EFFECTS OF PRIMORDIAL MASS SEGREGATION ON THE DYNAMICAL EVOLUTION OF STAR CLUSTERS

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ABSTRACT

In this paper, we use N-body simulations to study the effects of primordial mass segregation on the early and long-term evolution of star clusters. Our simulations show that in segregated clusters early mass loss due to stellar evolution triggers a stronger expansion than for unsegregated clusters. Tidally limited, strongly segregated clusters may dissolve rapidly as a consequence of this early expansion, while segregated clusters initially underfilling their Roche lobe can survive the early expansion and have a lifetime similar to that of unsegregated clusters. Long-lived initially segregated clusters tend to have looser structure and reach core collapse later in their evolution than initially unsegregated clusters. We have also compared the effects of dynamical evolution on the global stellar mass function (MF) of low-mass main-sequence stars. In all cases, the MF flattens as the cluster loses stars. The amount of MF flattening induced by a given amount of mass loss in a rapidly dissolving initially segregated cluster is less than for an unsegregated cluster. The evolution of the MF of a long-lived segregated cluster, on the other hand, is very similar to that of an initially unsegregated cluster.

Key words: globular clusters: general – methods: N-body simulations – stellar dynamics

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1. INTRODUCTION

Mass segregation, the tendency of more massive stars to preferentially populate the inner parts of a star cluster, is one of the consequences of two-body relaxation and of the evolution toward energy equipartition in stellar systems. The characteristic timescale for this process, \( T_{\text{ms}} \), is for a population of massive stars with mass \( m_{\text{s}} \), \( T_{\text{ms}} \sim \langle m \rangle / m_{\text{s}} T_{\text{relax}} \), where \( T_{\text{relax}} \) is the cluster relaxation time and \( \langle m \rangle \) is the mean mass of the cluster stars.

However, a number of young clusters with ages significantly smaller than the time needed to produce the observed mass segregation by standard two-body relaxation show a significant degree of mass segregation (e.g., Hillenbrand 1997; Hillenbrand & Hartmann 1998; Fischer et al. 1998; de Grijs et al. 2002; Sirianni et al. 2002; Gouliermis et al. 2004; Stolte et al. 2006; Sabbi et al. 2008).

The results of a number of theoretical studies (e.g., Klessen 2001; Bonnell et al. 2001; Bonnell & Bate 2006; but see also Krumholz et al. 2005; Krumholz & Bonnell 2007) showing that massive star would preferentially form in the center of star-forming regions suggest that the observed segregation in young clusters would be primordial and imprinted in a cluster by the star formation processes. Possible dynamical routes leading to early mass segregation in young star clusters have been studied by McMillan et al. (2007).

In this paper, we present the results of a survey of N-body simulations aimed at exploring the implications of primordial mass segregation for the dynamical evolution of star clusters. We have explored the evolution of clusters located at different galactocentric distances and with different degrees of initial mass segregation and compared the evolution of segregated clusters with that of clusters with the same initial density profile but no initial mass segregation. Our models focus on the effect of primordial mass segregation on a purely stellar system; primordial gas and the effects of its expulsion (see, e.g., Baumgardt & Kroupa 2007) are not included here.

In Section 2, we present a preliminary analytical calculation aimed at exploring the differences in the response of clusters with different initial degrees of mass segregation to the early mass loss due to stellar evolution. This is, in most cases, the first process affecting the cluster structure well before the effects of two-body relaxation become important. We continue, in Section 3, with the presentation of the results of our N-body simulations, focusing our attention on clusters lifetime, structural evolution, and the evolution of the stellar mass function (MF). We discuss and summarize our results in Section 4.

