Dynamical Evolution of Four Old Galactic Open Clusters traced by their constituent stars with *Gaia* DR3

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2024 - 9 - 23

1.Introduction

- In an old stellar system, internal dynamics is the dominant mechanism for mass loss (Meylan & Heggie 1997). A stellar system is led towards energy equipartition through the effect of short- and long-range gravitational interactions called two-body relaxation, eventually resulting in a steady segregation of cluster members based on their masses (Bianchini et al. 2016).

- These processes significantly affect commonly observed cluster populations, such as the main sequence stars (MSs), main sequence turnoff stars (MSTOs) and red giant branch stars (RGBs), and particulary affect the evolution of binary stars – leading to the formation of exotic cluster populations (Knigge et al. 2009) such as blue straggler stars (BSS; Stryker 1993; Bailyn 1995).

- Among the studies focusing on OCs, four OCs – Berkeley 39, Collinder 261, NGC 6819, and NGC 7789 – exhibit various dynamical stages in comparison to BSS with RGBs or MS stars. These OCs have ages ranging from 1.6 to 6 Gyrs and contain BSS $\geq$ 11.

2.DATA AND MEMBERSHIP IDENTIFICATION

Membership Determination

We determine members of the four OCs using the ML-MOC algorithm (Agarwal et al. 2021) on Gaia DR3 data. ML-MOC uses a combination of two unsupervised machine-learning algorithms the K-Nearest Neighbours algorithm and Gaussian Mixture Models – on Gaia parallaxes and proper motions to determine membership of OCs.

To use ML-MOC, generally a search radius of around 1.5 times the tidal radius of the cluster is considered. We download Gaia DR3 data for a search radius of 45′ for Berkeley 39, 30′ for both Collinder 261 & NGC 6819, and 60′ for NGC 7789 from the coordinates of cluster centers.

Cluster	RA (deg)	DEC (deg)	Age (Gyr)	[Fe/H] (dex)	d (kpc)	R (arcmin)	r_c (arcmin)	N_{BSS}	N_{SGB_RGB}	N_{MSTO}	N_{Total}
Berkeley 39	116.6965	−4.6689	6	−0.15	4.2	14	2.2	19	88	149	857
Collinder 261	189.5224	−68.3798	6	−0.03	2.8	20	2.8	36	257	350	2134
NGC 6819	295.3285	40.1875	2.7	0	2.5	18	2.6	13	59	267	1350
NGC 7789	359.3339	56.7233	1.6	0.04	1.9	35	6.7	11	159	430	2838

