

Introduction to Running Simulations with NBODY4 and NBODY6

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Software (including source code) and documentation downloads:

www.ast.cam.ac.uk/~sverre/web/pages/home.htm

This manual was designed and compiled by Vicki Johnson www.NBodyLab.org

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1. Introduction

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Over the past ten years, my colleagues and I have developed NBODY4 and NBODY6 for star cluster simulations. NBODY6 runs on workstations and laptops. NBODY4 runs with GRAPE supercomputer hardware, most recently the GRAPE-6 and GRAPE-6a. NBODY4 and NBODY6 are Hermite individual time step codes with two-body (KS) regularization and many other features. Both are described in my book Gravitational N-body Simulations Tools and Algorithms [AA2003], on my software downloads page and in research papers.

This manual is an introduction to running simulations with NBODY4 and NBODY6. I invite you to write me and tell me about your research interests. I'll be happy to assist you.

-- Sverre sverre@ast.cam.ac.uk

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2. Guidance on initial parameters

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This section provides general guidance for choosing parameters for several types of NBODY4 and NBODY6 simulations, such as a cluster density model, enhancing a star cluster model with primordial binaries, merging two clusters, studying the effect of an external massive perturber on a thin planetesimal disk, simulating evolution of a dominant binary, and scaling user defined input models.

To begin a simulation, a small input file initializes simulation options and integration parameters relating to accuracy and output control. Some of these simulation options are denoted by KZ1, KZ2... KZ40. The options and parameters are described in detail in sections 5, 6 and 13.

Cluster density model

A convenient cluster density model can be generated with $N=1000$ members and $KZ5 = 1$ which gives an isotropic Plummer model. Approximate equilibrium is achieved by setting $Q = 0.5$ while smaller values lead to initial collapse and an early core-halo configuration. As for suitable output times, try $DTADJ = 2$ for energy check interval and $DELTAT = 10$ for producing main results. The termination time, $TCRIT$, should be consistent with the maximum CPU time (in minutes) given by $TCOMP$.

Initial mass function

The initial mass function (IMF) may be generated in several ways using option $KZ20$, the simplest being a power-law distribution in decreasing order with exponent $ALPHA = 2.3$ and $KZ20 = 1$. Upper and lower mass limits are specified by $BODY1$ and $BODYN$ in solar mass units which are adjusted to yield a specified average, $ZMBAR$.

2. Guidance on initial parameters

Primordial binaries

More realistic star cluster simulations can be made by including a population of primordial binaries. The optional procedure $KZ8 = 1$ or 3 requires an extra input line after the virial ratio as shown on page 13. With a length unit scale factor $RBAR = 1$ pc, the maximum semi-major axis in AU becomes $a = 2.0D+05*SEMI$ which gives a period of $(a^3/MTOT)^{0.5}$ yr for binary mass $MTOT$ in M_{sun} . The minimum size, $AMIN = SEMI/RANGE$, should not be too small - the solar radius is 0.005 AU. If $ECC < 0$, the eccentricities are randomized with a 'thermal' distribution and average value = $2/3$. Since the pericentre distance is given by $a*(1 - e)$ and stellar radii tend to increase with time, the overlapping collision condition may be satisfied. In this case a new composite star is created (still conserving total energy). A variety of mass functions are available for $KZ20 > 1$, with the binary components selected independently from several types of IMF according to option values ($KZ20 = 4$ is recommended). When binaries are included, the most massive single star has identity $2*NBIN0 + 1$ and is usually more massive than the first binary component with identity 1. Note the meaning of the input value N here. Thus the number of single stars is $NS = N - 2*KS$ for KS hard binaries. Hint on input parameters: take $RMIN = 2*SEMI$ if possible in order for all hard binaries (but $RMIN < 1/N$) to be regularized initially. The choice $KZ8 = 3$ instead of 1 produces a binary output file `OUT9` containing the following quantities: binding energy, eccentricity, central distance, masses (solar), period (in days) and stellar type, ranging from 0 to 14 according to initial mass and age.

Merging of two clusters

The merging of two clusters is an interesting topic for study. The relevant initial conditions are given by $KZ8 = 2$ which distributes two Plummer spheres in bound orbit. Now the initial separation, APO , and orbital eccentricity, ECC , must be specified and read after the IMF parameters as shown on page 12. This produces a cluster binary orbit with semi-major axis $APO/(1+ECC)$. The membership of the second Plummer model, $N2$, and scale factor, $SCALE$, are also read here.

2. Guidance on initial parameters

External massive perturber on a thin planetesimal disk

Another optional procedure (KZ5 = 3) includes the effect of an external massive perturber on a thin planetesimal disk in the XY-plane. The planetesimals are distributed within a ring from 0.5 to 1.0 in circular orbits around the Sun, with a small total mass $0.001 \cdot M_{\text{sun}}$. The initial separation, APO, and predicted minimum distance, DMIN, are in N-body units. To avoid possible numerical problems due to large mass ratios, it is recommended to choose DMIN well outside the disk radius of 1. Since the length unit may be taken as 1 AU (Earth-Sun distance) here, the scale factor RBAR is converted from pc to AU by $1.0/2.0 \times 10^5$ in order to obtain the correct physical time. The choice of elliptic, parabolic or hyperbolic perturber orbit is governed by the eccentricity. Thus for hyperbolic two-body motion, $ECC > 1$ and the binding energy in all cases is proportional to $-1/SEMI = (ECC - 1)/DMIN$. The initial velocity is adjusted to the specified periastron distance DMIN ($< APO$) for the given energy. Since the disk system is displaced from the centre of mass, an external tidal field is not appropriate and this option is turned off. Also note that the standard scaling by the virial ratio Q is bypassed. Some suggested input values: APO = 6, ECC = 1.1, DMIN = 3, SCALE = 0.5 and TCRT=20. The total time for a parabolic passage can be estimated from $T_p = 2 \cdot DMIN^{1.5} / (2 \cdot MTOT)^{0.5}$, with $MTOT = 1 + SCALE$. The time in yr is then $T_p / 2 \cdot \pi$ or $TIME / 2 \cdot \pi$. This calculation is best done with conservative regularization parameters: DTMIN = 1.0×10^{-5} , RMIN = 1.0×10^{-4} , KZ16 = 0. From the theory of stellar dynamics, eccentricity is more sensitive to change than energy in fly-by systems. APO, ECC, DMIN and SCALE are specified on an input line as shown on page 12. Total disk energy, EDISK and average eccentricity, DISP are written to a file every output time.

Evolution of a dominant binary

An option is also included for studying the evolution of a dominant binary. As in the other special cases, KZ5 (= 4) is used to read a simple extra input line defined on page 12. Note that the initial value of the semi-major axis is changed a bit by the final scaling of coordinates and velocities. A good choice of dominant masses (in units of the average mass) might be around 25. The binary is placed at the cluster centre with no overall velocity. The semi-major axis (a), binding energy ($-M1 \cdot M2 / (2 \cdot a)$), cluster energy and eccentricity are written to a file every output

2. Guidance on initial parameters

time (DTADJ) provided at least one of the components is original. The evolution of the binding energy and effective cluster energy is plotted at the end, as well as the eccentricity. It is recommended to exclude stellar evolution mass loss (KZ19 = 0) for heavy binary components. Also note that an energetic binary may escape from the cluster after a strong interaction. The case of two free-floating bodies may be studied by taking $ECC > 1$, when the masses M1 and M2 are assigned to the two first cluster members. If significantly heavier than the average, a dominant binary may form following a stage of mass segregation. However, for some mass choices and values of TCRIT the binary plot may not appear.

Other parameter considerations

It is useful to distinguish between the integration itself and the purpose. For a standard test run, the main parameters in the first category may be taken as $ETA = 0.02$ (dimensionless time-step factor), $QE = 2.0D-05$ (relative energy tolerance), $ETAU = 0.2$ (regularization time-step factor). It may be a good idea to reduce ETA for small systems (e.g. $ETA = 0.005$ for $N < 100$). Other regularization parameters are assigned by the code with option $KZ16 > 0$. For a standard isolated cluster simulation, choose $KZ14 = 0$, while $KZ14 = 1$ specifies a circular orbit in a galactic tidal field with cluster half-mass radius near $RBAR$ pc. Note that the value of $RBAR$ should be consistent with the total cluster mass. A reasonable value would be 1 pc for $N = 1000$.

User defined input models

More experienced users may want to employ their own initial conditions. This can be achieved by generating a complete data file containing mass, position and velocity for each member. The data are scaled to the standard total energy (-0.25) and total mass (1.0), with velocity magnitudes adjusted by the input parameter Q for $KZ22 = 2$. There is no scaling with $KZ22 = 3$ which therefore requires the data set to be consistent (but without restriction on the masses).

