG* systems.

2. Data analysis

- Proper motions (PMs) measurements.

➢ Single-exposure star positions are transformed onto an epoch-matched reference frame (based on the Gaia DR2).

➢ At first iteration, PMs are assumed to be zero, and cluster members are defined based on their positions on a CMD.

➢ For each star, the transformed positions across different epochs are fitted with **linear least-squares**. The **slopes of these fits** are direct estimates of the stars PMs.

➢ Convergence is reached when the difference between the master-frame positions from one step to the next is negligible.

- PMs are corrected for any remaining **spatially variable** and **color-dependent systematic effects.**

3. Cluster Membership

- Proper motion: to remove the contamination from field stars (SMC+MW).

- Uncertainties are smaller: $m_{F555W} < 22.7$ in NGC 339; $m_{F555W} < 22.3$ in NGC 419.

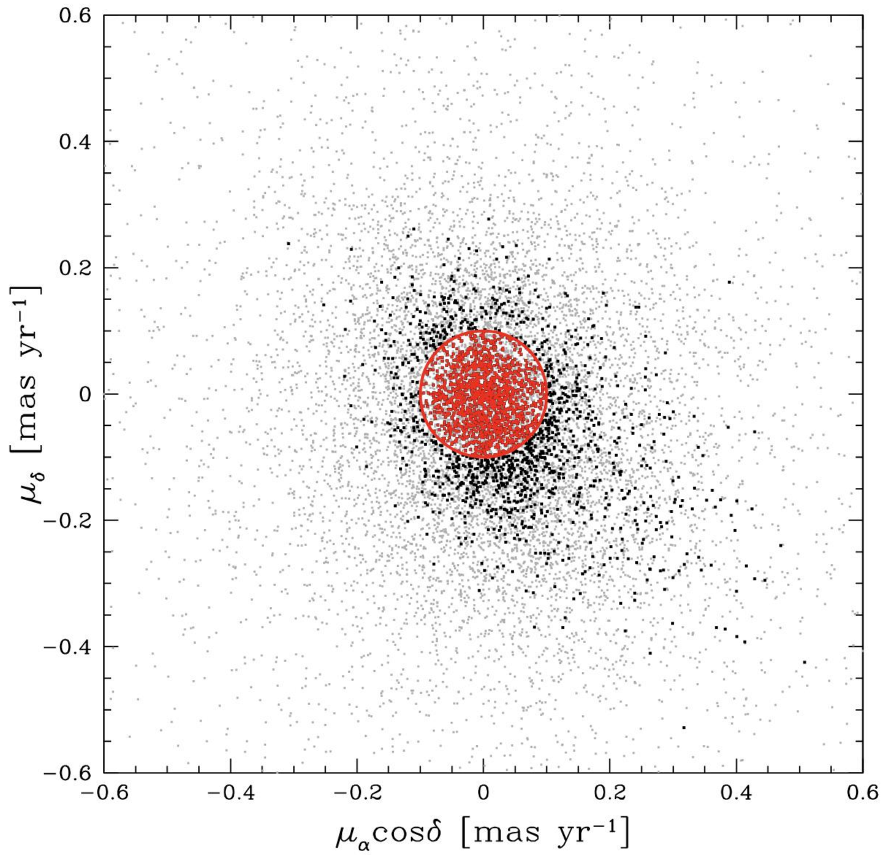

Fig. 1 Vector point diagram of NGC 339.