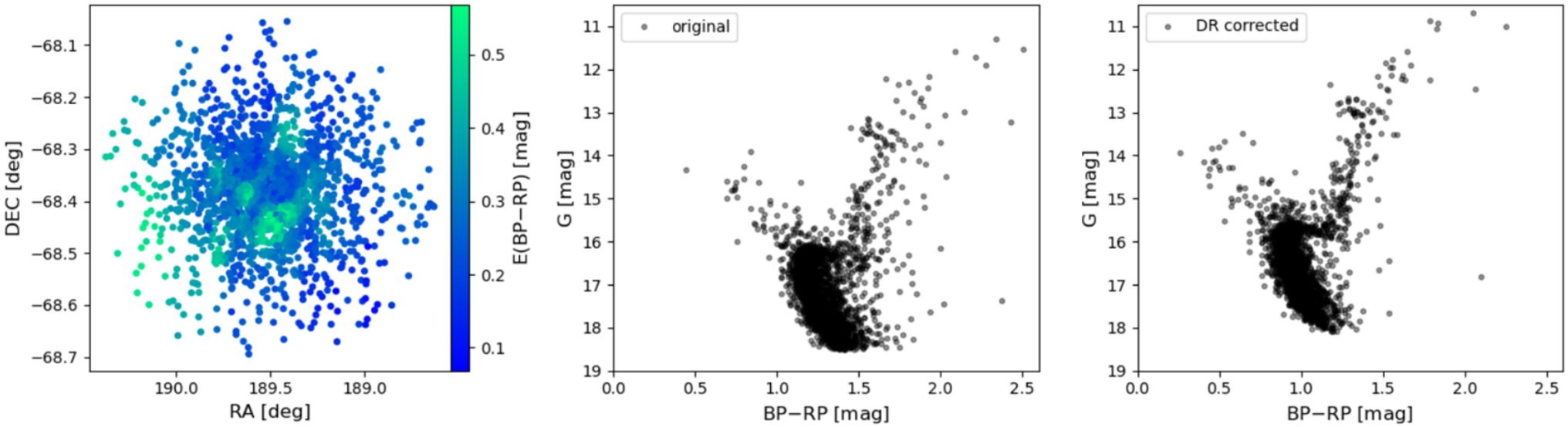
2.DATA AND MEMBERSHIP IDENTIFICATION

Differential Reddening Correction

First, we select the reddening vector, i.e. RG = AG/E(BP−RP), a quantity corresponding to the direction of the distortion of the red clump on the CMDs. We select RG = 0.789 from Rao et al. (2023), which is best fitted to red clump stars across all four OCs.

Next, we create a grid over the MS stars with the top border consisting of the reddening vector shifted to the MSTO point of a cluster and the bottom border containing the maximum G magnitude.

We compute the mean color (< BP − RP >) and mean magnitude (< G >) of those which fall within the MS grid. The number 25 is selected after a few trials to ensure that each cluster member has a sufficient number of neighboring sources within the main sequence grid.

