I review the Marseille GRAPE systems and the N-body simulations done with them. I first describe briefly the available hardware and software, their possibilities and their limitations. I then describe work done on interacting galaxies and groups of galaxies. This includes simulations of the formation of ring galaxies, simulations of bar destruction by massive compact satellites, of merging in compact groups and of the formation of brightest members in clusters of galaxies.

GRAPE hardware at Marseille Observatory

The idea behind GRAPE systems is at the same time very simple and very efficient. It stems from the realisation that most of the CPU time in N-body simulations is spent calculating the forces, with only a small percentage devoted to the remaining parts, like moving the particles. Thus the group around D. Sugimoto and J. Makino realised GRAPE (from GRAvity piPE), a card which performs the force calculation on custom-made chips and which can be put in a standard workstation, allowing one to achieve at relatively low cost an excellent CPU performance. A series of such GRAPE boards have been built by the group in Tokyo University, starting with GRAPE-1 and evolving steadily to GRAPE-4, while new members of this family, like GRAPE-5 and GRAPE-6, are in progress. For a brief history of this project and descriptions of the various GRAPE systems see Makino & Taiji [1] and references therein. Boards with even numbers have high accuracy arithmetic and can be used for collisional simulations, where close encounters play an important role in the evolution of the system, as for globular clusters and planetesimals. Boards with odd numbers have lower precision arithmetic and can only be used for simulating collisionless systems.

Two main GRAPE systems are presently working in Marseille Observatory. A 5-board GRAPE-3AF system, coupled via an Sbus/VMEbus converter to a Ultra 2/200 front end, and a GRAPE-4 system coupled via a PCI interface to an Alpha 500/500 workstation. Since the latter system was only made operational a few months before this conference, most of this talk will be devoted to the GRAPE-3AF system and the results obtained with it.

Our GRAPE-3AF system has 40 chips in total and gives us a peak speed equivalent of more than 20 Gflops. The boards are hardware limited to 131 072 particles, but it is
possible to use them for a much larger number by splitting the particles into groups of 131,072 particles or less, presenting the groups successively to the board and then adding the forces from all the groups on the front end machine.

Since GRAPE-3 boards are meant only for collisionless simulations they use low accuracy arithmetic (14 bits for the masses, 20 bits for the positions and 56 bits for the forces). As discussed by Athanassoula et al [2], this accuracy is sufficient for collisionless simulations.

Doing on-line analysis of the simulation on the same processor as that used to pilot the GRAPE boards would slow down the simulations in an unacceptable way. Thus a second processor is necessary. Such on-line analysis can include calculation of pattern speeds, amplitudes and shapes of different structures, energy and angular momentum exchange between different components etc. The processor piloting the boards spawns a task starting the analysis scripts at regular intervals. Several tasks, such as calculating the mass still bound to a given galaxy, can be carried out much faster on a GRAPE board. In such cases the analysis scripts are executed on a smaller GRAPE-3 system, piloted by another workstation.

A good description of the GRAPE-4 boards and of their performances has been given by Makino et al [3]. A description more specific to the Marseille system will be given in a forthcoming paper. Since the front end of our GRAPE-4 system has no second processor the on-line analysis is spawned to another workstation, acting as a slave to the Alpha 500/500 driving the GRAPE-4 system.

**GRAPE software at Marseille Observatory**

Two codes are routinely used on the Marseille GRAPE-3 systems: a direct summation code and a tree code [2, 4]. The latter follows the vectorisation scheme proposed by Barnes [5]. Thus the particles are first divided into blocks and then the tree traversal is executed for a block of particles at a time, rather than for each particle separately, as in the standard tree code. The optimum number of particles per block depends of course on the number of boards, the power of the front end and, to a lesser extent, on the number of particles and the tolerance parameter. We find that, for our 5-board GRAPE-3 configuration and the type of simulations we run, 7,000 to 15,000 particles per block are a good choice. The CPU time necessary for one time step increases roughly linearly with the number of particles N. It also increases with decreasing tolerance (or opening angle), but the dependence is less strong than for the standard tree code, being particularly small for values of the tolerance larger than 0.8. Because of the increased role of the direct summation in the force calculation, this tree code is much more accurate than the standard one.