2. EARLY EVOLUTION OF SEGREGATED CLUSTERS: ANALYTICAL ESTIMATES

A number of studies (see, e.g., Chernoff & Shapiro 1987; Chernoff & Weinberg 1990; Fukushige & Heggie 1995; Takahashi & Portegies Zwart 2000) have shown that early mass loss due to stellar evolution can have a significant impact on the evolution of clusters: this early mass loss causes a cluster to expand and, for a low-concentration cluster, leads to the cluster’s complete and rapid dissolution. For initially mass-segregated clusters, the mass lost due to the evolution of massive stars is removed preferentially from the cluster’s inner regions, and the early expansion of the cluster is stronger and potentially more destructive than when the same amount of mass is lost in a nonsegregated cluster.

Figure 1 shows the results of a simple semianalytical calculation illustrating the augmented destructive effect of stellar mass loss in a mass-segregated cluster. In this figure, we plot the virial ratio, \( T/V \), of an isolated cluster with an initial Plummer density profile,

\[
\rho = \frac{3M}{4\pi a^3} \left(1 + \frac{r^2}{a^2}\right)^{-5/2}
\]

(see, e.g., Heggie & Hut 2003), after the impulsive loss of a fraction, \( \Delta M \), of the total mass. In order to mimic the preferential
mass loss from the inner regions of a mass-segregated cluster, we have simply assumed that the density profile of the mass lost also follows a Plummer model, but with a scale radius \( a_{\text{ML}} \) equal to or less than the scale radius of the whole cluster, \( a_{\text{cluster}} \). The number beside each curve indicates the corresponding value of \( a_{\text{ML}}/a_{\text{cluster}} \).

For \( a_{\text{ML}} = a_{\text{cluster}} \), one recovers the well-known result that a system becomes unbound for \( \Delta M > 0.5 \) (Hills 1980; see Boily & Kroupa 2003 for a more detailed calculation showing that larger values of the mass loss are actually necessary to unbind a cluster). However, for a cluster preferentially losing mass from the inner regions, \( a_{\text{ML}} < a_{\text{cluster}} \), we see that a significantly smaller amount of mass loss, innocuous for an unsegregated cluster, can lead to the dissolution of a mass-segregated cluster.

This simple semianalytical calculation underscores the potentially crucial implication of initial mass segregation for the evolution of star clusters; the results of the N-body simulations presented in the rest of this paper illustrate these consequences in more detail.

3. DYNAMICAL EVOLUTION OF SEGREGATED CLUSTERS: N-BODY SIMULATIONS

3.1. Method and Initial Conditions

The results presented in this section are based on a survey of direct N-body simulations carried out using the starlab package (Portegies Zwart et al. 2001; http://www.manybody.org) and accelerated by a GRAPE-6 special-purpose board (Makino et al. 2003).

We have followed the evolution of clusters located at different galactocentric distances, \( R_g = 1, 4, 18, 40 \) kpc, in a Galactic tidal field modeled as a Keplerian potential determined by a point mass, \( M_g \), equal to the total mass of the Galaxy inside the distance, \( R_g \). We have studied both tidally truncated clusters and clusters underfilling their Roche lobe with a ratio, \( R/R_c \), of the total radius, \( R_c \), to the tidal radius, \( R_t \), equal to 0.75 and 0.5. A Kroupa (Kroupa et al. 1993) stellar initial MF with star masses between 0.1 and 100 \( m_\odot \) was adopted and star masses were generated by the analytical function in Equation (14) of Kroupa et al. (1993).

For segregated systems, mass segregation was set up by first letting the cluster evolve without including the effects of stellar evolution until a given degree of segregation was reached due to normal two-body relaxation. We emphasize that this is just the procedure we have used to generate a self-consistent initially segregated cluster and it is not meant to model any stage of cluster evolution. Alternative procedures to produce initially segregated clusters have recently been suggested (see, e.g., Subr et al. 2008; Baumgardt et al. 2008).

