Understanding disk morphology using Open Star Clusters

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Introduction

Open Star Clusters (OCs) are physically related group of stars that are bound together by mutual gravitational attraction. Since the member stars are formed from the same parent gas cloud, they have roughly the same age, distance and chemical composition. OCs are found to have a varied range of ages and are distributed throughout the Galaxy thus making them useful tracers to study the structure and dynamical evolution of the Milky Way.

Data

- Compiled a catalog of 6133 OCs from the literature and collected available information about their positions, parallax, proper motions, distance, age, and radial velocities.
- Of these, distance information is available for 4378 OCs while 2483 OCs have 3D kinematics

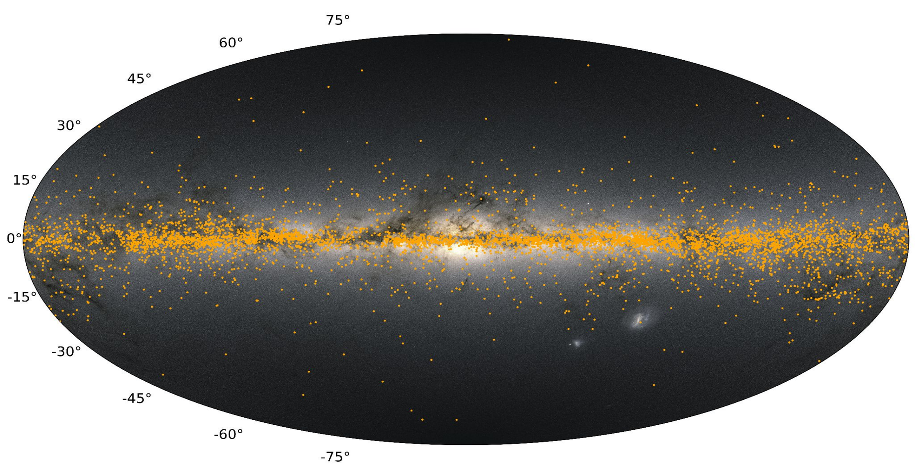

Figure 1: Aitoff projection of 6133 OCs

Spatial Distribution

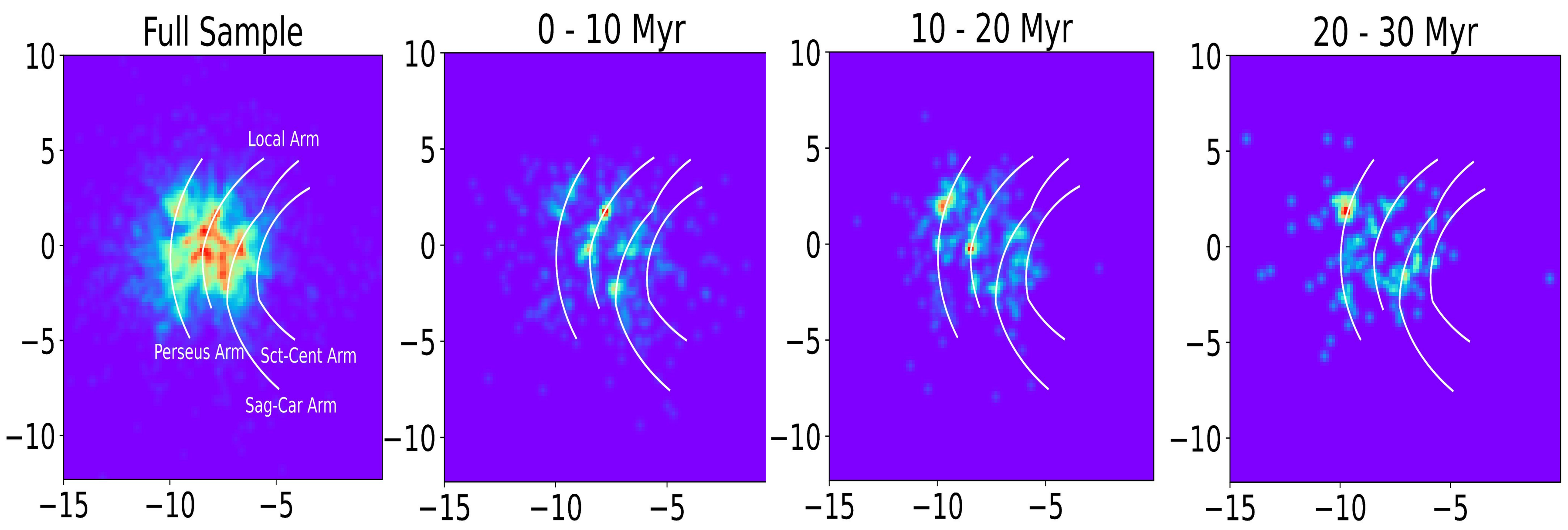

Figure 2: X_{GC} - Y_{GC} distribution of OCs belonging to different age intervals. From left: Full Sample, 0-10 Myr, 10-20 Myr, 20-30 Myr. Spiral Arms taken from *Hou 2021*

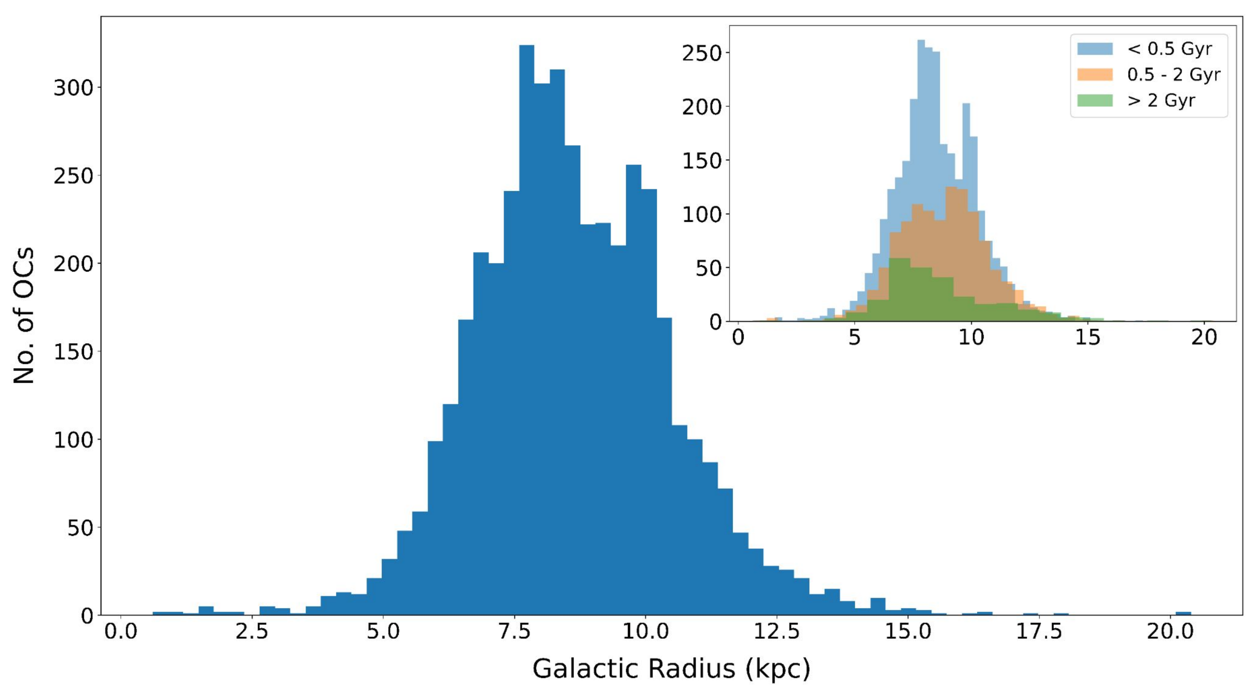

Figure 3: Number distribution of 4378 OCs as a function of the Galactic Radius (projected galactocentric distance). The inset shows the same distribution for different age intervals viz, < 0.5 Gyr, 0.5 - 2 Gyr, and > 2 Gyr. A dip is evident at about 8.5 kpc.