The accuracy of the force calculations by GRAPE-3 was tested in [2] with the help of the MISE/MASE formalism introduced by Merritt [6]. It was found that the forces are calculated as accurately as when full precision is used on the front end. The reason is that the errors on GRAPE-3 are due to round-off and thus can be considered as random.
They thus cancel out when the force contributions of a large number of particles are added. MISE/MASE tests also showed that the accuracy of the treecode is comparable to that of the direct summation. That can be easily understood since, in the version of the tree code in operation on our GRAPE systems, the force from nearby particles is calculated by direct summation.

Further tests include energy conservation during the simulations and the comparison of results of runs with different number of particles. Finally a few simulations were performed both on GRAPE-3 and GRAPE-4 and the comparison shows very good agreement. Thus it can be concluded that GRAPE-3 is well suited for N-body simulations of collisionless systems, both because of its accuracy and because of its high speed.

It is at present possible to execute three codes on our GRAPE-4 system, a direct summation and a tree code, both with a constant time step, and a direct N-body code with a variable time step. The latter uses an implementation of the Ahmad-Cohen scheme based on a fourth order Hermite integrator [7]. A description of their accuracy and performance, as well as a comparison with those of GRAPE-3, will be given elsewhere.

Main research areas

Our GRAPE-3 and GRAPE-4 systems are used for N-body simulations in many different areas of astronomical research, ranging from dynamics and evolution of clusters of galaxies, to the dynamical evolution of planetesimals. Most of it, however, centers around galaxies and groups of galaxies. Some of the latest results are briefly discussed below. To this list should be added the study of cusps (in collaboration with Ch. Siopis and H. Kandrup), the study of the effect of black holes in the central parts of elliptical galaxies (in collaboration with F. Leeuwin), the study of the dynamical evolution of planetesimals (in collaboration with P. Barge) and that of the gas flows in bars (in collaboration with I. Berentzen and C. Heller).

Ring galaxies

When a small compact galaxy hits the disc of a target disc galaxy head-on and near-vertically, then one or more expanding rings can be generated [8, 9, 10, 11, 12]. Indeed as the companion approaches the target it exerts an extra inwards gravitational force on the disc particles, which causes their orbits to contract. This is followed by a rebound, which, because of the decrease of the epicyclic frequency with radius, will result in a crowding of the orbits and the generation of a high amplitude, transient density wave, propagating outwards. We performed a number of fully self-consistent N-body simulations of such encounters, both on barred and on non-barred target disc galaxies [13]. One or two transient and short-lived rings form, the second considerably after the first one. The expansion velocity of the first ring is bigger than that of the second, and both decrease with time. The amplitude, width, lifetime and expansion velocity of the first ring are considerably higher for impacts of large
mass companions, than for lower mass ones. After the second ring has formed several simulations showed spokes in the region between the two rings. They are trailing, nearly straight and short-lived. An example is shown in Fig. 2. Rings formed from such head-on encounters need not be mistaken with those observed at the resonances of disc galaxies. Indeed, even when they are symmetric and have no spokes, they have considerable expansion velocities, which should be detectable spectroscopically.

The Cartwheel is probably the best studied ring galaxy [14, 15, 16, 17, 18, 19]. It has two clear rings and several spokes in the region between them. Three small galaxies can be found in its neighbourhood and one of them should be responsible for its structure. Although Higdon [15] proposed that it is the one farthest from the Cartwheel that is the culprit, a careful comparison of simulations and observations (Bosma, Puerari & Athanassoula, in preparation), taking into account both the morphological and the kinematical data, argues that it is G2 (in Higdon’s notation) which is to blame.

Is it possible to destroy a bar without destroying the disc it resides in?

