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NUMERICAL SIMULATIONS OF MERGING GALAXY CLUSTERS

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ABSTRACT

There are observational hints that galaxy clusters may lie close to a Fundamental Plane (FP) in the space of their basic observables, total luminosity, effective radius and velocity dispersion, just as elliptical galaxies do. Seemingly, a transformation of coordinates into the (k_1,k_2,k_3) coordinate system is possible: for fixed k_1, there appears to be a small dispersion of k_3 (i.e. of M/L). On the other hand merging of clusters results on temporary departures from virial equilibrium, and therefore tends to increase the dispersion about the FP. By means of N-body simulations and with a set of different initial distributions, we study the evolution of clusters in the k-space during merging processes, thus setting an upper limit for the recent merging rate from the observed FP thickness.

1. Introduction

There are observational hints that galaxy clusters may lie close to a Fundamental Plane (FP) in the space of their basic observables, total luminosity L, effective radius R_e and velocity dispersion σ_0^2, just as elliptical galaxies do[1]. A transformation of coordinates into the (k_1, k_2, k_3) coordinate system, introduced by Bender for galaxies[2], is possible also for clusters of galaxies:

$$\begin{cases} k_1 \equiv (\log \sigma_0^2 + \log R_e)/\sqrt{2} \\ k_2 \equiv (\log \sigma_0^2 + 2\log I_e - \log R_e)/\sqrt{6} \,, \\ k_3 \equiv (\log \sigma_0^2 - \log I_e - \log R_e)/\sqrt{3} \end{cases} \qquad (1)$$

where $I_e = L/2\pi {R_e}^2$. The (k_1,k_3) plane provides an edge-on view of the FP, while the (k_1,k_2) is close to being a face-on view.
At any fixed k_1 there appears to be a small dispersion in k_3. Specifically k_1 is proportional to the virial mass: from the Virial Theorem

$$M = c_2 R_e \sigma_v^2, \qquad (2)$$

where c_2 is a form factor defined by

$$c_2 = (2M^2/R_e)\left(\int \rho(r)|\phi(r)|4\pi r^2 dr\right)^{-1}. \tag{3}$$

Therefore

$$\sqrt{2}k_1 = \log(R_e\sigma_0^2) = \log\left(\frac{M}{c_2}\right), \tag{4}$$

where we have assumed that the velocity dispersion inside the effective radius and that derived from the Virial Theorem are equal. On the other hand k_3 is proportional to M/L,

$$\sqrt{3}k_3 = \log\left(\frac{\sigma_0^2}{R_e I_e}\right) = \log\frac{2\pi(M/L)}{c_2}. \tag{5}$$

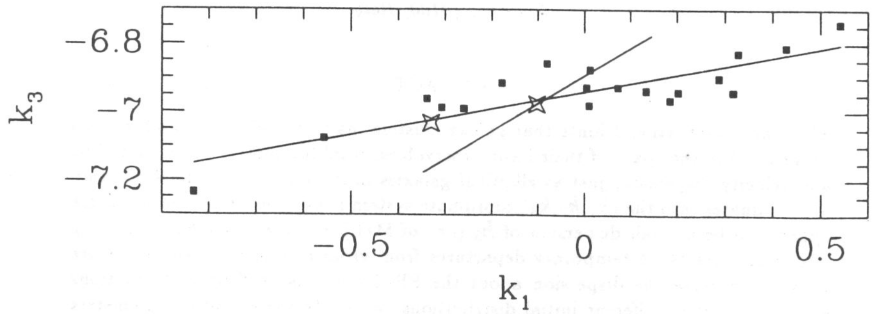

Fig. 1. The curve represents the evolution of a merging between two identical clusters of mass $1.1\times10^{15}M_\odot$ and effective radius $R_e = 1.3$Mpc, whose distribution of galaxies has been generated according to a Hernquist model. The initial and final position are marked by stars. The full symbols represent the 19 observed clusters for which the three coordinates are available[1].