Spiral Arm Pattern Speed

- OC overdensities in the *X-Y* plane were assigned to spiral arms.
- Backward integration of OCs' orbits was performed to determine their birthplaces where we assume that they correspond to a point on spiral arm time T (age of OC) ago
- Assuming spiral arms traverse a circular path, then for a particular pattern speed Ω

$$\beta\ (\text{present}) = \beta\ (\text{birth}) + \Omega \cdot T$$

where β is the Galactic azimuth and T is the age of OC.
- Optimal value of Ω was estimated by minimising the distance between present-day spiral arms and the integrated present-day locations of points on spiral arms.

Arm	N	Ω_{rot} [$km\ s^{-1}\ kpc^{-1}$] (10 - 80 Myr)	(10 - 30 Myr)	(30 - 80 Myr)
Perseus	93	27.07 ± 1.43	28.79 ± 2.4	26.12 ± 1.82
Local	148	31.21 ± 0.61	31.93 ± 0.49	31.0 ± 1.58
Sag-Car	98	27.3 ± 0.55	27.4 ± 0.39	24.67 ± 4.91
Sct-Cent	32	30.31 ± 1.3	30.51 ± 1.39	27.63 ± 7.76

Table 1: Spiral Arm rotation speeds for different age intervals. N denotes the number of OCs younger than 80 Myr assigned to each arm. The Spiral arms have not accelerated in last 80 Myrs