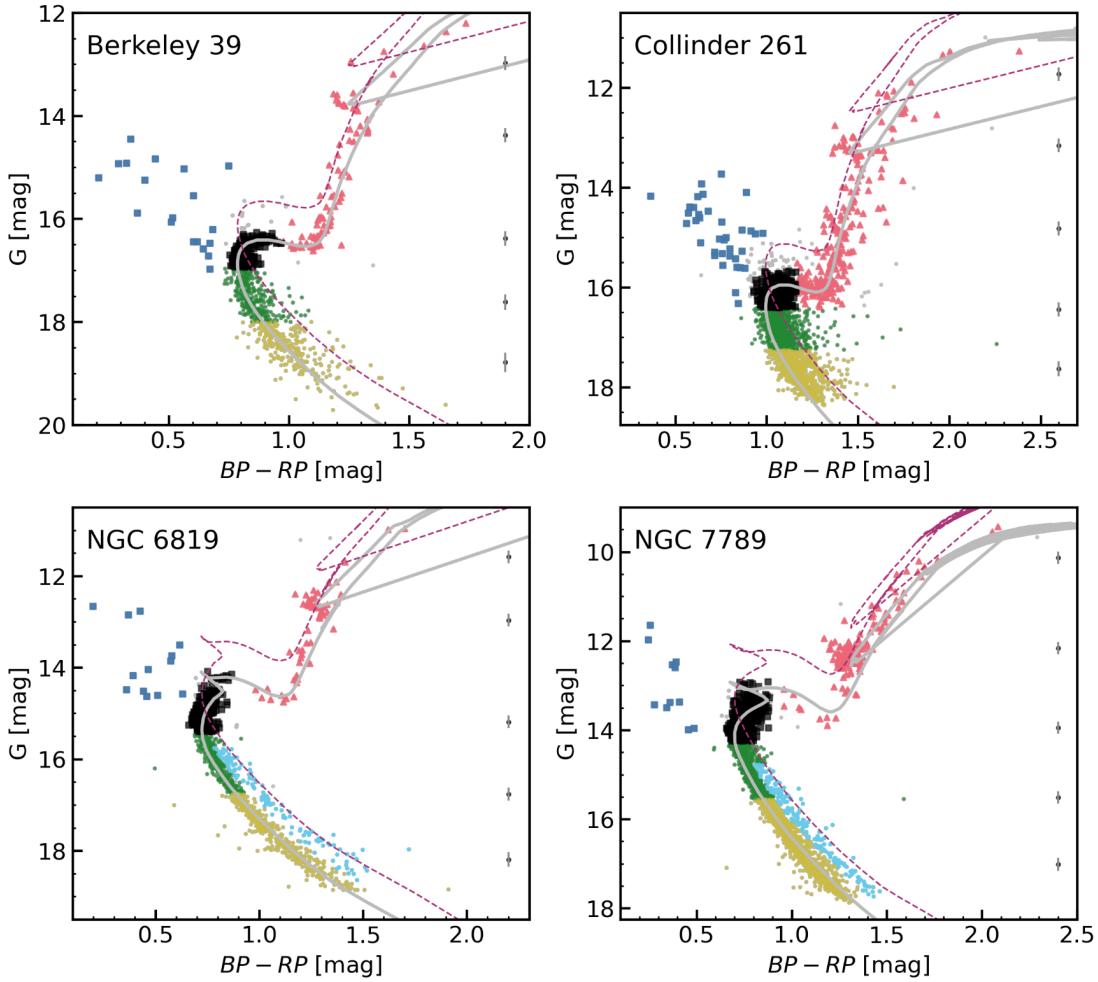


2.DATA AND MEMBERSHIP IDENTIFICATION

Selection of Cluster Populations

To explore the dynamical evolution of the four OCs, we primarily use five different populations in each of the clusters, namely the upper and lower MS, MSTOs, SGBs and RGBs, and BSS.

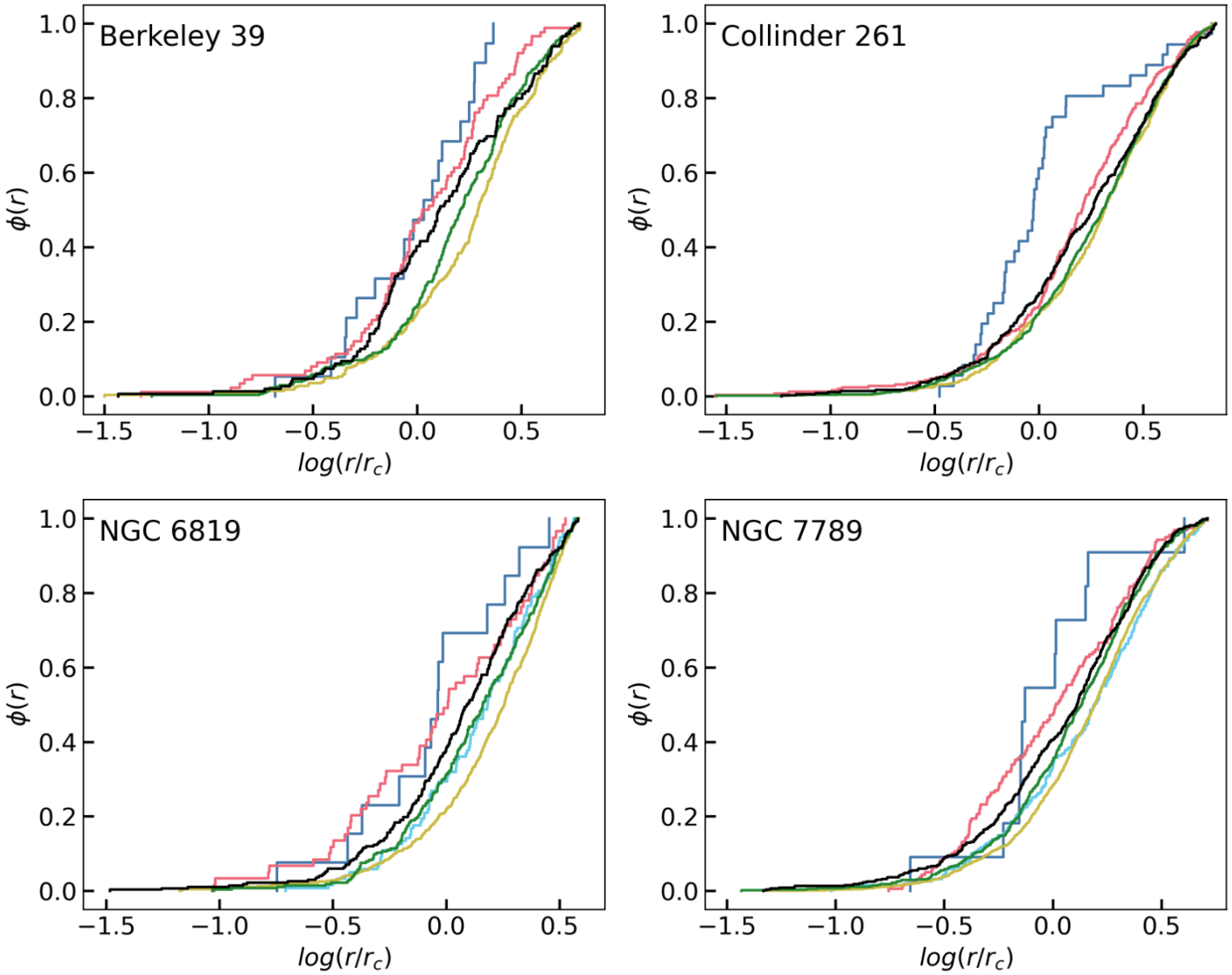
CMDs with fitted single-star PARSEC isochrones (grey solid line) and equal-mass binary isochrones (magneta dashed line). The BSS are shown as blue squares, the RGBs are shown as red triangles, the MSTOs are shown as black squares, and the upper and lower main sequence stars are shown as green and yellow dots. NGC 6819 and NGC 7789 have an equal mass binary track above the MS, and the selected binaries are shown as light blue dots.



