FRIZIONE DINAMICA

VS. SEGREGAZIONE

DELLE GALASSIE (D'AMMASSO)

IN VELOCITÀ

(SOLO LE PIÙ LUMINOSE / MASSICCE)

Vedi dietro →

CLUSTER
1st DATA CATALOG

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VELOCITY SEGREGATION IN GALAXY CLUSTERS

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ABSTRACT

We have investigated the velocity field of galaxies in clusters. Our sample consists of the 68 clusters with at least 30 galaxies for which redshifts are available in the literature; for 61 of these clusters we were also able to collect most of the galaxy magnitudes. We have unambiguously found that galaxies brighter than the magnitude of third-ranked object, m_3, have velocities lower than average. These galaxies are preferentially located in the central regions. The effect is not induced by morphological segregation, it is not restricted to cD clusters, and it does not depend on the presence of substructures. The energy equipartition status seems to be achieved by these low-velocity galaxies. This evidence of segregation stresses the importance of m_3 as a boundary between different dynamical statuses, and constrains the theory of structure and evolution of clusters of galaxies. A possible interpretation is given in terms of dynamical friction and merging.

Subject headings: galaxies: clustering — galaxies: distances and redshifts — galaxies: kinematics and dynamics

1. INTRODUCTION

The dynamical and evolutionary status of clusters of galaxies can be described by the galaxy velocity field. In this paper we want to examine whether the velocity distribution of cluster galaxies depends on their luminosities and/or distances from the cluster center. In the following, we will refer to velocity segregation of galaxies with respect to their luminosities as *VLS*, meaning that more luminous galaxies move more slowly than fainter ones.

Claims have been made in the literature that more luminous and/or more centrally located cluster galaxies have a lower velocity (with respect to the cluster mean) than other cluster galaxies (Rood 1965; Rood et al. 1972; Chincarini & Rood 1977, hereafter CR; Struble 1979; Cowie & Hu 1986; Mellier et al. 1988; Bothun & Schombert 1990), yet little (Merrifield & Kent 1991) or no evidence of segregation (Kent & Gunn 1982; Kent & Sargent 1983) has been found in other works.

The presence of velocity segregation in galaxy clusters is often taken as evidence of advanced dynamical evolution. While the process of violent relaxation is thought to produce a velocity distribution independent of the galaxy mass, the dynamical friction process transfers kinetic energy from more massive galaxies to less massive ones (see, e.g., Sarazin 1986). The more massive galaxies are slowed down and spiral in toward the cluster center. In this framework, a lower velocity dispersion should be seen in the central galaxies and in the more luminous ones as well, if a correlation exists between galaxy masses and luminosities.

Related topics are galaxy merging and accretion phenomena in the cluster cores (see, e.g., Tonry 1987; Schombert 1987; Bothun & Schombert 1990, and references therein). The low-velocity galaxies are natural candidates for merging and accretion, which lead to galaxies of higher luminosities and even lower velocities (and eventually to the formation of a single dominant galaxy).

In § 2 we describe our data sample; in § 3 we describe our analysis and results; in § 4 we provide the relevant discussion.

2. THE DATA SAMPLE

We have collected data for 68 clusters from the literature, selecting only those clusters with measured radial velocities (and positions) for at least 30 galaxies (for a total of $\simeq 6500$ galaxies). Clusters with mean redshift >0.15 have not been taken into account, in order to avoid dealing with evolutionary effects (see, e.g., Newberry, Kirshner, & Boroson 1988). Our clusters span a wide range of properties, from richness class 0 to 4, and are quite representative of the average cluster population.

Magnitude data are available in the literature for most galaxies in 61 clusters of our sample (i.e. $\simeq 5500$ galaxies). When necessary, we corrected these magnitudes for K-dimming effect and absorption by our Galaxy. We have taken the K-dimming corrections for the R, V, and B bands from Sandage (1973), for the r, g magnitude system from Schneider, Gunn, & Hoessel (1983), and for the J system from Phillips, Fong, & Shanks (1981). The absorptions by our Galaxy have been obtained by using the maps and prescriptions of Burstein & Heiles (1982), and the relations between absorption in different bands as given by Sandage (1973) and Schneider et al. (1983). We transformed these magnitudes into the same photometric band, i.e. the visual one using the formulas given by Oemler (1974), Schweizer (1976), Thuan & Gunn (1976), de Vaucouleurs (1977), Kirshner, Oemler, & Schechter (1978), Geller et al. (1984), Shanks et al. (1984), Postman, Huchra, & Geller (1986), and Colless (1989). The galaxy morphological types are known for most galaxies only in 38 clusters of our sample.