Figures 2 and 3 show, respectively, the initial density profile and the initial radial profile of the star mean mass for the systems we have studied; in particular, the solid line in Figure 3 shows the initial degree of mass segregation of the standard models on which we focus in this paper. The initial number of particles for the standard segregated (S) and unsegregated (U) runs is \( N = 25 \) K. Initial conditions for moderate and low initial mass segregation (the \( M-Rg18 \) and \( L-Rg18 \) runs, respectively) are obtained by extracting snapshots at earlier times of the same preliminary simulation mentioned above when the system has a lower degree of segregation and has lost a smaller number of particles; the initial numbers of particles for the \( M-Rg18 \) and the \( L-Rg18 \) runs are, respectively, \( N = 33 \) K and \( N = 38 \) K.

In order to explore the dependence on \( N \) of the evolution of clusters most affected by initial mass segregation, simulations with the same degree of initial segregation as \( S-Rg18, M-Rg18 \), and \( L-Rg18 \) have been repeated with a larger number of particles (\( N = 70 \) K, \( N = 103 \) K, and \( N = 120 \) K, respectively).

We summarize in Table 1 all the initial conditions considered, along with the identification used throughout the paper to refer to each simulation.

3.2. Results: Cluster Evolution and Lifetime

The analytical calculation presented in Section 2 showed that early impulsive mass loss associated with stellar evolution...
Figure 3. Initial radial profile of the stellar mean mass for the initially segregated systems investigated in our simulations: $S$ run (solid red line/filled dots), $M$ run (dotted green line/open triangles), and $L$ run (blue dot-dashed line/asterisk dots).

(A color version of this figure is available in the online journal.)

Table 1

| Id.          | $R_g$ (kpc) | $R/R_t$ | Initial Mass Segregation |
|--------------|-------------|---------|--------------------------|
| $S-Rg1$      | 1           | 1       | Strong                   |
| $S-Rg4$      | 4           | 1       | Strong                   |
| $S-Rg18$     | 18          | 1       | Strong                   |
| $S-Rg18R075$ | 18          | 0.75    | Strong                   |
| $S-Rg18R05$  | 18          | 0.5     | Strong                   |
| $S-Rg40$     | 40          | 1       | Strong                   |
| $U-Rg1$      | 1           | 1       | No segregation           |
| $U-Rg4$      | 4           | 1       | No segregation           |
| $U-Rg18$     | 18          | 1       | No segregation           |
| $U-Rg18R075$ | 18          | 0.75    | No segregation           |
| $U-Rg18R05$  | 18          | 0.5     | No segregation           |
| $U-Rg40$     | 40          | 1       | No segregation           |
| $M-Rg18$     | 18          | 1       | Moderate                 |
| $L-Rg18$     | 18          | 1       | Low                      |

Note. The columns list (1) Id (standard segregated run $S$, standard unsegregated run $U$, moderate-segregation run $M$, low-segregation run $L$), (2) galactocentric distance, $R_g$, in kpc, (3) ratio of the initial cluster radius to the tidal radius, $R/R_t$, and (4) degree of initial mass segregation.

can have a stronger impact on initially segregated cluster than unsegregated clusters.

For tidally truncated clusters with fixed initial mass, evolving in a host galaxy with constant circular velocity, the mean cluster density, $\rho_{\text{tid}} \propto M/R_t^3$, decreases with the galactocentric distance $R_g$, as $\rho_{\text{tid}} \propto 1/R_g^2$. The cluster dynamical time, defined using the mean density within the tidal radius, $t_{\text{tid}} \propto 1/\sqrt{\rho_{\text{tid}}}$, thus increases linearly with $R_g$ (note that this dynamical time is proportional to the circular orbital period of the cluster around the Galaxy at distance, $R_g$). This scaling implies that, for tidally truncated clusters, the amount of impulsive mass loss due to stellar evolution increases with $R_g$.

Figure 4 shows the dependence of the cluster dissolution time, $T_{\text{diss}}$, (defined as the time when 1% of the initial mass is left in the cluster) on the cluster galactocentric distance for mass-segregated and unsegregated clusters. At a given $R_g$, the
amount of impulsive mass loss is the same for both segregated and unsegregated clusters but, as anticipated by the analytical calculations presented earlier, the destructive effect of this mass loss is strongly augmented by mass segregation.