2. Numerical simulations

Merging of clusters results on temporary departures from virial equilibrium, and therefore tends to increase the dispersion about the FP. Thus, the size of the observed dispersion of k_3 about the FP can be used to constrain the past merging rate among clusters which, in turn, depends on the cosmological parameters. To put this expectation on a more quantitative bases we have proceeded with a series of N-body simulations. The simulations refer to a set of different initial distributions, and study the evolution of clusters in the k-space through the merging processes. The program used for the numerical simulations is that originally written by Aarseth[3]: the cluster is represented by a system of N point masses, whose equation of motion are integrated numerically. Each particle experiences a force, due to all the other ones, which can be written as

$$\mathbf{F}_i = -Gm^2\Sigma_j\frac{(\mathbf{x}_i - \mathbf{x}_j)}{(||\mathbf{x}_i - \mathbf{x}_j||^2 + \epsilon^2)^{3/2}}, \tag{6}$$

where ϵ is the softening lenght, fixed to 0.02 in simulation units (i.e. $\simeq$ 20Kpc). The initial ditribution of galaxies in clusters are choosen by the Monte Carlo extraction, according to two different models. The first group of models we investigate, is characterized by an initial density distribution described by an isotropic Plummer sphere[4]:

$$\rho(r) = \frac{3M}{4\pi} \frac{r_c^2}{(r^2 + r_c^2)^{5/2}}, \tag{7}$$

and the second one according to an isotropic Hernquist distribution[5]:

$$\rho(r) = \frac{M}{2\pi} \frac{r_c}{r} \frac{1}{(r + r_c)^3}. \tag{8}$$

The mass and effective radius of each cluster are selected so that they lie on the FP.

The accuracy of the simulations is checked verifying the conservation of total energy and angular momentum after each time step. The simulation is interrupted when the virial coefficient settles to -0.5 ($\pm$5%) for a fixed number of consecutive time-steps.

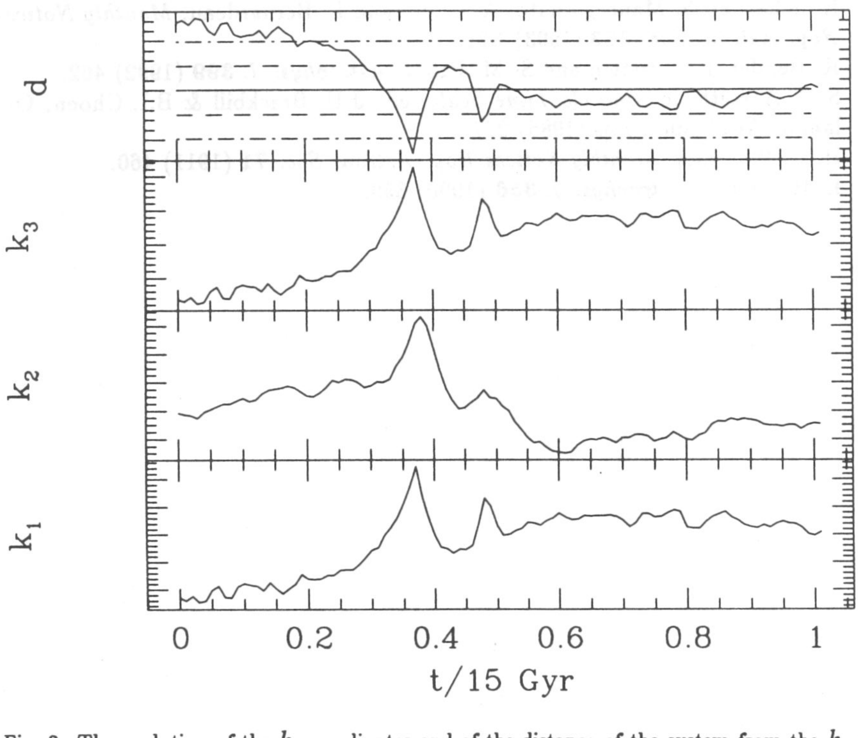

Fig. 2. The evolution of the k_i coordinates and of the distance of the system from the k_1-k_3 line of best-fit during the merging are shown. The dashed lines in the upper panel refer to a distance of 1σ and 2σ from the best fit, respectively.

3. Results and Conclusions

We summarize here the main results of our preliminary investigations.

• The time spent by the merging product outside the FP (where "outside" means 1σ away from the best-fit k_1-k_3 relation) is $\simeq 3Gyr$, as shown in Fig.2.

• The factor c_2 referred to the final product is not significantly different (less than 20%) from that of the initial clusters. This is not surprising since c_2 is related to global properties of the clusters. Even during the merging, when the system is still not virialised, c_2 doesn't vary much more; if we add the fact that the coordinate k_3 also undergoes small changes, we can say that the errors in measuring M/L are small.

• Looking at the merging events from different angles produces a significant difference of the trajectories in the (k_1,k_2) and (k_1,k_3) planes, particularly during the merging, while the final positions are, as one would expect, more similar.

4. References

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