Introduction to Running Simulations with NBODY4 and NBODY6

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Software (including source code) and documentation downloads:
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1. Introduction

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

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 Msun. 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*Msun. 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 1.0/2.0D+05 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 TCRIT=20. The total time for a parabolic passage can be estimated from Tp = 2*DMIN**1.5/(2*MTOT)**0.5, with MTOT = 1 + SCALE. The time in yr is then Tp/2*pi or TIME/2*pi. This calculation is best done with conservative regularization parameters: DTMIN = 1.0D-05, RMIN = 1.0D-04, 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*M2/(2*a)), cluster energy and eccentricity are written to a file every output 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

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

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 TCRIT 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 TCRIT 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

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	• =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 *APO ECC N2 SCALE* 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 *APO ECC DMIN SCALE* 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 *SEMI ECC M1 M2* 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 S*EMI ECC RATIO RANGE 0 0 0* 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).
KZ22	Read in user model and optionally scale data file of initial conditions, N rows of *m x y z vx vy vz*. • =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 >= 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 <= 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 Msun).

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

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
Tphys = 15*(RBAR**3/MTOT)**0.5*TIME, where MTOT is the total mass in solar units and TIME is the N-body time. For the velocity scaling,
VSTAR = 0.066*(MTOT/RBAR)**0.5 km/sec.
In the standard case, MTOT = ZMBAR*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 BODY*ZMBAR. Finally, the mean crossing time is simply 2*sqrt(2) which suggests a convenient output time 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 RMIN and the time-steps fall below DTMIN. With standard N-body units, typical values of the regularization parameters may be taken as RMIN = 1/N and DTMIN = 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 DTMIN = 1D-20, although this is not recommended in general.

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 RBAR = 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*RBAR*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*KS except for triples)
T6	Time in Myr (RBAR assumed = 1 nominally for isolated cluster)

```
 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  NKSHYP     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       0       804         0       46    0

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

```
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  NTESC
 #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   NTTRY  NTRIP  NQUAD  NCHAIN  NMERG  NEWHI  NSTEPC    NBCALL    NTPERT    NWARN  NHI
 #2     6407      34      31          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
```

```
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      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).

```
TIME =   28.00  Q = 0.61  DE =  0.000004  E = -0.257007  RMIN = 1.1E-03  DTMIN = 4.4E-05  ECLOSE = 0.81  TC =   4  EB/E = 0.6347  BIN =      1     5

 ESCAPE    N =   995     5   0  0.9942  -0.260098   0.10  25.15  0.500  0.00100    989      39

 ESCAPE ANGLES       44    45

 NEW CHAIN     1  T =   29.67  H =  -12.  R = 7.5E-04  M = 0.0277 0.0040  G4 = 2.6E-06  R1 = 8.7E-04  P = 8.6E-04  E1 = 0.075  NP = 5
 NEW CHAIN   N NP E RSUM RGRAV TCR RMAXS NAM    3   1  -0.10269  1.1E-03  5.3E-04  1.9E-03  6.7E-03     1     5    34

 CHAIN BINARY  NAM =     1     5  A = 1.0E-03  E = 0.92  EB = 0.89  GB = 3.4E-03  G4 = 0.0E+00  EB1 = 0.00  E1 = 0.13  ET = 0.353  DB = 0.1
 RECOIL:    E E1 PM/A RD A A1 RP GB IN   0.9190  0.84  0.8   2.7  1.01E-03  5.31E-03  3.85E-03  3.41E-03  145.6

 END CHAIN    1  2  3  1  RB = 1.0E-03  R13 = 3.5E-03  R24 = 1.0E+10  DE = 1.9E-06  TC =  0.5  #   13   1  1  DB = 0.11  EC = 0.395
 CHTERM:   T I3 I4 NT DT   29.6738   474   474   996  1.9E-06  1.9E-06  1.9E-06

TIME =   30.00  Q = 0.60  DE = -0.000004  E = -0.260099  RMIN = 1.2E-03  DTMIN = 5.4E-05  ECLOSE = 0.75  TC =   4  EB/E = 0.7717  BIN =      5     1
```

