Rapid mass segregation in young star clusters *without* substructure?

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Abstract. The young star clusters we observe today are the building blocks of a new generation of stars and planets in our Galaxy and beyond. Despite their fundamental role we still lack knowledge about the initial conditions under which star clusters form and the impact of these often harsh environments on the formation and evolution of their stellar and substellar members.

We present recent results showing that mass segregation in realistic models of young star clusters occurs very quickly for subvirial spherical systems without substructure. This finding is a critical step to resolve the controversial debate on mass segregation in young star clusters and provides strong constraints on their initial conditions. The rapid concentration of massive stars is usually associated with strong gravitational interactions early on during cluster evolution and the subsequent formation of multiple systems and ejection of stars.

Keywords. stellar dynamics, methods: n-body simulations, galaxies: star clusters

1. Introduction

It is commonly accepted that star formation does usually not occur in isolation but that a large majority of young stars – up to 90 % – are part of a cluster (e.g. Lada & Lada 2003). One of the most widely discussed aspect of the dynamical evolution of young star clusters is that of mass segregation (e.g. Raboud & Mermilliod 1998; Bonnell & Davies 1998; Gouliermis *et al.* 2004; Chen *et al.* 2007; Vesperini *et al.* 2009; Xin-Yue *et al.* 2009; Ascenso *et al.* 2009). A major question is whether the observed degree of mass segregation has developed dynamically (via two-body encounters) or whether it can be only explained via primordial mass segregation (i.e. inherent to the star formation process).

Though it has been shown that mass segregation in a stellar system with a mass spectrum (e.g. Spurzem & Takahashi 1995; Khalisi *et al.* 2007) occurs rapid enough to account for the observed mass segregation, recent investigations have focused on how substructure in stellar systems can accelerate this process (McMillan *et al.* 2007; Allison *et al.* 2009; Moeckel & Bonnell 2009, see also (Aarseth & Hills 1972)). However, all these works have simulated the evolution under subvirial initial conditions.

We thus investigate numerically the *pure* effect of subvirial conditions in young star clusters and infer to which degree they can speed-up mass segregation.

2. Numerical Setup

We have performed numerical simulations of isolated, non-rotating, moderately populated star clusters with 1000 stars initially, a Kroupa IMF in the range $0.08\,\mathrm{M_\odot}$ to $50\,\mathrm{M_\odot}$ Kroupa (2001), a density profile $\rho \propto r^{-2}$ and varying initial virial ratios Q. We
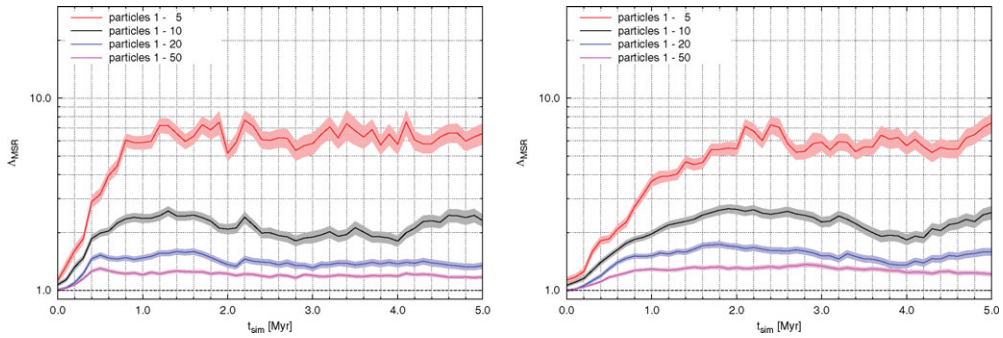
Figure 1. Evolution of mass segregation in a star cluster with $Q = 0.1$ (left) and $Q = 0.3$ (right) represented by Λ_{MST} of four different stellar groups (from top to bottom: 5, 10, 20, and 50 most massive stars). The shaded regions indicate the associated uncertainties. One dynamical crossing time corresponds to $0.19\,\mathrm{Myr}$ for $Q = 0.1$ and $0.28\,\mathrm{Myr}$ for $Q = 0.3$.

use the NBODY6-GPU code Aarseth (2003) to model the dynamics of these numerical models and analyze the degree of mass segregation, Λ_{MST}, via a minimum spanning tree algorithm as described by Allison *et al.* (2009).

3. Results

We find that mass segregation occurs rapidly in star clusters with subvirial initial conditions (see Fig. 1). If $Q = 0.1$, the maximum degree of segregation is reached in less than 1 Myr (or roughly five crossing times). The five most massive stars show strong mass segregation with $\Lambda_{\mathrm{MST}} \approx 7$. The first evidence of significant mass segregation, $\Lambda_{\mathrm{MST}} \gtrsim 2$, occurs even within 1-2 crossing times. For less cold initial conditions ($Q = 0.3$) the evolution is about two times slower yet still very rapid and equally pronounced.

The concentration of massive stars is accompanied by strong gravitational interactions that involve early on the formation of multiple systems and ejection of (massive) stars. This counteracts further mass segregation and quickly limits its maximum degree.

Compared with the time scale on which mass segregation occurs in the simulations of McMillan *et al.* (2007) and Allison *et al.* (2009) the present setup leads to an equally rapid evolution. This indicates that in fact subvirial initial conditions might be the dominant dynamical driver of rapid mass segregation in young star clusters.

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