Figure 4 shows that all of the unsegregated clusters survive the early mass loss due to stellar evolution and eventually dissolve as a result of the evaporation of stars due to two-body relaxation. On the other hand, early impulsive mass loss leads to the dissolution within just a few dynamical times of all of the initially mass-segregated clusters. Only the dissolution time of the cluster closest to the Galactic center (for which the dynamical time is short and the impulsive mass loss is negligible) is similar to that of the corresponding unsegregated cluster.

As already noted in a number of previous studies (see, e.g., Vesperini & Heggie 1997; Portegies Zwart et al. 1998; Baumgardt & Makino 2003), the dissolution time of tidally truncated unsegregated clusters increases linearly with $R_g$. This dependence is evident from the lower panel of Figure 4; in the upper panel it is incorporated in the dynamical time, $t_{\text{tid}}$, used to normalize the $T_{\text{diss}}$ as we pointed out above in this section, $t_{\text{tid}} \propto R_g$. The dissolution of the unsegregated clusters is driven principally by two-body relaxation, and for clusters more massive than those we have studied in our simulations, the ratio, $T_{\text{diss}}/t_{\text{tid}}$, increases with the initial number of stars $N$ as $\sim (N/\log N)^{x}$ with $x \sim 0.75$–0.8 (see Baumgardt & Makino 2003).

For initially mass-segregated systems the dependence of $T_{\text{diss}}$ on $R_g$ is determined by the initial degree of mass segregation, the ratio, $R/R_t$, and the amount of impulsive mass loss. As noted above, for example, for clusters like S-Rg1 with small dynamical times, the amount of impulsive mass loss is negligible and the dissolution time of a mass-segregated cluster is similar to that of an unsegregated cluster. On the other hand, for very large amounts of impulsive mass loss—larger than those in the systems we have studied—the dissolution time must converge to a value of $\sim t_{\text{tid}}$. It is therefore not possible to derive a single general power law to fit the scaling of $T_{\text{diss}}$ with $R_g$.

For the specific set of standard segregated $S$ runs, and limiting the fit to systems with $R_g = 4$, 18, 40, the dissolution time is much shorter than that of the unsegregated systems and has a weaker dependence on $R_g$, $T_{\text{diss}} \sim R_g^{0.43}$. The dissolution times of the mass-segregated clusters undergoing rapid dissolution do not depend on $N$, as shown by the results of simulations starting with the same degree of segregation but larger values of $N$ (see Figure 4).

The difference in response of segregated and unsegregated clusters to the same amount of impulsive mass loss is further illustrated in Figure 5, which shows the time evolution of the 10%, 25%, 50%, 75%, 90% Lagrangian radii for S-Rg18 and U-Rg18. Both clusters initially lose the same fraction of their initial mass and expand in response to this mass loss; however, the preferential removal of mass from the innermost regions in the segregated cluster leads to a much stronger expansion and to rapid cluster dissolution.

The longer dissolution times $L$-Rg18 and $M$-Rg18 plotted in Figure 4 show that as the initial degree of mass segregation decreases so does the disruptive effect of the early mass loss due to supernova (SN) ejecta.

The long-lived globular clusters we observe today might have had very low degrees of initial mass segregation which allowed them to survive. Alternatively, a cluster with a higher degree of initial mass segregation can survive if its initial size is significantly smaller than its tidal radius. In this case, most cluster stars remain within the tidal boundary during the early expansion, and the number of stars lost during this phase is smaller.

To illustrate this point, we have repeated the S-Rg18 and U-Rg18 runs, but setting the ratio of the initial cluster size, $R$, to the tidal radius, $R_t$, equal to 0.75 (S-Rg18R075 and U-Rg18R075) and 0.5 (S-Rg18R05 and U-Rg18R05). The dissolution times for these systems are plotted in Figure 4 and show that the lifetime of a mass-segregated cluster with the same degree of initial segregation increases as the ratio, $R/R_t$, decreases.