An interesting question that can be asked in this context is whether it is possible for a companion to destroy a bar in a disc galaxy, while not destroying the disc. To answer it I first tried trajectories where the companion, initially on a rectilinear orbit, hit the central part of the disc either vertically, or at a skew angle [20]. Such trajectories can bring substantial changes to the pattern speed of the bar, as well as to the amplitude of its m=2 component. The lowering of the m=2 component is in many cases very spectacular, so one could easily talk of a bar dissolution. In all these cases, however, the disc thickens unnaturally much. I was unable to find a case where the disc stayed thin and at the same time the bar was destroyed, although I must admit that my search was not exhaustive.

I then tried a different kind of trajectory [21]. Now the companion starts off in a quasi-circular orbit outside the halo, and spirals, via dynamical friction, to the central part of the galaxy. If it is sufficiently massive and compact, it will lose only a small fraction of its mass by the time it has reached the center. It will then contribute to the bulge population, or, if there was no bulge present before the companion fell in, it will form it. Thus the target galaxy will evolve along the Hubble sequence, from a late to an early type disc galaxy. While the companion spirals through the target disc it heats it up and makes it thicker (cf. [22, 23, 24, 25]). On the other hand the target also expands, because the system has to conserve angular momentum, so, comparing its axial ratio before and after the merging, we see that the disc has been somewhat, but not much, thickened. The m=2 amplitude of the disc decreases very abruptly when the companion reaches the center. At that time it increases considerably the central concentration of the galaxy, and, by so doing, increases the fraction of irregular orbits present in the disc to the detriment of the $x_1$ stable periodic orbits and the regular orbits trapped around them [26, 27, 28, 29]. Thus the bar, deprived of its most ardent supporters, will be destroyed. The final stage of such a simulation is
shown in the two upper panels of Fig. 3, the particles initially in the target disc shown in blue and the particles initially in the companion in red. Fig. 4 shows separately the particles initially in the target disc (upper two panels) and the satellite (lower two panels). Note that the satellite, which was initially spherical, has, after the merging, become oblate.

The situation is totally different in the case of a small mass, fluffy companion. In this case the companion looses a lot of its mass while spiraling through the disc and no substantial fraction of it will reach the center. Thus the bar will not be destroyed. Material stripped from the companion will form a thick disc, thicker than that of the original target. The final stage of such a simulation is shown in the lower two panels of Fig. 3. Again the particles initially in the target disc are shown in blue and the particles initially in the companion in red. Fig. 5 shows separately the particles initially in the target disc (upper two panels) and the satellite (lower two panels). Note that a substantial fraction of the companion mass is concentrated along the ends of the bar.

In both the above examples the plane of the companion’s orbit is the same as that of the target’s disc. Let us now consider cases where the two planes are initially at an angle. Then during the simulation the plane of the target disc will tilt [21, 30], so that the angular momentum of the system be conserved. In the case shown in [21], and other unpublished simulations, the mass of the companion is equal to that of the target disc, and the angle by which the disc tilts is comparable to, although smaller than, the angle between the orbit of the companion and the plane of the target disc at the beginning of the simulation. The remaining results are as in the case where the companion orbits initially in the plane of the target’s disc, except for an increased thickening of both the target disc and the disc made by the material shredded from the companion.

**Merging rates in compact groups**

Compact groups are groups of a few galaxies, close together in the sky, and far from other galaxies or groups of galaxies. Hickson, using a precise definition along these lines, catalogued 100 such groups from the Palomar sky survey [31]. He has also given a review of the relevant observational data about such groups [32]. One of the main questions that they raise is that of their life time. Indeed, if one simply calculates the crossing time in such groups from their size and their velocity dispersion, one finds very low values, from which it has often been inferred that mergings should occur quite frequently. Thus the question of why so many such groups are still observed is raised. One possibility is to generate such groups continuously from loose groups [33, 34], or add new galaxies from infalling new material [35]. The first of these alternatives introduces the problem of the merger remnants, both because the integrated luminosity of a compact group is three to four times higher than that of an average isolated elliptical galaxy, and because the number of such remnants could be quite high. For the second alternative one or more of the galaxies in each compact group would have to be the result of previous mergings, also introducing problems
concerning the fraction of ellipticals in compact groups, as well as their total luminosity. Together with Makino & Bosma [36] I have followed another alternative, namely we studied what parameters of the group affect the merging rate and thus obtained clues about how to form long-lived compact groups.