3. Research projects that have used NBODY4

3. Research projects that have used NBODY4

The Cambridge GRAPE-6 has been used with NBODY4 for a variety of N-body simulations. The study of realistic star clusters is concerned with modelling relevant aspects of stellar evolution combined with consistent dynamics. Typical models of rich open clusters studied have 30,000 single stars. Such calculations may require a month's dedicated effort in order to describe the behaviour until complete dispersal. Results of more complete models with up to 12,000 stars and 12,000 binaries have been compared with an actual cluster in order to understand the complex interplay between astrophysical processes and dynamics (Hurley et al., *MNRAS*, 363, 293, 2005). Most of these calculations were made at the American Museum of Natural History (Hurley et al. *MNRAS* 355, 1207, 2004).

An application to binary black hole evolution in stellar systems containing some 240,000 particles proved interesting when relativistic effects were included (Aarseth, *Astrophys. Space. Sci.*, 285, 367, 2003). Other simulations have been concerned with studying the evolution of core radii in small globular clusters (Wilkinson et al., *MNRAS*, 343, 1025, 2003) and the formation of stable hierarchical systems (Aarseth, *IAU Colloq.* 191, 2003).

4. Suggested simulations

1. Two unequal Plummer models with higher mean density in the second.
2. Comparison of escape rate for equal masses versus general IMF.
3. Study the remnant bound core for positive total energy ($Q = 1.1$).
4. Time of significant binary formation as function of N ($EB/E > 1/N$).
5. Compare energy errors by varying random seed ($DTADJ = 2$, $TCRIT = 10$).
6. Plot radii of mass fractions for initial collapse ($Q = 0$, $KZ7 = 3$).
7. Mass segregation (two specific mass groups; input with $KZ22 = 2$ or 3).
(Hint: look at mean mass in the core as function of time: MC/NC .)
8. Study the effect of one dominant binary ($KZ5 = 4$, extra input).
9. Binary formation of two free-floating bodies ($KZ5 = 4$, $ECC > 1$).

5. Input file summary for NBODY4 and NBODY6

5. Input file summary for NBODY4 and NBODY6

This table summarizes the input parameter file for NBODY4. It will be useful to print this page for reference. Key parameters are explained in the next section.

NBODY4 Parameters	Suggested Defaults
KSTART TCOMP GPID	1 10.0 0
N NFIX NCRIT NRAND NRUN	1000 1 5 50000 1
ETA DTADJ DELTAT TCRT QE RBAR ZMBAR	0.02 2.0 10.0 100.0 2.0D-05 1.0 0.5
KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10	0 0 1 0 1 0 5 0 0 0
KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20	0 0 0 0 1 0 0 0 3 0
KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30	1 0 2 0 1 2 0 0 0 2
KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40	0 0 0 0 0 0 1 0 0 0
DTMIN RMIN ETAU ECLOSE GMIN GMAX	1.0E-05 1.0D-04 0.2 1.0 1.0E-06 0.001
ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0 DTPLOT	2.3 10.0 0.2 0 0.02 0 10.0
APO ECC N2 SCALE (Line inserted only when KZ5=2)	6.0 0.5 500 .5
APO ECC DMIN SCALE (Line inserted only when KZ5=3)	6.0 1.1 3 .5
SEMI ECC M1 M2 (Line inserted only when KZ5=4)	1.0D-03 0.5 25.0 25.0
Q 0 0 0	0.5 0 0 0
SEMI ECC RATIO RANGE 0 0 0 (Above line inserted only when KZ8=1 or 3)	0.0005 -1.0 0.0 100. 0 0 0

NBODY6 Parameters

The parameter file for NBODY6 is very similar to NBODY4 (see define.f in both code distributions). Two input lines differ from the above:

```
N NFIX NCRIT NRAND NNBMAX NRUN          1000 1 5 50000 95 1
ETAI ETAR RS0 DTADJ DELTAT TCRT QE RBAR ZMBAR 0.02 0.03 0.3 2.0 10.0 100.0 2.0D-05 1.0 0.5
```

and NBODY4's KZ25 and KZ37 map to NBODY6's KZ12 and KZ18, respectively.

6. Selected input parameters

6. Selected input parameters

Definition of input parameters for experimentation:

TCOMP	Maximum computing time in minutes
N	Total particle number (singles + binary c.m).
NRAND	Random number seed to generate different conditions for KZ5 options.
TCRIT	Termination time (N-body units).
NCRIT	Final particle number (alternative termination criterion).
DTADJ	Time interval for energy check, parameter adjustment and plotting (N-body units). Integer value recommended. Recommend TCRIT be evenly divisible by DTADJ.
DELTAT	Output time interval (N-body units). Recommend DELTAT be evenly divisible by DTADJ. Recommend TCRIT be evenly divisible by DELTAT.
ETA	Time-step convergence parameter for total force polynomial.
QE	Relative energy tolerance. Calculations are halted if $DE/E > 5*QE$.
RBAR	Virial cluster radius in pc (set = 0 for isolated cluster; = 1 assumed for isolated cluster to get nominal time in Myr).
ZMBAR	Mean mass in solar units (nominal value 1.0 if 0).
DTMIN	Time-step criterion for regularization search.
RMIN	Distance criterion for regularization search.
ALPHA	Power-law index for initial mass function (used if $KZ20 < 2$). For choosing a general IMF the traditional (Salpeter 1953) value is $ALPHA = 2.3$.
BODY1	Maximum particle mass (solar mass units before scaling).
BODYN	Minimum particle mass (solar mass units).

6. Selected input parameters

NBIN0	Number of primordial binaries. See KZ8 for related parameters.
EPOCH	Epoch of star formation (in Myr; < 0 gives increased age).
DTPLOT	Plotting interval (N-body units).
KZ3	Output of N-body evolution for display and downloads. For each N rows of $m x y z vx vy vz$.
KZ5	<ul style="list-style-type: none"> • =0: Uniform and isotropic sphere. • =1: One Plummer sphere. • =2: Two Plummer models in orbit. Insert extra line (as shown in red in section 5), with parameters <i>APO ECC N2 SCALE</i> as defined in the KZ5=2 table on page 12. • =3: Model the effect of a passing perturber on a planetesimal disk. Insert extra line (as shown in red in section 5) with parameters <i>APO ECC DMIN SCALE</i> as defined in the KZ5=3 table on page 12. • =4: Include two bodies as a binary or free-floating members. Insert extra line (as shown in red in section 5), with parameters <i>SEMI ECC M1 M2</i> as defined in the KZ5=4 table on page 12.
KZ7	Radii of mass fractions (=2,4 as log10), density and velocity as function of average radii in increasing shells (=5).
KZ8	Primordial binaries (=1; >=3: special binary output in OUT9). Also set KZ20 and NBIN0. Insert extra line (as shown in red in section 5), with parameters <i>SEMI ECC RATIO RANGE 0 0 0</i> as defined in the "KZ8=1" table on page 13.
KZ14	External force (=1: linearized; -1: cutoff; =2: point-mass galaxy; =3: point-mass + disk + logarithmic halo in any combination). A tidal tail simulation requires careful construction of an extra input line; a template is included in the NBODY6 distribution. When used, it allows other values for KZ3.

6. Selected input parameters

KZ15	Efficient treatment of stable triples and quadruples (=1: standard; =2: extra output). Note that chain regularization requires non-zero value in addition to $KZ30 > 0$.
KZ16	Updating of regularization parameters (RMIN, DTMIN & ECLOSE).
KZ19	Stellar evolution and mass loss (=1: old supernova scheme; =3: 4)
KZ20	Initial mass function (=0,1: Salpeter; >1: various, see source code for routine IMF).
KZ21	Extra output (>0: model #, etc; >1: routine CENTRE; >2: MTRACE; >3: GLOBAL).
	Read in user model and optionally scale data file of initial conditions, N rows of $m \ x \ y \ z \ v_x \ v_y \ v_z$.
KZ22	<ul style="list-style-type: none"> • =2: Scaling of initial conditions: sum of masses = 1, total energy -0.25, and velocity scaling by virial ratio Q (BODY1 = BODYN preserves IMF with scaling) • =3: No scaling of input performed
KZ23	Output of escaper removal (=1: basic; >1: diagnostics in file ESC; =2: escape angles in main output; >1: cluster + tails output if $KZ14 = 3$.)
KZ25	HR plot of evolving stars (singles and binary components). Requires $KZ19 \geq 3$.
KZ26	Special treatment of binary motion (≥ 1 : two-body; =2: chain regularization. Recommended for energetic binaries).
KZ30	Chain regularization (=1: basic; >1: main output; >2: each step). Also requires $KZ15 > 0$.
KZ37	Step reduction for encounters with high-velocity particles.
ETAU	Regularized time-step parameter (6.28/ETAU steps/orbit).
Q	Virial ratio ($Q = 0.5$ for equilibrium).

All remaining NBODY4 input parameters are listed in define.f, in the NBODY4

6. Selected input parameters

source code distribution at

<http://www.ast.cam.ac.uk/~sverre/web/pages/nbody.htm>

Internal model generation options KZ5 and KZ8 are explained below.

If KZ5=2: For generation of two Plummer spheres in orbit, an additional input line *APO ECC N2 SCALE* is inserted as shown in red in section 5.

APO	Separation of two Plummer models ($SEMI = APO / (1 + ECC)$).
ECC	Eccentricity of two-body orbit ($ECC < 0.999$).
N2	Membership of second Plummer model ($N2 \leq N$).
SCALE	Second scale factor (=1 for normal size, less for smaller size, ≥ 0.2 for limiting minimum size).

