The Astrophysical Journal, 617:L111–L114, 2004 December 20

THE MORPHOLOGICAL AND LUMINOSITY CONTENT OF POOR GALAXY GROUPS

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Received 2004 July 5; accepted 2004 November 4; published 2004 November 16

ABSTRACT

We find that the fraction of early-type galaxies in poor groups (containing from four to 10 members) is a weakly increasing function of the number of the group members and is about 2 times higher than in a sample of isolated galaxies. We also find that the group velocity dispersion increases weakly with the fraction of early-type galaxies. Early-type galaxies in poor groups are brighter in the near-infrared with respect to isolated ones by $\Delta M_K \sim 0.75$ mag, and to a lesser degree also in the blue ($\Delta M_B \sim 0.5$ mag). We also find early-type galaxies in groups to be redder than those in the field. These findings suggest that the formation history for early-type galaxies in overdense regions is different from that in underdense regions, and that their formation in groups is triggered by merging processes.

Subject headings: galaxies: general — galaxies: kinematics and dynamics

1. INTRODUCTION

It is known that most galaxies in the universe occur in small groups (e.g., Geller & Huchra 1983; Tully 1987; Nolthenius & White 1987; Fukugita et al. 1998). In the dense and relatively low-velocity dispersion group environments, one expects frequent galaxy interactions. Indeed, Tran et al. (2001) showed that a certain fraction of galaxies in evolved, X-ray–luminous groups are significantly asymmetric, which is evidence of galaxy interactions. *N*-body simulations of isolated groups indicate that dynamical friction should also play an important role in the evolution of groups (Bode et al. 1993, 1994; Athanassoula et al. 1997).

In such a scenario the groups are not in a dynamical equilibrium because of the high frequency of galaxy interactions. Interactions and merging of galaxies have been shown to play a major role in the evolution of galaxy morphology (e.g., Toomre & Toomre 1972; Schweizer & Seitzer 1992). The general belief is that early-type (E/S0) galaxies are formed by the merging of spiral galaxies (Barnes & Hernquist 1992; Mihos 1995). As a result of multiple merging, a massive central galaxy can be formed. Obviously this phenomenon must be especially rapid in compact groups. For this reason much effort has been devoted to the study of dynamical evolution and morphological content of compact groups (e.g., Hickson et al. 1992; Mendes de Oliveira & Hickson 1994; Tovmassian 2001, 2002; Kelm & Focardi 2004; Lee et al. 2004; Coziol et al. 2004). Contrary to expectations, Shimada et al. (2000) found no statistical difference in the frequency of occurrence of emission-line galaxies between the Hickson compact groups (Hickson 1982; Hickson et al. 1992) and the field. However, Kelm & Focardi (2004) found that compact groups identified in the Updated Zwicky Catalog (UZC) of galaxies contain a higher fraction of early-type galaxies with respect to the field. On the other hand, Colbert et al. (2001) have shown that early-type galaxies in the field appear to have more shells and tidal features than those in groups, a fact that they attribute to merging events that occur also in the field, and whose signatures probably survive because of the isolation of these galaxies. These results seem to be confirmed by Marcum et al. (2004), although they have also identified a small fraction of isolated early-type galaxies that show no evidence of a merger history and thus appear to be passively evolving primordial galaxies.

Recently we have used the Ramella et al. (2002) UZC-SSRS2 group catalog (USGC), based on the UZC (Falco et al. 1999) and the Southern Sky Redshift Survey (SSRS2; da Costa et al. 1998), to show that poor groups have a prolate spheroidal shape configuration with a mean intrinsic axial ratio (β) of $\langle\beta\rangle \approx 0.3$ and standard deviation $\sigma_\beta \approx 0.15$ (Plionis et al. 2004, hereafter P04). As interactions are more likely in such elongated systems, poor groups are good laboratories to test galaxy formation theories and study their evolution. In this Letter, we compare the morphological and luminosity content (in the *K* and *B* bands) of the group galaxy (GG) members with those of isolated galaxies (IGs).

2. OBSERVATIONAL DATA

We have used the poor groups of the USGC (Ramella et al. 2002) as defined in P04, i.e., groups with galaxy membership n_m (“richness” in what follows) in the range $4 \leq n_m \leq 10$ and radial velocity $cz \leq 5500$ km s^{-1}, since within this velocity limit the groups appear to have constant space density and, therefore, they are assumed to constitute a roughly volume-limited sample. As in P04, we divide groups into different richness classes. All candidate fake groups (see P04) were excluded from our analysis. Furthermore, we excluded those of our $n_m = 4$ groups that Focardi & Kelm (2002) identified as triplets (due to possible projection contamination), i.e., USGC U033, U039, U066, U070, U076, and U127 (which correspond to FK 12, 14, 26, 27, 29, and 35). As a starting point for our analysis, we use 169 groups containing in total 932 galaxies, out of which 58, 59, 35, and 17 groups have a richness (n_m) of 4, 5–6, 7–8, and 9–10 galaxies, respectively.

For comparison we used the catalog of IGs compiled by Karachentseva et al. (1986). This catalog is widely used as a source of IGs (e.g., Marcum et al. 2004; Varela et al. 2004). It contains 1051 entries, among which there are 329 galaxies with $cz \leq 5500$ km s^{-1}. Note that this galaxy sample has the same magnitude limit as our GGs ($m_{\rm lim} \sim 15.5$). Two of the IGs, PGC 008220 and PGC 059971, were found in USGC groups and were deleted from the IG list.