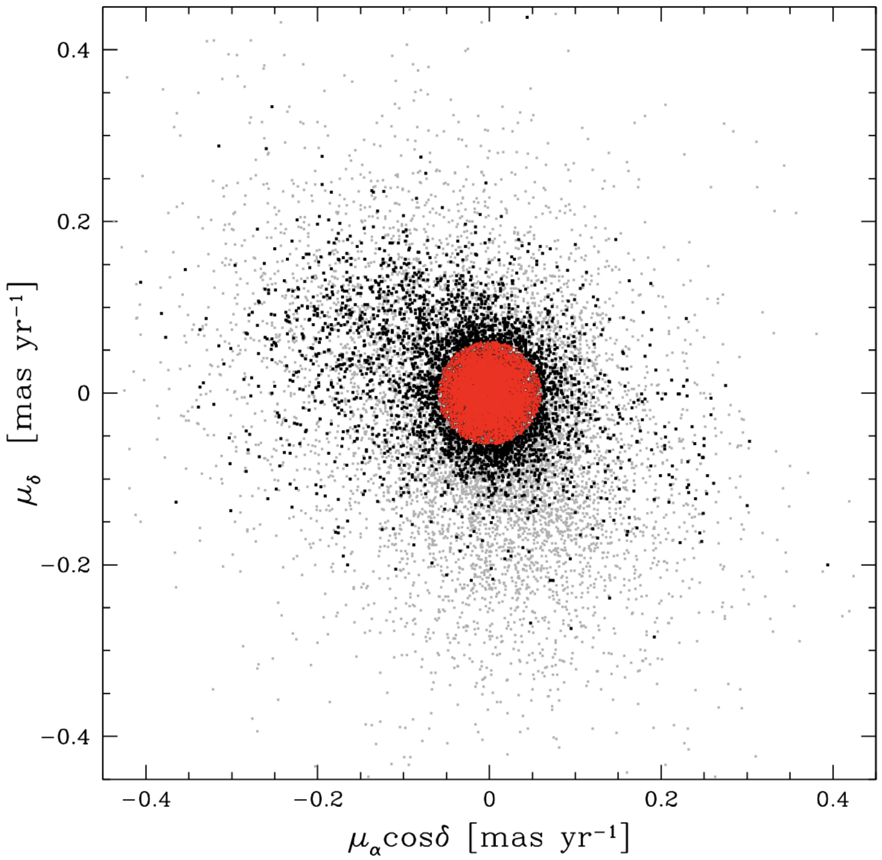

Fig. 2 Vector point diagram of NGC 419.

3. Cluster Membership

- Cluster members: centered around (0, 0) mas yr^{-1} and within a radius **twice the total dispersion** of members (sum in quadrature of two independent terms, $\sigma = \sqrt{\sigma_{disp}^2 + \sigma_{PM}^2}$).

➢ **Isotropy:** dispersion along the two PM components coincides with the dispersion along the line of sight (both σ_{disp} correspond to ~0.01 $mas\ yr^{-1}$).

➢ $\boldsymbol{\sigma_{PM}}$**:** select the average value of the PM error at the faintest magnitude ($\sigma_{PM} = 0.05\ mas\ yr^{-1}$ at $\boldsymbol{m_{F555W} = 22.7}$ for NGC 339; $\sigma_{PM} = 0.03\ mas\ yr^{-1}$ at $\boldsymbol{m_{F555W} = 22.3}$ for NGC 419).

- $\sigma_{339} = 0.05\ mas\ yr^{-1}$; $\sigma_{419} = 0.03\ mas\ yr^{-1}$.