If KZ5=3: To model the effect of a passing perturber on a planetesimal disk, an additional input line *APO ECC DMIN SCALE* is inserted as shown in red in section 5.

APO	Separation between the perturber and Sun.
ECC	Eccentricity of orbit (=1 for parabolic encounter).
DMIN	Minimum distance of approach (periastron).
SCALE	Perturber mass scale factor (=1 for M_{sun}).

If KZ5=4: To study a massive binary or two free-floating bodies, an additional input line *SEMI ECC M1 M2* is inserted as shown in red in section 5.

SEMI	Initial semi-major axis (ignored if $ECC > 1$).
ECC	Eccentricity (free-floating if $ECC > 1$).

6. Selected input parameters

M1	Mass of first body (in units of mean mass).
M2	Mass of second body.

If KZ8=1: For primordial binary information, an additional input line *SEMI ECC RATIO RANGE 0 0 0* is inserted as shown in red in section 5. Also set NBIN0 (described above).

SEMI	Maximum semi-major axis in N-body units (given by $a = 2.0D+05 * RBAR * SEMI$ in AU).
ECC	Initial eccentricity (>0: constant = ECC; <0: randomized).
RATIO	Mass ratio (KZ20 ≤ 1: fixed value; KZ20 > 1: independent IMF).
RANGE	Range in semi-major axis for uniform logarithmic distribution.

7. N-body units and astrophysical units

7. N-body units and astrophysical units

The code employs so-called N-body units which are defined by the sum of masses =1, total energy of bound systems -0.25 and the gravitational constant of unity. This implies a mean square velocity 0.5 at equilibrium and a harmonic mean separation of 1. Hence the average mass is 1/N and the half-mass radius for a Plummer density distribution is 0.8 model units. In order to obtain results for astronomical length units in pc (1 pc = 3 light years), scale the coordinates by the input parameter RBAR and velocities by VSTAR. From dimensional analysis (AA2003, p.112), the physical time in Myr is given by

$T_{\text{phys}} = 15 \cdot (\text{RBAR}^3 / \text{MTOT})^{0.5} \cdot \text{TIME}$, where MTOT is the total mass in solar units and TIME is the N-body time. For the velocity scaling,

$\text{VSTAR} = 0.066 \cdot (\text{MTOT} / \text{RBAR})^{0.5} \text{ km/sec}$.

In the standard case, $\text{MTOT} = \text{ZMBAR} \cdot N$ with ZMBAR specified as the mass unit (in Msun) at input. After the scaling, ZMBAR continues to have the meaning of solar mass unit and is therefore rescaled (divided) by 1/N such that individual masses in Msun become $\text{BODY} \cdot \text{ZMBAR}$. Finally, the mean crossing time is simply $2 \cdot \sqrt{2}$ which suggests a convenient output time $\text{DTADJ} = 2$.

8. Stellar evolution

Stars more massive than the Sun undergo significant changes over the life-time of a typical rich open cluster. Synthetic stellar evolution procedures are used to model the effect of continuous wind mass loss during the giant stage. Full descriptions of the relevant algorithms are given in Tout et al. MNRAS 291, 732, 1997 and Hurley et al. MNRAS 315, 543, 2000. The most massive stars ($M > 8$ Msun) are given a velocity kick in supernovae explosions. Corrections are made for the mass loss from the cluster such that total energy is still conserved. Strong interactions involving binaries often lead to their escape by recoil which also modifies the total energy of the remaining system. The stellar luminosity and effective temperature can be plotted in Hertzsprung-Russel (HR) diagrams for single stars and binaries.

9. Integration methods

The basic integration employs the Hermite scheme, as summarized in the GRAPE book by Makino and Taiji. The special-purpose GRAPE hardware evaluates the force and first derivative for up to 48 particles at each cycle from the predicted coordinates and velocities. These values are used to construct the two next force derivatives whose contributions to the predicted quantities are added as a corrector on the host. We take advantage of the parallel architecture by introducing hierarchical time-steps (divisible by 2) such that many particles can be advanced as a group. In general, there are few members at the smallest time-steps and about 12-15 different levels in the hierarchy, depending on N and the range in density.

NBODY4 does not rely on softening of the force and several powerful procedures are included on the host to deal with strong point-mass interactions. In the first instance, close two-body encounters are handled by the Kustaanheimo--Stiefel regularization method (as discussed in AA2003). Two particles are selected for treatment when their separation becomes smaller than R_{MIN} and the time-steps fall below DT_{MIN} . With standard N -body units, typical values of the regularization parameters may be taken as $R_{\text{MIN}} = 1/N$ and $DT_{\text{MIN}} = 0.01/N$ for $N > 1000$ and a bit more conservative for smaller N . If option $KZ16 = 1$, these parameters are updated at every energy check according to the core density. An arbitrary number of binaries and hyperbolic encounters can be treated simultaneously. Likewise, stable triples are converted temporarily into two-body systems where the inner binary is replaced by the combined mass until such time as the stability condition is violated. The stability of a hierarchical system is defined in terms of the orbital elements of the inner and outer binary (Mardling & Aarseth 1999). Strong interactions involving three or four members (of the type B--S or B--B) are selected for chain regularization ($KZ15 > 0$, $KZ30 > 0$), provided similar time-step and distance criteria are satisfied as for the two-body case. Note that all close encounter procedures may be bypassed by setting $KZ16 = 0$ and $DT_{\text{MIN}} = 1D-20$, although this is not recommended in general.

10. NBODY4 sample output and interpretation

10. NBODY4 sample output and interpretation

In this section, output from a short NBODY4 simulation run is listed and briefly interpreted.

For initial conditions a Plummer model (cf. AA2003, p.121) was adopted using a realistic Salpeter mass function with mean stellar mass of 0.5 solar masses. The cluster moves in a circular Galactic orbit in the Solar neighbourhood. The resulting tidal force is included in the equations of motion (cf. AA2003, p.128). The termination time of 100 time units corresponds to 60 Myr with length unit $R_{\text{BAR}} = 1$ pc, which is sufficient to illustrate some general features of the evolution.

Models of this type and size can be quickly and easily run with NBODY4 (1-2 mins) and NBODY6 (~10 minutes).

For more realistic models of star clusters, stellar evolution should be switched on (KZ19=3) and somewhat longer termination times used. This section concludes with a final snapshot of a run with stellar evolution.

The following is intended only to be an introduction to the extensive output produced by NBODY4. Note that runs made with other versions of NBODY4 may not yield the same results, due to differences in software versions, GRAPE libraries, compilers and other factors.

10. NBODY4 sample output and interpretation

Quantities printed include:

Q	Ratio of kinetic and potential energy (=0.5 for equilibrium)
DE	Relative energy error (every energy check, summed with sign main output)
E	Total energy (should be constant except for escape removal)
RMIN	Distance criterion for regularization search
DTMIN	Time-step criterion for regularization search
ECLOSE	Binding energy per unit mass for hard binary (positive)
EB/E	Energy in binaries (relative to total energy)
TC	Number of crossing times as an integer
BIN	Name of closest binary components
NSTEPS	Number of integration steps (direct Hermite and regularized pairs)
<R>	Half-mass radius (N-body units or pc where appropriate)
DMIN	Closest two-body separation (first is all-time and 2nd is since last main output time)
N	Cluster membership (reducing after escape removal)
DETOT	Final sum of all energy changes (relative and total)
AMIN	Semi-major axis of dominant binary (in AU: $2.0D+05 \cdot RBAR \cdot AMIN$)
RC	Core radius (size of high-density region, membership NC)
RTIDE	Tidal radius (N-body units; typically around 10)
DISP	Eccentricity dispersion (rms value) for KZ5 = 3
EDISK	Total energy of disk particles for KZ5 = 3
KS	Number of regularized binaries (energetically important or eccentric)
MC	Core mass (N-body units; average is MC/NC)
NS	Number of single stars ($N = NS + 2 \cdot KS$ except for triples)
T6	Time in Myr (RBAR assumed = 1 nominally for isolated cluster)