In order to reject the noncluster members from our samples, we first adopted a limiting radius of 3 h_{100}^{-1} Mpc from the cluster center (we assume $q_0 = \frac{1}{2}$ throughout this paper; however, this choice is not very important); we used the biweight location estimator for α, δ (see e.g., Beers, Flynn, & Gebhardt 1990), to define the center of each cluster. Then we eliminated the "obvious interlopers" in the redshift space following the procedure developed by Zabludoff, Huchra, & Geller (1990). For the remaining galaxies, we computed the "biweight center" again in order to select galaxies inside different limiting radii, from 0.25 to 3 h_{100}^{-1} Mpc. To identify the "true" cluster members, we applied the classical 3 σ clipping procedure (Yahil & Vidal 1977, hereafter YV). The "gapping"

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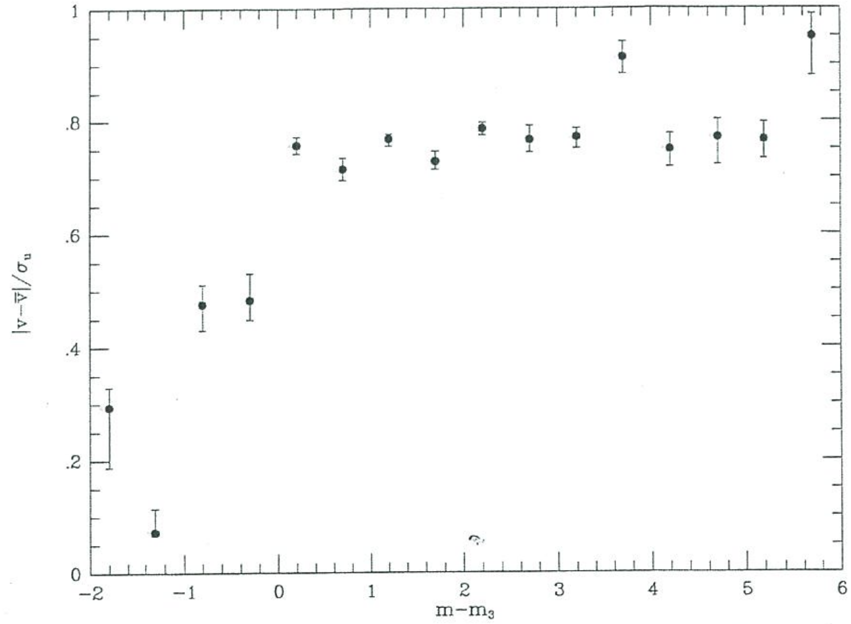

FIG. 2.—Normalized velocities $|v - \bar{v}|/\sigma_u$ binned in intervals of 0.5 mag vs. $m - m_3$; the error bars (at the 68% confidence level) are obtained via a bootstrap resampling procedure.

Both the S and W tests showed that σ_u is larger than $\sigma_{\rm ldw}$ at a significance level >99.99%. The cumulative distributions for σ_u and $\sigma_{\rm dlw}$ are plotted in Figure 4. The increased difference between the weighted and unweighted dispersions can be seen by comparing Figure 4 with Figure 1.

4. DISCUSSION

We detected significant evidence for *VLS* in a sample of 61 clusters. The velocity dispersions are significantly lower for galaxies with higher luminosities. There is no evidence for *VLS* of galaxies fainter than the third ranked. The segregated galaxies are those with $m \leq m_3$; these are preferentially early-type galaxies and are located in the central regions. The segregation was clearly detected by using the velocity dispersions weighted both on galaxy luminosities and on the inverse of their clustercentric distances.

Clear-cut evidence of segregation in each of our clusters was not detected; this may be due to the smallness of the effect and/or to the limited quantity of data available for each single cluster. The fact that previous analyses based on a few clusters have sometimes failed to detect a significant amount of segregation is, then, not surprising. Moreover, clusters are likely to be in different evolutionary stages, and, consequently, in different dynamical statuses (see, e.g., Yepes et al. 1991).

The segregation we detected could be a natural characteristic of galaxies formed at the highest density peaks. Being at the cluster center, these galaxies are free enough from size limitations imposed by the mean tidal field of the cluster (see, Dressler 1984; Merritt 1984; Richstone 1990). Another possible explanation is the process of dynamical friction. The relaxation time for this process depends on the mass of the galaxy considered, as well as on the cluster velocity dispersion and core radius. We took the core radii, r_c's for 20 clusters in our sample from Sarazin (1986), and estimated their $\sigma_{\rm rob}$'s, and the luminosities, l_3, of their third-ranked galaxies. From these values we computed the relaxation time, t_3, for the third-ranked galaxy in each cluster—using equation (2.36) in Sarazin (1986):

$$t_3 \simeq 6 \times 10^9 \text{ yr} \left(\frac{\sigma_{\rm rob}}{1000 \text{ km s}^{-1}}\right)\left(\frac{r_c}{0.125\, h_{100}^{-1} \text{ Mpc}}\right)^2 \times \left(\frac{l_3}{l^*}\right)^{-1}\left[\frac{(\mathcal{M}/l)_{\rm gal}}{10\, \mathcal{M}_\odot/l_\odot}\right]^{-1}, \quad (6)$$

