N-BODY SIMULATIONS OF REALISTIC OPEN CLUSTERS

Elena Terlevich
Royal Greenwich Observatory
Herstmonceux Castle
UK

ABSTRACT. N-body simulations of dynamical evolution of open clusters have been computed with the purpose of comparing them with observations. Special effort has been put into reproducing conditions present in galactic clusters. Most of the models contain 1000 bodies with masses following a power-law mass function of slope $\alpha = -2.75$ and mean mass $0.5M_\odot$. Neutron stars or white dwarfs (depending on the initial stellar mass) are generated by instantaneous changes in individual masses, when stars reach the end of their main sequence life. Close approaches between particles are treated by a two-body regularization technique that allows to follow binary evolution in detail. Two types of tidal perturbation are considered: a smooth linearized galactic tidal field is simulated assuming that the clusters move in a circular orbit at 10kpc from the galactic centre; transient shocks are simulated by encounters with extended interstellar clouds of different mass-spectrum, densities and space concentration. It is found that the combined action of evolutionary mass loss and binaries (when the cluster has a realistic mass function) is enough to arrest the core collapse. Tidal heating shapes the halo of the cluster. There is good agreement with the observed density and velocity distribution of open clusters and with reported changes in their mass function.

1. INTRODUCTION

Assuming that the observed age distribution of open clusters is not biased by selection effects (Wielen 1971; Lyngå 1982), that the rate of formation in the galaxy has been constant for the last few billion years and that the lifetime of the clusters depends on individual parameters but not on the time of formation, the total lifetime of galactic clusters can be deduced from their observed age distribution (Oort 1958).

The purpose of this work is to put limits to the conditions that determine the total lifetime of clusters: total initial mass, stellar mass distribution, external forces, evolutionary mass loss and internal dynamical evolution; using new observational and theoretical

J. Goodman and P. Hut (eds.), Dynamics of Star Clusters, 471–475.

parameters. Both the asymmetry involved in these effects and the small number of stars concerned, make open clusters ideal targets for N-body solutions. The models described in this paper have been produced using Aarseth's N-body code in which the equations of motion are regularized in the case of close encounters between pairs of particles (Aarseth 1985). To produce realistic simulations of open clusters, the following effects have been included in addition to direct N-body interactions: mass function of the cluster components, mass loss due to stellar evolution, galactic tidal field and transient tidal shocks produced by passing interstellar clouds. In order to compare the results with observations, careful consideration has been given to the selection of the initial parameters which I describe in the following section. A detailed analysis of the initial conditions and the method in general is given elsewhere (Terlevich 1983).

2. THE MODELS

The equations of motion used correspond to the direct N-body solution (exact newtonian potential) plus tidal terms assuming that the cluster follows a direct plane circular orbit with uniform velocity at 10kpc from the galactic centre, in an axially symmetric tidal field (Wielen 1965; Hayli 1967). For close two-body encounters the equations of motion are regularized according to a Kustaanheimo-Stiefel scheme. The critical distance for regularization is given by the force between two approaching particles relative to the perturbing force by the rest.

The initial mass function chosen is assumed to follow a power law. The values adopted for the slope α, the mean mass <M> and the mass range are taken from published observations of open clusters (Taff 1974; Tarrab 1982; van Altena 1966). Table I shows the relevant parameters for selected models.

Table I- Model parameters

MODEL	N	<R> pc	α f(M)	R_t pc	$T_{1/2}$ 10 yr	T_{cr} 10 yr
I	250	2	2.35	7	174	10.8
IV	500	2	2.35	9	252	7.6
V	1000	2	2.35	11	420	5.4
VI	1000	2	2.75	11	460	5.5
VII	1000	3	2.75	11	365	9.9
IX(1)	1000	2	2.75	11	460	5.4
XII(2)	1000	2	2.75	11	770	5.4
XIII(3)	1000	2	2.75	11	30	5.4
XV	1000	2	1.10	27	47	1.4

Notes to Table I-(1) Includes encounters with Spitzer's standard clouds. (2) Initial mass segregation: more massive stars outside; Q=0.5. (3) Identical to Model VI until T=100 million years when it suffers a catastrophic encounter with one GMC.

https://doi.org/10.1017/S0074180900147709 Published online by Cambridge University Press

All but model XV (with $\langle M\rangle=7M_\odot$) have a $\langle M\rangle$ of $0.5M_\odot$; $\langle R\rangle$, sometimes called the virial radius, has the meaning of a mass weighted harmonic radius averaged over time; R_t is the tidal radius (King 1962). Stars at a distance of $2R_t$ are considered escapers. $T_{1/2}$ is the time when half of the initial number of stars have escaped from the cluster. T_{cr} is the crossing time defined as $2\langle R\rangle/(r.m.s.)v$.

