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The influence of dynamical relaxation and tidal shocking on the evolution of star clusters

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We report results of collisional N-body calculations, aimed to study the evolution of star clusters moving on elliptic orbits through their parent galaxies. Our clusters consist of equal-mass stars and their initial density distributions are given by King-profiles. The tidal radii of the King-profiles are adjusted such that they match the tidal radii of the clusters at perigalacticon.

We study the mass-loss of the clusters under the influence of two destruction mechanisms: relaxation due to two body encounters; and tidal heating/tidal stripping due to successive pericenter passages. Tidal effects play a role in the initial phases, but their influence decreases since stars that are most influenced by the tidal field are quickly lost from the clusters. We conclude that relaxation is the dominant escape mechanism for compact clusters which do not extend their perigalactic tidal radii.

KEY WORDS stellar dynamics, globular clusters: dynamical evolution, galaxies: star clusters

1 Introduction

The evolution of star clusters in galaxies is driven by several processes. In the initial phases the removal of unprocessed gas out of which the cluster was formed and the mass-loss of individual stars are the most important destruction mechanisms. They are able to disrupt loosely bound systems due to the quick drop in cluster mass (Fukushige & Heggie 1995, Goodwin 1997).

Later, clusters dissolve under the combined influence of two-body relaxation and tidal shocks from their parent galaxy. Two-body relaxation causes stars to change their energies through mutual encounters with other cluster stars. The process is more important for low-N clusters and is efficient enough to destroy clusters moving on circular orbits within a few half-mass relaxation times (Baumgardt 2000).

Clusters on more realistic orbits are subject to gravitational shocks from the varying external tidal field. These can be either compressive, arising for example from passages through galactic discs, or disruptive due to passages near galactic bulges. Gnedin et al. (1999) have shown that tidal shocks can significantly speed up the evolution of clusters due to the changes in the stellar energies which they give rise to.

In this paper we present first results of N-body simulations of star clusters which dissolve under the combined effect of relaxation and external tidal shocks. We restrict ourselves to spherical symmetric potentials and study the evolution of clusters moving on elliptic orbits around point-mass galaxies.

2 The Simulations

All simulated clusters consist of equal-mass stars and have King $W_0 = 3.0$ density profiles. The tidal radii of the King profiles are equal to the perigalactic tidal radii of the clusters. The galaxies are modelled as point masses and the clusters move around them on elliptic orbits, starting at apogalacticon. Orbits with eccentricities between $e = 0.1$ to $e = 0.7$ are studied.

Different methods are used to follow the evolution of the clusters. We first perform fully collisional simulations with the N-body code NBODY6++ (Spurzem & Baumgardt 2000). Here, the particle number is varied from $N = 1024$ to $N = 16384$. To extend the results of the fully collisional simulations to higher N, we perform softened calculations. One set of clusters is studied with a Treecode, using the program treecode developed by Joshua Barnes. As a check, we also run a series of simulations on the Edinburgh GRAPE 3AF board with an N-body code developed by Douglas Heggie. In both cases, a Plummer softening with fixed softening length of $\epsilon^2 = 0.001$ is used. The results are matched to the unsoftened case by requiring that the relaxation time is the same in all cases. To be able to do this, the relaxation time is measured in the different cases by numerical experiments, similar to those described in Fellhauer et al. (2000).

We finally study the evolution of a cluster in which stars move through a smooth cluster potential. This simulation should give the $N = \infty$ limit, since the orbits of the stars are not changed by relaxation and tidal shocking is the only dissolution mechanism.

3 Results

Figure 1 shows the evolution of the bound mass for clusters moving on orbits with $e = 0.2$. Stars are defined to be bound if they lie within the current tidal radius of the cluster. The number of bound stars drops during the pericenter passages and remains nearly constant afterwards. The mass-loss decreases with increasing particle number, due to the increase in the relaxation time. Since even the cluster without relaxation loses stars, relaxation cannot be the only escape mechanism.

The left panel of Figure 2 shows the dissolution times calculated from the mass-loss after two orbital revolutions, assuming that the decrease in cluster mass per