3. Cluster Membership

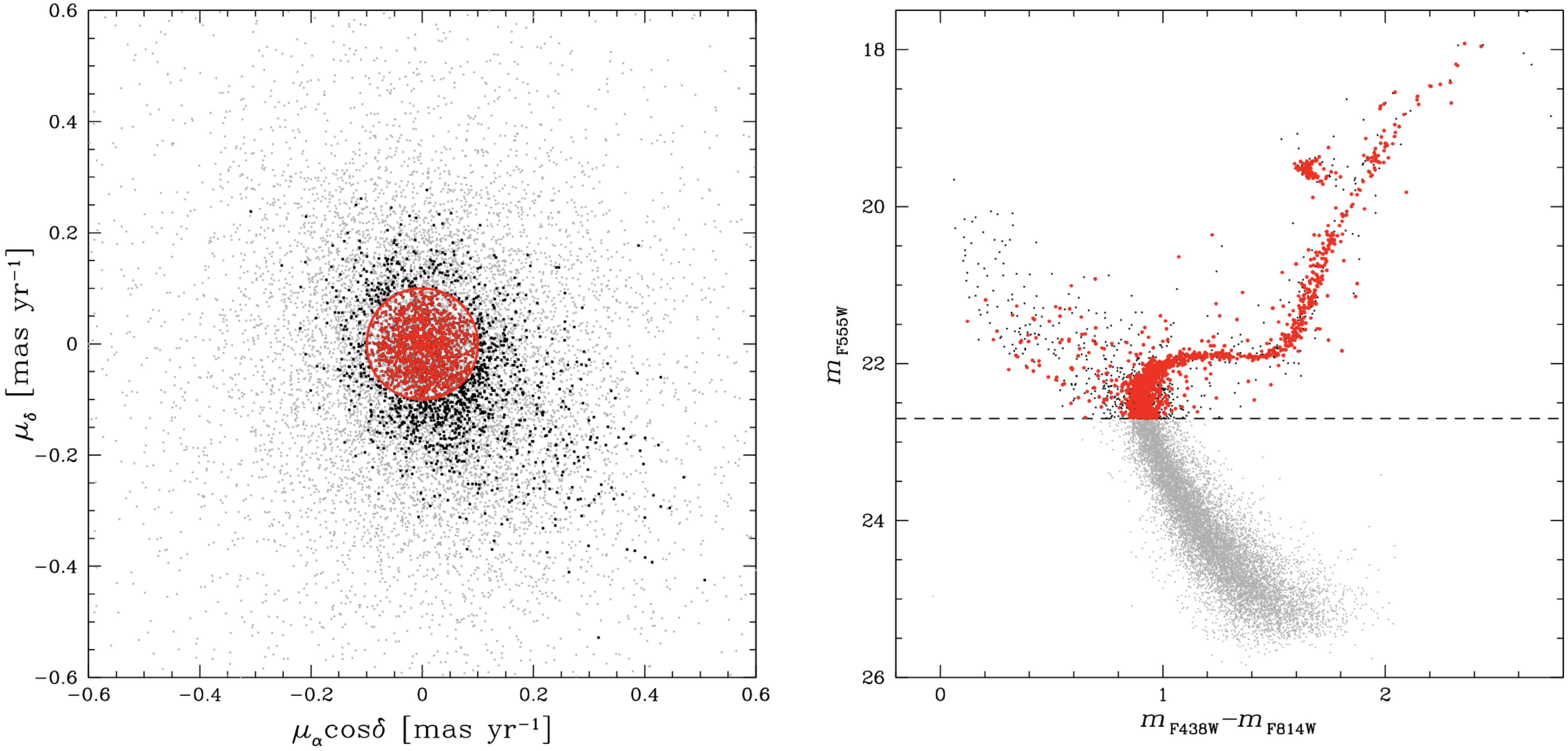

Fig.3 VPD (left) and CMD (right) of NGC 339.

