## Exercise 3: Globular Clusters

handed out: 20.11.2007 handing in: 04.12.2007

**Problem 6: $N$-body simulations**
It's about time to embark upon some "real" simulations with 100 and more particles! To this extent you need to adapt your existing code developed in exercise #2.

1. **adaptation of $N$-body code**

   - *input:*
     Modify your code in a way that it can read the initial conditions from a file. Let the user choose the filename and use the following format for the file:
     $x_i \quad y_i \quad z_i \quad v_{x,i} \quad v_{y,i} \quad v_{z,i}$
     where $x_i, y_i, z_i$ is a particle's position and $v_{x,i}, v_{y,i}, v_{z,i}$ a particle's velocity. Use one line for each particle $i \in N$.
   - *units:*
     The files to be read in contain positions in $pc$ (globular cluster files, see below) or $Mpc$ (output of `PM2asciiM/PMstartM`); do not forget to convert them to the units used by your code! By the way, it is recommended to use $M_\odot$, $pc$, and $Myr$ as your internal code units.
   - *output:*
     Modify your code in a way that it dumps all particle positions and velocities in the same format as the input data. It is not necessary to store every individual timestep, but introduce a new variable (e.g. `dtout`) that determines the frequency of your outputs.

   **(10 points)**

2. **globular clusters**

   Please download the file `king100.dat` from the web page of the exercises to the lecture Computational Cosmology[1]. This file contains the initial conditions $(x, y, z, v_x, v_y, v_z)$ for 100 particles describing a globular cluster. The positions are given in $pc$ and the velocities in $km/sec$. Note that all stars have the same mass $1M_\odot$ and are therefore not stored in the file; you need to assign them "manually". Use this file as initial conditions for you $N$-body code. As an initial "guess"

[1] `http://www.aip.de/People/AKnebe/page3/files/king100.dat`

for the time step try $\Delta t = 0.001 Myr$ and write an output file every `dtout`$= 0.01 Myr's$. How does the globular cluster look initially? How after $10 Myr's$? Try to visualise the temporal evolution of the globular cluster.

**(10 points)**

**supplementary:**

If you dare try the file `king1000.dat`; it contains a globular cluster consisting of 1000 particles. Please note the $N^2$ scaling of your $N$-body code!

**(+5 points)**

3. **cosmological simulations (supplementary)**

   Use the already familiar `PMstartM` (cf. exercise #4) to generate initital conditions of a ΛCDM cosmological model. Use $16^3$(=4096) particles in a box of side length $10 Mpc/h$. After conversion of the binary output of `PMstartM` with `PM2asciiM` adapt your $N$-body code to read in the ASCII file. The positions are given in $Mpc/$ and the velocities in $km/sec$. Assign the same mass $m_i = 2.03284 \times 10^{10} M_\odot/h$ to all particles[2]. As an initial guess for the time step use 1000 $Myr's$ (or 100 $Myr's$ if you have enough computing power at our disposal) and let the simulation evolve for about 13000 $Myr's$. Please note that this is **not** a cosmological simulation as we are not accounting for the Hubble expansion of the Universe (which has though been considered when generating the initial conditions); this is a mere "toy model" to show the limitations of your code...

   **(+5 points)**

[2]For the time being ignore the $h$ in the spatial and mass units.