The initial coordinates follow a random spherical distribution with density proportional to $1/r^2$. The initial velocities are isotropic. To simulate violent relaxation through an initial contraction of the cluster (Henon 1967) the parameter Q relating kinematic and potential energy is chosen as 0.25 for all the models but one; for a virialized system Q=0.5.

In the range of masses that is relevant for open clusters (0.3 to $15M_\odot$) processes of mass loss like supernova events or formation of planetary nebulae can be assumed to occur on time scales which are very short compared with the characteristic dynamical times for the cluster. The pattern used for instantaneous mass loss is as follows: at the end of its mass dependent main sequence life, a star suffers a single mass loss event. If its mass is lower than $6M_\odot$ it becomes a $0.7M_\odot$ white dwarf. Otherwise it becomes a supernova with a $1.5M_\odot$ remnant to which high velocity is given (four times the r.m.s. velocity of the stars in the cluster) to account for the recoil effect.

Standard HI clouds (Spitzer 1958) are simulated as polytrope spheres of index 5, with masses between 50 and 500 $M_\odot$ and half mass radii of 3.6 to 7.7 pc. Five clouds are confined inside a boundary of radius R =28pc to give a number density of 5.4×10^{-5} pc^{-3} . A cloud reaching the boundary is replaced by another at a random position over the sphere, using a "cloud rise" and "cloud set" procedure to avoid sudden changes in the force. The three dimensional velocity of the clouds is taken at random from a maxwellian distribution with mean value $\langle V\rangle$=10km/sec and dispersion σ=6.25km/sec. The mean field inside the boundary is subtracted when including the force due to the individual clouds. Models XIII suffer a single encounter with one Giant Molecular Cloud of $1\text{-}5\times10^4$ $M_\odot$ and 10pc radius, approaching the cluster from a distance of 75pc at a speed of 5km/sec (Solomon, private communication).

3. DISCUSSION

Mass loss from the stars affects the cluster in various ways. The most obvious one, though it seems to be only marginal, is the effect on the cluster lifetime. Model V, losing more mass up to half-life due to its initial mass function, disrupts quicker; model XII, for which the energy increment due to mass loss is smaller (because the more massive stars are originally in the outer regions) lives longer. It is evident from the analysis of model XV that if clusters originally containing around a thousand stars are going to survive as we see them today, they cannot have formed with a mass function much flatter than the Salpeter one.

More striking is the effect of stellar evolution on the density distribution and the time evolution of the mass function, through a combined action with binary activity. The components of dynamically formed binaries, tend to be the most massive stars in the cluster and therefore mass loss occurs frequently among them. This causes the pair to lose binding energy inducing frequent change of components. As a result, binaries attain a larger cross section and remain "active" for longer periods (avoiding the final hardening process, Heggie 1972) in scattering light stars towards the halo. Consequence of this process are: preferential depletion of light stars, arrest of the core collapse and enhanced mass segregation. The contraction of the core can be analysed by plotting the time evolution of the radii containing 5, 10, 50 and 90% of the cluster mass (Figure 1). Figure 2 shows the density profile for four mass groups in model VI, where the different behaviour of light and heavy stars in the core and halo are apparent. In order to by-pass the small number problem, five consecutive time steps have been combined in figure 2.

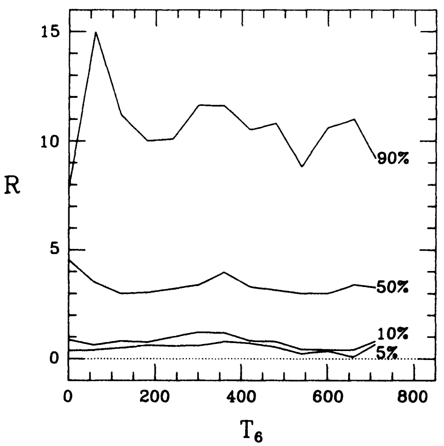

Figure 1-Evolution of the radii for 5, 10, 50 and 90% of the cluster total mass.