where l^* is the characteristic visual luminosity of galaxies in the Schechter luminosity function (Schechter 1976), and $\mathcal{M}/l$ is the galaxy mass-to-luminosity ratio. The values of $t_3[(\mathcal{M}/l)_{\rm gal}/(10\, \mathcal{M}_\odot/l_\odot)]$, for the clusters considered are listed in Table 3, in units of 10^9 yr. We denote as $t_{\rm eff}$, the effective time during which the dynamical friction process operates, in 10^9 yr. We found that t_3, averaged over these 20 clusters, is less than a cluster lifetime, if reasonable values for the galaxy mass-to-luminosity ratio are assumed, i.e. $\sim 50/t_{\rm eff}$, in solar units. The extreme values found for t_3 allow us to constrain the average mass-to-luminosity ratio of cluster galaxies, in the visual band, from a minimum of $\simeq 10/t_{\rm eff}$ to a maximum of $\simeq 150/t_{\rm eff}$, in solar units. Moreover, we divided this sample of 20 clusters into two subsamples: clusters with t_3 higher and, respectively, lower than the median value. We noticed that the evidence for *VLS* is somewhat stronger for the low t_3 subsample (S: 99.90% and W: 99.90% s.l.) than for the high t_3 one (S: 94.53% and W: 95.80% s.l.). These results are compatible with the segregation being induced by the dynamical friction process.

As a further consideration, we have fitted the logarithm of the normalized velocities $\log(|v_i - \bar{v}|/\sigma_u)$ versus the normalized magnitudes $m_i - m_3$ (see Fig. 2), using a standard least-squares procedure. The straight line fitted on the data for galaxies brighter than m_3 was found to have a slope of 0.2, just

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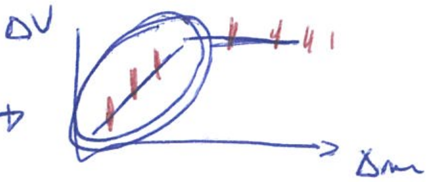

Dati - fit $\nearrow \frac{V-\bar{V}}{\sigma}$

$\Rightarrow \quad \log \Delta V \propto 0{,}2\ \Delta m \nearrow$ mag

Impongo cost. Ecinetica (Da equidistribuz. di energie)

$\frac{1}{2} M \Delta V^2 = \text{cost}$ M = massa della galassia

$\Delta V \propto M^{-1/2}$

$M/L \sim \text{cost.}$

$\Delta V \propto L^{1/2}$

$\log \Delta V \propto 0.5 \log L$ $\nearrow$ luminosità $L \propto 10^{0,4\Delta m}$

$\log \Delta V \propto 0.5 \cdot 0,4\ \Delta m$

$\log \Delta V \propto 0,2\ \Delta m$ → coincide con il risultato del fit.

quindi OK con equidistribuzione di energie come aspettato in frizione dinamica (come anche per rilassamento 2-corpi)

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Segregations in clusters of galaxies*

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Abstract. We analyse a sample of about 2000 galaxies in 40 regular clusters, to look for evidence of segregation with respect to galaxy luminosities and morphological types.

We find evidence of luminosity segregation for galaxies brighter than $M_R < -21.5$, i.e. typically the four brightest members of each cluster. We also find evidence of morphological segregation: both the core-radius and the velocity dispersion increase along the Hubble sequence (ellipticals - S0 - early spirals - late spirals).

Galaxies of different types have different velocity dispersion profiles, being steeper for later type galaxies. Simple modelling allows us to show that elliptical (and, to a lesser extent, S0) orbits are mostly tangential in the cluster core, and nearly isotropic outside, while spiral (in particular late-spiral) orbits are predominantly radial.

A viable interpretation of our results is that (1) late spirals, at variance with other type galaxies, are a non-virialized cluster population, still on partially radial infalling orbits, (2) the elliptical phase-space distribution is evolving towards energy equipartition through the process of dynamical friction, (3) S0 and early-spirals have intermediate distributions between these two extremes.

Key words: galaxies: clusters: general-cluster: individual: Coma cluster

1. Introduction

The analysis of the phase-space distributions of cluster galaxies helps to constrain models of galaxy formation and evolution. In particular, it is important to distinguish among galaxies of different luminosities and morphological types, as they may not have formed and evolved in the same way. Moreover, it is important to know the phase-space distributions of different cluster galaxies for a proper determination of the cluster mass (Girardi et al. 1996).

The observational evidence that early-type galaxies occupy denser environments than late-types dates back to Curtis (1918) and Hubble & Humason (1931), and was quantified by Oemler (1974). Melnick & Sargent (1977) showed that the relative fraction of S0 and spiral galaxies depends on the distance from the cluster centre. Most subsequent studies were based on the data sample of Dressler (1980a) containing over 6000 galaxies in 55 cluster fields. While Dressler (1980b) concluded that the basic correlation is between morphology and *local density* in clusters, Sanromà & Salvador-Solé (1990) and Whitmore & Gilmore (1991), based on the same sample, have independently reached the conclusion that the fundamental correlation is between morphology and *global cluster properties,* such as the the clustercentric distance. For more complete reference, we refer the reader to Whitmore et al. (1993).

More recently, ellipticals and S0 were found to have smaller velocity dispersions (σ in the following) than spirals and irregulars (Tammann 1972; Melnick & Sargent 1977; Moss & Dickens 1977; Sodré et al. 1989; Biviano et al. 1992, hereafter B92; Andreon (1996); Stein 1997, hereafter S97). As morphologies are usually more difficult to reliably determine than colours, and colours and morphologies are correlated, many authors have analysed the correlation between kinematics and colours. Biviano et al. (1996), Colless & Dunn (1996), all found that the ratio between the σ of the blue and the red galaxy populations in the Coma cluster is $\sim$ 1.3–1.4. Similar evidence has recently been found by Carlberg et al. (1997) in their analysis of the CNOC survey medium-z clusters. Based on a sample of $\sim$ 600 galaxies in 15 clusters, S97 has recently confirmed the larger σ for spirals as compared to early-type galaxies, and has shown that within the class of early-type galaxies, S0 have a larger σ than ellipticals.