10. NBODY4 sample output and interpretation

```

N  NFIX  NCRIT  NRAND  NRUN
1000   1     5 50000   1

ETA      DTADJ      DELTAT      TCRIT      QE      RBAR      ZMBAR
2.0E-02  2.0E+00  1.0E+01  1.0E+02  2.2E-05  1.0E+00  5.0E-01

KZ OPTIONS
1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
0  0  0  0  1  0  6  0  0  0  0  0  0  1  1  1  0  0  0  0  1  0  2  0  1  2  0  0  0  2  0  0  0  0  0  0  1  0  0  0

DTMIN      RMIN      ETAU      ECLOSE      GMIN      GMAX
1.0E-05  1.0E-04  2.0E-01  1.0E+00  1.0E-06  1.0E-03

STANDARD IMF      ALPHA = 2.30  BODY1 = 10.0  BODYN = 0.20

SCALING:  SX = 0.97  E = -2.58E-01  M(1) = 1.65E-02  M(N) = 3.30E-04  <M> = 1.00E-03

TIME SCALES:  TRH = 1.6E+01  TCR = 2.8E+00  2<R>/<V> = 2.3E+00

PHYSICAL SCALING:  R* = 1.0  M* = 607.0  V* = 1.615  T* = 0.606  <M> = 0.61  SU = 4.4E+07

TOTAL MASS = 607.0  TIDAL(1&3) = 1.52E-03 -6.07E-03  PC/GM = 2.33E-08

TIDAL PARAMETERS:  5.83E-04  0.00E+00 -2.33E-03  3.27E-02  TSCALE = 6.06E-01 (10**6 YRS)  RTIDE = 11.97

TIME = 0.00  Q = 0.50  DE = 0.000000  E = -0.249563  RMIN = 1.7E-03  DTMIN = 8.9E-05  ECLOSE = 1.00  TC = 0  EB/E = 0.0000  BIN = 0  0

T = 0.0  N = 1000  KS = 0  NM = 0  MM = 0  NS = 1000  NSTEPS = 0  0  DE = 0.000000  E = -0.249563

RUN = 1  M# = 0  CPU = 0.0  DMIN = 1.0E+02  1.0E+02  AMIN = 1.0E+02  RMAX = 0.0E+00  NBLOCK = 0  NIRECT = 0  NURECT = 0  NEFF = 325

<R>  RTIDE  RDENS  RC      NC      MC      RHOD  RHOM      UN  NPT  RCM  VCM      AZ      EB/E  EM/E  TCR      T6  NTESC
#1  0.78  12.0  0.10  0.240  61  0.070  6.2  34.2  0  0  0.000  0.0000 -0.021152  0.000  0.000  2.84  0  3

NKSTRY  NKSREG  NKSHPY      NKSPER  NPRECT  NKSMOD  NTTRY  NTRIP  NQUAD  NCHAIN  NMERG  NEWHI  NSTEPC  NBCALL  NTPERT  NWARN  NHI
#2      0      0      0      0      0      0      0      0      0      0      0      0      804      0      46  0

TWO MASS GROUPS:  NM1 NM2 M1 M2 RM1 RM2      152  848  0.501  0.499  0.736  0.801
    
```

10. NBODY4 sample output and interpretation

```

TIME = 2.00 Q = 0.51 DE = 0.000000 E = -0.249564 RMIN = 1.7E-03 DTMIN = 9.2E-05 ECLOSE = 1.02 TC = 0 EB/E = 0.0000 BIN = 0 0
TIME = 4.00 Q = 0.52 DE = 0.000000 E = -0.249564 RMIN = 1.7E-03 DTMIN = 8.7E-05 ECLOSE = 1.04 TC = 1 EB/E = 0.0000 BIN = 0 0
TIME = 6.00 Q = 0.53 DE = 0.000000 E = -0.249564 RMIN = 1.8E-03 DTMIN = 9.4E-05 ECLOSE = 1.06 TC = 2 EB/E = 0.0000 BIN = 0 0
TIME = 8.00 Q = 0.50 DE = 0.000000 E = -0.249564 RMIN = 1.7E-03 DTMIN = 9.2E-05 ECLOSE = 1.00 TC = 2 EB/E = 0.0000 BIN = 0 0
TIME = 10.00 Q = 0.52 DE = 0.000000 E = -0.249563 RMIN = 1.7E-03 DTMIN = 9.2E-05 ECLOSE = 1.05 TC = 3 EB/E = 0.0000 BIN = 0 0

T = 10.0 N = 1000 KS = 0 NM = 0 MM = 0 NS = 1000 NSTEPS = 1535962 614 DE = 0.000000 E = -0.249563
RUN = 1 M# = 0 CPU = 0.2 DMIN = 5.8E-05 5.8E-05 AMIN = 1.0E+02 RMAX = 0.0E+00 NBLOCK = 38547 NIRECT = 0 NURECT = 0 NEFF = 325

<R> RTIDE RDENS RC NC MC RHOD RHOM UN NPT RCM VCM AZ EB/E EM/E TCR T6 NTEC
#1 0.70 12.0 0.10 0.291 72 0.117 4.1 16.3 0 0 0.000 0.0000 -0.020921 0.000 0.000 2.84 6 15

NKSTRY NKSREG NKSHYP NKSPER NPRECT NKSMOD NTRY NTRIP NQUAD NCHAIN NMERG NEWHI NSTEPC NBCALL NTPERT NWARN NHI
#2 6407 34 31 0 0 0 0 0 0 0 0 0 0 0 5055 0 368 0

TWO MASS GROUPS: NM1 NM2 M1 M2 RM1 RM2 152 848 0.501 0.499 0.632 0.868
TIME = 12.00 Q = 0.50 DE = 0.000000 E = -0.249563 RMIN = 1.6E-03 DTMIN = 8.4E-05 ECLOSE = 1.00 TC = 4 EB/E = 0.0000 BIN = 0 0
TIME = 14.00 Q = 0.52 DE = 0.000000 E = -0.249563 RMIN = 1.5E-03 DTMIN = 7.1E-05 ECLOSE = 1.05 TC = 4 EB/E = 0.0000 BIN = 0 0
ESCAPE N = 999 1 0 0.9996 -0.250145 0.01 24.48 0.500 0.00100 996 874
ESCAPE ANGLES 84 7
    
```

With RBAR = 1, RTIDE=12 pc so escapers are removed outside 24 pc.

```

TIME = 16.00 Q = 0.51 DE = 0.000000 E = -0.250145 RMIN = 1.4E-03 DTMIN = 6.8E-05 ECLOSE = 1.03 TC = 5 EB/E = 0.0000 BIN = 0 0
TIME = 18.00 Q = 0.53 DE = 0.000000 E = -0.250145 RMIN = 1.3E-03 DTMIN = 5.8E-05 ECLOSE = 1.06 TC = 6 EB/E = 0.0000 BIN = 0 0
ESCAPE N = 998 2 0 0.9990 -0.250690 0.01 24.95 0.500 0.00100 994 461
ESCAPE ANGLES 43 10
TIME = 20.00 Q = 0.55 DE = 0.000000 E = -0.250690 RMIN = 1.0E-03 DTMIN = 4.2E-05 ECLOSE = 1.12 TC = 7 EB/E = 0.0000 BIN = 0 0
    
```

10. NBODY4 sample output and interpretation

```

T = 20.0 N = 998 KS = 0 NM = 0 MM = 0 NS = 998 NSTEPS = 2881172 2374 DE = 0.000001 E = -0.250690
RUN = 1 M# = 0 CPU = 0.3 DMIN = 2.0E-05 2.0E-05 AMIN = 1.0E+02 RMAX = 1.3E-02 NBLOCK = 80845 NIRECT = 0 NURECT = 0 NEFF = 324
<R> RTIDE RDENS RC NC MC RHOD RHOM UN NPT RCM VCM AZ EB/E EM/E TCR T6 NTESC
#1 0.83 12.0 0.11 0.085 9 0.074 64.4 142.7 0 0 0.014 0.0008 -0.020246 0.000 0.000 2.81 12 28
NKSTRY NKSREG NKSHYP NKSPER NPRECT NKSMOD NTTRY NTRIP NQUAD NCHAIN NMERG NEWHI NSTEPC NBCALL NTPERT NWARN NHI
#2 17858 72 59 0 0 0 0 0 0 0 0 0 0 0 8735 0 679 1
TWO MASS GROUPS: NM1 NM2 M1 M2 RM1 RM2 151 847 0.499 0.500 0.577 1.096
    
```

The heavy mass group already shows significant mass segregation (mean radius RM) towards centre. Note first energetic binary next output, involving two massive members.

```

TIME = 22.00 Q = 0.60 DE = 0.000002 E = -0.250690 RMIN = 9.4E-04 DTMIN = 3.7E-05 ECLOSE = 0.96 TC = 5 EB/E = 0.3101 BIN = 1 5
ESCAPE N = 997 3 0 0.9984 -0.251049 0.01 24.14 0.500 0.00100 992 426
ESCAPE ANGLES 26 18
TIME = 24.00 Q = 0.58 DE = 0.000001 E = -0.251048 RMIN = 1.1E-03 DTMIN = 4.3E-05 ECLOSE = 0.89 TC = 5 EB/E = 0.3335 BIN = 1 5
ESCAPE N = 996 4 0 0.9978 -0.257011 0.01 25.08 0.500 0.00100 991 452
ESCAPE ANGLES 59 17
TIME = 26.00 Q = 0.53 DE = 0.000012 E = -0.257008 RMIN = 1.1E-03 DTMIN = 4.5E-05 ECLOSE = 0.80 TC = 6 EB/E = 0.3610 BIN = 5 1
NEW CHAIN 1 T = 27.49 H = -5. R = 1.1E-03 M = 0.0277 0.0039 G4 = 3.3E-06 R1 = 8.2E-04 P = 8.8E-05 E1 = 1.764 NP =64
NEW CHAIN N NP E RSUM RGRAV TCR RMAXS NAM 3 4 -0.07201 1.1E-03 5.4E-04 3.3E-03 5.8E-03 1 5 35
CHAIN BINARY NAM = 1 5 A = 1.5E-03 E = 0.29 EB = 0.88 GB = 9.3E-03 G4 = 0.0E+00 EB1 = 0.00 E1 = 0.26 ET = 0.246 DB = 0.9
RECOIL: E E1 PM/A RD A A1 RP GB IN 0.2859 0.99 0.1 3.5 1.46E-03 7.50E-03 3.80E-03 9.32E-03 105.6
END CHAIN 1 2 3 1 RB = 1.8E-03 R13 = 4.5E-03 R24 = 1.0E+10 DE = 3.7E-06 TC = 0.3 # 12 2 4 DB = 0.89 EC = 0.280
CHTERM: T I3 I4 NT DT 27.4910 35 35 997 1.9E-06 1.9E-06 1.9E-06
    
```

The first strong (chain) interaction. Note the virial ratio Q=0.61 next time. This means at least one high-velocity body was produced during this event. This is connected with increased energy in hard binaries (or just one).