In particular, the lifetimes of S-Rg18R05 and U-Rg18R05 are very similar, as the early mass loss disruptive effects for the initially mass-segregated system are strongly suppressed by the fact that the cluster is expanding well within its tidal radius and not immediately losing stars as it expands. Since the system is initially denser and has a shorter dynamical time, the amount of impulsive mass loss is smaller than for the tidally truncated system; this effect also contributes, although to a lesser extent, to the extension of the cluster lifetime.

The evolution of the 10%, 25%, 50%, 75%, 90% Lagrangian radii for S-Rg18R05 and U-Rg18R05 are shown in Figure 6. Although the lifetimes of these two systems are similar, Figure 6 clearly shows important differences in the structural evolution of the two clusters: the mass-segregated cluster undergoes a stronger initial expansion which, although it does not lead to its prompt dissolution, significantly delays the cluster core collapse and keeps the cluster concentration lower than that of the unsegregated cluster. This is further illustrated by Figure 7 which shows the time evolution of the cluster concentration as measured by the ratio of the core and half-mass radii, $r_c/r_h$, for S-Rg18R05 and U-Rg18R05.

3.3. Results: Evolution of the Stellar Mass Function

An important issue related to a cluster mass loss is the evolution of the stellar MF. It has been shown in a number
of investigations of initially unsegregated clusters (see, e.g., Vesperini & Heggie 1997; Baumgardt & Makino 2003) that mass loss due to two-body relaxation leads to the preferential escape of low-mass stars and to the flattening of the stellar MF.

In particular, for long-lived clusters losing mass due to two-body relaxation the extent of the flattening of the slope of the stellar MF is strictly correlated to the fraction of the initial cluster mass left (see, e.g., Figure 16 in Vesperini & Heggie 1997 and Equation (14) in Baumgardt & Makino 2003).

For long-lived initially unsegregated clusters, the dynamical mass-loss timescale is closely related to the two-body relaxation timescale and is, in general, much longer than the stellar evolution timescale of the most massive stars. In this case, the range of stellar masses involved in segregation and evaporation processes after a few billion years includes the most massive dark remnants (1.2–1.4 $m_{\odot}$), the more numerous white dwarfs, and the remaining main-sequence stars ($m \lesssim 1 m_{\odot}$). The most massive main-sequence stars usually included in the calculation of the slope of the MF fall in the high-mass end of this range, and hence tend to sink to the cluster center, while low-mass main-sequence stars (e.g., $m \sim 0.1–0.2 m_{\odot}$) preferentially escape from the cluster, flattening the MF.

For an initially mass-segregated cluster, on the other hand, the range of stellar masses affected by segregation is much broader. The most massive stars in this broad range preferentially populate the innermost regions, while the long-lived main-sequence stars with ($m \lesssim 1 m_{\odot}$) all have very similar spatial distributions.

This point is illustrated in Figure 8, which shows the initial mean distance of stars from the cluster center as a function of the mean stellar mass in a number of mass bins for the S and U runs. The same information later in the evolution of the U-Rg18R05, when a significant degree of mass segregation has been reached and the cluster hosts stars with a narrower range of masses, is also shown.

Figure 8 shows that the initial degree of segregation for stars with masses in the range $0.1 < m/m_{\odot} < 0.5$ (hereafter, we focus on the evolution of the MF of main-sequence stars with initial masses in this range) is negligible and similar in clusters with and without primordial segregation. As discussed above, primordial mass segregation affects mainly the most massive stars initially present in the cluster. The
segregation profile attained later in the evolution by an unsegregated cluster shown in Figure 8 clearly illustrates the differences with the initial segregation profile of a cluster with primordial segregation. This is an important point in understanding the implications of primordial mass segregation for the evolution of the MF.