3. Cluster Membership

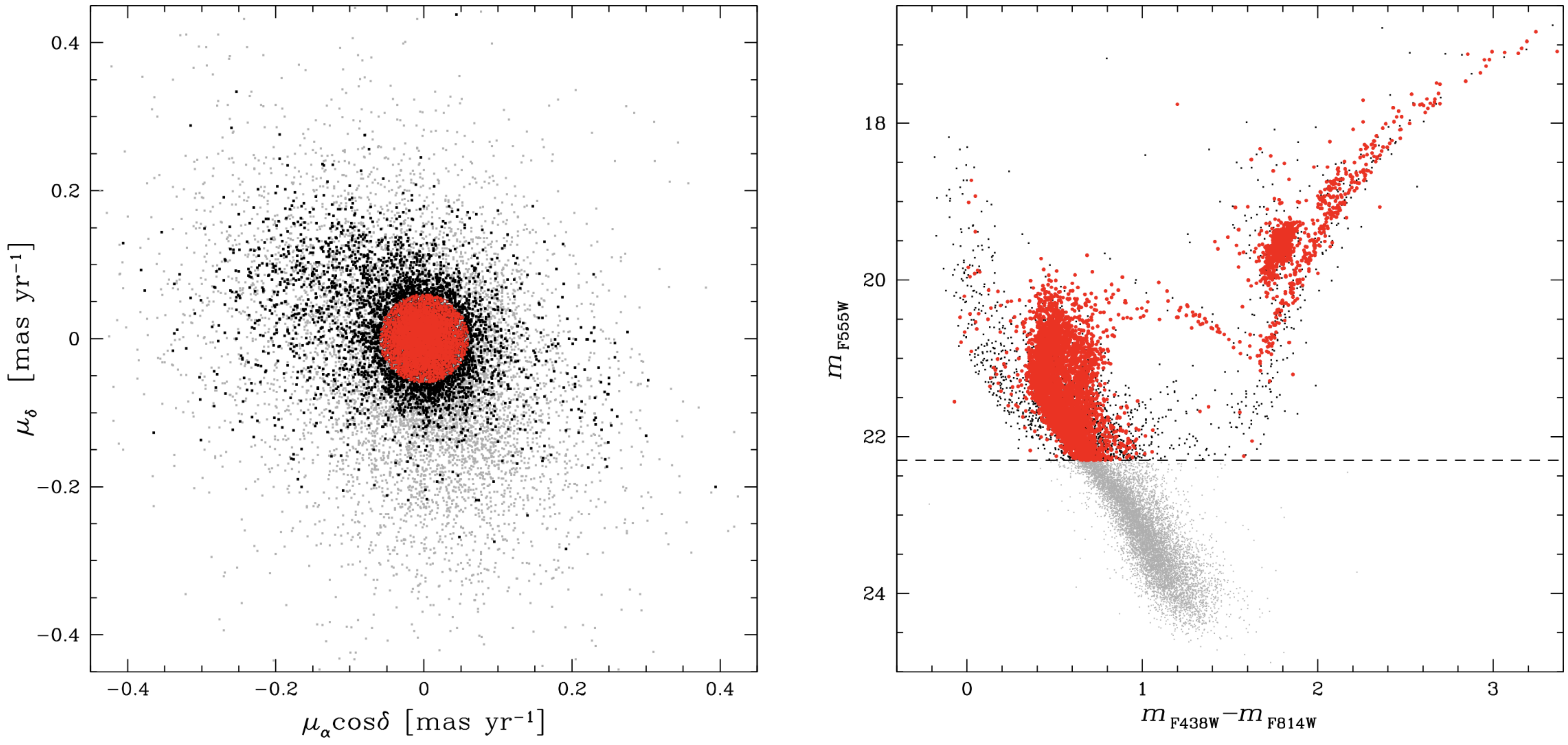

Fig.4 VPD (left) and CMD (right) of NGC 419.

4. Dynamical State of the Clusters

- **The level of segregation of BSSs.**

➢ Calculated A^+_{rh} (defined by Alessandrini et al. 2016) :

$$A^+_{rh}(x) = \int_{x_{min}}^{x} (\phi_{BSS}(x') - \phi_{REF}(x'))dx', \qquad x = \log(r/r_h).$$

➢ The value of A^+_{rh} increases with the level of segregation of the BSSs: tracing the dynamical evolution of the cluster.

4. Dynamical State of the Clusters

- **Selecting BSSs and reference populations (TO stars, RGB stars and RC stars).**

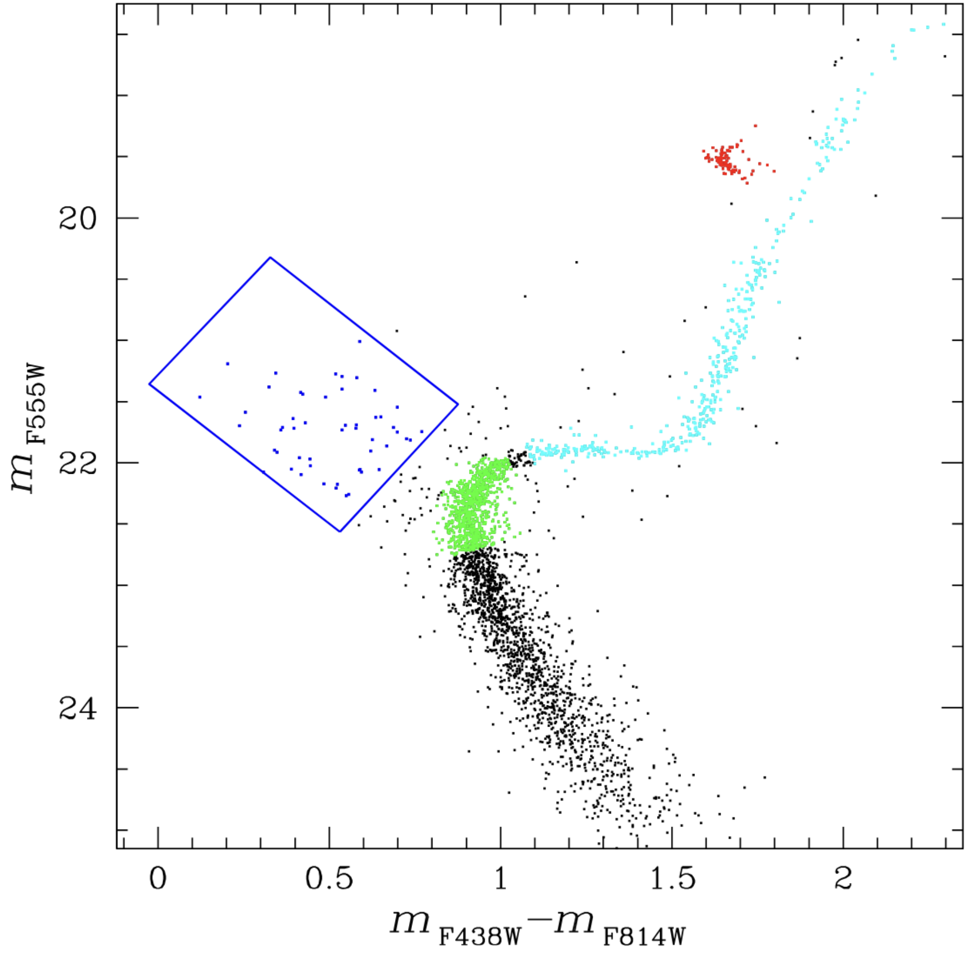

Fig. 5 CMD of NGC 339.