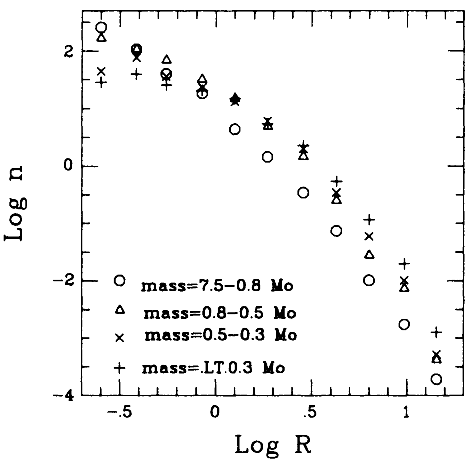

Figure 2-Density profiles for Model VI at time=580 million years.

The tidal field has two effects on the cluster. The equipotential surfaces around a non-isolated cluster are non spherical. There is a compression in the direction perpendicular to the galactic plane (Z). Figure 3 shows the projection on the (X.,Z) plane of model VI at half life, where this flattening is most notorious. X is the direction towards the galactic centre. The second effect is a "heating" of the halo by the galactic tidal field and by tidal shocks. Figure 4 shows the tangential velocity dispersion as a function of distance to the cluster centre, for three models with tidal heating. The difference in slope with the one obtained for isolated models (Aarseth 1974) is notorious. In spite of the difficulties inherent in velocity distribution studies of haloes in open clusters, a similar flat slope seems to be observed (van Leeuwen 1983). A more detailed comparison with observations is to be published elsewhere (Terlevich and van Leeuwen, in preparation).

An inspection of Table I shows that the lifetime of open clusters is not affected by encounters with HI clouds, but an eventual encounter with a giant molecular cloud is catastrophic (Wielen, this symposium).

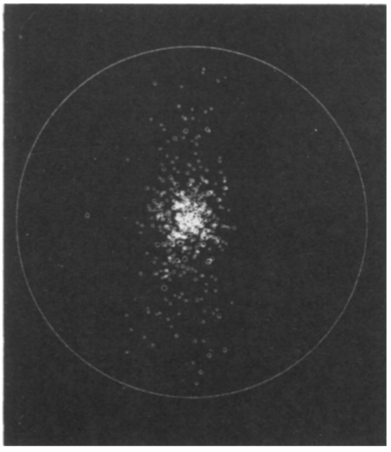

Figure 3-Tidal flattening; (x,z) projection of model VI at half life. $R=2R_t$.

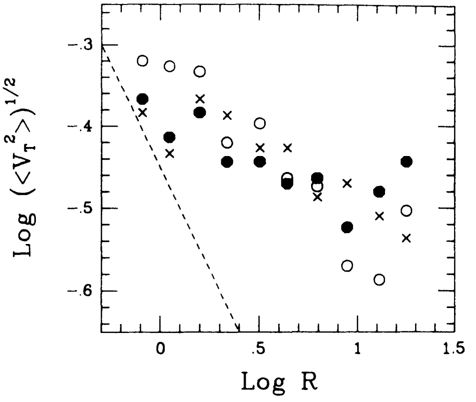

Figure 4-Tangential velocity disp. as a function of radius for models with tidal heating. O:model VI; ●:model VII; X:model IX; straight line for isolated models (Aarseth 1974)

It is a pleasure to thank the IAU and the Cambridge Philosophical Society for financial support to attend this Symposium.

REFERENCES

Aarseth, S.J. 1974, A.and A., 35, 237
Aarseth, S.J. 1985, to appear in Multiple Time Scales by J.U. Brackbill and B.I. Cohen, Academic Press, N.Y.
Altena, W.F. van 1966, A.J. 71, 482.
Hayli, A. 1967, Bull.Astr. (3) 2, 67.
Heggie, D.C. 1972, Ph.D. Thesis, Cambridge University.
Henon, M. 1967, Mem.Soc.Roy.Sci.Liege, Series 5 15, 243.
King, I.R. 1962, A.J. 67, 471
Leeuwen, F.van 1983, Ph.D. Thesis, Leiden.
Lyngå, G. 1982, A.and A. 109, 213.
Oort, J.K. 1958, Stellar Populations (ed.D.J.K.O'Connell), Vatic. 5, 63
Spitzer, L. 1958, Ap.J. 127, 17.
Taff, L.G. 1974, A.J. 79, 1280.
Tarrab, I. 1982, A.and A. 109, 285.
Terlevich, E. 1983, Ph.D. Thesis, Cambridge University.
Wielen, R. 1965, Ph.D. Thesis, Heidelberg.
Wielen, R. 1971, A.and A. 13, 309.