Our simulations start with five identical spherical galaxies disposed in a compact group which has, in all cases, the same mass and binding energy. Two different types of halos have been considered: Either halos around individual galaxies (hereafter individual halos, or IH), or halos encompassing the whole group and centered at its center (hereafter common halos, or CH). We have also considered different luminous-to-dark mass ratios, individual halos of different spatial extents, as well as different density distributions and different kinematics, both for the common halos and the distributions of the centers of the galaxies. Once these parameters were fixed, we made five different realisations, with different random number seeds, in order to allow some, albeit small, statistics, and be able to make averages over different realisations. We thus ran over 200 simulations, but even so, we are far from covering all possible cases. For all simulations we counted the number of galaxies still present in the group as a function of time and thus were able to measure merging rates.

The first question we addressed is whether groups with individual halos merge faster or slower than corresponding groups with common halos, since two contradictory results had been previously reported in the literature [37, 38, 39]. Indeed, there are two different effects influencing the outcome in an opposite sense. On the one hand dynamical friction is more important in the case of denser halos, and this should lead to shorter merging times. On the other hand more massive halos would entail less massive galaxies (since the total mass of the group is the same in all simulations) and therefore less mutual attractions between them, which would lead to longer merging times. Which of the two effects is dominant depends on the configurations. Thus groups with individual halos merge faster than groups with common halos if the configuration is centrally concentrated. For less centrally concentrated groups the merging is initially faster for IH cases, and slower after part of the group has merged.

In the case of common halos we find that the more massive the common halo, the longer it will take the group to merge. This can be easily understood, since the mutual attractions between galaxies is smaller for relatively more massive common halos, and, in the extreme case where the masses of the individual galaxies was zero, then they could be considered as test particles and encounters would happen only accidentally, determined by their trajectories and cross sections.

Another factor influencing the merging rate is the central concentration of the configuration. In particular for common halos and a high halo-to-total mass ratio, centrally concentrated groups merge considerably faster. This can be understood because of the important dynamical friction that galaxies will feel in the central regions of such centrally concentrated configurations. As far as the initial kinematics of the group are concerned, groups with initially cylindrical rotation merge slower.
Taking into account all the effects enumerated above, it is possible to construct long-lived compact groups. Thus Athanassoula, Makino & Bosma [36] followed the evolution of a group with a common halo, a high halo-to-total mass ratio and a density distribution with little central concentration and found that the merging occurred only after a large number of crossing times, corresponding to a time larger than a Hubble time. This provides a solution to the longevity problem of compact groups, and could explain why we observe so many of them.

**Formation of brightest cluster members and cD galaxies**

We have performed a number of simulations to follow the dynamical evolution of groups of 50 to 100 identical spherical galaxies [40, 41, and in preparation]. They can be thought of as simulating groups, poor clusters, or sub-condensations within rich clusters, provided that the dynamical influence of the remaining part of the cluster can be neglected. A large variety of initial conditions have been considered. This includes the case of individual halos (where each halo is centered around a galaxy), or a common halo encompassing the whole group or cluster. We have also considered different density distributions of the halo material and of the galaxies in the group or cluster, different ratios of halo-to-total mass and different initial kinematics.

The standard evolution shows important merging in the central regions and the formation of a massive central object. The only way to avoid this is to consider initial conditions such that the central parts do not contain any galaxies. This is obviously artificial, but has the advantage of stressing the role of the initial seed in the formation of the massive central object. It also predicts that initial configurations with low central concentration should form the central massive object slower than configurations with high initial central concentrations, as we were able to confirm with further simulations. Let me also note that it is in good agreement with our results on compact groups described above.