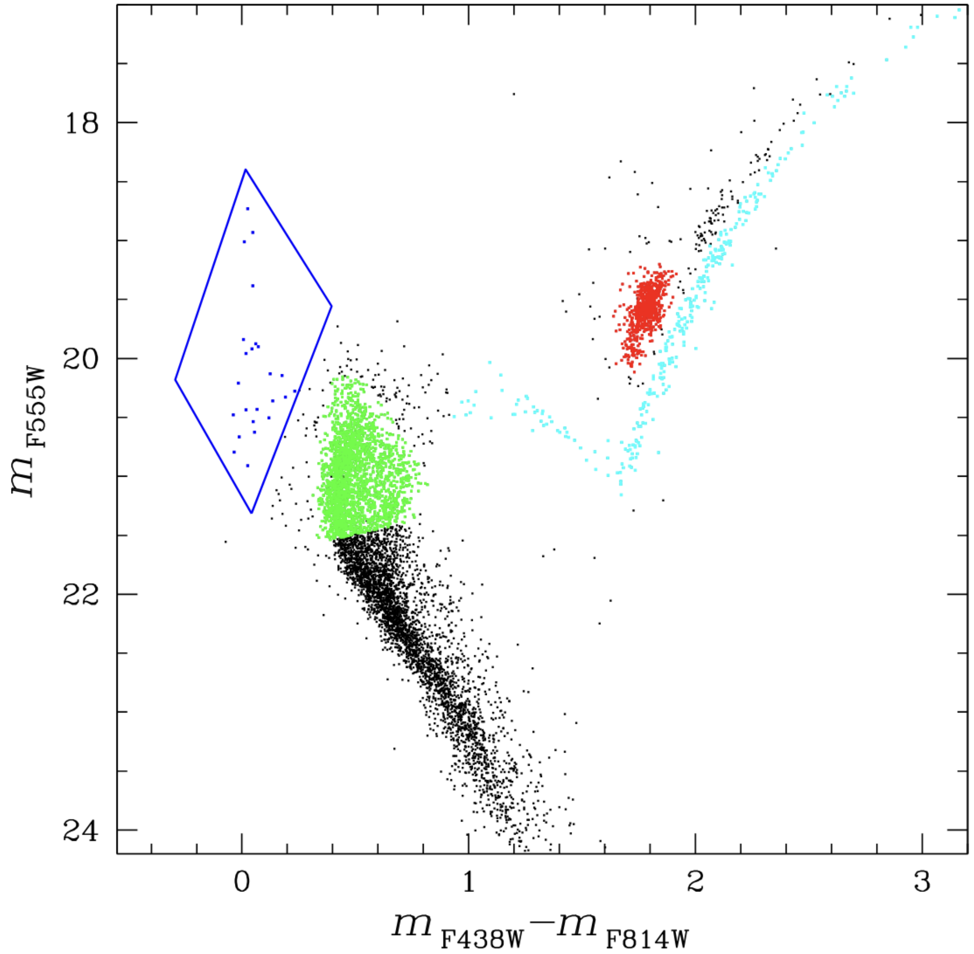

Fig. 6 CMD of NGC 419.

4. Dynamical State of the Clusters

- Computing respective the cumulative radial distribution of NGC 339 and NGC 419.