3.INVESTIGATING MASS SEGREGATION

Cumulative Radial Distribution

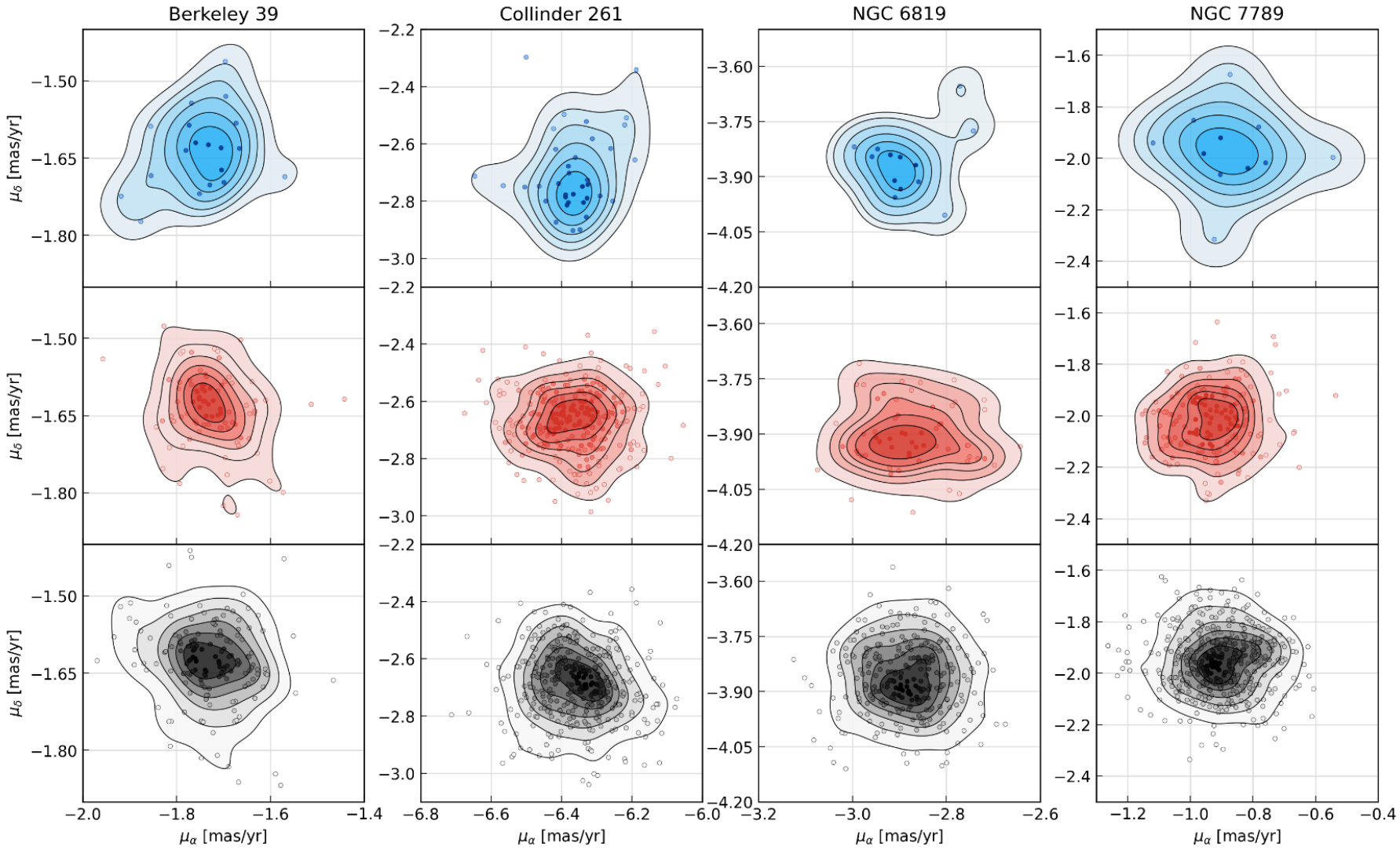
CRDs of the four clusters plotted as a fraction of the sources in each population against the distance from the cluster center normalized by the core radius. The BSS are shown in deep blue, RGBs in red, MSTOs in black, UMS in green, and LMS in yellow. For NGC 6819 and NGC 7789, the additional binary populations are shown in light blue.



