SHORTENING OF CORE COLLAPSE TIME IN STAR CLUSTERS WITH TWO MASS COMPONENTS

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We present high–accuracy Nbody simulations of isolated star clusters consisting of two distinct mass components, m_1 and m_2, and vary their relative ratio $\mu = m_2/m_1$. The mass fraction of the more massive component to the total mass, $q = M_2/M_{\rm tot}$, is set equal to 0.1 in all cases. We determine the average star mass within a fixed "Lagrangian shell". It is found that the time of first core collapse is reduced by the ratio μ with respect to a cluster with uniform masses.

INTRODUCTION

Stars are usually formed in the community of clusters, which may range from small associations of some tens of stars (Hillenbrand & Hartmann, 1998) to very dense and rich ones containing some thousand stars such as the Trapezium in the Orion Nebula Cloud (McCaughrean & Stauffer, 1994). The most massive stars are often found near the cluster centres, indicating an undergone process of mass segregation. There are two different physical explanations for the mechanism: On one side, the fragmentation of a star forming cloud occurs with tendency of the high mass stars forming near the bottom of the potential well due to the accelerated accretion of more and more gas; they remain near their place of birth at the cluster centre from the early stages of the star forming scenario (Bonnell & Davies, 1998). On the other side, massive stars may form elsewhere and sink to the centre through two–body relaxation after the formation process has already finished (Spitzer, 1969). Both mechanisms are reasonable, but they should differ in the time scales until the cluster achieves its observed radial mass stratification. Dynamical models are challenged to answer this question by comparison with models of star formation.

SIMULATION TOOLS AND CONDITIONS

The simple case of a two–component cluster is regarded as a first step of tackling a mass spectrum to the single–component models hitherto. A pioneering work by Spitzer & Hart (1971) used Monte Carlo methods to study the evolution of a system with two types of stars. The heavy stars of individual masses m_2 were chosen five times heavier than the light ones, m_1, and they made up a fraction $q = M_2/M_{\rm tot}$ of 10% of the total cluster mass. Inagaki & Wiyanto (1984) varied this fraction q and found that the evolution is delayed for different values: For higher fractions, the massive stars play a more dominant role in the dynamics, and for smaller fractions their total number becomes too small to make significant contributions.

In this paper, we fix q throughout all models to Inagaki & Wiyanto's value, and examine the evolutionary differences for various ratios of individual masses $\mu = m_2/m_1$ ranging from 2 to 15. We use the most accurate method in order to follow the evolution of a two–mass component cluster, the direct force integration with Nbody6 (Aarseth, 1999a,b) in its special version Nbody6++ for massively parallel computers (Spurzem, 1999). Moreover, we deal with point masses without softening or merging of close particles. Close encounters are regularized, *i.e.*, the time between two integration steps is reduced for the sake of exactness. The scaling is done to standard Nbody–units (Heggie & Mathieu, 1986). In these units the crossing time of a particle is $t_{\rm cr} = t_{\rm NBU}/(2\sqrt{2})$, and the virial radius is 1.

The simulations have been performed with various particle numbers (N = 500, 1000, 2500, and 5000). Initially, all particles are distributed randomly according to a Plummer sphere, and the system is in a global virial equilibrium. Moreover, we neglect any kind of stellar evolution, external galactic field, and primordial binaries. The renunciation of stellar evolution is permissible, since this study aims to isolate the essential physical process of mass segregation; with μ being a *relative* quantity, these simulations can be applied to dynamics of any kind of self–gravitating system which does not require stellar evolution (*e.g.*, cometary fragments, asteroids or brown dwarfs).

