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Evolution of Spatial Structure of Star Clusters

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Abstract. We present the results of a pilot project to study the structure of star clusters with the 2MASS database. While the 2MASS cannot resolve the cores or detect much of the main sequence of globular clusters, the homogeneity and extended angular coverage make the star database suitable to study young star clusters. Even the youngest star clusters which are not yet dynamically relaxed have their stars – regardless of the stellar masses – concentrated progressively towards the cluster centers, a result due more to the cluster formation process than from subsequent gravitational interaction. We show evidence that, as a cluster ages, effects of mass segregation and external disturbances start to dominate the evolution of the spatial distribution of stars in a star cluster.

1. Introduction

The *initial* stellar distribution in a star cluster is dictated by the structure in the parental molecular cloud. As the cluster evolves, the distribution is modified by *internal* gravitational interaction among member stars. Eventually stellar evaporation and *external* disturbances – Galactic tidal force, differential rotation, and collision with molecular clouds – would dissolve the cluster. Star clusters therefore provide a laboratory to study stellar dynamics. The youngest clusters in particular still bear the imprint of their formation history, so their structure, when compared with that of molecular clouds, would shed crucial light on the fragmentation process during cloud collapse.

Stars in a globular clusters are known to concentrate progressively towards the center, more so for massive stars than for low-mass stars. The density distribution is well described by the King model (1962), which is understood as a combination of an isothermal sphere (i.e., dynamically relaxed) in the inner part of the cluster, and tidal truncation by the Milky Way in the outer part.

On the other hand, open clusters appear irregularly shaped, with member stars sparsely distributed. Our perception, or even recognition, of an open cluster is largely biased towards the appearance of the brightest members. Do star clusters form preferentially by sequential star formation, so that low-mass stars would occupy a location different from that for high-mass stars? How do stars of different masses suffer the dynamical interaction and external perturbation during the evolution of a cluster? Are young clusters mass segregated, and if so, to what extent is this due to dynamical relaxation, as opposed to the relics of the structure in the molecular cloud? To answer these questions, it is desirable to study the spatial structure of the youngest star clusters, and see how it evolves as the cluster ages.

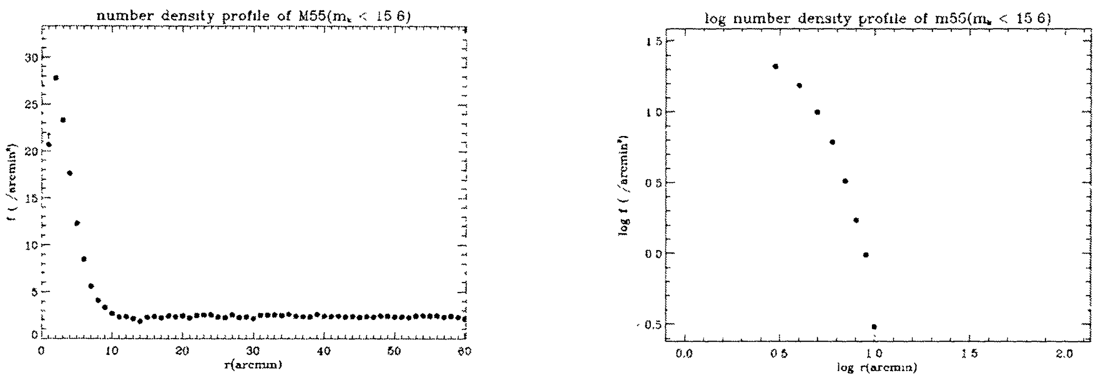

Figure 1. The radial surface density distribution of M 55 by 2MASS. A uniform background (left panel) extends out to large radii. While the core is too crowded to resolve by 2MASS, the outer part (right panel) of the cluster is clearly seen, and follows the King model.

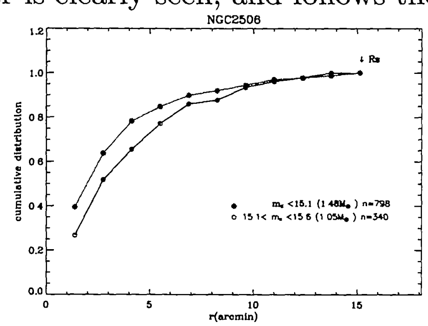

Figure 2. Comparison of the radial distribution of bright and faint stars in NGC 2506 suggests that mass segregation has occurred.

2. Structure of Open Clusters

We analyzed the spatial structure of a star cluster by its stellar density distribution within concentric annuli in the Two-Micron All-Sky Survey (2MASS) star catalogue.

Figure 1 shows the radial density profile of the globular cluster M 55 detected by the 2MASS. A well defined background, important in our star-count study, is seen out to large radii, something leisurely available with a sky survey star caalogue. While the angular resolution and sensitivity ($K \sim 15.6$ mag., 3σ) of the 2MASS cannot resolve the cores or detect much of the main sequence for distant and old globular clusters, the homogeneity and extended angular cover-

