EVOLUTION OF GLOBULAR CLUSTERS WITH TIDALLY-CAPTURED BINARIES THROUGH CORE COLLAPSE

Thomas S. Statler and Jeremiah P. Ostriker

Princeton University Observatory

Haldan N. Cohn

Indiana University

We present calculations of globular cluster evolution performed by a modified Fokker-Planck approach, in which binaries formed by tidal capture are followed explicitly, along with subsequent heating mechanisms. The cluster is simulated by a two component model, using the cross sections of Press and Teukolsky (1977) for tidal capture, those of Hut (1984) for the single-binary encounters and for distant binary-binary encounters, and those of Mikkola (1983) for the strong binary-binary encounters. The initial state of the cluster is a Plummer model with $N = 3 \times 10^5$ and scale radius $r_0 = 1.13\,\mathrm{pc}$. All stars are identical, with mass $M_* = 0.7 M_\odot$ and $R_* = 0.57 R_\odot$. This gives an initial core radius $r_c = 0.8\,\mathrm{pc}$, and one-dimensional dispersion $\sigma = 11.6\,\mathrm{km\,s^{-1}}$. All binaries are assumed to be identical, with separation $a = 2.5 R_*$. There are no binaries in the cluster initially. Additional important effects, such as tidal truncation, tidal shocks, stellar evolution and mass loss, and stellar mergers, are not included.

The number of binaries expected to form prior to core collapse can be estimated by integrating the formation rate over the self-similar single-component solution (*e.g.*, Cohn 1980). One finds $N_b = 90[N(0)/\ln\Lambda(0)](v_h/v_*)^{1.8}$, where v_h is the rms velocity at the half-mass radius and v_* is the escape velocity from the surface of the star. For the parameters typical of globular clusters, this gives $N_b \sim 10^3$. Fig. 1 shows the evolution of the core and half-mass radii in the full calculation with all heating processes included. The cluster bounces at a central density of about $1.5 \times 10^8\, M_\odot\,\mathrm{pc}^{-3}$. Bounce occurs when the core has shrunk by only a factor of 100 in radius, and several hundred stars remain in it. By comparison, the first hard binary formed by three-body processes is expected to appear when $N_{core} \sim 40$. We find that the three-body formation rate is always less than 10^{-4} of the tidal capture rate until late in the re-expansion.

A criterion for core bounce may be derived by equating the gravitational heating (due to ejection of stars) of the binaries to the losses to single stars in the core. One finds that, ignoring the time variation of $\ln\Lambda$, the core bounces when the ratio of central to half-mass dispersion reaches a value which is quite independent of cluster parameters. The numerical results indicate $(v_0/v_h)_{bounce} \approx 1.3$. During the re-expansion, gravitational heating always dominates over direct heating because the central potential becomes shallower and it becomes progressively easier to eject stars.

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At late times, the evolution of the half-mass point is governed by the local conduction rate; this and conservation of energy lead to r_h scaling as $t^{2/3}$ and v_h as $t^{-1/3}$. Since the cluster evolves on a time-scale of many half-mass relaxation times, the region interior to r_h is very nearly isothermal, so that v_0 also scales as $t^{-1/3}$. Most of the energy from gravitational heating is deposited far out in the cluster, so that *heat is conducted inward* from the half-mass point into the core. The evolution of the central density and core radius is not easy to understand, and may be due to the (necessary!) non-self-similarity of the solution, and/or to cumulative numerical errors and the large time step employed. When a much smaller time step is used, this solution is found to become unstable to large-amplitude gravothermal oscillations (see Cohn, this volume).

In the idealized case of an isolated cluster made entirely out of main-sequence stars, these calculations show that binaries formed by tidal capture dominate the dynamics of core bounce and re-expansion. The applicability of this result to real systems is limited by our exclusion of processes known to be important, such as tidal effects in superelastic encounters (McMillan 1986) and stellar mergers and mass loss (Lee 1986). Nevertheless, it is clear that the objects formed by tidal capture, whether they be binaries or merged stars, influence the dynamics of the cluster long before three-body binaries can. In other words, for a cluster made predominantly of normal stars, it is the effects of intercations between stars of finite size, rather than point-mass effects, that dominate the dynamics as the cluster passes through core collapse.

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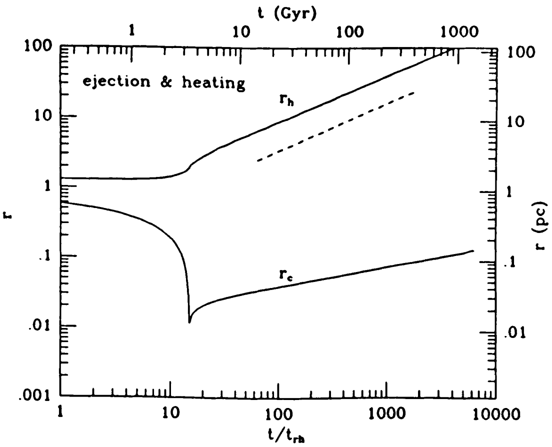

Fig. 1. Evolution of the core and half-mass radii. The dashed line indicates a logarithmic slope of 2/3.

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