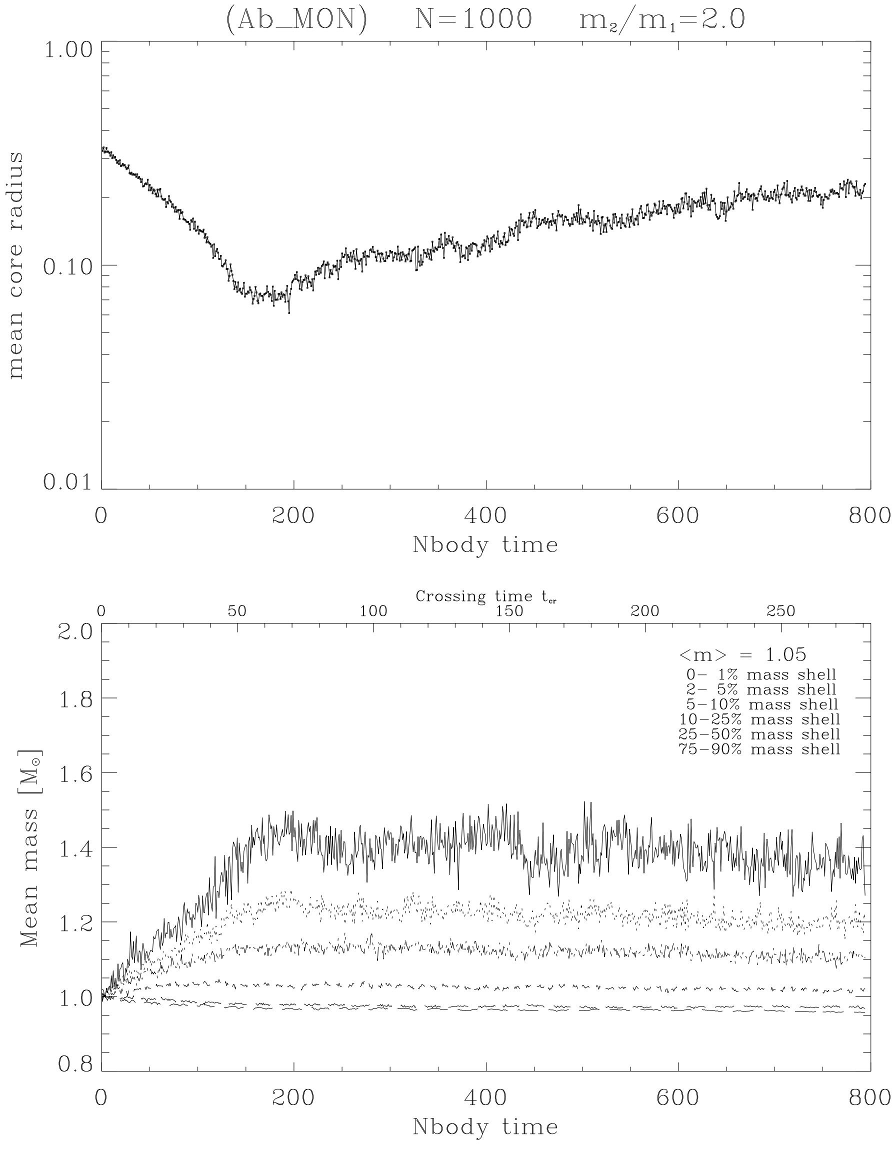

Figure 1: The time evolution of the core radius (upper panel), and the stratification of masses (lower panel) for a model with $N = 1000$ and $\mu = 2$. A conversion from Nbody time units to crossing times $t_{\rm cr}$ is given at the upper axis