Further, possibly related, observational evidence is the existence of luminosity segregation: the most luminous galaxies are closer to the cluster centres (e.g. Rood & Turnrose 1968, Capelato et al. 1981, Yepes et al. 1991), and have a significantly lower velocity dispersion (Rood et al. 1972, Chincarini & Rood 1977, Struble 1979, Kent & Gunn 1982, B92, S97). The anti-correlation between luminosity and velocity dispersion seems however to hold for the very bright galaxies only (luminosity $\geq 5L^*$), and to depend on the galaxy morphological type, being

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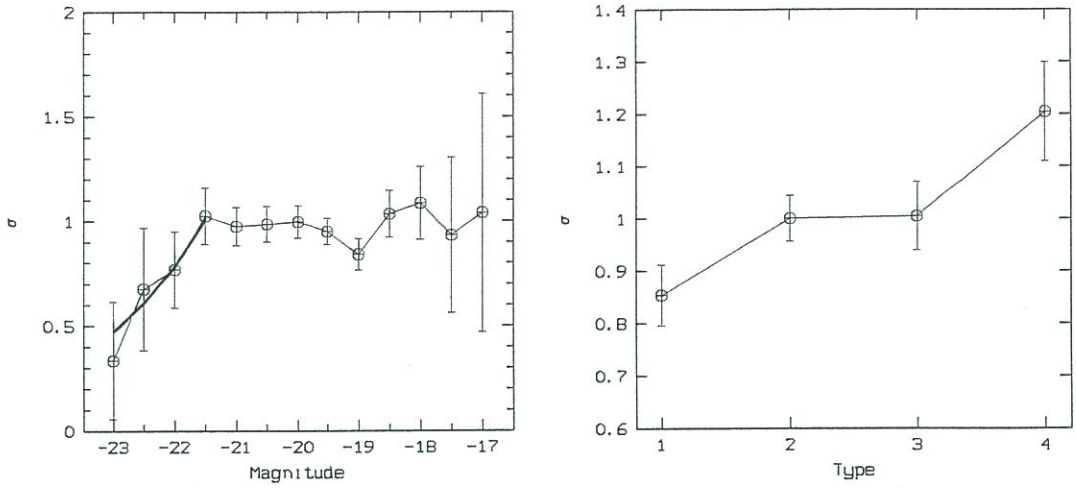

Fig. 1. a (left panel) normalized σ vs. M_R magnitude for all galaxies in the synthetic cluster (1997 galaxies). We show the relation $\sigma \propto 10^{0.2 M_R}$, normalized at $M_R = -21.5$; **b** (right panel) normalized σ vs. morphological type for galaxies in the synthetic cluster with 1: E, 2: SO, 3: Se and 4: Sl.

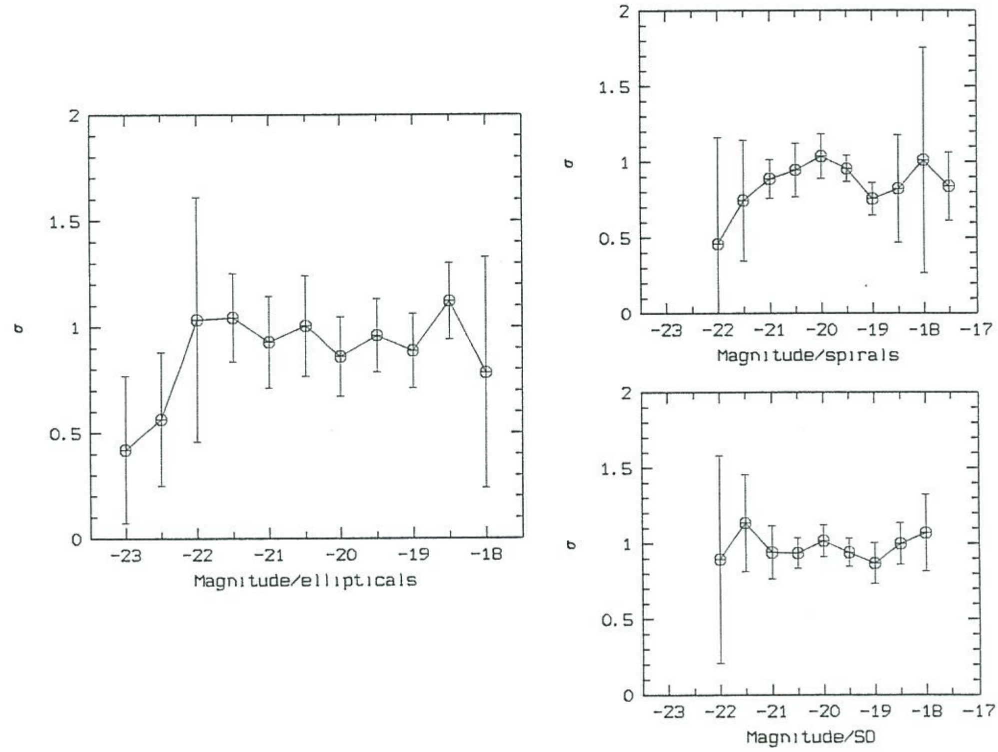

Fig. 2a–c. Normalized σ vs M_R magnitude for the galaxies in the synthetic clusters, split into three morphological classes; **a** (left panel) E (479 galaxies); **b** (bottom-right panel) S0 (982 galaxies); **c** (top-right panel) spirals (536 galaxies).

