GRAPE クラスターを利用する並列 SPH コード

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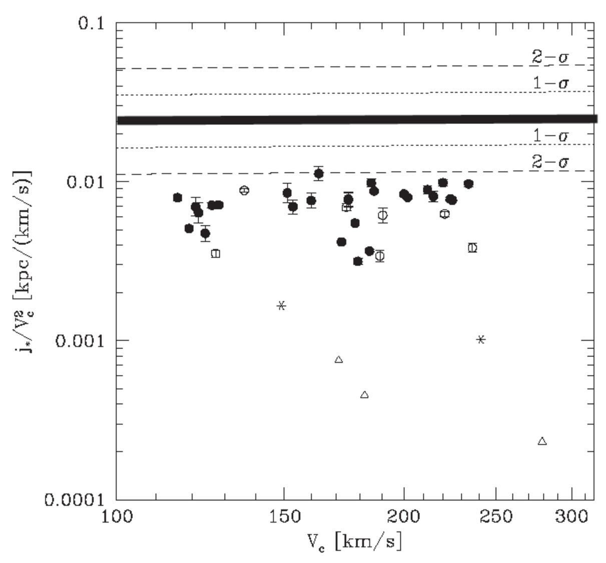
1. Introduction

The Smoothed Particle Hydrodynamics (SPH) method, which has been introduced in late '70s, is the most popular and sccessful method when we construct a N-Body model of galaxy formation including hydrodynamics. Despite the great success of the SPH method, it is not clear that the number of particle (numerical resolution) usually used in galaxy models is sufficient. A example of this problem is presented in the work by Sommar-Larsen etal (2001). They try to solve the problem known as ``angular momentum problem''. This problem is that when we numerically model the collapse of gas within a dark halo (cosmological SPH simulation), the formed gas disk has much less angular momentum than observed disk galaxies (see left figure). One of thier conclusions is that the resulted specific angular momentum of the disk highly depends on the numerical resolution. To address this problem with a much higher resolution SPH model, we are developing own Parallel Tree-SPH code.

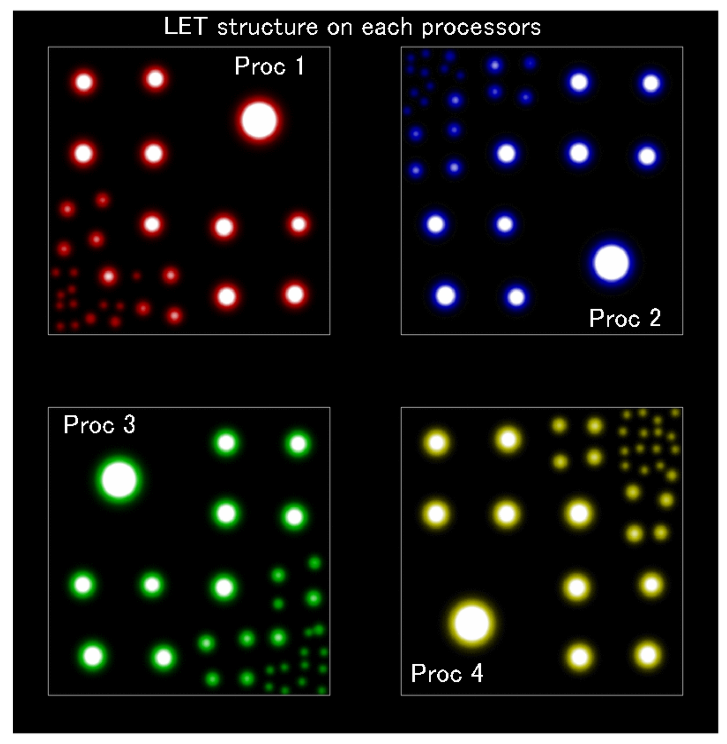


2. Implementation

The tree method consists of three stages: (1) tree construction, (2) tree walking and (3) summation. The details about each stage are explained in the right panel. A highlight of our code is to take a full advantage of the GRAPE cluster in NAOJ, Tokyo. There are many possible choice of algorithms when we implement a parallel tree code, however, all choices are made to maximise the performance with this GRAPE cluster. The SPH part of the code is easily implemeted if we already implement the parallel tree code. Also, an indivisual time step scheme is incorporated to further obtain a greater performance. The elapsed time of the largest model (Model 3 below) ever is 140 hour (total ~ 52000 steps) from z ~ 24 to 1.6 (~ 3 Gyr).