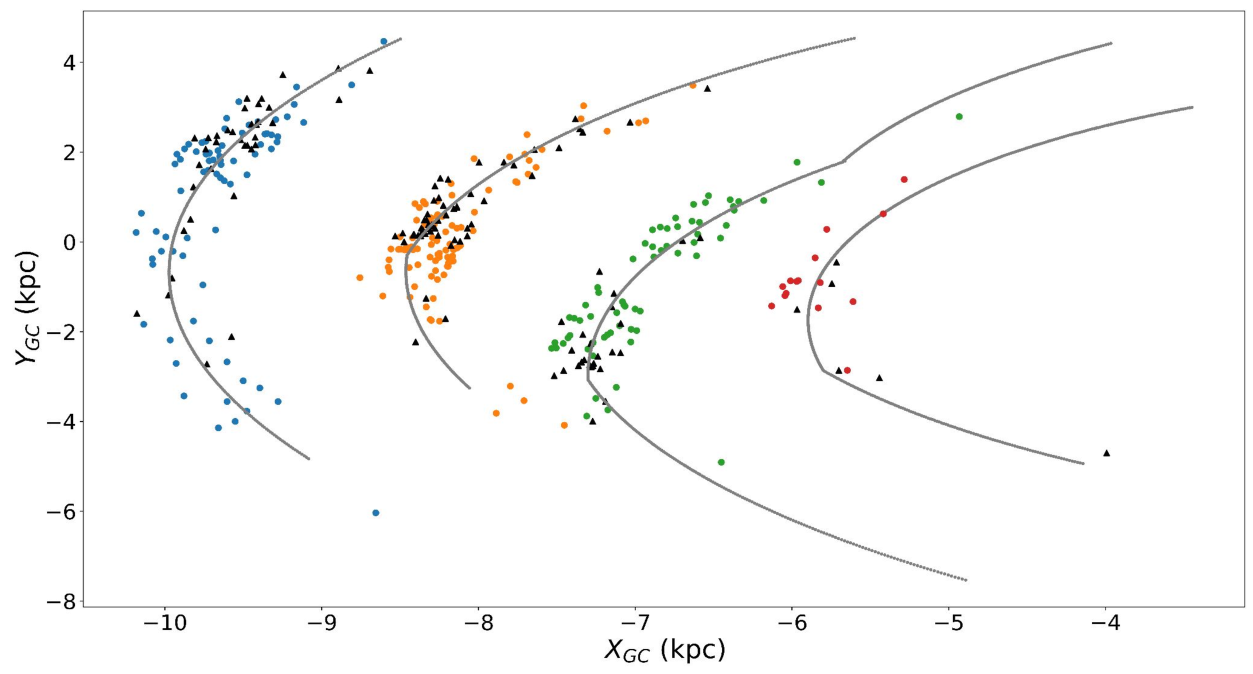

Figure 4: Locations of recovered spiral arms shown by black triangles in the *X-Y* plane using the estimated angular velocities of each arm. Grey curves depict the present day spiral arms while the color points denote the present day locations of assigned OCs.

Corotation Radius

- Corotation radius, R_C is defined as the one where circular velocity of stars in the Milky Way is equal to the circular velocity of spiral arms.

$$v_C(R_C) = \Omega_{rot} \times R_C$$

- R_C is estimated to be **$8.13^{0.29}_{-0.24}$ kpc** which is close to the position of gap.
- A strong resonance develops at this radius which leads to a minimum in gas density thereby resulting in inhibited star formation.

Distribution of OCs perpendicular to Galactic Plane

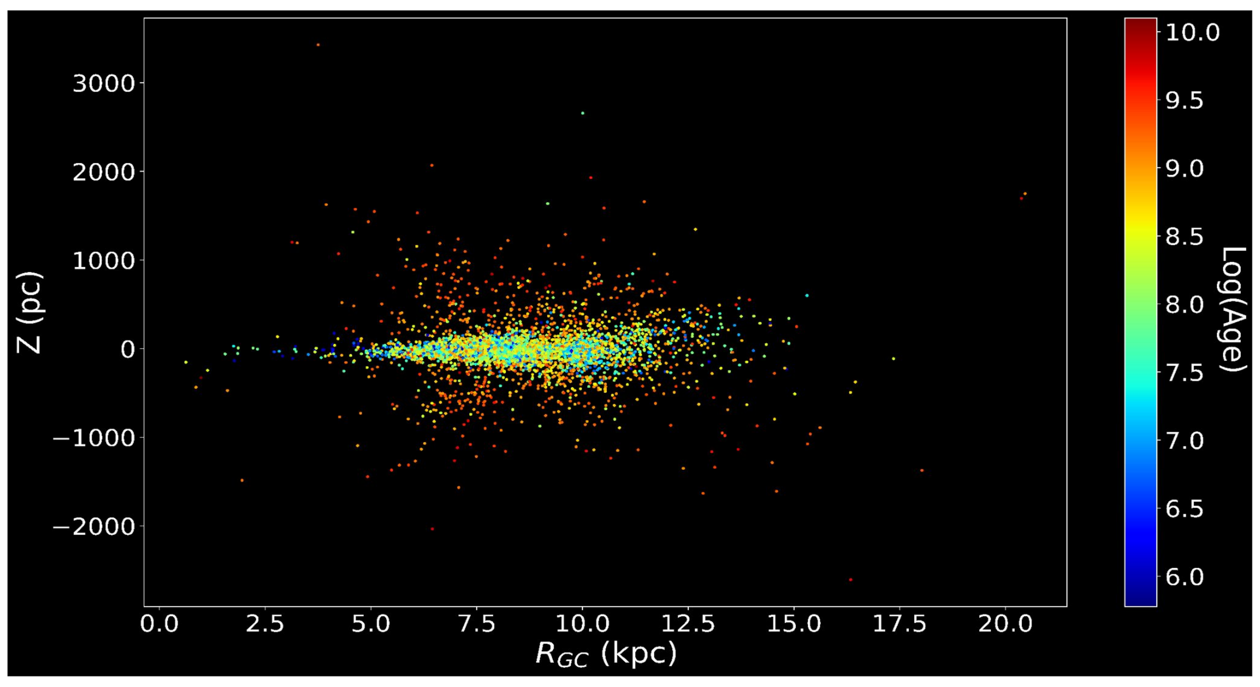

Figure 5: Distribution of OCs in Z as a function of the galactocentric distance R_{GC} where each data point is colored according to the cluster age. Most of the young OCs are confined to the Galactic plane while older OCs occupy regions of high altitudes.