Following a temporary exchange of star #30 with the heavier members #1 and #5, the former is ejected with velocity 6.7 km/s and the binary increases its energy by 60 %. In the next strong interaction, the light star #556 acquires escape velocity of 10.7 km/s.

```
CHAIN BINARY  NAM =    1    5  A = 6.1E-04  E = 0.68  EB = 1.31  GB = 1.1E-04  G4 = 0.0E+00  EB1 = 0.00  E1 = -0.38  ET = 0.584  DB = 0.6
RECOIL:      E E1 PM/A RD A A1 RP GB IN  0.6829  1.28  0.8   5.8  6.09E-04 -1.66E-03  3.98E-03  1.10E-04  109.9
```

```
END CHAIN    1  2  3  1  RB = 3.6E-04  R13 = 4.1E-03  R24 = 1.0E+10  DE = 9.7E-12  TC = 0.4  #  19  0  1  DB = 0.59  EC = 0.445
CHTERM:     T I3 I4 NT DT  30.9192   12   12  996  9.5E-07  9.5E-07  9.5E-07
```

```
NEW CHAIN    1  T =  31.47  H =    0.  R = 3.0E-04  M = 0.0118  0.0165  G4 = 8.1E-08  R1 = 5.9E-04  P = 2.0E-04  E1 =*****  NP =16
NEW CHAIN    N NP E RSUM RGRAV TCR RMAXS NAM  3  0  -0.15166  1.2E-03  5.8E-04  8.0E-04  1.5E-02  5  556  1
CHAIN ESCAPE:  IESC NM RI RDOT2 2*M/R VF  2  556  5.4E-03  5.4E+01  1.0E+01  10.7
EXCHANGE     T NAM E0 E A0 A EBO EB   31.47   5  556   5   1  1.000  0.627  5.4E-04  5.7E-04  -7.9E-03  -1.6E-01
```

```
CHAIN BINARY  NAM =    5    1  A = 5.7E-04  E = 0.63  EB = 1.07  GB = 4.2E-05  G4 = 0.0E+00  EB1 = 0.00  E1 = -1.42  ET = 0.626  DB =****
RECOIL:      E E1 PM/A RD A A1 RP GB IN  0.6273  1.31  0.4   7.4  5.69E-04 -6.39E-04  5.42E-03  4.22E-05  83.7
```

```
END CHAIN    1  3  2  1  RB = 7.5E-04  R13 = 5.7E-03  R24 = 1.0E+10  DE = 0.0E+00  TC = 2.5  #  83  6  0  DB =*****  EC = 0.583
CHTERM:     T I3 I4 NT DT  31.4717   2   2  996  9.5E-07  9.5E-07  9.5E-07
```

```
NEW CHAIN    1  T =  31.92  H = -24.  R = 9.2E-04  M = 0.0277  0.0006  G4 = 8.2E-08  R1 = 7.4E-04  P = 6.5E-04  E1 = 0.016  NP = 1
NEW CHAIN    N NP E RSUM RGRAV TCR RMAXS NAM  3  0  -0.16231  1.2E-03  6.1E-04  7.3E-04  1.4E-02  5  1  416
CHAIN ESCAPE:  IESC NM RI RDOT2 2*M/R VF  3  416  6.3E-03  1.1E+01  9.0E+00  2.0
```

```
END CHAIN    1  2  3  1  RB = 9.2E-04  R13 = 6.6E-03  R24 = 1.0E+10  DE = 0.0E+00  TC = 2.1  #  31  2  0  DB = 0.00  EC = 0.624
CHTERM:     T I3 I4 NT DT  31.9248  414  414  996  3.8E-06  3.8E-06  3.8E-06
```

```
TIME =  32.00  Q = 0.73  DE = 0.000001  E = -0.260098  RMIN = 1.5E-03  DTMIN = 7.2E-05  ECLOSE = 0.74  TC =  2  EB/E = 1.6429  BIN =  5  1
```

```
TIME =  34.00  Q = 0.71  DE = -0.000001  E = -0.260098  RMIN = 1.4E-03  DTMIN = 6.9E-05  ECLOSE = 0.69  TC =  2  EB/E = 1.6344  BIN =  5  1
```

A lot of activity leading to quite large binary energy ratio (> 100 % because fast escaping members are still included).

```
TIME =  36.00  Q = 0.71  DE = 0.000005  E = -0.260097  RMIN = 1.4E-03  DTMIN = 6.7E-05  ECLOSE = 0.70  TC =  3  EB/E = 1.6256  BIN =  5  1
```

```
ESCAPE      N =  993   7  0  0.9925  -0.270603  0.14  28.77  0.500  0.00100  980   195  556
```

```
ESCAPE ANGLES      48   4   45   4
```

```
NEW CHAIN    1  T =  37.54  H = -24.  R = 8.9E-04  M = 0.0277  0.0012  G4 = 8.8E-07  R1 = 6.4E-04  P = 3.7E-04  E1 = -0.036  NP = 2
NEW CHAIN    N NP E RSUM RGRAV TCR RMAXS NAM  3  4  -0.16262  1.4E-03  7.0E-04  7.7E-04  7.0E-03  5  1  187
```

```
END CHAIN    1  2  3  1  RB = 5.6E-04  R13 = 2.9E-03  R24 = 1.0E+10  DE = 1.6E-07  TC = 3.4  #  69  5  4  DB = -0.02  EC = 0.601
CHTERM:     T I3 I4 NT DT  37.5413  186  186  994  1.9E-06  1.9E-06  1.9E-06
```

```

NEW CHAIN 1 T = 37.54 H = -23. R = 1.1E-03 M = 0.0277 0.0012 G4 = 7.5E-07 R1 = 6.8E-04 P = 2.9E-04 E1 = 0.118 NP = 3
NEW CHAIN N NP E RSUM RGRAV TCR RMAXS NAM 3 4 -0.16262 1.4E-03 7.0E-04 7.7E-04 7.9E-03 5 1 187
CHAIN ESCAPE: IESC NM RI RDOT2 2*M/R VF 3 187 3.9E-03 2.2E+01 1.5E+01 4.5
    
```

```

CHAIN BINARY NAM = 5 1 A = 5.5E-04 E = 0.84 EB = 1.04 GB = 3.8E-05 G4 = 0.0E+00 EB1 = 0.00 E1 = -0.04 ET = 0.622 DB = 0.1
RECOIL: E E1 PM/A RD A A1 RP GB IN 0.8387 1.21 1.1 4.7 5.50E-04 -2.85E-03 3.94E-03 3.83E-05 29.1
    
```

```

END CHAIN 1 2 3 1 RB = 3.7E-04 R13 = 3.8E-03 R24 = 1.0E+10 DE = 1.5E-07 TC = 1.0 # 24 1 4 DB = 0.10 EC = 0.601
CHTERM: T I3 I4 NT DT 37.5457 186 186 994 1.9E-06 1.9E-06 1.9E-06
    
```

```

NEW CHAIN 1 T = 37.63 H = -26. R = 1.0E-03 M = 0.0277 0.0067 G4 = 1.6E-05 R1 = 1.2E-03 P = 1.2E-03 E1 = -0.027 NP = 3
NEW CHAIN N NP E RSUM RGRAV TCR RMAXS NAM 3 2 -0.16906 1.4E-03 7.0E-04 1.1E-03 5.3E-03 5 1 15
    
```

```

END CHAIN 1 2 3 1 RB = 9.5E-04 R13 = 2.6E-03 R24 = 1.0E+10 DE = 3.6E-06 TC = 0.3 # 15 0 2 DB = 0.03 EC = 0.625
CHTERM: T I3 I4 NT DT 37.6322 448 448 994 9.5E-07 9.5E-07 9.5E-07
    
```

```

TIME = 38.00 Q = 0.72 DE = 0.000005 E = -0.270602 RMIN = 1.6E-03 DTMIN = 8.2E-05 ECLOSE = 0.69 TC = 2 EB/E = 1.9124 BIN = 5 1
    
```

```

ESCAPE N = 990 10 0 0.9710 -0.324470 0.28 25.18 0.500 0.00098 974 30 35 3
    
```

```

ESCAPE ANGLES 22 23 25 46 43 24
    
```

```

TIME = 40.00 Q = 0.53 DE = -0.000009 E = -0.324472 RMIN = 1.4E-03 DTMIN = 6.8E-05 ECLOSE = 0.65 TC = 6 EB/E = 1.2301 BIN = 5 1
    
```

```

ESCAPE N = 988 12 0 0.9688 -0.326463 0.27 23.99 0.500 0.00098 971 135 376
    
```

```

ESCAPE ANGLES 53 38 8 24
    
```