Further increase of binary energy after another chain interaction. One binary now has 77 % of the total energy.

```
 T =   30.0  N =   995  KS =    1  NM =  0  MM = 0  NS =   993  NSTEPS =    4060357      166372  DE =  0.000015  E = -0.260099

 RUN =  1  M# =  0  CPU =    0.4  DMIN = 1.6E-05 1.6E-05  AMIN = 8.1E-04  RMAX = 1.6E-02  NBLOCK =    150265  NIRECT = 0  NURECT = 0  NEFF =   288

    <R>  RTIDE  RDENS   RC     NC   MC   RHOD   RHOM    UN  NPT  RCM    VCM        AZ     EB/E   EM/E   TCR      T6  NTESC
 #1 1.06  12.0   0.21  0.166   13  0.065  26.4   92.5    0    3  0.109  0.0042 -0.022192  0.772  0.000  6.25     18     66

      NKSTRY  NKSREG  NKSHYP     NKSPER  NPRECT  NKSMOD   NTTRY  NTRIP  NQUAD  NCHAIN  NMERG  NEWHI  NSTEPC    NBCALL    NTPERT    NWARN  NHI
 #2    30743     133      91         61       0      87      78      0      0       2      0      0      25     20389      2200     3129    2

 TWO MASS GROUPS:    NM1 NM2 M1 M2 RM1 RM2     150    844   0.497  0.497  0.780  1.408

 OR =   0  EX =  0  DB =  0.456  SB =  0.0000  BB =  0.0000  CH = -0.0390  NC =  1  N(A) =   0   1
 <E> = 0.79  EMAX = 0.789  NPOP =   1  0   993     5   0  0  0  0  0  EB/KT =   0   0   0   0   0   0   0   0   0   1
 ENERGIES    -0.11411  0.00000 -0.14599  0.01054  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  ETOT = -0.260099

 NEW CHAIN     1  T =   30.90  H =   -7.  R = 7.8E-04  M = 0.0208 0.0112  G4 = 4.2E-07  R1 = 8.9E-04  P = 1.2E-04  E1 = 4.814  NP =35
 NEW CHAIN   N NP E RSUM RGRAV TCR RMAXS NAM    3   1  -0.11572  1.2E-03  6.1E-04  1.7E-03  1.3E-02     1    30     5
 EXCHANGE    T NAM E0 E A0 A EB0 EB     30.91     1    30     1     5  0.943  0.831  1.6E-03  9.2E-04  -2.3E-02  -1.0E-01

 CHAIN BINARY  NAM =     1     5  A = 9.2E-04  E = 0.83  EB = 0.87  GB = 1.7E-03  G4 = 0.0E+00  EB1 = 0.00  E1 = 0.67  ET = 0.387  DB = 3.5
 RECOIL:    E E1 PM/A RD A A1 RP GB IN   0.8309  0.90  0.4   1.9  9.20E-04  4.02E-03  5.10E-03  1.71E-03   99.1

 END CHAIN    1  3  2  1  RB = 1.2E-03  R13 = 5.5E-03  R24 = 1.0E+10  DE = 1.8E-11  TC =  4.0  #   70   7  1  DB = 3.48  EC = 0.445
 CHTERM:   T I3 I4 NT DT   30.9111     2     2   996  3.8E-06  3.8E-06  3.8E-06

 NEW CHAIN     1  T =   30.92  H =  -14.  R = 9.9E-04  M = 0.0277 0.0043  G4 = 2.3E-07  R1 = 1.0E-03  P = 5.0E-04  E1 = 0.164  NP = 3
 NEW CHAIN   N NP E RSUM RGRAV TCR RMAXS NAM    3   1  -0.11572  1.2E-03  6.1E-04  1.7E-03  1.3E-02     1     5    30
 CHAIN ESCAPE:    IESC NM RI RDOT2 2*M/R VF   3    30  4.0E-03  3.3E+01  1.6E+01   6.7
```

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 EB0 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, <R>, 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   NTTRY  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  EB/KT =   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  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
```

```
 ESCAPE    N =   987    13   0  0.9681  -0.327300   0.31  25.35  0.500  0.00098    968     410

 ESCAPE ANGLES       43    33

TIME =   44.00  Q = 0.62  DE = -0.000018  E = -0.327305  RMIN = 1.6E-03  DTMIN = 7.9E-05  ECLOSE = 0.81  TC =   7  EB/E = 1.2044  BIN =      5     1