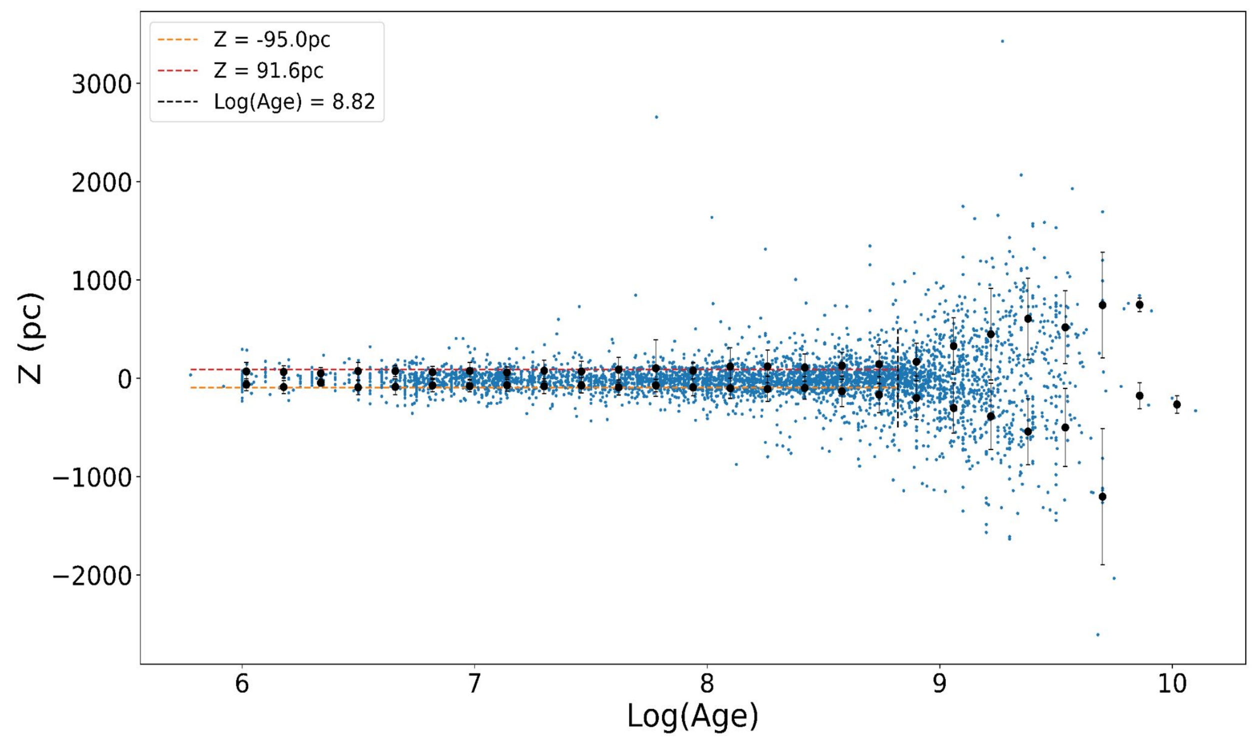

Figure 6: Variation of Z as a function of Log(Age) of OCs denoted by blue points where mean Z for each bin in Log(Age) is shown by black circles. The horizontal dashed lines show the mean z for the two samples of OCs younger than ~ 700 Myr (denoted by a vertical dashed line)