Note total energy increase after fast escapers removed. This leads to almost overall equilibrium (denoted by $Q=0.50$). At this time, smallest binary size is $AMIN = 5.1E-04$. By now, half-mass radius, $\langle R \rangle$, has increased to 1.28 because the binaries have expelled other members.

```

T = 40.0 N = 988 KS = 1 NM = 0 MM = 0 NS = 986 NSTEPS = 4896023 413143 DE = 0.000002 E = -0.326463
    
```

```

RUN = 1 M# = 0 CPU = 0.6 DMIN = 1.6E-05 2.2E-05 AMIN = 5.1E-04 RMAX = 1.8E-03 NBLOCK = 206909 NIRECT = 0 NURECT = 0 NEFF = 292
    
```

```

<R> RTIDE RDENS RC NC MC RHOD RHOM UN NPT RCM VCM AZ EB/E EM/E TCR T6 NTESC
#1 1.28 11.8 0.28 0.129 6 0.032 69.6 241.6 1 0 0.270 0.0201 -0.013566 1.230 0.000 5.99 24 88
    
```

```

NKSTRY NKSREG NKSHYP NKSPER NPRECT NKSMOD NTRY NTRIP NQUAD NCHAIN NMERG NEWHI NSTEPC NBCALL NTPERT NWARN NHI
#2 51295 154 102 8582 0 656 1123 0 0 9 0 0 336 49046 14714 6550 1
    
```

```

TWO MASS GROUPS: NM1 NM2 M1 M2 RM1 RM2 154 833 0.485 0.484 0.918 1.559
    
```

```

OR = 0 EX = 0 DB = 0.721 SB = 0.0000 BB = 0.0000 CH = -0.3548 NC = 1 N(A) = 0 1
<E> = 0.91 EMAX = 0.911 NPOP = 1 0 986 12 0 0 0 0 0 0 0 0 0 0 0 0 1
ENERGIES -0.18018 0.00000 -0.14429 0.07690 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 ETOT = -0.324472
    
```

```

TIME = 42.00 Q = 0.53 DE = 0.000042 E = -0.326456 RMIN = 1.6E-03 DTMIN = 8.4E-05 ECLOSE = 0.65 TC = 7 EB/E = 1.2116 BIN = 5 1
    
```


10. NBODY4 sample output and interpretation

```

NEW CHAIN  N NP E RSUM RGRAV TCR RMAXS NAM      3  2 -0.27243  1.7E-03  8.3E-04  6.1E-04  1.2E-02   5   1   10
CHAIN ESCAPE:  IESC NM RI RDOT2 2*M/R VF   3  10  3.6E-03  2.6E+01  2.0E+01   3.9

END CHAIN   1  2  3  1  RB = 3.7E-04  R13 = 3.5E-03  R24 = 1.0E+10  DE = 7.6E-12  TC =  1.1  #  26  1  0  DB = 0.10  EC = 0.756
CHTERM:  T I3 I4 NT DT   99.8364   13   13  945  9.5E-07  9.5E-07  9.5E-07
    
```

```

TIME = 100.00  Q = 0.64  DE = 0.000103  E = -0.360422  RMIN = 2.0E-03  DTMIN = 1.1E-04  ECLOSE = 0.39  TC =  4  EB/E = 5.5969  BIN =  5  1

ESCAPE  N =  940   60   0  0.9191 -0.365072  1.94  23.68  0.500  0.00098  882   17  592  664

ESCAPE ANGLES  19   33   54   0   82  22
    
```

A total of 60 escapers at T6 = 60 Myr, with $\langle R \rangle = 2.05$. Now the core has decreased to NC = 8 members only. Hence a tightly bound group has formed so that the average density contrast (RHOD=45) is large. The CPU time was 1.4 mins on the Cambridge micro-Grape. Finally there are two hard binaries, with EB/E = 5.6 which is quite pronounced. Note members #1 & #5 still remain together, with AMIN = 3.1E-04. Some 8 million direct integration steps were taken and 2 million regularized steps. Final evolution of the mass groups shows considerable expansion, mostly of the light bodies. The highest escape velocities (in file ESC) were 7 and 10 km/s. This compares with typical initial member velocities of 1.1 km/s which declined a bit later due to the cluster expansion. Finally, the actual energy in binaries amounts to -0.29 compared to -0.05 binding the cluster itself (-0.25 initially), given by ENERGIES below.

```

T = 100.0  N =  940  KS =  2  NM =  0  MM =  0  NS =  936  NSTEPS =  8279038  1981903  DE = 0.000091  E = -0.365072

RUN = 1  M# =  0  CPU =  1.4  DMIN = 1.6E-05  1.8E-05  AMIN = 3.1E-04  RMAX = 2.4E-02  NBLOCK =  548764  NIRECT = 0  NURECT = 0  NEFF =  249

  <R>  RTIDE  RDENS  RC      NC  MC  RHOD  RHOM  UN  NPT  RCM  VCM      AZ  EB/E  EM/E  TCR      T6  NTEC
#1  2.05  11.6   2.32  0.234   8  0.061  45.4  147.6   1  96  1.943  0.0438  0.058436  5.518  0.079  23.67   60  235

      NKSTRY  NKSREG  NKSHYP      NKSPER  NPRECT  NKSMOD  NTRY  NTRIP  NQUAD  NCHAIN  NMERG  NEWHI  NSTEPC  NBCALL  NTPERT  NWARN  NHI
#2  271730   333    129    153001     0    2570  33910     0     0     21    63     0    749   214436   70095   82916   1

TWO MASS GROUPS:  NM1 NM2 M1 M2 RM1 RM2      147  791  0.460  0.459  1.550  2.456

OR =  0  EX =  0  DB = 1.228  SB = 0.0000  BB = 0.0000  CH = -0.4696  NC =  2  N(A) =  1  0  1
<E> = 0.64  EMAX = 0.885  NPOP =  1  1  936  60  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1
ENERGIES  -0.29537 -0.00734 -0.05337  0.11553  0.00000  0.00000  0.00000  0.00000  0.00000 -0.00434  0.00000  ETOT = -0.360422

      END RUN  TIME = 100.0  CPUTOT =  0.0  ERRTOT = 0.000147  DETOT = 0.000019
    
```

End of Plummer model run without stellar evolution

Final snapshot of a run with stellar evolution

Same parameters as standard case, except tolerance $QE = 1.0D-04$ for last output and $KZ19 = 3$. The three heaviest stars (above 8 solar masses) have become neutron stars with high escape velocity due to asymmetrical mass loss and there are two white dwarfs. Now the final binary consists of stars #9 & #8 so their dynamical effect is considerably less than before. This leads to somewhat fewer stars escaping. The total mass lost from the stellar evolution represents 34 solar masses out of 607 initially. At $T = 60$ Myr, stars above 6.3 solar masses (TURN) have evolved off the main sequence. Because of compensating factors, a simulation with stellar evolution is expected to attain a greater age before disruption.

```

TIME = 100.00 Q = 0.57 DE = -0.000159 E = -0.615727 RMIN = 2.1E-03 DTMIN = 1.2E-04 ECLOSE = 0.40 TC = 6 EB/E = 2.3257 BIN = 9 8
ESCAPE N = 959 41 0 0.9083 -0.629030 0.60 23.60 0.500 0.00095 917 315 282
T = 100.0 N = 959 KS = 1 NM = 0 MM = 0 NS = 957 NSTEPS = 8195483 1540382 DE = -0.000285 E = -0.629030

RUN = 1 M# = 0 CPU = 1.3 DMIN = 8.1E-07 8.6E-05 AMIN = 2.5E-04 RMAX = 9.1E-03 NBLOCK = 433849 NIRECT = 0 NURECT = 0 NEFF = 363

<R> RTIDE RDENS RC NC MC RHOD RHOM UN NPT RCM VCM AZ EB/E EM/E TCR T6 NTEC
#1 2.10 11.6 0.57 0.172 8 0.051 81.6 169.4 1 0 0.599 0.0168 -0.023746 2.328 -0.002 15.71 60 205

NKSTRY NKSREG NKSHYP NKSPER NPRECT NKSMOD NTRY NTRIP NQUAD NCHAIN NMERG NEWHI NSTEPC NBCALL NTPERT NWARN NHI
#2 215944 342 120 172655 0 5083 30484 0 0 10 42 0 960 201658 69610 77043 0

NMDOT NRG NHE NRS NNH NWD NSN NBH TURN ZMRG ZMHE ZMRS ZMNH ZMWD ZMSN ZMDOT NTYPE
#4 1250 6 6 5 0 2 3 0 6.34 0.0 0.0 0.2 0.0 0.0 21.1 34.5 781 175 0 0 1 0 0 0 0 0
0 0 2

TWO MASS GROUPS: NM1 NM2 M1 M2 RM1 RM2 163 795 0.454 0.454 1.327 2.733

OR = 1 EX = 0 DB = 0.643 SB = 0.0000 BB = 0.0000 CH = -0.1533 NC = 1 N(A) = 0 0 1
<E> = 0.39 EMAX = 0.394 NPOP = 1 0 957 41 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
ENERGIES -0.16077 0.00000 -0.06812 0.37943 0.00000 0.00000 0.00000 0.00000 0.00014 0.00000 ETOT = -0.615727
END RUN TIME = 100.0 CPUTOT = 0.0 ERRTOT = -0.000336 DETOT = -0.00003