 ESCAPE    N =   986    14   0  0.9674  -0.327545   0.35  24.39  0.500  0.00098    965     353

 ESCAPE ANGLES       42    26
```

---------- Output from T=46 to T=88 omitted to save space ------------------

```
 T =   90.0  N =   952  KS =    1  NM =  0  MM = 0  NS =   950  NSTEPS =    7800737     1686032  DE =  0.000000  E = -0.359742

 RUN =  1  M# =  0  CPU =    1.2  DMIN = 1.6E-05 2.7E-04  AMIN = 3.5E-04  RMAX = 4.6E-04  NBLOCK =    480603  NIRECT = 0  NURECT = 0  NEFF =   282

    <R>  RTIDE  RDENS   RC     NC   MC   RHOD   RHOM    UN  NPT  RCM    VCM        AZ     EB/E   EM/E   TCR      T6  NTESC
 #1 2.01  11.7   1.90  0.284   10  0.069  31.6   92.7    1    0  1.554  0.0422  0.033596  3.077  0.050 11.62     54    217

      NKSTRY  NKSREG  NKSHYP     NKSPER  NPRECT  NKSMOD   NTTRY  NTRIP  NQUAD  NCHAIN  NMERG  NEWHI  NSTEPC    NBCALL    NTPERT    NWARN  NHI
 #2   222412     319     127     124750       0    2199   25877      0      0      20     63      0     723    177528     55693    57687    0

 TWO MASS GROUPS:    NM1 NM2 M1 M2 RM1 RM2     149    802   0.466  0.465  1.462  2.644

 OR =   0  EX =  0  DB =  1.091  SB =  0.0000  BB =  0.0000  CH = -0.4436  NC =  1  N(A) =   0   0   1
 <E> = 0.21  EMAX = 0.206  NPOP =   1  0   950    48   0  0  0  0  0  EB/KT =   0   0   0   0   0   0   0   0   0   0   0   1
 ENERGIES    -0.26837  0.00000 -0.08696  0.11019  0.00000  0.00000  0.00000  0.00000 -0.00434  0.00000  ETOT = -0.359661

TIME =   92.00  Q = 0.53  DE = -0.000014  E = -0.359743  RMIN = 2.4E-03  DTMIN = 1.5E-04  ECLOSE = 0.45  TC =   7  EB/E = 3.1095  BIN =      5     1

 ESCAPE    N =   946    54   0  0.9278  -0.360076   1.67  23.67  1.000  0.00098    893     309   902   388   445   526   752

 ESCAPE ANGLES       56     5      27     7      19     0      46     4      17    18      18     7

TIME =   94.00  Q = 0.54  DE = -0.000017  E = -0.360078  RMIN = 2.2E-03  DTMIN = 1.3E-04  ECLOSE = 0.46  TC =   8  EB/E = 3.0834  BIN =      5     1

 ESCAPE    N =   945    55   0  0.9273  -0.360076   1.75  23.54  0.500  0.00098    890     527

 ESCAPE ANGLES       61     6

TIME =   96.00  Q = 0.59  DE =  0.000000  E = -0.360076  RMIN = 1.3E-03  DTMIN = 5.7E-05  ECLOSE = 0.52  TC =   8  EB/E = 3.0802  BIN =      5     1

TIME =   98.00  Q = 0.52  DE =  0.000020  E = -0.360074  RMIN = 1.7E-03  DTMIN = 8.5E-05  ECLOSE = 0.45  TC =   8  EB/E = 3.0768  BIN =      5     1

 ESCAPE    N =   943    57   0  0.9262  -0.360434   1.89  23.96  1.000  0.00098    887     416   784

 ESCAPE ANGLES        6    21       6     1

 NEW CHAIN     1  T =   99.84  H =  -40.  R = 4.3E-04  M = 0.0277 0.0083  G4 = 7.7E-07  R1 = 1.2E-03  P = 2.3E-04  E1 = 0.022  NP = 1
```