3.INVESTIGATING MASS SEGREGATION

Proper Motion Distribution

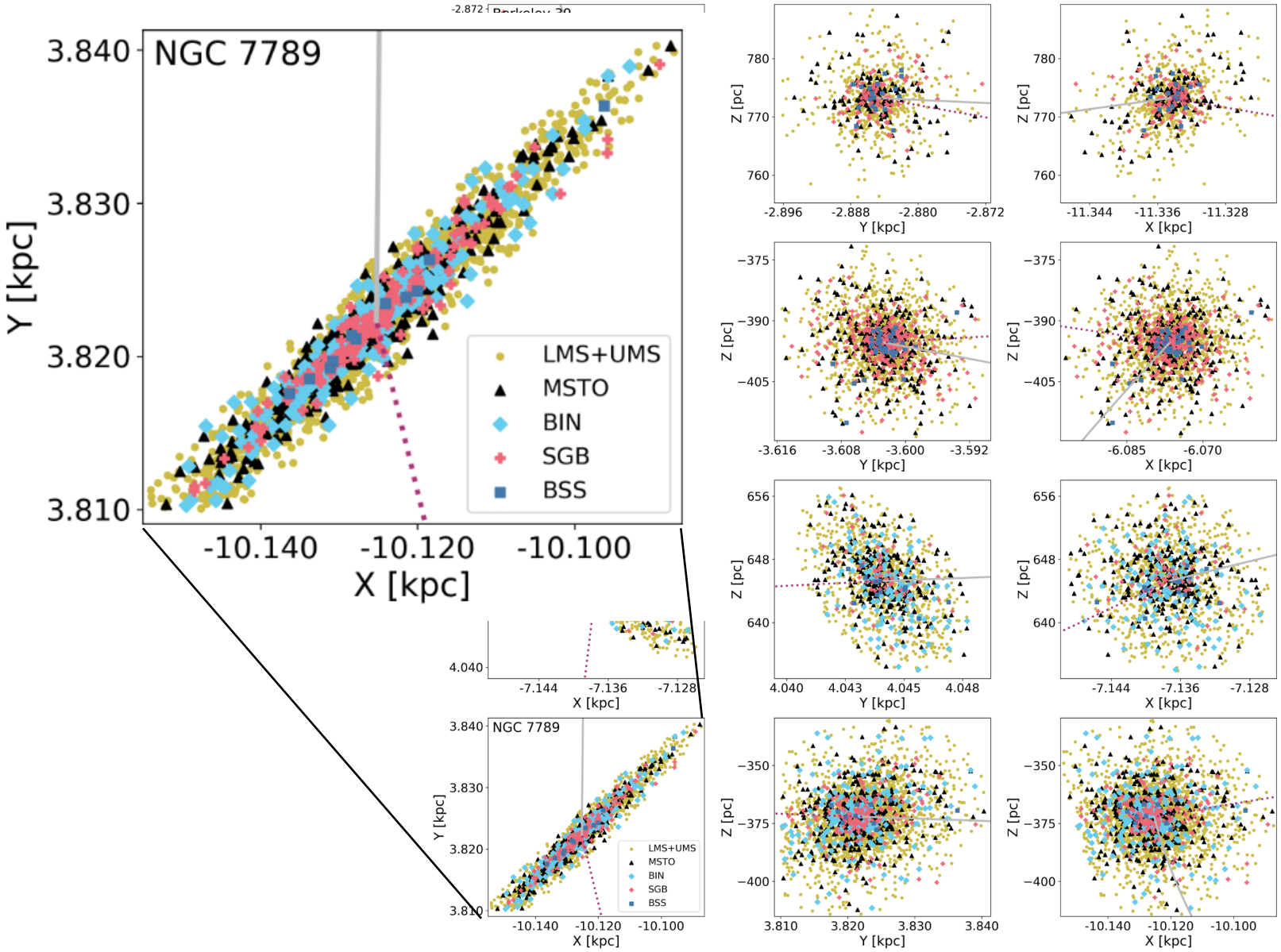
Proper motion distribution with overlaid density contour plots of the four clusters. The BSS are shown in blue, RGBs in red and MSTOs in black. The populations are arranged in decreasing order of mass from top to bottom.