Two mechanisms contribute to the formation of the massive central objects. One is cannibalism of the small galaxies by the big central object (e.g. (42, 43)), and the other is accretion onto the central object of material that has been stripped off individual small galaxies [44, 45, 46]. Both are present in all simulations, but to a varying degree, depending on the initial conditions.

We compared the properties of the central massive object with those of observed brighter cluster members and found fairly good agreement, concerning the morphology, the surface photometry and the kinematics. For example we find that, as is observed [47, 48], the triaxiality is stronger in the outer than in the inner parts. Also we found that, in the case of non-spherical anisotropic initial conditions, the central massive objects “remember” the orientation of the initial configuration. This should be linked to the fact that the orientations of brighter cluster members are not random, but correlate with that of the cluster in which they reside [49, 50, 51, 52, 53, 54, 55, 56].
Schombert [57] did photometry of a large sample of brightest cluster members and showed that they fall in three classes. In the first class we find objects whose projected light profile follows a $r^{1/4}$ over most of the galaxy. In the second the projected light distribution falls, in the outer parts, somewhat below the $r^{1/4}$ that fits the main body of the galaxy, while in the third class it is higher than that of the $r^{1/4}$ law. Brighter cluster members falling in that third category are called cD galaxies, are rather frequent and have a light “halo”. The term “halo” is perhaps rather unfortunate, since it could lead to confusion with the dark halos around galaxies, and it must be stressed that the “halo” of cD galaxies is luminous material in the outer part of the galaxy, in excess of the $r^{1/4}$ law.

Assuming that the $M/L$ ratio does not depend on radius, we also calculated projected density profiles of the central massive objects formed in our simulations and found that they fall in the same three classes as those outlined by Schombert for his observed sample. We have then set out to determine which properties in the initial conditions determine in which of the three classes a central massive object will fall. Although our results for this are still preliminary, they nevertheless allow us to make a few tentative conclusions. Some of the objects we have found so far in the second class originated from rather non-spherical initial conditions. More interesting are the objects falling in the third class. Our simulations suggest a link between the percentage of the mass of the central massive object that came via accretion and the excess matter in the outer parts, in the sense that we find in the third class objects for which a high fraction of their mass is due to accretion. This of course shifts the question to what types of initial conditions result in a considerable accretion, a question which we are currently investigating. In order to have considerable accretion we have to have a considerable amount of material which was stripped from the initial galaxies. One way of achieving this is to have a quite centrally concentrated common dark matter halo. In such a case the galaxies passing near the centre of the group or cluster are torn to pieces, thus creating the material necessary for the accretion. An alternative way, which we have not yet verified by numerical simulations, would be to have important interactions between the individual galaxies before they merge to form the central massive object. Such interactions could tear material off the small galaxies by tidal forces, and this material could be at later times accreted by the central object. The amount of material thus stripped should depend on the initial distribution of matter in the individual galaxies, e.g. on whether they are disc or elliptical galaxies. Thus more elaborate N-body simulations are necessary to verify this possibility.

**ACKNOWLEDGMENTS**

I am grateful to Albert Bosma and Jean-Charles Lambert, since without their help and encouragement this work would not have been possible. It is also a pleasure to thank all my collaborators in the projects mentioned in this paper, and particularly Jun Makino, Carlos Garcia-Gomez, Tony Garijo and Ivanio Puerari. I would also like to thank Philippe Balard
for producing figures 2 to 5. I also thank the INSU/CNRS, the University of Aix-Marseille I and the Institut Gassendi (IGRAP) for funds to develop the necessary computing facilities. The final draft of this manuscript was written at the Newton Institute for Mathematical Sciences, whose support I acknowledge gratefully.