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Astronomy
&
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Morphology and luminosity segregation of galaxies in nearby loose groups

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Abstract. We study morphology and luminosity segregation of galaxies in loose groups. We analyze the two catalogs of groups identified in the Nearby Optical Galaxy (NOG) sample, by means of hierarchical and percolation "friends-of-friends" methods (HG and PG catalogs, respectively). In the first part of our analysis we consider 387 and 436 groups of HG and PG and compare morphology- (luminosity-) weighted to unweighted group properties: velocity dispersion, mean pairwise distance, and mean groupcentric distance of member galaxies. The second part of our analysis is based on two ensemble systems, one for each catalog, built by suitably combining together galaxies of all groups (1584 and 1882 galaxies for HG and PG groups). We find that earlier-type (brighter) galaxies are more clustered and lie closer to the group centers, both in position and in velocity, than later-type (fainter) galaxies. Spatial segregations are stronger than kinematical segregations. These effects are generally detected at the $\gtrsim$3-sigma level. Luminosity segregation is shown to be independent of morphology segregation. Our main conclusions are strengthened by the detection of segregation in both hierarchical and percolation catalogs. Our results agree with a continuum of segregation properties of galaxies in systems, from low-mass groups to massive clusters.

Key words. galaxies: clusters: general – galaxies: fundamental parameters – galaxies: evolution – cosmology: observations

1. Introduction

Groups and clusters of galaxies are complex systems involving a variety of interacting components (galaxies, X-ray emitting gas, dark matter). Their investigation offers a rare opportunity to link many aspects of astrophysics and cosmology and, in particular, to clarify the interplay between dark and baryonic matter.

Different galaxy populations, i.e. families of galaxies with different morphology – color – spectral type – luminosity, show different distributions in projected position and LOS velocity. These phenomena, known as segregation effects, provide a way to explore the connection between the distributions of dark matter and galaxies.

Segregation phenomena are well studied in galaxy clusters. Since the first studies (e.g. Oemler 1974; Moss & Dickens 1977; Dressler 1980; Dressler et al. 1997), a long sequence of analyses has shown that galaxies of early morphological type (red color – low star formation rate) are more concentrated in regions of higher projected density and lie closer to the cluster center both in position and in velocity than galaxies of late morphological type (blue color – high star formation rate), cf. Biviano et al. (2002) and references therein. Evidence for luminosity segregation is also found, although only very luminous, possibly early-type galaxies seem really to be segregated from the rest of the population (e.g. Biviano et al. 1992; Stein 1997; Biviano et al. 2002).

Observational evidence that in galaxy surveys the clustering strength depends on morphology, luminosity, and colors (e.g. Benoist et al. 1996; Hermit et al. 1996; Guzzo et al. 1997; Norberg et al. 2001) suggests that segregation phenomena in galaxy systems might be connected with the large-scale-structure formation, perhaps in the context of biased galaxy formation or in the hierarchical growth of structure via gravitational instability.

Alternatively and/or additionally, some environmental effects could play an important rôle in segregation phenomena (e.g. White 1983; Richstone 1990; Moss 2001). In fact, after a fast stage of violent relaxation, when the dynamics is controlled by a collective potential (Lynden-Bell 1967), galaxy systems should undergo a secondary relaxation phase, characterized by a longer time scale. In this second phase, several physical effects could modify member galaxies as regards their internal properties, as well as their distribution in space and in velocity. Some of these environmental effects, such as ram pressure stripping (Gunn & Gott 1972) and galaxy harassment (Moore et al. 1996), are less effective in group environments, where the X-ray temperature and global potential are smaller than in clusters. On the contrary, galaxy-galaxy interactions, such as close tidal encounters or mergers, and dynamical friction should be

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HG e PG

TWO DIFFEREN WAYS TO ASSIGN MEMBERSHIP AND DETECT GROUPS

Table 5. Rich ($n \geq 5$) groups.