Solar Offset from the Galactic Plane

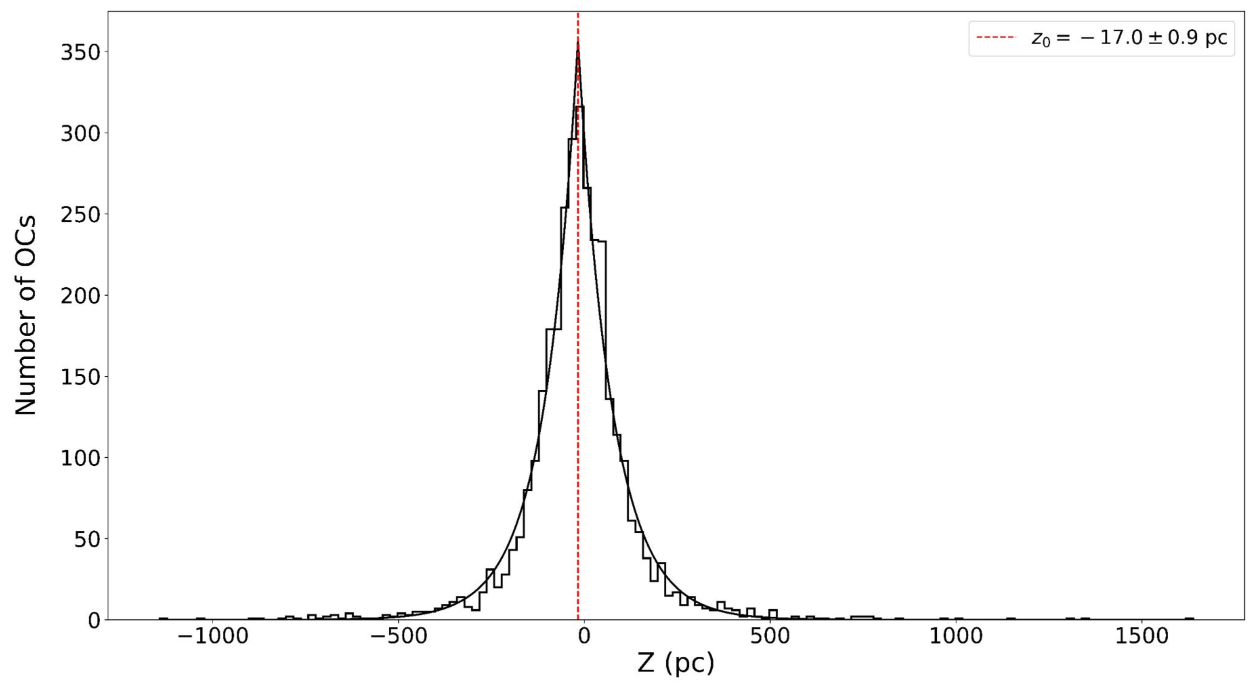

Figure 7: Histogram of OCs younger than 700 Myr distributed in Z where the solid curve shows the best-fit exponentially decaying profile. The red dashed line indicates the position of the plane of symmetry.

The Sun is located at a distance of 17 ± 0.9 pc from the plane of symmetry. We interpret this as its distance from the Galactic plane towards the direction of north Galactic pole.

Take-Aways

- OCs younger than 10 Myr trace out the spiral arms clearly whereas the older clusters tend to occupy the inter-arm regions.
- The dip in the number density of OCs at about 8.5 kpc can be explained by its proximity to the corotation circle, a consequence of the rigid rotation of spiral arms.
- Young OCs are confined to the Galactic plane with old clusters located at very high altitudes. We also observe disk flaring in the outer disk.
- The thickness of the Galactic disk has not changed much since last 700 Myr with most of the young OCs being formed within 100 pc of the Galactic plane.
- The Sun is located above the Galactic plane at a distance of 17 ± 0.9 pc.

References

- Cantat-Gaudin, T., Anders, F., Castro-Ginard, A., et al., 2020, A&A, 640, A1
- Hou L. G., 2021, FrASS, 8, 103
- Joshi Y. C., 2007, MNRAS, 378, 768