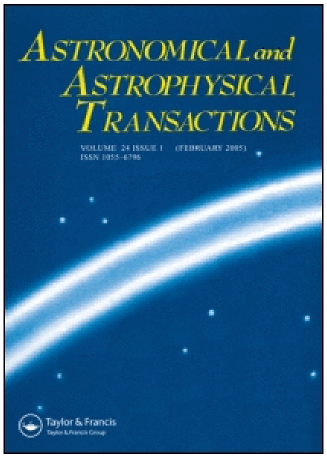

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MULTI-MASS GASEOUS MODELS OF GLOBULAR CLUSTERS WITH STELLAR EVOLUTION

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Gaseous models have proven to be a computationally cheap and reliable tool to investigate the dynamical behaviour of globular clusters. But to compete with other approaches for modelling the evolution of star clusters various important effects have to be taken into account. These are for example the dynamical effects of a stellar mass spectrum, stellar evolution, a consistent treatment of the tidal field of the galaxy, or primordial binaries. Here we report on the effects of a mass spectrum and stellar evolution on the dynamical evolution of the cluster's post-collapse evolution (gravothermal oscillations) and show how only small changes in the mass loss rate can change the internal dynamics of the cluster.

KEY WORDS Globular clusters, stellar dynamics

1 INTRODUCTION

Observations of globular clusters with the Hubble Space Telescope (HST) now provide a very deep insight into several cluster properties (see Meylan and Heggie, 1997 for a review, or for recent observations e.g. Piotto *et al.*, 1999a, b). Such observations pose great challenges to theoretical models. As far as the dynamical evolution of star clusters is concerned you have the choice between three different methods and two basic concepts. On the one hand there are N-body models, where the trajectory of every particle is integrated individually. Unfortunately, the direct simulation of such rich stellar systems as globular clusters with star-by-star modelling is not yet possible.

The gap between the largest useful N-body models ($N \leq 64000$) and the median globular star cluster ($N \sim 5 \times 10^5$) can only be bridged at present by use of theory. Here a continuous distribution function in phase space is used, thereby assuming, that when the system has a large enough particle number this is an appropriate treatment. There are two main classes of theory: Fokker–Planck models, which are based on the Boltzmann equation of the kinetic theory of gases (Cohn *et al.*, 1989; Murphy *et al.*, 1990; Einsel and Spurzem, 1999; Takahashi, 1995, 1996, 1997; Takahashi, Lee and Inagaki, 1998; Takahashi and Portegies Zwart, 1999), and gas models (Lynden-Bell and Eggleton, 1980; Bettwieser, 1983; Heggie, 1984; Louis and Spurzem, 1991; Spurzem, 1992, 1994), which can be thought of as a set of moment equations of the Fokker–Planck model, closed by a phenomenological equation of heat conduction.

2 UNEQUAL-MASS GASEOUS MODELS WITH STELLAR EVOLUTION

Having obtained promising results from the comparisons of direct high-precision N-body simulations and the simplified, especially gaseous models in the single point mass case (Giersz and Heggie, 1994a, b; Giersz and Spurzem, 1994; Spurzem, 1996; Spurzem and Aarseth, 1996), and less exhaustive but still good results for the case of unequal point mass systems (two mass components, Spurzem, 1992; Spurzem and Takahashi, 1995, and also one test calculation in Aarseth and Heggie, 1992) the time has come to improve the anisotropic gaseous models in order to get more realistic gaseous models of star clusters. Two very important aspects are the treatment of unequal-mass systems with many mass components, approximating a steady mass spectrum, and the inclusion of the dynamical effects due to stellar evolution (stellar mass loss and the generation of compact remnants like neutron stars or black holes).

In the following we give a progress report of such a project being currently undertaken. The system is divided into several mass groups, consisting each of particles with the same individual mass, thus modelling the effect of a mass spectrum. For each of the mass groups the full set of moment equations is solved, which is very similar to standard gasdynamical equations; the different components are coupled by local collisional terms, which have been calculated self-consistently and analytically in the Fokker–Planck approximation, and assume a locally anisotropic Maxwell–Boltzmann distribution (Schwarzschild–Boltzmann) for the background distribution of field stars.