Sample	x vs. y	$N_{\rm GALs}$	$K_{xy.n}$, $P_{xy.n}$	$K_{xy.n.m-m3}$, $P_{xy.n.m-m_3}$	$K_{xy.n.T}$, $P_{xy.n.T}$
HG	R–M	1007	0.13, >99.9		0.12, >99.9
	R–T	993	0.10, >99.9	0.09, >99.9	
	V–M	1007	0.06, 99.9		0.05, 99.7
	V–T	993	0.05, 99.4	0.05, 98.6	
PG	R–M	1177	0.09, >99.9		0.08, >99.9
	R–T	1163	0.10, >99.9	0.09, >99.9	
	V–M	1177	0.03, 92.4		0.03, 93.1
	V–T	1163	0.00, 58.5	−0.01, 64.7	

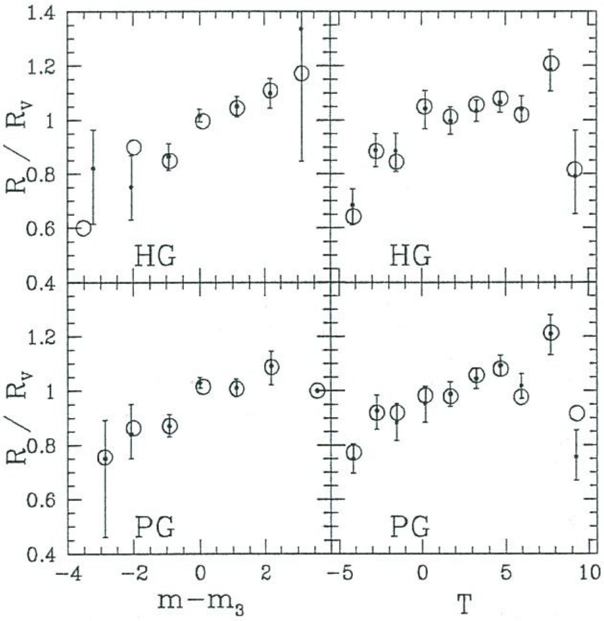

Fig. 3. Groupcentric-distance vs. magnitude, and morphological type: R–M and R–T relations in the left and right panels, respectively. Points are biweight mean values for all groups (filled circles) and rich $n \geq 5$ groups only (open circles). Error bars are 68% bootstrap estimates. For the sake of clarity, error bars are shown for one sample only. Observational results are normalized point by point with results from simulated groups (cf. text).

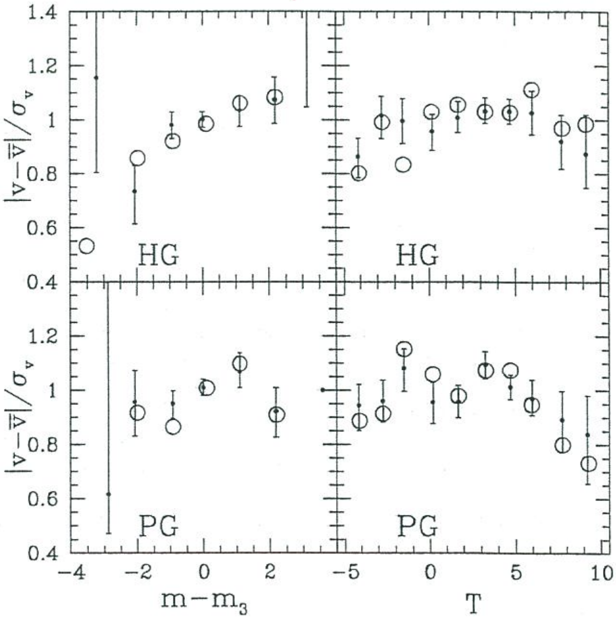

Fig. 4. Velocity vs. magnitude, and morphological type: V–M and V–T relations in the left and right panels, respectively. Points are biweight mean values for all groups (filled circles) and rich $n \geq 5$ groups only (open circles). Error bars are 68% bootstrap estimates. For the sake of clarity, error bars are shown for one sample only. Observational results are normalized point by point with results from simulated groups (cf. text).

The analysis of rich groups confirms the correlations found for the whole sample. In particular, the V–T correlation is now significant in the case of the HG catalog.

As for poor groups, they show fainter spatial segregation effects than rich groups and no kinematical segregation effects at all (cf. also Fig. 5). This result could be due 1) to the dilution effect of a significant number of spurious groups or 2) to some physical difference between poor and rich groups. The most relevant difference is probably the $\sigma_{\rm v}$, which is, on average, smaller in poor than in rich groups (cf. Table 1). However, segregation effects are poorly or not dependent on $\sigma_{\rm v}$ (cf. Sect. 4.5); thus we are inclined to believe in the first hypothesis.

Hereafter, we consider only more reliable, rich $n \geq 5$ groups.

4.4. Luminosity vs. morphology effects

It is well known that galaxies of different morphological types have different luminosity functions (e.g., Sandage et al. 1985; Marzke et al. 1998). In particular, very late-type galaxies strongly differ from other types having typically fainter magnitudes (e.g., Sandage et al. 1985; Sandage 2000). In our case, morphological type T and normalized magnitude $m - m_3$ correlate at the 98.8% and 97.8% c.l. for HG and PG, respectively.