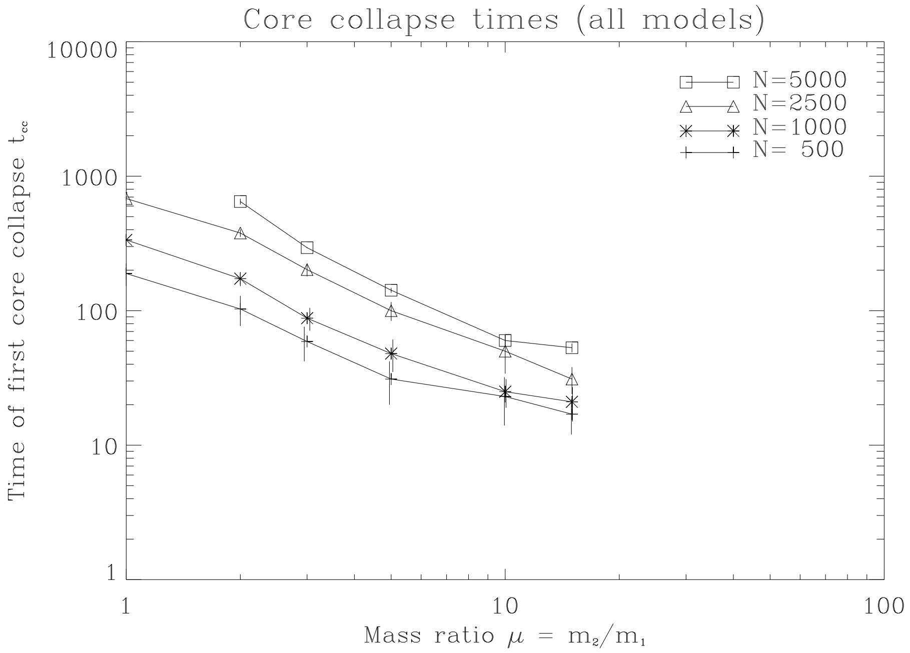

Figure 2: Shortening of the core collapse time in two–component star clusters

RESULTS

Our simulations are summarized in Table 1. Each model, depending on N and μ, is averaged over the number of particular runs given in brackets of the first column. The particular runs differ in the initial seed only, which leads to a randomized setup. Giersz & Heggie (1994) pointed out that the statistical value of such ensemble averages are well balanced. For example, a set of 40 runs containing 500 particles is statistically comparable with one single run containing 20,000 particles. Because of the large calculation efforts only some few simulations for $N = 5000$ are available.

Table 1: Times of first core collapse [in Nbody–time units]

$\mu = \frac{m_2}{m_1} =$	1	2	3	5	10	15
$N = 500$	189	103	59	31	23	17
(40×)	±36	±26	±18	±11	±9	±5
$N = 1000$	336	173	88	48	25	21
(20×)	±36	±21	±17	±13	±6	±6
$N = 2500$	683	378	202	100	50	31
(8×)	±27	±24	±22	±16	±16	±7
$N = 5000$	–	648^a	294^a	142^a	60^b	53^b
		± 32	± 2	± 6	± 6	± 4

[a]based on 2 simulations
[b]based on 3 simulations

In the field of intersection, the mean time of the core collapse and its standard deviation is given. The core collapse has been determined from the minimum core radius and the maximum of the central density. An example for the averaged evolution of the core radius is given in the upper panel of Figure 1 (model $N = 1000$ and $\mu = 2.0$).

For investigating mass segregation, the cluster has been split up into shells, in which the average mass of the particles within is computed. The lower panel of Figure 1 demonstrates the time evolution of the mean mass in the inner shells for a the same model. At the beginning the heavier masses are distributed throughout the cluster in the same way as the light masses, and all shells show a similar value of the mean mass. In the course of the dynamical evolution the innermost shell (solid line) gathers a large number of the heavier particles, and its average mass increases at the expense of the outer shells (dashed lines). The core collapse occurs at 170 Nbody-time units when the mass segregation has been largely completed. After that, a binary–driven post–collapse follows.

The results of all simulations are shown in Figure 2. It illustrates the gradual shrinking of the core collapse time with increasing μ. For all particles numbers investigated, the slope is -0.98 ± 0.06.

SUMMARY

Our results can be summarized as follows: (i) The process of mass segregation is governed by the ratio of the individual particles $\mu = m_2/m_1$. (ii) The time of core collapse is reduced by μ in comparison to the core collapse time of a cluster with uniform masses ($\mu = 1$):

$$t_{cc,\mu} \propto \frac{1}{\mu} t_{cc,1}.$$

This result is not a big surprise for experts in the field, but it has never been directly and quantitatively proven in ensemble averaged N-body models with two mass components, as in the present work. Further studies are in preparation (Spurzem, Lin & Khalisi, 2001).

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