Tree Construction

In this stage, a tree data structure is created according to the position of particles. The particles are divided into boxes (8 boxes in 3-D case) recusively and this division is represented by the tree structure. For the parallel implementation, we adopt the locally essential tree (LET) method. Specifically, first the local tree is created in each proccesors, and then the LET is computed by exchanging tree data. On each processor, another LET is constructed for the SPH computation.

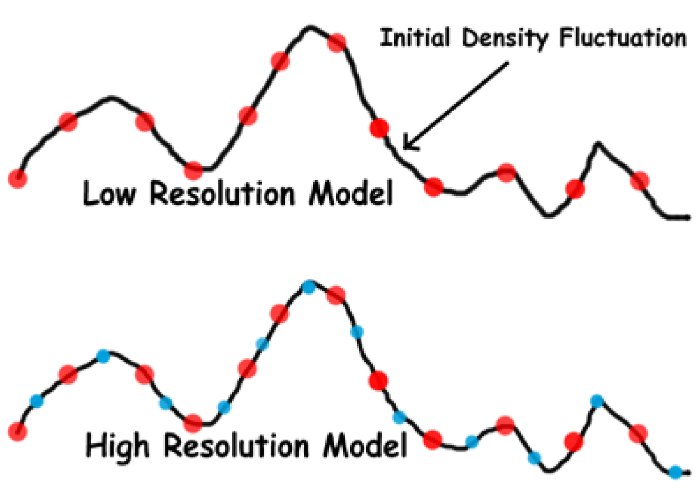


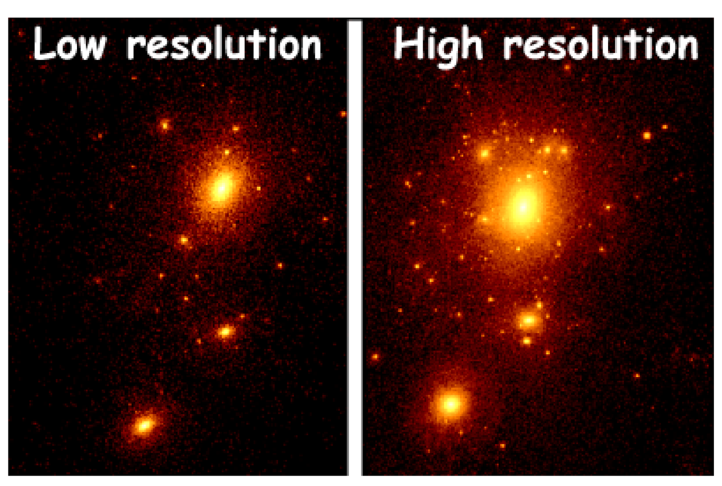
Tree Walking and Summation

Here, we define *sink particles* as the particles which are need to compute the gravity and *source particles* as the particles wihch exert the gravity. In our parallel version of code, a list of *source particles* (interaction list) are computed by walking the LET with apripiate conditions. In the tree method with GRAPE, the interaction lists are shared within a group of particles. First things to do is that we divide the *sink particles* into the *sink groups* (typical number in a sink group is a few thousand). For each group, we compute the shared interaction list. To obtain the maximum performance, better the interaction list is longer. Once the shared interaction list is computed for a group, the gravity is computed with GRAPE according to the particles in the interaction list. We repeat this procedure until there are no *sink particles*. For the simulations in this presentation, we use 4 processors in parallel. Each computer has one GRAPE-6 board.