REFERENCES

1. MAKINO, J. & M. TAIJI. 1998. Scientific simulations with special purpose computers: The GRAPE. Wiley (Chichester).
2. ATHANASSOULA, E., A. BOSMA, J.-C. LAMBERT & J. MAKINO. 1998. Performance and accuracy of a GRAPE-3 system for collisionless N-body simulations. Mon. Not. R. Astron. Soc. 293: 369-380.
3. MAKINO, J., M. TAIJI, T. EBISUZAKI & D. SUGIMOTO. 1997. GRAPE-4: A Massively Parallel Special-Purpose Computer for Collisional N-body Simulations. Astrophys. J. 480: 432-446.
4. MAKINO, J. 1991. Treecode with a Special-Purpose Processor. Publ. Astron. Soc. Japan 43: 621-638.
5. BARNES, J. 1990. A modified tree code: Don’t Laugh; It Runs. J. Comp. Phys. 87: 161-170.
6. MERRITT, D. 1996. Optimal smoothing for N-body codes. Astron. J. 111: 2462-2464.
7. MAKINO, J. & S. AARSETH. 1992. On a Hermite Integrator with Ahmad-Cohen Scheme for Gravitational Many-Body Problems. Publ. Astron. Soc. Japan 44: 141-151.
8. LYND, R. & A. TOOMRE. 1976. On the interpretation of ring galaxies: The binary ring system II Hz 4. Astrophys. J. 209: 382-388
9. THEYS, J.C. & E.A. SPIEGEL. 1976. Ring galaxies I. Astrophys. J. 208: 650-661.
10. THEYS, J.C. & E.A. SPIEGEL. 1977. Ring galaxies II. Astrophys. J. 212: 616-633.
11. TOOMRE, A. 1978. Interacting systems. in The large scale structure of the Universe. Eds. M.S. Longair & J. Einasto, I.A.U. Symp. 79: 109-116.
12. APPLETON, P.N. & C. STRUCK-MARCELL. 1996. Collisional ring galaxies. Fundamentals of Cosmic Phys. 16: 111-220.
13. ATHANASSOULA, E., I. PUERARI & A. BOSMA. 1997. Formation of rings by infall of a small companion galaxy. Mon. Not. R. Astron. Soc. 286: 284-302.
14. HIGDON, J. 1995. Wheels of Fire I. Massive Star Formation in the Cartwheel Ring Galaxy. Astrophys. J. 455: 524-535.
15. HIGDON, J. 1996. Wheels of Fire II. Neutral Hydrogen in the Cartwheel Ring Galaxy. Astron. J. 467: 241-260.
16. AMRAM, P., C. MENDES DE OLIVEIRA, J. BOULESTEIX, & C. BALKOWSKI. 1998. The Hα Kinematics of the Cartwheel Galaxy. Astron. Astrophys. 330: 881-893.
17. STRUCK, C., P.N. APPLETON, K.D. BORNE, & R.A. LUCAS. 1996. Hubble
Space Telescope Imaging of Dust Lanes and Cometary Structures in the Inner Disk of the Cartwheel Ring Galaxy. Astron. J. 112: 1868-1876.

18. HERNQUIST, L. & M.L. WEIL. 1993. Spokes in ring galaxies. Mon. Not. R. Astron. Soc. 261: 804-818.

19. STRUCK-MARCEL, C. & J. HIGDON. 1993. Hydrodynamic Models of the Cartwheel Ring Galaxy. Astrophys. J. 411: 108-124.

20. ATHANASSOULA, E. 1996. Evolution of bars in isolated and interacting disc galaxies in *Barred Galaxies*, eds. R. Buta, D. A. Crocker and B. G. Elmegreen. Astron. Soc. Pac. Conference series 91: 309-321.

21. ATHANASSOULA, E. 1996. The fate of barred galaxies in interacting and merging systems; in *Barred Galaxies and Circumnuclear Activity. Nobel Symposium No. 89*, eds. Aa. Sandqvist, P.O. Lindblad, Lecture Notes in Physics, Springer Verlag (Berlin), Vol. 474: 59-66.

