NUMERICAL SIMULATIONS OF GALAXIES WITH THE MARSEILLE GRAPE-3 SYSTEMS

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Abstract. We briefly describe the performance and accuracy of the Marseille GRAPE-3 systems. We first give the description of the configurations. We then outline the modifications necessary to optimize the tree code for use on a GRAPE system, and discuss performance and accuracy issues. We summarize the results of several science projects executed with our hardware and software.

1. GRAPE Hardware at Marseille Observatory

Our group acquired a hand-wired GRAPE-3A board in March 1993, consisting of 4 LSI chips operating at 20 MHz and giving a peak speed equivalent of more than 2 Gflops. It is coupled via a Solflower SFVME-110 Sbus/VMEbus converter to a Sparc 10/412 workstation, which drives it (cf. Figure 1, left panel). This hardware is limited to 32 768 particles. More particles than this limit can be used, simply by dividing the total number of particles into packages of 32 768 or less, presenting one package at a time to the board, and then adding the contributions of all packages on the front end machine. Further details on the GRAPE-3A chips and the relevant software can be found in Ebisuzaki *et al.* (1993) and Makino & Funato (1993).

In August 1994 we acquired five GRAPE-3AF boards, each having 8 chips, giving us a peak speed equivalent of more than 20 Gflops. These are printed-circuit boards and occupy the five slots of a Solflower SFVME-110 Sbus/VMEbus converter, which links them to the host machine. As such we have used consecutively a Sparc 10/41, a Sparc 10/512, an Ultra 1/170 and, since August 1996, an Ultra 2/200 with two processors. The second processor is used for real time data processing, which can be useful for calculating various quantities, such as pattern speeds of bars or energy and angular momentum exchange between different components in the simulation, at more frequent intervals than those used for storing the results on a hard disk. The configuration is illustrated in the middle panel of Figure 1. GRAPE-3AF boards are hardware limited to 131 072 particles, but, as for the GRAPE-3A boards, it is possible to use them for a larger number of particles with the help of appropriate software.

In June 1997 a GRAPE-4 board was made operational, by coupling it to an Alpha 500/500 workstation via the newly developed PCI-bus interface (Kawai et al. 1997). On this system, whose properties will be described in a forthcoming paper, we can execute a direct N-body code, a tree code, and a variable time step code.

2. Tree code software modification

We modified the standard tree code (Barnes & Hut 1986) for use on GRAPE-3 following the scheme described by Barnes (1990) : the particles are first divided into blocks and then the tree traversal is performed for a block of particles, instead of separately for each particle in the system. Then GRAPE hardware is used to calculate the forces from the nodes in the interaction list created by this tree traversal to all particles in the block.

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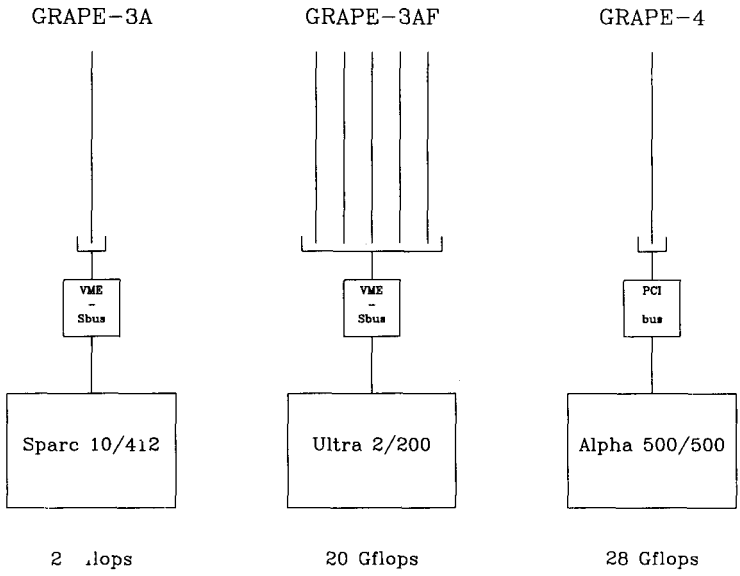

Figure 1. GRAPE systems available in Marseille

The speed of the tree traversal, which is performed on the front end, depends on the number of particles in the block. Generally speaking, if we make the number of particles in a block larger, we can reduce the amount of work of the front end, but we increase the cost of the calculation on GRAPE, since the average length of the interaction list becomes longer (Makino 1991). Thus, the number of particles in a block should be chosen so that the total calculation cost is minimum. This optimal number depends mainly on the relative speed of GRAPE and the front end, but also, though to a smaller extent, on the number of particles and their distribution in the system. For our GRAPE-3AF system, we use a block size of 8 000 particles, which is optimum for our configuration. The CPU time per time step increases roughly linearly with the total number of particles in the simulation and depends also, although less than does a standard tree code, on the tolerance. For further details, see Athanassoula et al. (1997). Because of the increased role of the direct summation in the force calculation, our tree code is much more accurate than the standard one.

3. Performance and accuracy

The performance and accuracy of both direct summation and the tree code has been tested extensively by Athanassoula et al. (1997) on our GRAPE-3AF system. In some tests we used the MISE/MASE quantities (Merritt 1996), while others involved energy conservation. Amongst other tests, we have followed the evolution of an isolated barred galaxy using different hardware and software in order to assess the reliability and reproducibility of our results. We find excellent agreement between the pattern speed of the bar in direct summation simulations run on the high precision GRAPE-4 machine and that in direct summation simulations run on our GRAPE-3 system. The agreement with the tree code is also very good provided the tolerance values are smaller than about 1.0.

4. Scientific results

We have addressed the following subjects using the above described hardware and software.

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4.1. CLUSTERS OF GALAXIES

We have followed the evolution of poor clusters or sub-condensations within larger clusters with, as a main goal, to study the formation of brightest cluster members.

The dynamical evolution of clusters needs a rather large number of particles, particularly since two obvious shortcuts, namely the explicit methods and the use of a rigid halo, have proved to be inadequate (García-Gomez, Athanassoula & Garijo 1996, Athanassoula, Garijo & García-Gomez 1997).

4.2. COMPACT GROUPS

The problem of merging rates in compact groups has been studied by Athanassoula, Makino & Bosma (1997) using simulations of five galaxies in a group. They studied the effect of the amount of halo mass in individual or common halos, as well as the effect of different types of kinematics, on the merging times of galaxies in the group. The most interesting result is that it is possible to prevent the merging during a Hubble time by adequately distributing a sufficient amount of dark matter in a common halo of low central concentration. The properties of merger remnants produced in these simulations are treated by Vozikis & Athanassoula (1998).

4.3. IMPACT OF A SATELLITE ON A DISC GALAXY

Athanassoula, Puerari & Bosma (1997) readdressed the problem of ring galaxies, and found conditions under which one can form spokes, such as seen in the Cartwheel galaxy. Athanassoula (1996a, 1996b) followed the evolution of bars in interacting galaxies. The pattern speed, form and amplitude of the bar may change, the bar can become off-centered, or, more drastically, it can disappear altogether. Companions can also form or destroy lenses, thick discs or warps. Finally a sufficiently dense companion can spiral inwards to the center of a target galaxy and contribute towards the formation of a bulge. Thus such mergings can drive the evolution of disc galaxies along the Hubble sequence.

4.4. ISOLATED GALAXIES

Work in progress in this field includes the analysis of the slowdown of a stellar bar due to energy and angular momentum exchange between the bar and other components of the galaxy, as well as a study of the shape of the bar.

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