3. Early Results

Using our serial and parallel version of our Tree-GRAPE-SPH code, we have computed the evolution of an isolated halo. According to Sommar-Larsen etal, we generate a initial model with the warm dark matter (WDM) spectrum by dumping the small scale fluctuation. We adopt a transfer function as $P_{wdm} = \exp(-0.5{*}a1 - 0.5{*}a1{*}a1)\ P_{cdm}$, where a1 is the cutoff radius. Our adopted size corresponds to the cutoff mass Mc = 1.9 x 10^{10} Mo/h, where h is the Hubble parameter. Namely, the fluctuations smaller than Mc are completely reduced. We use the GRAFIC2 software to generate initial models. With the GRAFIC2, we easily generate multi-scale initial models. In this panel, we show example results of the CDM comological simulation with the GRAFIC2. Both panels show the projected density of dark matter particles where the model in the right panel is 8 times higher mass resolution than the left.

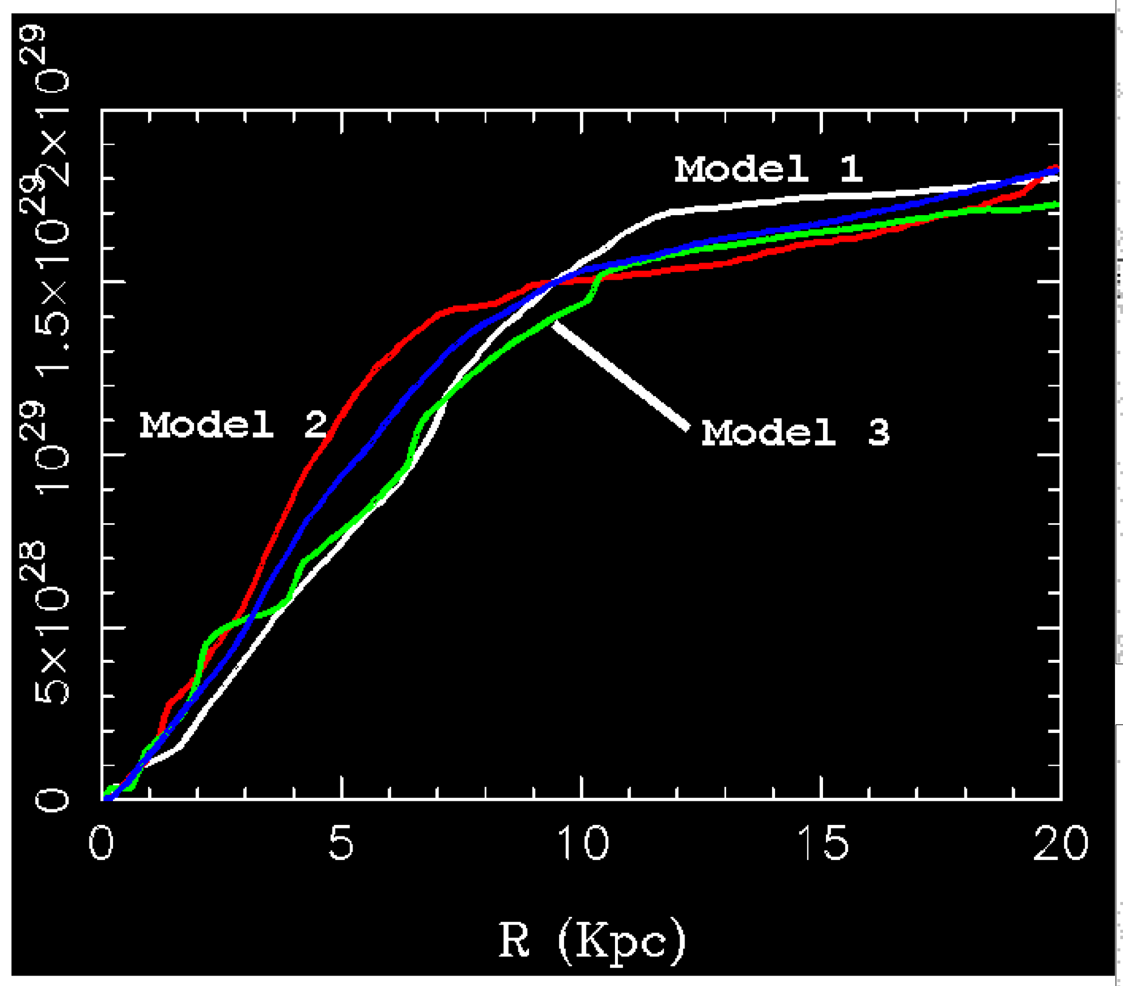


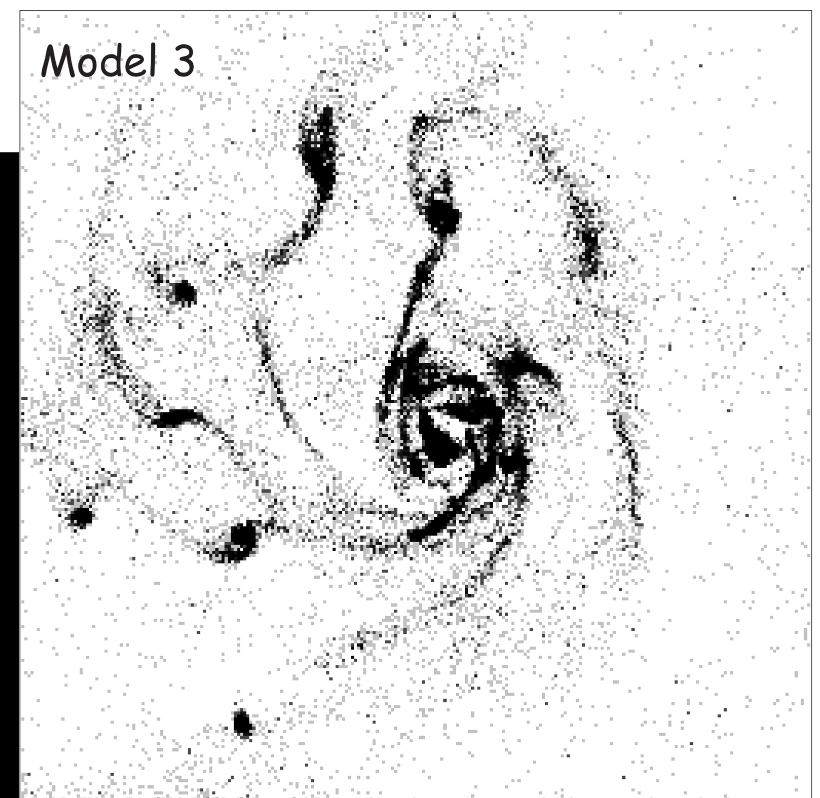


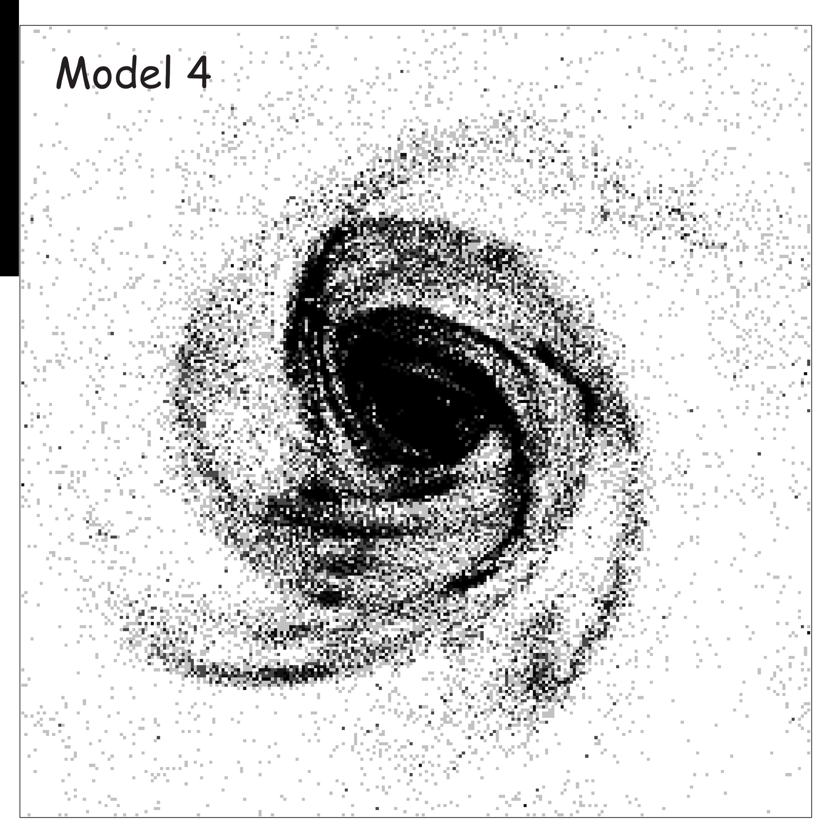
We have done four WDM cosmological SPH simulations. The adopted cosmological parameters are h = 0.5 and the flat universe without the cosmological constant and the baryon fraction is 0.1. Using the GRAFIC2, we generate two levels of a