22. QUINN, P.J. & J. GOODMAN. 1986. Sinking satellites of Spiral Systems. Astrophys. J. 309: 472-495.

23. TÓTH, G. & J.P. OSTRIKER. 1992. Galactic disks, infall and the global value of Ω. Astrophys. J. 389: 5-26.

24. QUINN, P.J., L. HERNQUIST & D. FULLAGAR. 1993. Heating of galactic Disks by Mergers. Astrophys. J. 403: 74-93.

25. WALKER, I.R., J.C. MIHOS & L. HERNQUIST. 1996. Quantifying the fragility of galactic discs in minor mergers. Astrophys. J. 460: 121-135.

26. HASAN, H. & C. A. NORMAN. 1990. Chaotic orbits in barred galaxies with central mass concentration. Astrophys. J. 361: 69-77.

27. HASAN, H., D. PFENNIGER & C. A. NORMAN. 1993. Galactic bars with central mass concentrations. Three-dimensional dynamics. Astrophys. J. 409: 91-109.

28. NORMAN, C. A., J.A. SELLWOOD & H. HASAN. 1996. Bar dissolution and bulge formation: An example of secular dynamical evolution in galaxies. Astrophys. J. 462: 114-124.

29. FRIEDLI, D. & W. BENZ. 1993. Secular evolution of isolated barred galaxies. I Gravitational coupling between stellar bars and interstellar matter. Astron. Astrophys. 268: 65-85.

30. HUANG, S. & R.G. CARLBERG. 1997. Sinking Satellites and Tilting Disk Galaxies. Astrophys. J. 480: 503-523.

31. HICKSON, P. 1982. Systematic properties of compact groups of galaxies. Astrophys. J. 255: 382-391

32. HICKSON, P. 1997. Compact Groups of Galaxies. Annu. Rev. Astron. Astrophys. 35: 357-388

33. DIAFERIO, A., M.J. GELLER & M. RAMELLA. 1994. The formation of compact groups of galaxies. I. Optical properties. Astron. J. 107: 868-879

34. DIAFERIO, A., M.J. GELLER & M. RAMELLA. 1994. The formation of compact
groups of galaxies. II. X-Ray properties. Astron. J. 109: 2293-2304.
35. GOVERNATO, F., P. TOZZI A. & CAVALIERE. 1996. Small groups of galaxies: a clue to a critical Universe. Astrophys. J. 458: 18-26.
36. ATHANASSOULA, E., J. MAKINO & A. BOSMA. 1997. Evolution of compact groups of galaxies I. Merging rates. Mon. Not. R. Astron. Soc. 286: 825-838.
37. BARNES, J.E. 1985. The dynamical state of groups of galaxies. Mon. Not. R. Astron. Soc. 215: 517-536.
38. BODE, P.W., H.N. COHN & P.M. LUGGER. 1992. Simulations of Compact Groups of Galaxies: The effect of the Dark Matter Distribution. Astrophys. J. 416: 17-25.
39. ATHANASSOULA, E. & J. MAKINO. 1995. Simulations of compact groups of galaxies: some preliminary results. in Compact Groups of Galaxies, eds. O. Richter & K. Borne, A.S.P. conf. series 70: 143-149.
40. GARCÍA GÓMEZ, C., E. ATHANASSOULA & A. GARIJO. 1996. Dynamical evolution of galaxy groups: A comparison of two approaches. Astron. Astrophys. 313: 363-376.
41. GARIJO, A., E. ATHANASSOULA & C. GARCÍA GÓMEZ. 1997. The formation of cD galaxies. Astron. Astrophys. 327: 930-946.
42. OSTRIKER, J.P. & S.D. TREMAINE. 1975. Another evolutionary correction to the luminosity of giant galaxies. Astrophys. J. 202: L113-L117.
43. OSTRIKER, J.P. & M.A. HAUSMAN. 1977. Cannibalism among the galaxies - Dynamically produced evolution of cluster luminosity functions. Astrophys. J. 217: L125-L129.
44. GALLAGHER, J.S. & J.P. OSTRIKER. 1972. A note on mass loss during collisions between galaxies and the formation of giant systems. Astron. J. 77: 288-291.
45. RICHSTONE, D.O. 1975. Collisions of galaxies in dense clusters. I. Dynamics of collisions of two galaxies. Astrophys. J. 200: 535-547.
46. RICHSTONE, D.O. 1976. Collisions of galaxies in dense clusters. II. Dynamical evolution of cluster galaxies. Astrophys. J. 204: 642-648.
47. PORTER, A.C., D.P. SCHNEIDER & J.C. HOESSEL. 1991. CCD observations of Abell clusters. V - Isophotometry. Astron. J. 101: 1561-1594.
48. MACKIE, G., N. VISVANATHAN & D. CARTER. 1990. The stellar content of central dominant galaxies. I - CCD surface photometry. Astrophys. J. Suppl. 73: 637-660.
49. SASTRY, G.N. 1968. Clusters associated with supergiant galaxies. Publ. Astron. Soc. Pac. 80: 252-262.
50. ROOD, H.J. & G.N. SASTRY. 1972. Static properties of galaxies in the cluster Abell 2199. Astron. J. 77: 451-458.
51. AUSTIN, T.B. & J.V. PEACH. 1974. Studies of rich clusters II. The structure and luminosity function of the cluster A1413. Mon. Not. R. Astron. Soc. 168: 591-602.
52. CARTER, D. & N. METCALFE. 1980. The morphology of clusters of galaxies. Mon. Not. R. Astron. Soc. 191: 325-337.
53. BINGELLI, B. 1982. The shape and orientation of clusters of galaxies. Astron. Astrophys. 107: 338-349.