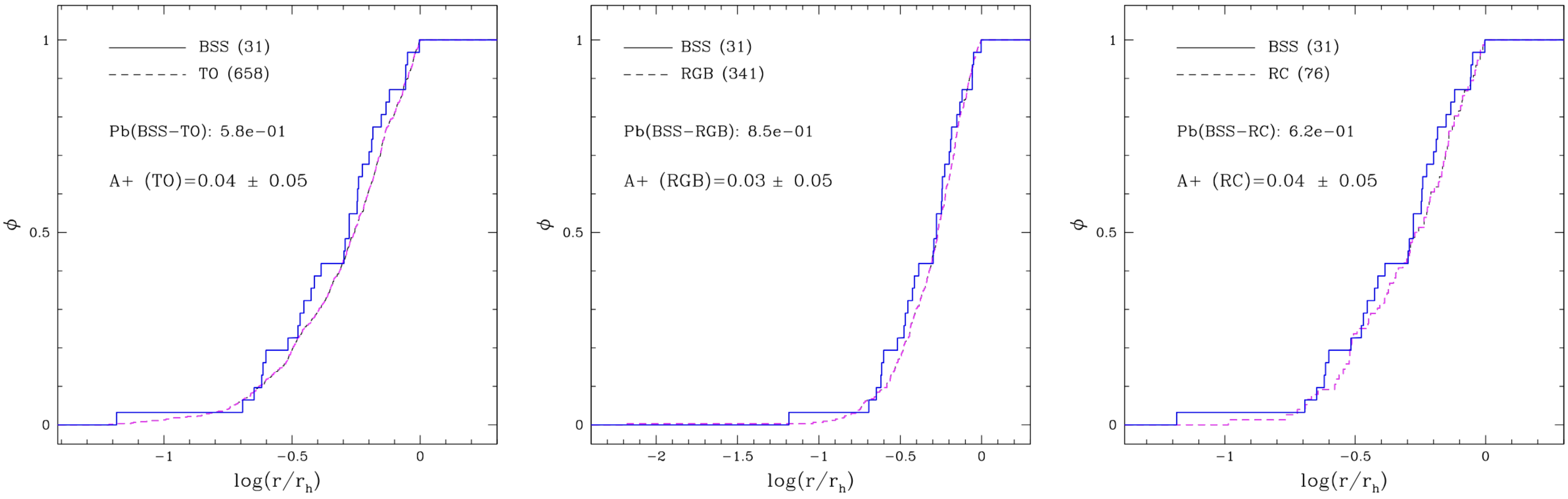

Fig. 7 Cumulative radial distribution of BSSs and reference stars in **NGC 339**.

4. Dynamical State of the Clusters

- Computing respective the cumulative radial distribution of NGC 339 and NGC 419.

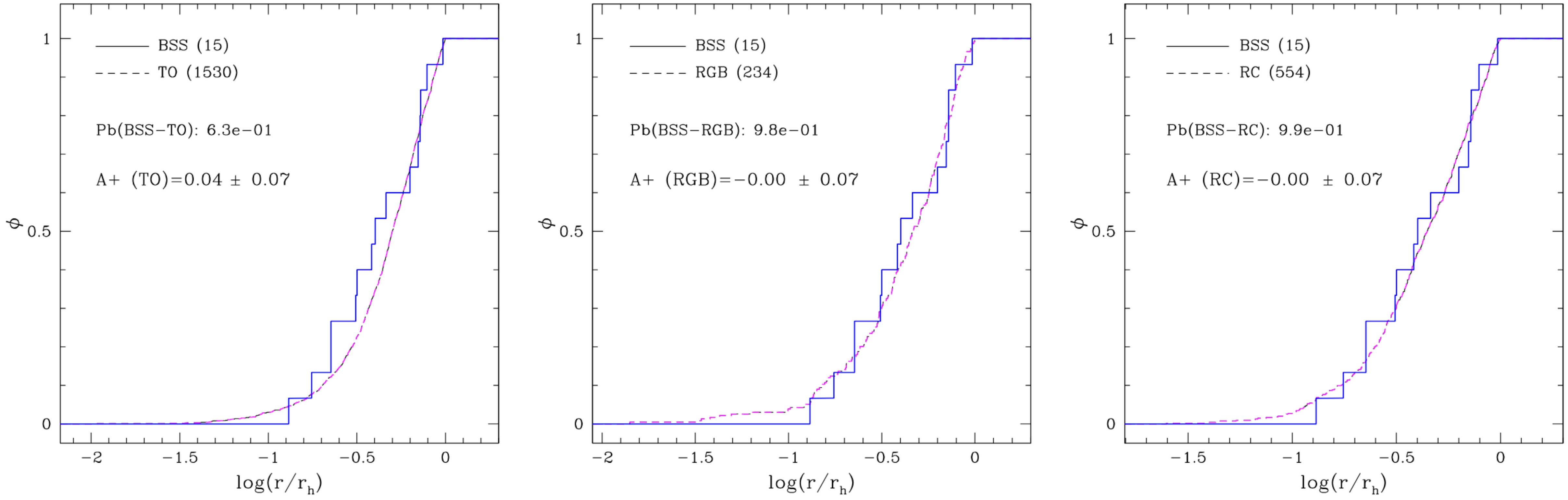

Fig. 8 Cumulative radial distribution of BSSs and reference stars in **NGC 419**.

4. Dynamical State of the Clusters

- **Value of A_{rh}^{+} that is consistent with zero within 1σ for each cluster.**

For NGC 339:

ref	$A_{\rm rh}^{+}$	ε_{A^+}	$N_{\rm BSS}$	$N_{\rm ref}$
TO	0.04	0.05	31	658
RGB	0.03	0.05	31	341
RC	0.04	0.05	31	76

For NGC 419:

ref	$A_{\rm rh}^{+}$	ε_{A^+}	$N_{\rm BSS}$	$N_{\rm ref}$
TO	0.04	0.07	15	1530
RGB	0.00	0.07	15	234
RC	0.00	0.07	15	554

- BSSs of these two clusters are **not centrally segregated**.
- As expected for two **dynamically young** clusters.