grid, i.e., Level-1 (L1) grid and Level-2 (L2) grid. L2 grid is 8 times higher mass resolution model than L1 grid. Each SPH particles and dark matter (DM) particles, there are its own L2 and L1 grid. To summarise, we have four grids as L1SPH, L1DM, L2SPH, and L2DM. With the adopted value of the baryon fraction, the mass ratio of particles between L1SPH and L1DM is ~ 0.1 and L1SPH and L2DM is ~ 1.0. By combining the four grids, we generate four initla models. We summarize the four models in the table. 4-th and 7-th column show the gravitational softening length for SPH particles and DM particles, respectively. Here, we adopt the Plummer softening length. The last column shows the mass ratio between SPH particles and DM particles. Model-1 is the standard model with a modest number of particles. Model-3 is the high resolution model and both mass and force resolutions are 8 times higher than Model-1 (also the number of particles is 8 times larger). Model-2 is the mixed model using L1SPH grid and L2DM grid. Model-1 and 2 are computed with the serial code, and Model-3 and 4 are computed with the parallel code. Radiative cooling is always effectve in all models.

	SPH Mass	N_{SPH}	SPH eps	DM Mass	N_{DM}	DM eps	ratio
Model 1	5.1 x 10^6 Mo	40778	1.0 Kpc	4.6 x 10^7 Mo	40769	2.0 Kpc	0.1