To get a first impression of the consequences of a mass spectrum and stellar evolution in an anisotropic gaseous model we used a preliminary and simple approach for modelling the effects of stellar evolution. We used an IMF $\propto m^{-2.5}$ (Salpeter $\propto m^{-2.35}$) and a total particle number of $N = 5.0 \times 10^5$. After a given time $\tau_{\rm pre}(M_i)$ the stars of one mass component will start changing their mass to a given remnant mass $M_f(M_i)$ (details are given in Deiters and Spurzem, 2000). All the ejected mass is instantaneously lost from the cluster. This assumption is justified due to the low escape velocities compared to the velocities of the stellar winds.

In our first tests we used a model with seven mass groups (M_i = 0.13, 0.38, 0.71, 1.0, 1.5, 2.5 and $4.0 M_\odot$). We were interested to find out how the central density is changing with time. But instead of a normal core collapse with or without gravothermal oscillations (Bettwieser and Sugimoto, 1984), we observed intermittent oscillations. The intermittence seems to be related to the assumed evolution time $\tau_{\rm pre}(M_i)$ of the mass groups and thus to the mass loss rate.

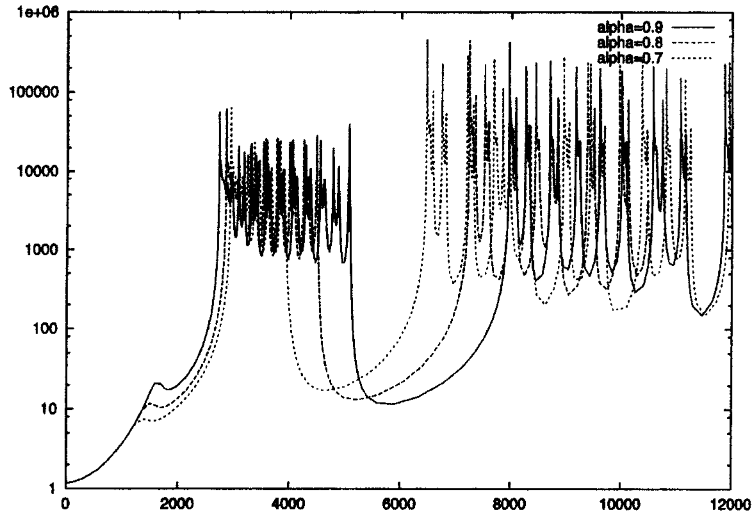

Figure 1 Central density versus time plot for three 7 component gaseous model with different α (see text for details). Time and density are given in computing units. To get the approximate time in years you have to multiply by 10^5, for the density in g cm^{-3} multiply by 10^{-18}

To see this effect in more detail, we changed the mass loss rate directly in our code: now the mass group starts to lose its mass at $\alpha \times \tau_{\rm pre}(M_i)$, with $\alpha = 0.7$, 0.8, 0.9, which makes the mass loss rate smoother. A smaller α corresponds to a more extended mass loss time for a mass group. Of course this should not and can not mimic real stellar evolution, but provides a simple tool to investigate the effects of the mass loss rate for our intermittent oscillations. The evolution of the central density is shown in Figure 1 for the three different α. This result gives further evidence for the importance of a correct and detailed description of mass loss when one is interested in the internal dynamics of globular clusters.

3 FUTURE PLANS

There are two directions to investigate further the dynamical evolution under the influence of mass loss: one possibility is to increase the number of mass groups. Unfortunately this is a rather serious problem from the computational point of view: For N_m mass groups we presently solve $6 \times N_m + 1$ equations simultaneously. A 14 component run for example took several weeks on one of our fastest workstations, so that we had to think about a different approach to solve the system of equations of our gaseous model. One possibility is to decouple the dynamics of each mass group from each other – as in the Fokker–Planck models – and solve the equations for each mass group separately. In this form one loses some accuracy, thus requiring smaller time steps, but the code is parallelizable with respect to the number of mass groups. The second point, which can and should be combined with the parallel approach is to include a more detailed and properly interpolated description of stellar evolution in our gaseous model, which provides correct time scales for the stellar mass loss even for more massive stars. Furthermore we want to follow the evolution of binaries in detail with a stochastic approach and produce theoretical Hertzsprung–Russell diagrams for direct comparison with observations.

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