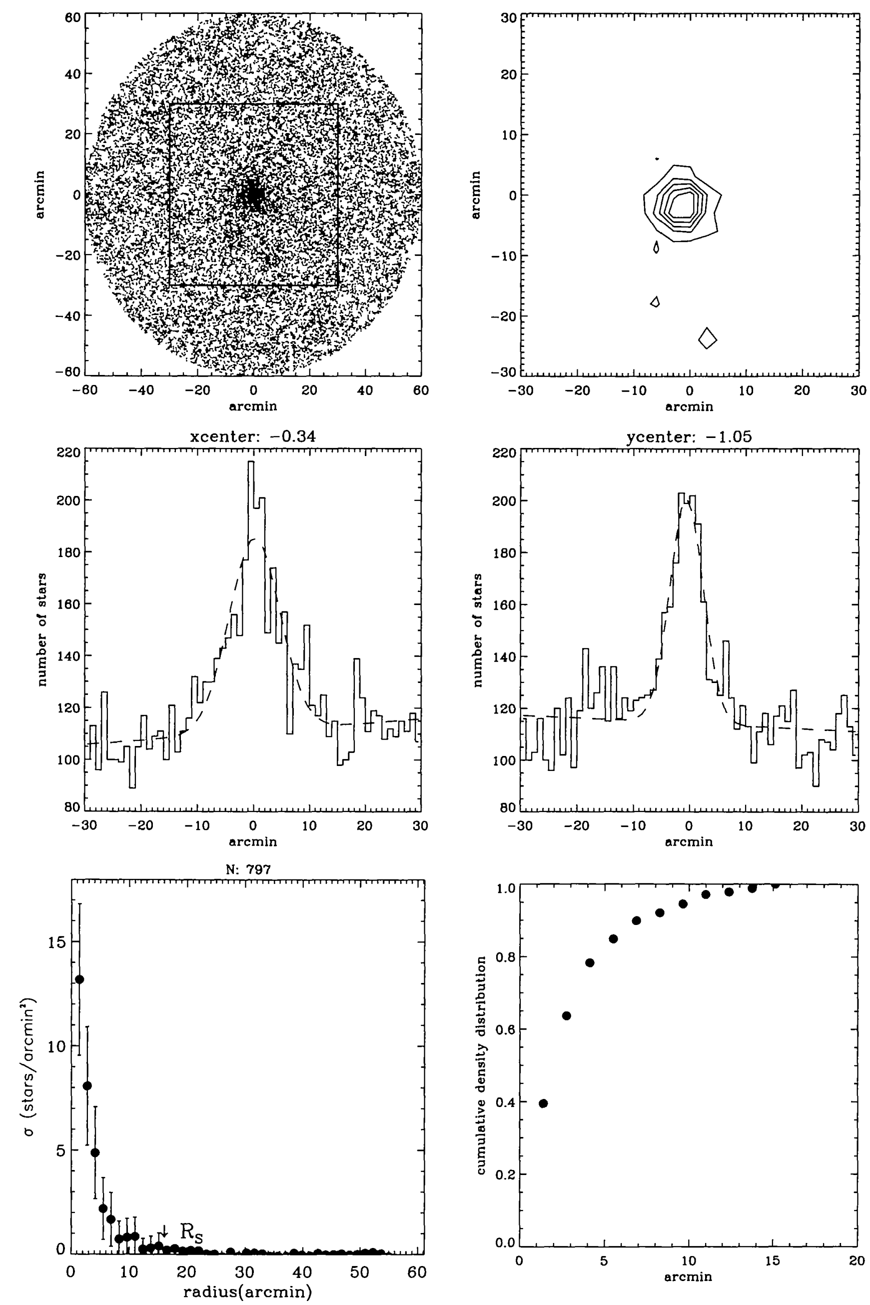

Figure 3. Density distribution of bright stars (K$\lesssim$15.1 mag) in NGC 2506. (*Top*) Each dot on the left panel represents a star entry in the 2MASS catalogue. The right panel plots the the surface number density. (*Center*) The stellar density, projected onto the R.A. (left) and the dec. axis (right), respectively, each with a Gaussian fit. The peak position defines the center of the cluster. The slope of the background is due to the stellar density gradient of the galactic disk. (*Bottom*) The radial (left) and cumulative density profile of the cluster, with the background subtracted.

age of the database make it suitable to study young star clusters (Chen & Chen 2001).

The sample of our pilot study consists of star clusters with a variety of ages and distances. As an example, Figure 2 compares the cumulative density distribution for bright and faint stars in NGC 2506. The age of this cluster (1.9 Gyr, Twarog et al. 1999) is several times the relaxation time (~300 Myr), so NGC 2506 should have been dynamically relaxed already, as indeed seen in Figure 2. Figure 3 shows how the bright stars in NGC 2506 distribute. Even though no membership information for individual stars is available, integration of the density distribution within the cluster boundary (3σ background) allows us to estimate the total number of stars in the cluster. Given the 2MASS sensitivity, we then estimate for each cluster the stellar mass range being detected, from which the relaxation time scale is calculated. Table 1 summarizes the parameters and our results for the seven clusters we have studied.

3. Summary

The 2MASS star catalogue provides a very useful database for open cluster study. As in globular clusters, stars in open clusters, regardless of their masses, are concentrated progressively toward the center. Even the youngest star clusters show evidence of mass segregation. This suggests that spatial structure of a star cluster is governed by the structure of the molecular cloud from which the cluster was formed, and then later modified by the dynamical relaxation and external perturbation.

Table 1. Parameters for open clusters

Cluster	ℓ, b	D (kpc)	τ (Myr)	$N*$	M ($M_\odot$)	R (pc)	$\tau_{\rm re}$	$\tau/\tau_{\rm re}$	Segr.
				Young					
NGC1893	174,-02	4.4	4	498	309	8.9	291	0.01	?
IC348	160,-18	0.32	5	322	200	1.6	14	0.2	Y
				Intermediate					
NGC1817	186,-13	2.1	800	236	146	7.9	139	6	N?
NGC2506	231,+10	3.3	1,900	1,038	643	17.3	605	3	Y
NGC2420	198,+20	2.5	2,200	450	279	9.4	223	10	Y
				Old					
NGC6791	070,+11	4.2	8,000	1,095	679	13.2	543	15	?
Be17	176,-04	2.5	9,000	370	229	7.1	142	63	N

References

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