4. Dynamical State of the Clusters

- Studied the relation between the measured values of A^{+}_{rh} and the dynamical/structural properties of the systems.

➢ **A correlation** (Ferraro et al. 2018): between A^{+}_{rh} and N_{relax}.

$$\boldsymbol{N_{relax} = t/t_{rc}}$$

t: cluster age.

t_{rc}: central relaxation time of the system

- **For NGC 339:** t_{rc} = 4.16 Gyr , t = 6 Gyr and N_{relax} = 1.44.
- **For NGC 419:** t_{rc} = 1.56 Gyr , t = 1.5 Gyr and N_{relax} = 0.962.

4. Dynamical State of the Clusters

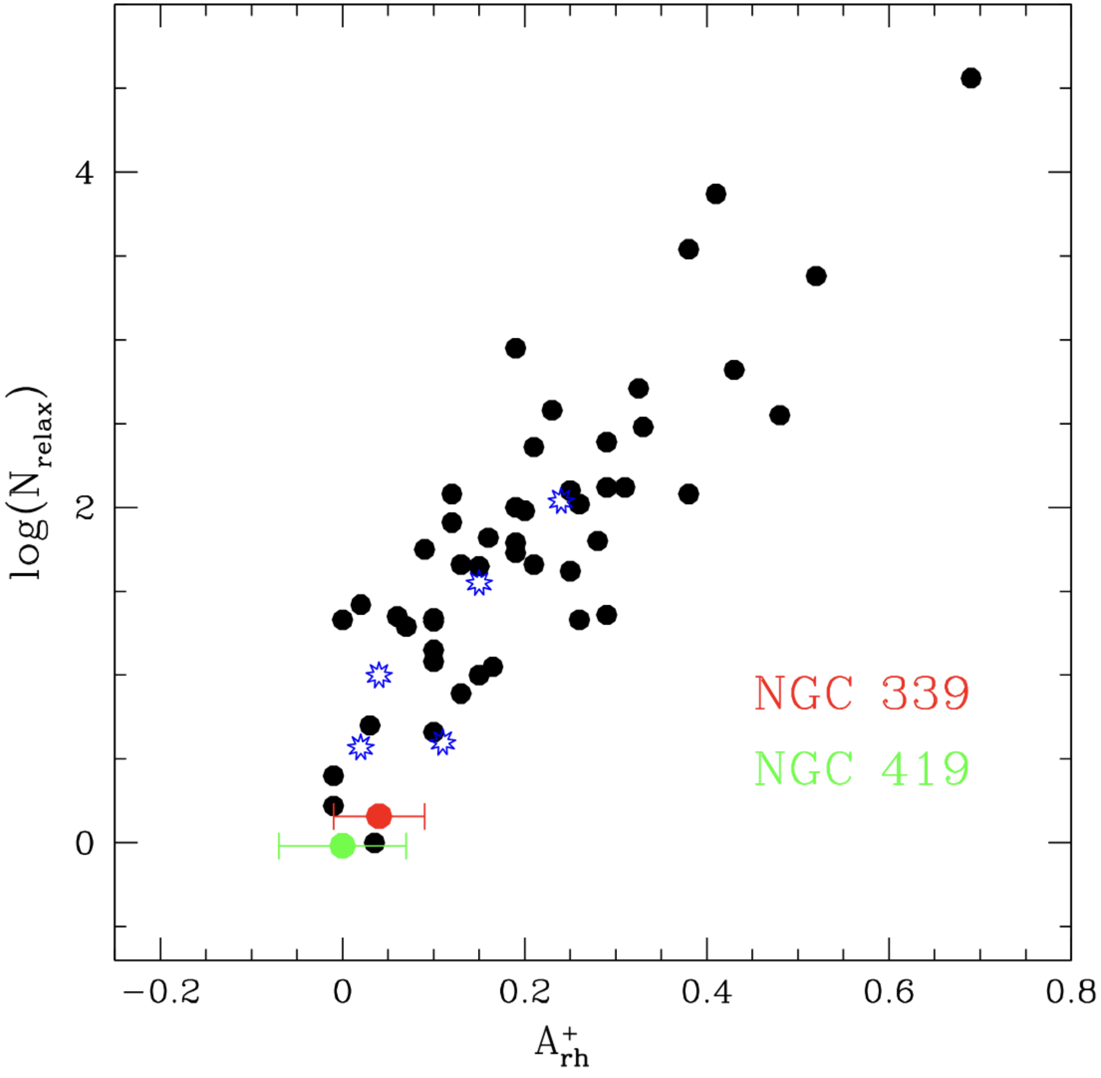

Fig 9. Relation between N_{relax} and the A^{+}_{rh} for Galactic clusters (black), for LMC clusters (blue).