```
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 <R> = 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  NTESC
#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   NTTRY  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  EB/KT =   0   0   0   0   0   1   0   0   0   0   0   1
ENERGIES    -0.29537 -0.00734 -0.05337  0.11553  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  NTESC
 #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   NTTRY  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  EB/KT =   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
```

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 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 <NNB>) 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

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

Single Plummer sphere cluster model (KZ5=1)

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-05 1.0 0.5	ETA DTADJ DELTAT TCRIT QE RBAR ZMBAR
0 0 1 0 1 0 6 0 0 0	KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10
0 0 0 1 1 1 0 0 3 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
0.5 0 0 0	Q 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-05 1.0 0.5	ETAI ETAR RS0 DTADJ DELTAT TCRIT QE RBAR ZMBAR
0 0 1 0 1 0 6 0 0 0	KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10
0 1 0 1 1 1 0 1 3 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 1	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
0.5 0 0 0	Q 0 0 0

For the extra input parameters with NBODY6, NNBMAX = 2*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 DTPLOT
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

1 10.0 0	KSTART TCOMP GPID
1000 1 5 60000 1	N NFIX NCRIT NRAND NRUN
0.02 2.0 10.0 100.0 2.0D-05 1.0 0.5	ETA DTADJ DELTAT TCRIT QE RBAR ZMBAR
0 0 1 0 2 0 6 0 0 0	KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10
0 0 0 0 1 1 0 0 0 0	KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20
1 0 0 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 .5 500 .5	APO ECC N2 SCALE
0.5 0 0 0	Q 0 0 0

NBODY6

1 10.0 0	KSTART TCOMP
1000 1 5 60000 95 1	N NFIX NCRIT NRAND NNBMAX NRUN
0.02 0.03 0.22 2.0 10.0 100.0 2.0D-05 1.0 0.5	ETAI ETAR RS0 DTADJ DELTAT TCRIT QE RBAR ZMBAR
0 0 1 0 2 0 6 0 0 0	KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10
0 1 0 0 1 1 0 1 0 0	KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20
1 0 0 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 1	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
6.0 .5 500 .5	APO ECC N2 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: 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

1 10.0 0	KSTART TCOMP GPID
2000 1 5 50000 1	N NFIX NCRIT NRAND NRUN
0.02 2.0 10.0 200.0 1.0D-04 1.0 0.5	ETA DTADJ DELTAT TCRIT QE RBAR ZMBAR
0 0 1 0 4 0 5 0 0 0	KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10
0 0 0 1 1 1 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
1.0D-03 0.5 25.0 25.0	SEMI ECC M1 M2
0.5 0 0 0	Q 0 0 0

NBODY6

1 10.0 0	KSTART TCOMP
1000 1 5 50000 95 1	N NFIX NCRIT NRAND NNBMAX NRUN
0.02 0.03 0.3 2.0 10.0 200.0 1.0D-04 1.0 0.5	ETAI ETAR RS0 DTADJ DELTAT TCRIT QE RBAR ZMBAR
0 0 1 0 4 0 5 0 0 0	KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10
0 1 0 1 1 1 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 1	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
1.0D-03 0.5 25.0 25.0	SEMI ECC M1 M2
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: 270 secs, NBODY6: 180 secs.

13. Example input templates for NBODY4 and NBODY6

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

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-05 1.0 0.5	ETA DTADJ DELTAT TCRIT QE RBAR ZMBAR
0 0 1 0 1 0 6 0 0 0	KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10
0 0 0 1 1 1 0 0 3 0	KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20
1 2 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 1.0 1.0 0 0.02 0 10.0	ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0 DTPLOT
0.5 0 0 0	Q 0 0 0

NBODY6

1 10.0 0	KSTART TCOMP
1000 1 5 50000 95 1	N NFIX NCRIT NRAND NNBMAX NRUN
0.02 0.03 0.3 2.0 10.0 200.0 1.0D-04 1.0 0.5	ETAI ETAR RS0 DTADJ DELTAT TCRIT QE RBAR ZMBAR
0 0 1 0 4 0 5 0 0 0	KZ1 KZ2 KZ3 KZ4 KZ5 KZ6 KZ7 KZ8 KZ9 KZ10
0 0 0 1 1 1 0 0 0 0	KZ11 KZ12 KZ13 KZ14 KZ15 KZ16 KZ17 KZ18 KZ19 KZ20
1 2 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 1	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
0.5 0 0 0	Q 0 0 0

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

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

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