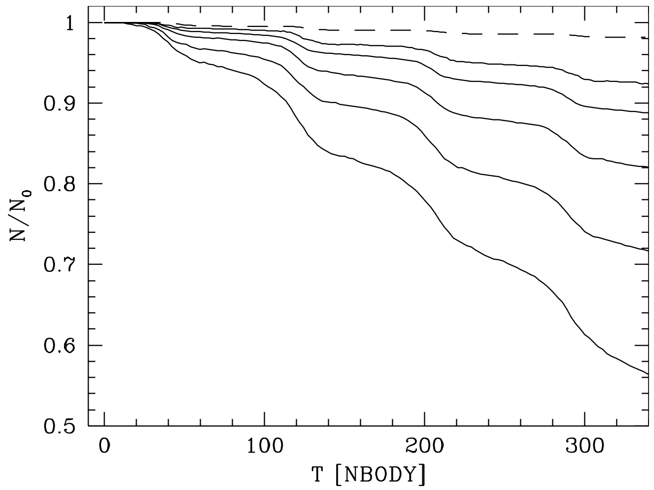

Figure 1 Fraction of bound stars for cluster moving on orbits with an eccentricity of $e = 0.2$. Shown is the evolution of clusters with (from bottom to top) $N = 1024$, 2048, 4096, 8192 and 16384 stars initially. The number of bound stars drops during the perigalactic passages and remains almost constant afterwards. Clusters with a higher particle number lose a smaller fraction of stars. The dashed line at the top shows the evolution of the relaxation-free model.

orbit is constant. They first increase linearly with the relaxation time, since relaxation is the dominant escape mechanism for stars in low-N clusters. For large N, one can see a turnover and the mass-loss approaches that of the relaxation-free model (shown by a solid line). The turnover might be due to tidal shocking, but could also be caused by the loss of a primordial fraction of potential escapers.

In order to study this question, we further follow the evolution of the clusters. The results of softened runs get unreliable by the time an unsoftened cluster with the same relaxation time goes into core-collapse, since core-collapse increases the mass-loss considerably but is much weaker and later in softened runs. We therefore use the time it takes to lose 25 % of the mass to estimate the dissolution time. In our simulations, this happens for all eccentricities before core-collapse is reached. The right panel of Figure 2 shows the dissolution times estimated this way. As can be seen, there is no sign of a levelling off at the high-N end any more. The dissolution times can be fitted by a scaling law $T_{Diss} \sim t_{rh}^{0.66}$ where t_{rh} is the half-mass relaxation time. A slope of 0.66 is very similar to the one found by Baumgardt (2000) for the circular case, in which relaxation is the only dissolution mechanism.

The run without relaxation lost 25 % of its stars at $T = 45.000$, which gives a dissolution time of $T_{Diss} = 1.8 \cdot 10^5$. Even this high value should be regarded as a lower limit, since the mass-loss rate of the relaxation free cluster decreases with time. The high initial mass-loss rate is probably due to the set-up of the clusters, which produces stars that can easily escape. After they have left, the clusters shrink in radius and are much less influenced by tidal shocking. Relaxation is therefore

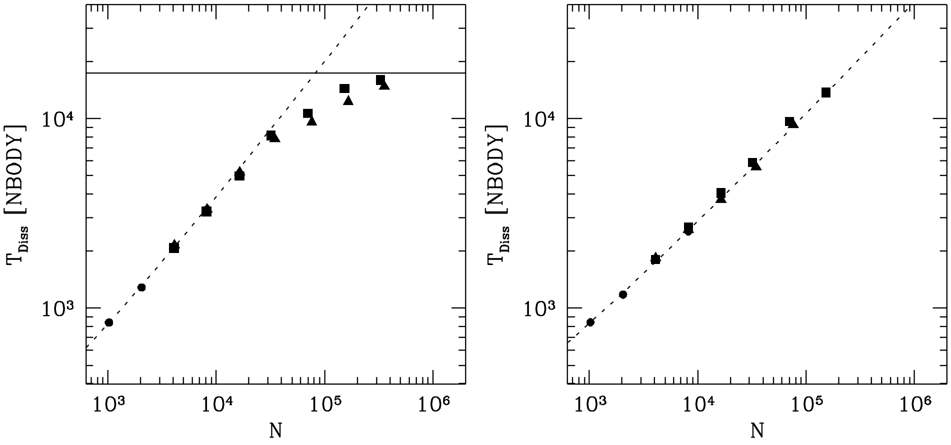

Figure 2 Lifetimes estimated after 2 cluster orbits (left panel) and after the clusters have lost 25 % of their stars (right panel) for the case $e = 0.2$. Results of the fully collisional simulations are shown with dots, softened N-body runs by triangles and results from the treecode by squares. The solid line in the left panel gives the result of the relaxation-free run. From the time it takes to lose 25 % of the stars, this runs has an estimated lifetime of at least $T = 1.8 \cdot 10^5$.

the dominant escape mechanism if $N < 10^7$. So far, we considered only the case $e = 0.2$, but we find a similar behaviour for the other eccentricities. Since most globular clusters have particle numbers smaller than 10^7, relaxation should be the dominant escape mechanism for them if they are smaller than their perigalactic tidal radii.

4 Discussion

The evolution of clusters moving on elliptic orbits around point-mass galaxies was studied. It was found that the importance of tidal shocks diminishes with time. As a result, the dominant escape mechanism for clusters limited by their perigalactic tidal radii is relaxation.

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