```

10. NBODY4 sample output and interpretation

11. Relationship of NBODY6 to NBODY4

The code NBODY6 is intended for different types of star cluster simulations and runs on standard laptops and workstations. A closely related code, NBODY6++, is available for conventional parallel supercomputers (Spurzem 1999). The main difference with NBODY4 is that a neighbour scheme is used to speed up the integration while the GRAPE versions rely on superior computing power to obtain the particle accelerations. A description of a few additional parameters is given in AA2003. All these codes employ the full range of close encounter procedures as well as the Hermite integration scheme. Although NBODY6 advances the particles sequentially, it still relies on the hierarchical time-step algorithm.

NBODY6 requires a few extra input parameters to deal with combining two force polynomials. This includes a second time-step tolerance, ETAR, for the so-called regular (or distant) force which is only updated on a somewhat longer (factor of 10) time-scale. A neighbour list of maximum size NNBMAX for each member is employed to obtain the force and first derivative due to particles inside a given radius (denoted RS0). Each list is updated during the total force evaluation, using a neighbour radius criterion based on the local density contrast. Particles at larger central distances are therefore assigned a decreasing number of neighbours because of the weaker irregular force. Because of compensating factors, the actual performance of the scheme is not a sensitive function of the neighbour membership. Replacing summation of the background force by prediction at each irregular time-step leads to a considerable speed-up while the self-consistent (or collisional) nature of the total contribution is preserved. A convenient feature is that derivative corrections for both the force polynomials due to change of neighbours may be avoided for the single particles, provided that the output times are commensurate with the maximum time-step of one time unit. However, this still entails introducing three explicit force derivatives to be used for neighbour changes relating to perturbed c.m. motion.

The treatment of regularization is formally the same as in NBODY4, hence all the corresponding routines are employed. However, NBODY6 exploits the

11. Relationship of NBODY6 to NBODY4

advantage of selecting perturbers for KS or chain regularization from the existing c.m. neighbour list. The frequent check on extending unperturbed KS motion in NBODY4 makes use of the fast GRAPE function in determining the closest particle only. Some care is needed to ensure that sufficient neighbours are available for selection by using a more generous value of NNBMAX but the situation improves with increasing N.

Output from NBODY6 is fairly similar but contains a few additional data points. The ratio of irregular to regular time-steps is a good indicator for the efficiency of the scheme and this tends to increase slowly with N. These step counters are printed as the first and third entries at main output, while the fourth gives the number of regularized steps. Provided the average neighbour number (denoted $\langle \text{NNB} \rangle$) is well behaved (say around \sqrt{N}), profiling shows that an increasing fraction of the CPU time is spent evaluating the total force in larger systems. Even so, the number of irregular time-steps are very similar to the actual time-steps in NBODY4. As for a direct performance comparison, the neighbour scheme already becomes favourable for quite small cluster memberships (e.g. $N = 50$).

NBODY4 and NBODY6 have been designed to use similar data structures and options. A few options relate to incompatible features. Example input templates and timings are given in section 13 and further information can be found in the documentation accompanying the code download.

12. NBODY4 simulations on the web via NbodyLab.org

Short NBODY4 simulations with a GRAPE-6a can be run on the web at www.NBodyLab.org

NBodyLab.org also shows examples of plots and animations that can be generated from NBODY4 and NBODY6 output. NbodyLab.org discusses how to compile NBODY6 for Windows and Mac OS and provides sample binaries.

13. Example input templates for NBODY4 and NBODY6

13. Example input templates for NBODY4 and NBODY6

See section 2 for an overview of the following types of simulations.

Single Plummer sphere cluster model (KZ5=1)

NBODY4

<pre> 1 10.0 0 1000 1 5 50000 1 0.02 2.0 10.0 100.0 2.0D-05 1.0 0.5 0 0 1 0 1 0 6 0 0 0 0 0 0 1 1 1 0 0 3 0 1 0 2 0 1 2 0 0 0 2 0 0 0 0 0 0 1 0 0 0 1.0E-05 1.0D-04 0.2 1.0 1.0E-06 0.001 2.3 10.0 0.2 0 0.02 0 10.0 0.5 0 0 0 </pre>	<pre> KSTART TCOMP GPID N NFIX NCRIT NRAND NRUN ETA DTADJ DELTAT TCRIT QE RBAR ZMBAR KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10 KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20 KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30 KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40 DTMIN RMIN ETAU ECLOSE GMIN GMAX ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0 DTPL0T Q 0 0 0 </pre>
---	--

NBODY6

<pre> 1 20.0 0 1000 1 5 50000 95 1 0.02 0.03 0.3 2.0 10.0 100.0 2.0D-05 1.0 0.5 0 0 1 0 1 0 6 0 0 0 0 1 0 1 1 1 0 1 3 0 1 0 2 0 0 2 0 0 0 2 0 0 0 0 0 0 0 0 0 1 1.0E-05 1.0D-04 0.2 1.0 1.0E-06 0.001 2.3 10.0 0.2 0 0.02 0 10.0 0.5 0 0 0 </pre>	<pre> KSTART TCOMP N NFIX NCRIT NRAND NNBMAX NRUN ETA1 ETAR RS0 DTADJ DELTAT TCRIT QE RBAR ZMBAR KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10 KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20 KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30 KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40 DTMIN RMIN ETAU ECLOSE GMIN GMAX ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0 Q 0 0 0 </pre>
---	---

For the extra input parameters with NBODY6, $NNBMAX = 2 \cdot \sqrt{N}$ is usually sufficient. However a slightly larger value (say 95 here) may be prudent if there are energetic binaries. $RS0 = 0.30$ for most examples with $N = 1000$.

Sample run times on a 2.6 Ghz P4: NBODY4: 90 secs, NBODY6: 150 secs.

See www.NBodyLab.org for example output from NBODY4 and NBODY6 for these templates.

13. Example input templates for NBODY4 and NBODY6

Single Plummer sphere cluster model with additional 200 primordial binaries (KZ8=3)

NBODY4

1 10.0 0	KSTART TCOMP GPID
1000 1 5 50000 1	N NFIX NCRIT NRAND NRUN
0.02 2.0 10.0 100.0 2.0D-04 1.0 0.5	ETA DTADJ DELTAT TCRIT QE RBAR ZMBAR
0 0 1 0 1 0 6 3 0 0	KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10
0 0 0 1 1 1 0 0 3 4	KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20
1 0 2 0 1 2 0 0 0 1	KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30
0 0 0 0 0 0 1 0 0 0	KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40
1.0E-05 1.0D-03 0.2 1.0 1.0E-06 0.001	DTMIN RMIN ETAU ECLOSE GMIN GMAX
2.3 10.0 0.2 200 0.02 0 10.0	ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0 DTPL0T
0.5 0 0 0	Q 0 0 0
0.0005 -1.0 0.0 100. 0 0 0	SEMI ECC RATIO RANGE 0 0 0

NBODY6

1 20.0 0	KSTART TCOMP
1000 1 5 50000 95 1	N NFIX NCRIT NRAND NNBMAX NRUN
0.02 0.03 0.3 2.0 10.0 100.0 2.0D-04 1.0 0.5	ETAI ETAR RS0 DTADJ DELTAT TCRIT QE RBAR ZMBAR
0 0 1 0 1 0 6 3 0 0	KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10
0 1 0 1 1 1 0 1 3 4	KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20
1 0 2 0 0 2 0 0 0 1	KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30
0 0 0 0 0 0 0 0 0 1	KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40
1.0E-05 1.0D-03 0.2 1.0 1.0E-06 0.001	DTMIN RMIN ETAU ECLOSE GMIN GMAX
2.3 10.0 0.2 200 0.02 0 10.0	ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0
0.5 0 0 0	Q 0 0 0
200 0.0005 -1.0 0.0 100. 0 0 0	NBIN SEMI ECC RATIO RANGE 0 0 0

See www.NBodyLab.org for example output from NBODY4 and NBODY6 for these templates.

Sample run times on a 2.6 Ghz P4: NBODY4: 510 secs, NBODY6: 270 secs.