The problem of the independence of morphology and luminosity segregations can be addressed by methods of partial correlation (cf. Sect. 4.2). Thus, for the four relations considered in Table 5 we estimate the Kendall partial rank correlation coefficient considering the effect of luminosity (morphology) in the relations involving morphology (luminosity). Table 5 lists the values of $K_{xy.n.m-m_3}$ and $K_{xy.n.T}$, and the respective c.l.: they are similar to or just slightly smaller than the values of

SDSS CLUSTER CATALOG

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Velocity dispersion of 335 galaxy clusters selected from the Sloan Digital Sky Survey: statistical evidence for dynamical interaction and against ram-pressure stripping

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ABSTRACT

There has been plenty of observational evidence of cluster galaxy evolution, such as the Butcher–Oemler effect and the morphology–density relation. However, it is hard to identify the origin of cluster galaxy evolution, simply because it is difficult to trace the complicated process of galaxy evolution over a time-scale of several gigayears using observations that only give information about a single epoch. Here we show that gravitational interaction/friction between galaxies is the statistically dominant physical mechanism responsible for cluster galaxy evolution, and that the well-favoured ram-pressure stripping by the cluster gas is not statistically driving cluster galaxy evolution. We have constructed the largest composite cluster with 14 548 member galaxies out of 335 clusters with $\sigma > 300$ km s^{-1} carefully selected from the Sloan Digital Sky Survey. By measuring the velocity dispersions of various subsamples of galaxies in this composite cluster, we found that bright cluster galaxies ($M_z < -23$) have significantly smaller velocity dispersion than faint galaxies ($M_z \geqslant -23$), with much greater precision than previous results (e.g. those of Adami et al.). We interpret this as direct evidence of the dynamical interaction/friction between cluster galaxies, where massive galaxies lose their velocity through energy equipartition during the dynamical interaction/friction with less massive galaxies. We also found that star-forming late-type galaxies have a larger velocity dispersion than passive late-type galaxies. This is inconsistent with the ram-pressure stripping model; since ram pressure is proportional to σv^2 (i.e. stronger for galaxies with high velocity), ram-pressure stripping cannot explain the observed trends of passive (evolved) galaxies having low velocity rather than high velocity. On the other hand, the result is again consistent with the dynamical galaxy–galaxy interaction/friction, where more evolved (passive) galaxies lose their velocity through dynamical interaction/friction.

Key words: galaxies: clusters: general.

1 INTRODUCTION

It is well known that cluster galaxies evolve with redshift. Butcher & Oemler (1978, 1984) found that the fraction of blue galaxies in clusters increases with increasing redshift (see also Couch et al. 1994, 1998; Rakos & Schombert 1995; Margoniner & de Carvalho 2000; Margoniner et al. 2001; Ellingson et al. 2001; Kodama & Bower 2001; Goto et al. 2003a, 2004; but see also Andreon & Ettori 1999; Andreon, Lobo & Iovino 2004). In a modern version, high-redshift clusters are known to have a larger fraction of star-forming galaxies than local clusters (Postman, Lubin & Oke 1998, 2001; Finn, Zaritsky & McCarthy 2004). It is also known that cluster galaxies show morphological evolution as well, i.e. the fraction of S0 galaxies is found to be lower in high-redshift clusters (Dressler et al. 1997; van Dokkum et al. 2000; Fasano et al. 2000; Jones, Smail & Couch 2000; Fabricant, Franx & van Dokkum 2000; Goto et al. 2003b; but see also Andreon 1998). Goto et al. (2003a, 2004) used 516 clusters found in the Sloan Digital Sky Survey (Goto et al. 2002a, b) to verify this effect with greater statistical significance.

Such numerous observational evidence suggests that a certain physical mechanism (or mechanisms) is changing the morphology and star formation rate (SFR) of cluster galaxies as a function of redshift. However, to date, it has been difficult to specify what physical mechanisms determine morphology and SFR of galaxies in clusters. Since observations only provide us with a snapshot of cosmic history, it is difficult to trace the complicated process of galaxy evolution using traditional observational information on photometry

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galaxies with a cluster-centric radius of more than two virial radii in angular direction using virial radii computed in Goto (2005a). This process nicely limits analysis to the regions with similar gas density when measuring the velocity dispersions of various subsamples of galaxies in the composite cluster.

Among the SDSS DR2 sample, we have found 335 clusters with >20 members and $\sigma > 300$ km s^{-1}. This cluster catalogue contains one of the largest numbers of clusters with measured velocity dispersion. Among the member galaxies, we adopted the position of the brightest (in z band) cluster galaxy as an angular position of the cluster. This cluster catalogue contains positions (RA, Dec., J2000), redshift, number of member galaxies, and measured velocity dispersion of the clusters, and is presented electronically.[1] The created composite cluster has 14 548 member galaxies, which is larger by two orders of magnitude than the typical number of member galaxies available in the literature. Thereby, we have obtained the first opportunity to investigate velocity dispersion of various subsamples of cluster galaxies with unprecedented high precision. We have remeasured the velocity dispersion of this cluster, obtaining $\sigma_{\mathrm{normalized}} = 0.9937^{+0.0058}_{-0.0057}$. We take a conservative approach in computing errors using Danese, de Zotti & di Tullio (1980), which usually returns larger values than a jack-knife estimator. None the less, the errors are extremely small owing to the large number of member galaxies, making the composite cluster an ideal sample to investigate the velocity dispersion of different subsamples of galaxies.

3 ANALYSIS AND RESULTS

In the following subsections, we measure the velocity dispersion of different subsamples of cluster galaxies using the biweight estimator and the errors of Danese et al. (1980). In Section 3.1, we investigate the velocity dispersion as a function of absolute magnitude. In Sections 3.2–3.5, we separate subsamples using morphology, colour and SFR.

