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Rapid Mass Segregation in Massive Star Clusters

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Abstract. Several dynamical scenarios have been proposed that can lead to prompt mass segregation on the crossing time scale of a young cluster. They generally rely on cool and/or clumpy initial conditions, and are most relevant to small systems. As a counterpoint, we present a novel dynamical mechanism that can operate in relatively large, homogeneous, cool or cold systems. This mechanism may be important in understanding the assembly of large mass-segregated clusters from smaller clumps.

Keywords. globular clusters: general, galaxies: star clusters, stellar dynamics

Early mass segregation may be critical to the long-term survival of a stellar system (Vesperini *et al.* 2009a). It also defines the early cluster environment within which stars move and interact. In recent years, several dynamical studies have explored routes to early mass segregation that do not simply require that a cluster formed in that state. McMillan *et al.* (2007) found that mergers of mass-segregated "clumps" tend to preserve that segregation in the final merger product, so that, if the clumps are formed segregated, or have time to segregate before they merge, the result is a strongly mass-segregated cluster. Allison *et al.* (2009) found similar behavior, starting from fractal clumpy initial conditions in small, cool model clusters.

Ultimately, these scenarios rely on normal relaxation processes in small stellar systems. However, as illustrated in Figure 1, rapid segregation is also possible in significantly larger systems. The initial conditions of the simulation shown here consist of a cold (virial ratio $q = 0.001$), homogeneous sphere with a Kroupa (2002) mass distribution. No segregation is seen before the "bounce" at $t \sim 1.5$ initial dynamical times, while immediately afterward the highest mass groups are clearly ordered by radius. This behavior was also noted by Vesperini *et al.* (2006) and Vesperini *et al.* (2009b).

The phenomenon of rapid segregation cannot be due to enhanced relaxation around the high density bounce. This would only be possible if the system were still cold at that time, and our simulations clearly indicate that this is not the case. Instead, as shown in Figure 2, we find that the system fragments as it collapses, as discussed in detail by Aarseth *et al.* (1988), and the fragments mass segregate quite early on during the collapse process. Significant segregation within the clumps is already established by $t \sim 1$, well before the bounce, and is preserved when the clumps subsequently merge at $t = 1.5$, essentially as described by McMillan *et al.* (2007).

The phenomenon persists as we vary the initial system parameters, and is still measurable even for fairly "warm" initial conditions ($q \sim 0.1$), with and without initial clumping (fractal dimension $d \sim 2-3$), and for large systems, up to $N \sim 10^5$. Thus it may provide the basis of a viable mechanism for extending earlier dynamical segregation scenarios to substantially larger systems.

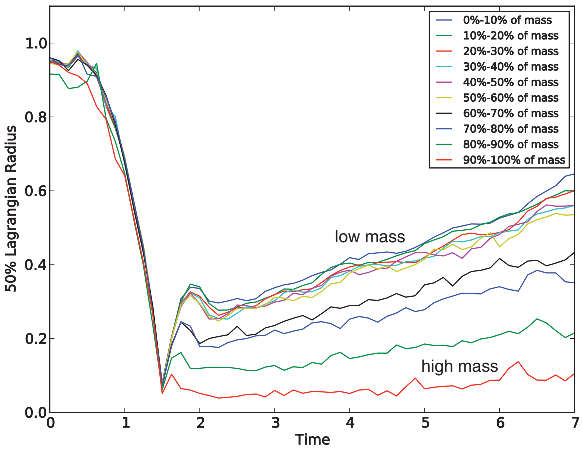

Figure 1. Collapse of an initially cold, homogeneous spherical system containing 10^4 particles with a Kroupa (2002) mass function. The half-mass radii of the particles making up the bottom 10 percent, 10–20 percent, 20–30 percent, etc., of the cumulative mass distribution are shown. The bottom four lines after the collapse represent the top four mass groups, their half-mass radii decreasing with mass, indicating strong mass segregation.

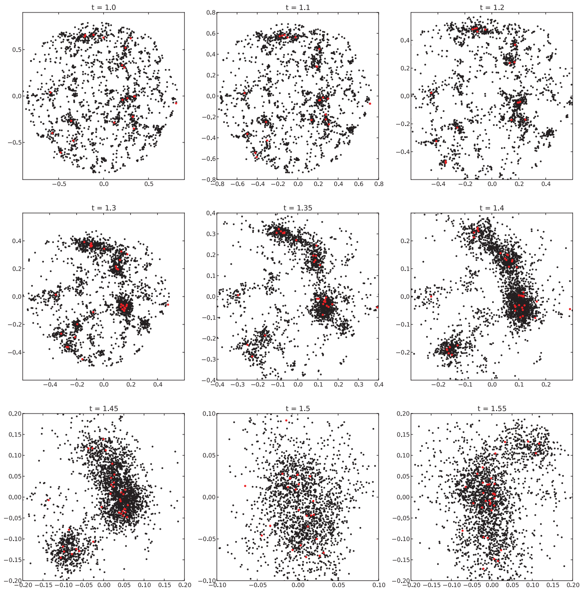

Figure 2. Fragmentation and mass segregation during the collapse can be seen in this sequence of frames running from $t = 1$ to $t = 1.55$, just after the moment of collapse. The spatial scale of the frames shrinks to follow the collapsing system, from ±0.9 at top left ($t = 1$) to ±0.4 at center ($t = 1.35$), to ±0.1 at bottom center ($t = 1.5$) and ±0.2 at bottom right ($t = 1.55$).

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