54. STRUBLE, M.F. & P.J.E. PEEBLES. 1985. A new application of Binggeli’s test for large-scale alignment of clusters of galaxies. Astron. J. 90: 582-589.

55. RHEE, G. & P. KATGERT. 1987. A study of the elongation of Abell clusters I. A sample of 37 clusters studied earlier by Binggeli and Struble & Peebles. Astron. Astrophys. 183: 217-227.

56. LAMBAS, D.G., E.J. GROTH & P.J.E. PEEBLES. 1988. Alignments of brightest cluster galaxies with large-scale structures. Astron. J. 95: 996-998.

57. SCHOMBERT, J.M. 1986. The structure of brightest cluster members I. Surface photometry. Astrophys. J. Sup. 60: 603-693.
FIGURE CAPTIONS

FIGS. 1 Schematical representation of the two main GRAPE systems in Marseille observatory. To the left GRAPE-3 and to the right GRAPE-4.

FIGS. 2 Snapshot from an N-body simulation of the formation of a ring galaxy. Only particles initially in the target disc are plotted. Both rings, as well as the spokes in the region between them, are clearly visible.

FIGS. 3 One of the final instants from an N-body simulation of a target disc galaxy and a satellite, after the merging has been completed. The particles of the target disc are shown in blue and those of the satellite in red, while particles in the halo of the target are not plotted. Face-on views are given by the left panels and edge-on views by the right panels. In the simulation shown in the top two panels the companion was initially massive and compact. After merging it has lost little of its mass and forms a bulge in the center of the target disc. In the simulation shown in the bottom two panels the companion was initially fluffy and less massive and has been shredded to pieces while spiraling in the target’s disc.

FIGS. 4 Same simulation as the top two panels of Figure 3, but now the particles from the target disc and companion are shown separately, the target disc in the top two panels and the companion in the two bottom ones.

FIGS. 5 Same simulation as the bottom two panels of Figure 3, but now the particles from the target disc and companion are shown separately, the target disc in the top two panels and the companion in the two bottom ones.
This figure "fig2.gif" is available in "gif" format from:

http://arxiv.org/ps/astro-ph/9809374v1
This figure "fig3.jpg" is available in "jpg" format from:

http://arxiv.org/ps/astro-ph/9809374v1
This figure "fig4.jpg" is available in "jpg" format from:

http://arxiv.org/ps/astro-ph/9809374v1
This figure "fig5.jpg" is available in "jpg" format from:

http://arxiv.org/ps/astro-ph/9809374v1