3.1 Velocity dispersion as a function of absolute magnitude

In this subsection, we investigate the velocity dispersion as a function of z-band absolute magnitude (M_z). We use the z-band absolute magnitude as the closest approximation to the galaxy mass among the five SDSS colour bands. It is estimated that the variation in the mass-to-light ratio is only a factor of ~3 in the z band (Kauffmann et al. 2003). In the following, we use the absolute magnitude in the z band as a galaxy mass estimator. We use Petrosian magnitude corrected for galactic extinction using the reddening map of Schlegel, Finkbeiner & Davis (1998). We use the k-correction given in Blanton et al. (2003, v3_2) to calculate absolute magnitudes. Fig. 1 shows the measured velocity dispersion as a function of M_z. An immediately notable feature is that, at $M_z < -23.0$, the velocity dispersion decreases towards brighter absolute magnitude. Also, it is seen that, between $M_z = -20.0$ and -23.0, the velocity dispersions are consistent with a constant. When we divide the sample using morphology and colour in the following sections, we limit galaxies to $-22.5 \leqslant M_z \leqslant -20.5$ in order to minimize the mass-dependent (or M_z-dependent) bias.

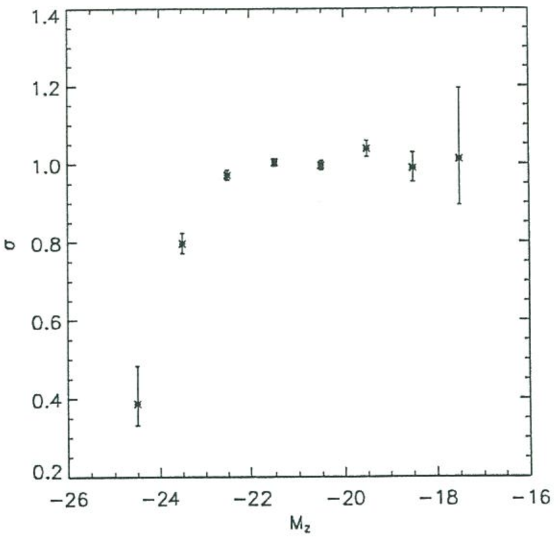

Figure 1. Velocity dispersion of the composite cluster as a function of absolute magnitude in the z band. Dispersions are computed using galaxies in ±0.5 mag bins. The result is consistent with Adami et al. (1998), but presented with much greater precision.

3.2 Velocity dispersion as a function of galaxy morphology

Next, we investigate the velocity dispersion for different morphological types of galaxies. We use the ratio of Petrosian 50 per cent light radius to Petrosian 90 per cent light radius, *Cin*, measured in the r-band image to quantify galaxy morphology. The analysis will reveal if the kinematic structures of galaxies depend on the morphological galaxy types. To avoid magnitude-dependent bias, we only use galaxies with $-22.5 \leqslant M_z \leqslant -20.5$, where velocity dispersion is constant as a function of M_z (Fig. 1). We regard galaxies with $Cin > 0.4$ as late-type galaxies and with $Cin \leqslant 0.4$ as early-type galaxies. This parameter *Cin* is known to be well correlated with eye-classified morphology (Shimasaku et al. 2001; Strateva et al. 2001), and thus has been used in many previous studies (e.g. Gómez et al. 2003; Kauffmann et al. 2004).

We show the results in Table 1, where the late-type galaxies ($Cin > 0.4$) have $\sigma = 1.040^{+0.012}_{-0.012}$ and the early-type galaxies ($Cin \leqslant 0.4$) have $\sigma = 0.963^{+0.007}_{-0.007}$. Since both samples have more than 3000 galaxies, the difference is quite significant (>4σ significance level). The difference is larger than the magnitude dependence we saw in the $-22.5 \leqslant M_z \leqslant -20.5$ mag range in Fig. 1. Therefore, the results indicate that late-type galaxies have larger velocity dispersions than early-type galaxies. We discuss the physical implications of the result in Section 4.

3.3 Velocity dispersion as a function of galaxy colour

Next, we investigate the velocity dispersion for populations of galaxies with different colour. The rest-frame colour of galaxies generally correlates well with the star formation activity of galaxies (e.g. Kennicutt 1992). Therefore, by investigating the velocity dispersion as a function of galaxy colour, we can test if the dynamical state of each cluster galaxy affects the star formation activity of individual galaxies. We intend to separate blue and red galaxies using the rest-frame $u - r = 2.22$. Strateva et al. (2001) showed that this colour separates early- and late-type galaxies well at $z < 0.4$. We use the same magnitude range of $-22.5 \leqslant M_z \leqslant -20.5$ to minimize the mass-dependent (or M_z-dependent) bias.

The resulting velocity dispersions of blue/red galaxies in the composite cluster are presented in Table 1. The blue galaxies in the composite cluster have a velocity dispersion of $\sigma = 1.085^{+0.016}_{-0.015}$,

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[1] http://acs.pha.jhu.edu/~tomo

2015 (?)

GIRARDI + IN PREPARATION

→ FOGO = CATALOG OF FOSSIL GROUPS ($\Delta m_{12} > 2$)