Model 2	5.1 x 10^6 Mo	40778	1.0 Kpc	5.7 x 10^6 Mo	326866	1.0 Kpc	0.9
Model 3	6.3 x 10^5 Mo	326842	0.5 Kpc	5.7 x 10^6 Mo	326866	1.0 Kpc	0.9
Model 4	6.3 x 10^5 Mo	326842	1.0 Kpc	5.7 x 10^6 Mo	326866	1.0 Kpc	0.9

Figure 2







The resulted angular momentum content of baryon (SPH particles) after 3 Gyr of evolution is compared in the Figure 2. Model 1, 2, 3, and 4 correspond to the lines with black, red, green, and blue, respectively. The higher resolution models tend to have higher angular momentum content inside 10 Kpc. The difference between Model-1 and Model-3 is not as large as 2 times noted in Sommar-Larsen etal. Model-2 has highest angular momentum. Note that the mass ratio between a SPH and darkmatter particle in Model 2 is most desirable in terms of artificial numerical effects. Another intersting point to be noted is that the force resolution (gravitational softening length) significantly affects the evolution of SPH particles. We compare the face on density of baryon disk for Model-3 and Model-4. The projected density for Model-3 (high force resolution) clearly shows more clumpy density distribution. From these results, it is shown that the inplementation of our parallel Tree-GRAPE-SPH code works well. We will do higher resolution simulation in the coming year.