As the results presented in the previous sections show the fate of initially mass-segregated clusters and the processes driving their dissolution depend on the degree of initial mass segregation and on a cluster’s initial size relative to its tidal radius. Hereafter, we focus on the S-Rg18, S-Rg18R05, U-Rg18, and U-Rg18R05 runs, to explore the difference between the MF evolution in systems with and without primordial mass segregation.

We fitted the MF of main-sequence stars with masses in the range \(0.1 < m/m_\odot < 0.5\) with a power law \(dN(m) = Am^{-\alpha}dm\); the upper panel of Figure 9 shows the time evolution of \(\alpha\) for S-Rg18 and U-Rg18. As discussed in the previous section, the initially mass-segregated system rapidly dissolves as its outer layers expand in response to mass loss due to SN ejecta. As the system quickly loses mass, the MF slope also rapidly flattens; the evolution, mass loss, and MF flattening occur on a much longer timescale for the unsegregated system.

The lower panel in Figure 9 shows the MF slope versus the fraction of the initial mass left in the cluster, clearly illustrating an important difference between mass-segregated and unsegregated clusters: for a given amount of mass loss, the degree of MF flattening is significantly larger for the initially unsegregated cluster. This is due to the differences in the range spanned by stellar masses during the cluster evolution. For the slowly evolving initially unsegregated cluster, the narrower range of star masses present in the cluster during much of its evolution results in greater preferential loss of stars at the low-mass end of the range \(0.1 < m/m_\odot < 0.5\), while stars at the high-mass end of this range sink to the cluster center. This is not the case for the initially mass-segregated system, in which rapid dissolution ensures that stars much more massive than \(0.5m_\odot\) are present during most of the evolution, preventing the development of strong differences in the mass-loss rate and the spatial segregation of stars with masses in the range \(0.1 < m/m_\odot < 0.5\).

The time evolution of \(\alpha\) and the dependence of \(\alpha\) on the fraction of mass remaining in the cluster for the long-lived S-Rg18R05 and U-Rg18R05 systems are also shown in Figure 9. The evolution of \(\alpha\) is very similar for these two systems. The initial segregation profiles for U-Rg18R05 and S-Rg18R05 in Figure 8 clearly show that the degree of mass segregation for stars with masses in the range \(0.1 < m/m_\odot < 0.5\) is very similar in these two systems. If a mass-segregated cluster survives its early expansion, as in the case of S-Rg18R05, it will enter the evolutionary phase driven by two-body relaxation (after the most massive stars have evolved off the main sequence) with a segregation profile similar to that of an initially unsegregated cluster (see the mass segregation profiles of S-Rg18R05 and U-Rg18R05 at \(t = 1\) Gyr in Figure 8), and the MFs of both systems will evolve similarly.

For clusters initially underfilling their Roche lobes, our simulations show that a given amount of mass loss leads to a stronger MF flattening than for tidally truncated unsegregated clusters. This is a consequence of the slower mass-loss rate of clusters initially lying inside their tidal radii; it takes longer for these clusters to lose a given amount of mass, and during this additional time a higher degree of mass segregation for stars with masses \(0.1 < m/m_\odot < 0.5\) is reached.

4. DISCUSSION AND CONCLUSIONS

The results of our study show that initial mass segregation can significantly affect the dynamical evolution of star clusters. For clusters initially filling their Roche lobes, our simulations show that mass-segregated clusters can quickly dissolve as a result of the early expansion triggered by mass loss due to stellar evolution, unless the initial degree of mass segregation is low. We have studied the evolution of mass-segregated and unsegregated clusters undergoing the same amount of early impulsive mass loss and find that, for segregated clusters, the preferential removal of this mass from the innermost regions strongly augments the strength of the early expansion and leads to rapid cluster dissolution.
We have also explored the evolution of clusters initially underfilling their Roche lobes, showing that in this case mass-segregated clusters can survive the early expansion phase; a mass-segregated cluster still undergoes a strong expansion in this case, but much of this expansion occurs within its tidal radius without significant loss of stars. The subsequent cluster evolution, lifetime, and mass-loss rate do not differ significantly from those of an initially unsegregated cluster.