13. Example input templates for NBODY4 and NBODY6

Two Plummer models in orbit (KZ5=2)

NBODY4

<pre> 1 10.0 0 1000 1 5 60000 1 0.02 2.0 10.0 100.0 2.0D-05 1.0 0.5 0 0 1 0 2 0 6 0 0 0 0 0 0 0 1 1 0 0 0 0 1 0 0 0 1 2 0 0 0 2 0 0 0 0 0 0 1 0 0 0 1.0E-05 1.0D-04 0.2 1.0 1.0E-06 0.001 2.3 10.0 0.2 0 0.02 0 10.0 6.0 .5 500 .5 0.5 0 0 0 </pre>	<pre> KSTART TCOMP GPID N NFIX NCRIT NRAND NRUN ETA DTADJ DELTAT TCRT QE RBAR ZMBAR KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10 KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20 KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30 KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40 DTMIN RMIN ETAU ECLOSE GMIN GMAX ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0 DTPL0T APO ECC N2 SCALE Q 0 0 0 </pre>
---	--

NBODY6

<pre> 1 10.0 0 1000 1 5 60000 95 1 0.02 0.03 0.22 2.0 10.0 100.0 2.0D-05 1.0 0.5 0 0 1 0 2 0 6 0 0 0 0 1 0 0 1 1 0 1 0 0 1 0 0 0 0 2 0 0 0 2 0 0 0 0 0 0 0 0 0 1 1.0E-05 1.0D-04 0.2 1.0 1.0E-06 0.001 2.3 10.0 0.2 0 0.02 0 10.0 6.0 .5 500 .5 0.5 0 0 0 </pre>	<pre> KSTART TCOMP N NFIX NCRIT NRAND NNBMAX NRUN ETA1 ETAR RS0 DTADJ DELTAT TCRT QE RBAR ZMBAR KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10 KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20 KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30 KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40 DTMIN RMIN ETAU ECLOSE GMIN GMAX ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0 APO ECC N2 SCALE Q 0 0 0 </pre>
--	---

See www.NBodyLab.org for example output from NBODY4 and NBODY6 for these templates.

Sample run times on a 2.6 Ghz P4: NBODY4: 130 secs, NBODY6: 250 secs.

13. Example input templates for NBODY4 and NBODY6

Massive perturber and planetesimal disk (KZ5=3)

NBODY4

1 10.0 0	KSTART TCOMP GPID
1000 1 5 50000 1	N NFIX NCRIT NRAND NRUN
0.02 1.0 1.0 20.0 2.0D-05 1.0 0.5	ETA DTADJ DELTAT TCRIT QE RBAR ZMBAR
0 0 1 0 3 0 0 0 0 0	KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10
0 0 0 0 1 0 0 0 0 0	KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20
1 0 2 0 1 2 0 0 0 2	KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30
0 0 0 0 0 0 1 0 0 0	KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40
1.0E-05 1.0D-04 0.2 1.0 1.0E-06 0.001	DTMIN RMIN ETAU ECLOSE GMIN GMAX
2.3 10.0 0.2 0 0.02 0 10.0	ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0 DTPLOT
6.0 1.1 3 .5	APO ECC DMIN SCALE
0.5 0 0 0	Q 0 0 0

NBODY6

1 10.0 0	KSTART TCOMP
1000 1 5 50000 60 1	N NFIX NCRIT NRAND NNBMAX NRUN
0.02 0.03 0.05 1.0 1.0 20.0 2.0D-05 1.0 0.5	ETAI ETAR RS0 DTADJ DELTAT TCRIT QE RBAR ZMBAR
0 0 1 0 3 0 0 0 0 0	KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10
0 0 0 0 1 0 0 1 0 0	KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20
1 0 2 0 0 2 0 0 0 2	KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30
0 0 0 0 0 0 0 0 0 0	KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40
1.0E-05 1.0D-04 0.2 1.0 1.0E-06 0.001	DTMIN RMIN ETAU ECLOSE GMIN GMAX
2.3 1.0 1.0 0 0.02 0 10.0	ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0
6.0 1.1 3 .5	APO ECC DMIN SCALE
0.5 0 0 0	Q 0 0 0

See www.NBodyLab.org for example output from NBODY4 and NBODY6 for these templates.

Sample run times on a 2.6 Ghz P4: NBODY4: 12 secs, NBODY6: 40 secs.

13. Example input templates for NBODY4 and NBODY6

Evolution of dominant binary (KZ5=4)

NBODY4

<pre> 1 10.0 0 2000 1 5 50000 1 0.02 2.0 10.0 200.0 1.0D-04 1.0 0.5 0 0 1 0 4 0 5 0 0 0 0 0 0 1 1 1 0 0 0 0 1 0 2 0 1 2 0 0 0 2 0 0 0 0 0 0 1 0 0 0 1.0E-05 1.0D-04 0.2 1.0 1.0E-06 0.001 2.3 10.0 0.2 0 0.02 0 10.0 1.0D-03 0.5 25.0 25.0 0.5 0 0 0 </pre>	<pre> KSTART TCOMP GPID N NFIX NCRIT NRAND NRUN ETA DTADJ DELTAT TCRIT QE RBAR ZMBAR KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10 KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20 KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30 KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40 DTMIN RMIN ETAU ECLOSE GMIN GMAX ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0 DTPLOT SEMI ECC M1 M2 Q 0 0 0 </pre>
---	---

NBODY6

<pre> 1 10.0 0 1000 1 5 50000 95 1 0.02 0.03 0.3 2.0 10.0 200.0 1.0D-04 1.0 0.5 0 0 1 0 4 0 5 0 0 0 0 1 0 1 1 1 0 1 0 0 1 0 2 0 0 2 0 0 0 2 0 0 0 0 0 0 0 0 0 1 1.0E-05 1.0D-04 0.2 1.0 1.0E-06 0.001 2.3 10.0 0.2 0 0.02 0 10.0 1.0D-03 0.5 25.0 25.0 0.5 0 0 0 </pre>	<pre> KSTART TCOMP N NFIX NCRIT NRAND NNBMAX NRUN ETAI ETAR RS0 DTADJ DELTAT TCRIT QE RBAR ZMBAR KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10 KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20 KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30 KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40 DTMIN RMIN ETAU ECLOSE GMIN GMAX ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0 SEMI ECC M1 M2 Q 0 0 0 </pre>
---	--

See www.NBodyLab.org for example output from NBODY4 and NBODY6 for these templates.

Sample run times on a 2.6 Ghz P4: NBODY4: 270 secs, NBODY6: 180 secs.

13. Example input templates for NBODY4 and NBODY6

Input your own data set (KZ22=2,3)

NBODY4

<pre> 1 10.0 1000 1 5 50000 1 0.02 2.0 10.0 100.0 2.0D-05 1.0 0.5 0 0 1 0 1 0 6 0 0 0 0 0 0 1 1 1 0 0 3 0 1 2 2 0 1 2 0 0 0 2 0 0 0 0 0 0 1 0 0 0 1.0E-05 1.0D-04 0.2 1.0 1.0E-06 0.001 2.3 1.0 1.0 0 0.02 0 10.0 0.5 0 0 0 </pre>	<pre> KSTART TCOMP GPID N NFIX NCRIT NRAND NRUN ETA DTADJ DELTAT TCRIT QE RBAR ZMBAR KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10 KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20 KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30 KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40 DTMIN RMIN ETAU ECLOSE GMIN GMAX ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0 DTPL0T Q 0 0 0 </pre>
--	--

NBODY6

<pre> 1 10.0 1000 1 5 50000 95 1 0.02 0.03 0.3 2.0 10.0 200.0 1.0D-04 1.0 0.5 0 0 1 0 4 0 5 0 0 0 0 0 0 1 1 1 0 0 0 0 1 2 2 0 1 2 0 0 0 2 0 0 0 0 0 0 1 0 0 1 1.0E-05 1.0D-04 0.2 1.0 1.0E-06 0.001 2.3 10.0 0.2 0 0.02 0 10.0 0.5 0 0 0 </pre>	<pre> KSTART TCOMP N NFIX NCRIT NRAND NNBMAX NRUN ETA1 ETAR RS0 DTADJ DELTAT TCRIT QE RBAR ZMBAR KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10 KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20 KZ21 KZ22 KZ23 KZ24 KZ25 KZ26 KZ27 KZ28 KZ29 KZ30 KZ31 KZ32 KZ33 KZ34 KZ35 KZ36 KZ37 KZ38 KZ39 KZ40 DTMIN RMIN ETAU ECLOSE GMIN GMAX ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0 Q 0 0 0 </pre>
---	---

Input file consists of N rows with: m x y z vx vy vz

See www.NBodyLab.org for example output from NBODY4 and NBODY6 for these templates, and a sample input data set.

14. For more information

14. For more information

See the book Gravitational N-body Simulations Tools and Algorithms,
Sverre Aarseth, Cambridge University Press, 2003

NBODY4 and NBODY6 source code distributions (see downloads link)
<http://www.ast.cam.ac.uk/~sverre/web/pages/home.htm>

Please send comments and suggestions for this manual to:

sverre@ast.cam.ac.uk (Sverre Aarseth) and
nbodylab@interconnect.com (Vicki Johnson, maintainer).