3.INVESTIGATING MASS SEGREGATION

Spatial and Kinematic distribution in Galactocentric coordinates

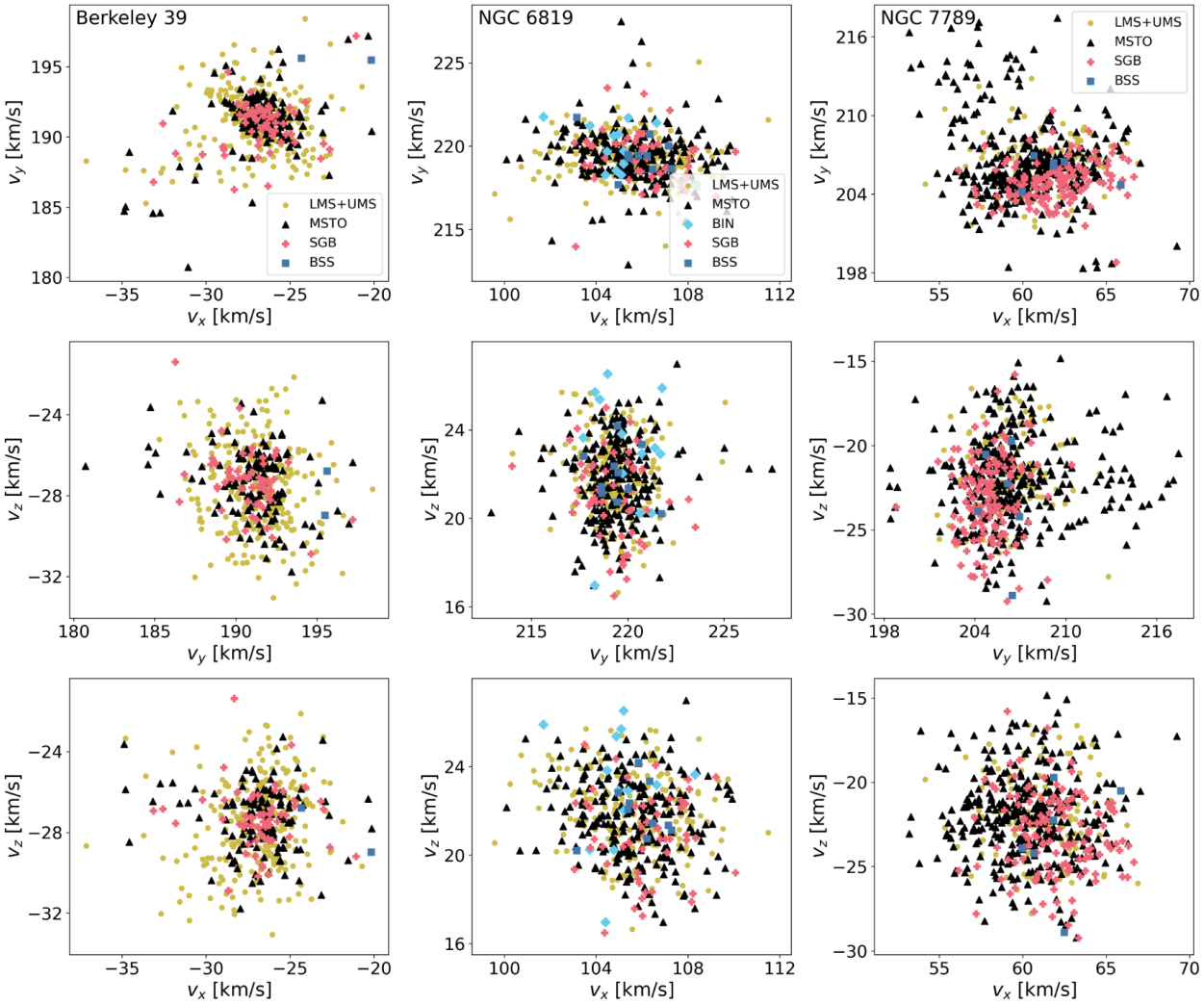
Positions of sources in Berkeley 39, Collinder 261, NGC 6819 and NGC 7789 in galactocentric coordinates, arranged row-wise. Different populations are represented by colored dots as per the inset legend, while the black dotted line represents the line-of-sight to the cluster and the solid line represents the cluster orbital direction.



3.INVESTIGATING MASS SEGREGATION

Spatial and Kinematic distribution in Galactocentric coordinates

Velocities of the sources in Berkeley 39, NGC 6819, NGC 7789 in galactocentric coordinates, arranged columnwise. Different populations are represented by colored dots as per the inset legend.



4.DISCUSSION

- **Berkeley 39** and **NGC 6819**: These clusters show moderate signs of mass segregation, meaning that heavier stars are more concentrated towards the center compared to lighter stars.

- **Collinder 261**: This cluster exhibits a high degree of central segregation of Blue Straggler Stars (BSS), which is unusual and might be related to its formation mechanisms or the initial conditions of the cluster.

- **NGC 7789**: This is the youngest cluster in the study and shows almost no signs of mass segregation. It is classified as a dynamically young cluster.

- General Observations: The study found that none of the clusters are fully evolved in terms of mass segregation, which is expected as open clusters typically disintegrate before reaching such a state due to their location in the galactic plane where they experience more interactions.

Thank you!