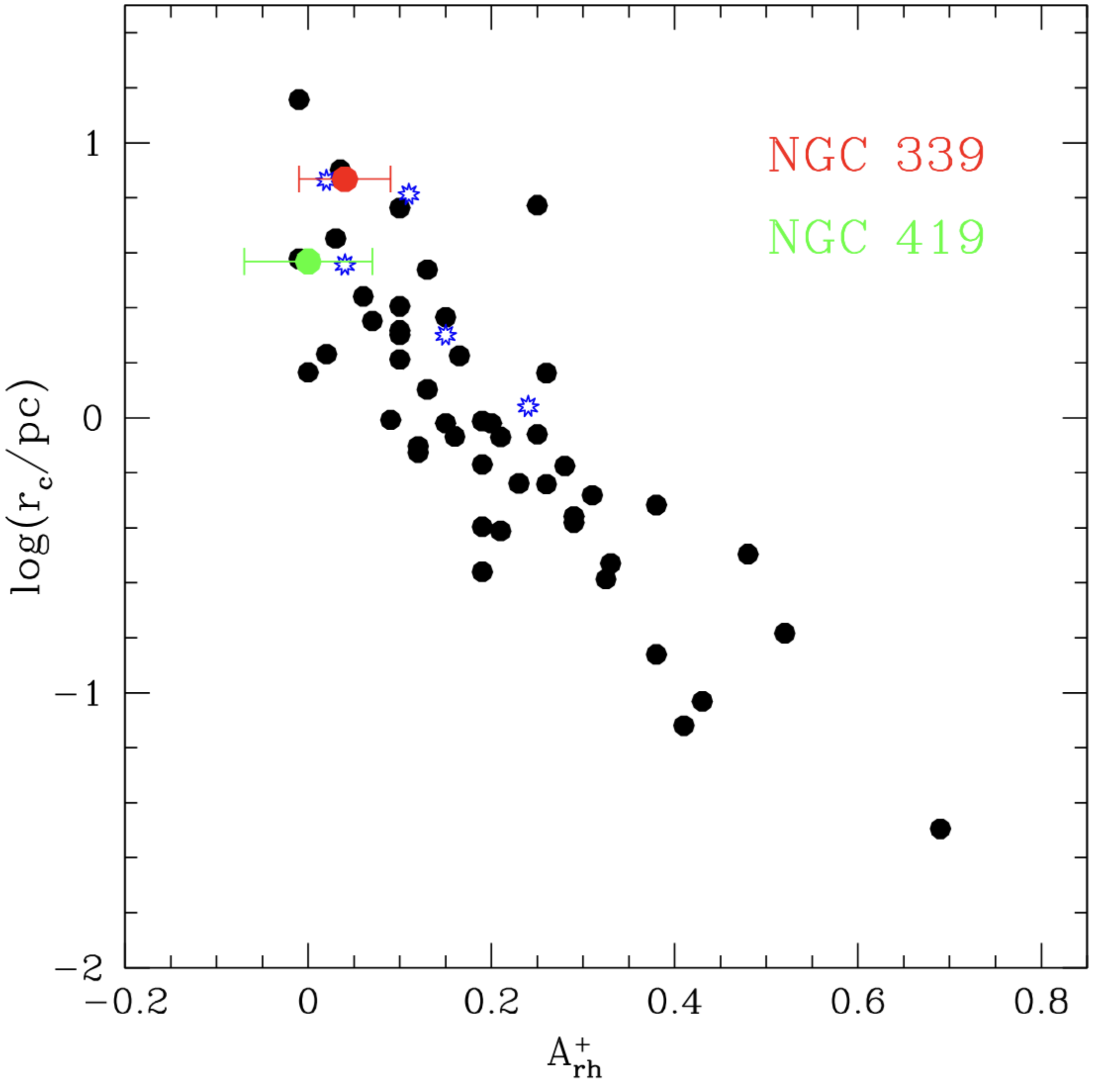

Fig 10. Relation between r_c and the A^{+}_{rh} for Galactic clusters (black), for LMC clusters (blue).

5. Conclusions

a) Values of A_{rh}^{+} consistent with zero for both clusters, indicative of an absence of segregation.

b) Comparing these results with the dynamical properties of the systems (central relaxation times and core radii), they determined that both clusters are dynamically young.

c) A_{rh}^{+} parameter is an efficient hand of the "dynamical clock" even for young and intermediate-age clusters.

Thank you!