The stronger expansion of the segregated cluster, while not leading to rapid dissolution, does drive the cluster toward a less concentrated structure, significantly delaying core collapse. The less concentrated structure of an initially segregated cluster throughout most of the evolution is the main difference between long-lived segregated and unsegregated clusters. If clusters still surviving today were initially segregated, this is one of the possible evolutionary routes they might have followed. Another possible scenario has been studied by D’Ercole et al. (2008), who demonstrate the role of primordial segregation in the evolution of clusters which form a second generation of stars in the innermost regions of a first-generation population. The early expansion in this case plays a key role in causing the loss of a large fraction of the first-generation stars, while most of the centrally concentrated second generation remains in the cluster, resulting in a system containing a mixture of first- and second-generation stars that eventually survives until the present day.

We have also studied the differences in the evolution of the stellar MF for segregated and unsegregated clusters, focusing on the evolution of the MF of low-mass ($0.1 < m/m_\odot < 0.5$) main-sequence stars. Our simulations show that the MF of a rapidly dissolving segregated cluster flattens quickly as the system loses stars. However, the extent of the MF flattening induced by a given amount of mass loss for a tidally truncated segregated cluster (our S runs) is smaller than for an initially unsegregated system (our U runs).

The difference is a consequence of the rapid dissolution of segregated clusters. We have shown that the initial degree of segregation adopted in our simulations mostly affects massive stars with $m \gtrsim 5$–10 $m_\odot$, while low-mass stars with $m \lesssim 1 m_\odot$, initially have a similar spatial distribution to stars in unsegregated clusters. Segregated clusters initially filling their Roche lobe quickly lose mass before two-body relaxation can produce a significant difference in the spatial distribution (and in the mass-loss rate) of stars with masses $m \lesssim 1 m_\odot$. Unsegregated clusters, on the other hand, lose stars more slowly and a large fraction of their initial mass is lost late in the evolution, when the most massive stars in the range $0.1 < m/m_\odot < 0.5$ are significantly more concentrated than stars of lower masses. The differences between the S and U systems in the degree of MF flattening for a given amount of mass-loss result from differences in the processes driving the cluster dissolution and, more importantly, from differences in the dissolution timescales associated with these processes.

Segregated clusters initially well confined within their Roche lobe may survive their early expansion and, in this case, we have shown that both segregated and unsegregated clusters display very similar MF evolution. As pointed out above, the main fingerprint of initial segregation might be looser cluster structure during a larger fraction of the cluster lifetime. However, we emphasize that, unless some other mechanism continues to drive the cluster expansion, long-lived segregated clusters also eventually undergo core collapse; therefore it cannot be ruled out that high-concentration and post-core collapse clusters might have been initially segregated.

It has recently been suggested by Baumgardt et al. (2008) that the low-concentration clusters with strongly flattened MFs found in the observational study by De Marchi et al. (2007) can result only from the dynamical evolution of initially segregated clusters (see also Marks et al. 2008 for the possible role of primordial gas expulsion). In particular, the simulations of Baumgardt et al. show that a cluster must initially be significantly mass segregated and fill its Roche lobe in order to evolve into a system with properties resembling those of the loose, flat-MF clusters observed by De Marchi et al. The initial degree of segregation adopted by Baumgardt et al. is significantly larger than that of our simulations, as shown in Figure 8. However, the Baumgardt et al. study focuses on the effects of two-body relaxation, and does not include the early mass loss due to stellar evolution which, as shown by our simulations, can play a crucial role in cluster evolution. As discussed above, initially tidally limited segregated clusters may dissolve rapidly due to the expansion triggered by early mass loss, even when starting with a degree of initial segregation much smaller than that adopted by Baumgardt et al.

In a future investigation, we will focus on detailed comparisons between our simulations and observational data, with the goal of assessing which, if any, observed cluster properties might represent unique signatures of initial mass segregation.

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