Galaxy morphological types for both poor GGs and isolated ones were taken from the NASA/IPAC Extragalactic Database

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(NED).[4] Since the galaxies with which we are dealing are nearby and sufficiently bright ($m_{\rm lim} \simeq 15.5$), we expect that the NED morphological classification into the two broad categories (early and late types) is very accurate.

We deduce absolute magnitudes in the K band for two families of galaxies: (1) E/S0 galaxies and (2) spiral galaxies (Sa and later, including irregulars) for both the considered USGC group members and the IGs. We used the Two Micron All Sky Survey (2MASS) $K_{\rm total}$ magnitudes (see Jarrett et al. 2000[5]), corrected for the extinction in our Galaxy according to Schlegel et al. (1998) as given in NED. The quoted 2MASS average magnitude 1 σ uncertainty is ∼0.04 for $m_k < 11$ and ∼0.09 for $m_k \geq 11$. The absolute B magnitudes for all studied galaxies were extracted from Leda (Paturel et al. 1997[6]), and their quoted individual 1 σ uncertainties are quite large, the average of which is estimated to be ∼0.3.

Note that in order to determine absolute magnitudes, the radial velocities of groups or individual galaxies were corrected for the peculiar velocity of the local group and a local velocity field that contains a Virgo-centric infall component and a bulk flow given by the expectations of linear theory (see Branchini et al. 1996), assuming a Hubble constant of $H_0 = 70$ km s^{-1} Mpc^{-1}. We excluded from our analysis groups and IGs that have $cz \leq 1000$ km s^{-1}, as their radial velocities may be significantly contaminated by peculiar velocities.

In order to investigate the mutual completeness of the GG and IG samples, we employed the nonparametric Kolmogorov-Smirnov (K-S) test and found that their redshift distributions can be considered (at a $\gtrsim$25% level) as having been drawn from the same parent population. This also implies that there is no systematic difference in their limiting magnitudes.

3. THE FRACTION OF EARLY-TYPE GALAXIES

We determine the mean fraction of E/S0 galaxies, $f_{\rm E/S0}$ [$\equiv n({\rm E/S0})/n_m$], over our group sample, as well as in the sample of IGs. We use only those groups of which all members have known morphological type, in total 102 groups spanning the whole original sample richness range, and that contain in total 583 galaxies (38, 27, 27, and 10 groups with $n_m = 4$, 5–6, 7–8, and 9–10 members, respectively).

For the sample of 329 IGs we find $f_{\rm E/S0} \sim 0.15$, while for the GGs we obtain a significantly higher mean fraction of $f_{\rm E/S0} \sim 0.23$. This result is in accordance with the "morphology-density" relation of Dressler (1981). Kuntschner et al. (2002) also noted that early-type galaxies are rare in low-density environments. The higher relative number of E/S0 galaxies in groups favors the view that they are formed by the interaction and merging of spiral galaxies. The number of such galaxy encounters is expected to be even higher in high-density environments, i.e., in groups with large n_m. To test this we estimate the mean fraction of early-type galaxies as a function of increasing group richness (n_m) and find $f_{\rm E/S0} \sim 0.21$, 0.19, 0.29, and 0.26 for groups with $n_m = 4$, 5–6, 7–8, and 9–10 members, respectively, suggesting a weak dependence of $f_{\rm E/S0}$ on the group richness. However, it seems surprising that the relative number of E/S0 galaxies and possibly their formation rate depend only weakly on the group richness and thus on the group mass. We investigate this issue further by correlating $f_{\rm E/S0}$ with the velocity dispersion, σ_v, of the corresponding groups (Fig. 1), and we find that there is indeed a significant although weak correlation with the group velocity dispersion increasing with $f_{\rm E/S0}$ (in agreement with Zabludoff 2001). The Spearman rank correlation coefficient is 0.2, and the probability of random correlation is 0.045. Meanwhile, such a correlation is not seen for groups of a given richness class, which confirms that the effect is due to an increase of the velocity dispersion with the group mass. The true underlying correlation should be even stronger than the observed one since the dependence of the measured group velocity dispersion on group orientation can weaken it. This effect results from the fact that elongated prolate-like groups orientated roughly along the line of sight will appear to have a higher velocity dispersion, while when seen orthogonal to the line of sight they will appear to have smaller velocity dispersions.

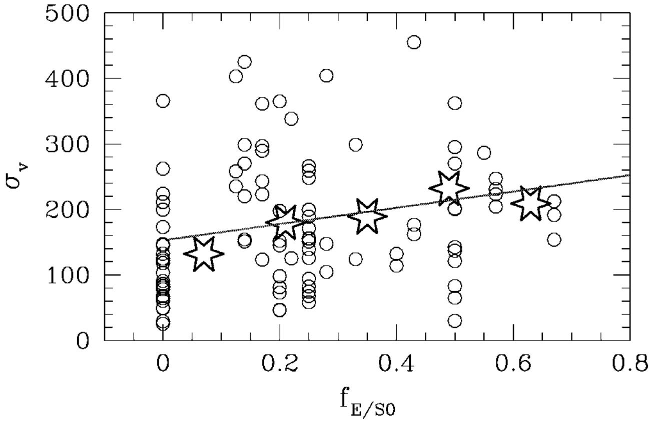

FIG. 1.—Group velocity dispersion as a function of the fraction of early-type galaxies for individual groups with $4 \leq n_m \leq 10$. The continuous line represents the best least-square fit, while the large star symbols represent the average velocity dispersion in five $f_{\rm E/S0}$ bins.

Another parameter that should play a significant role in the quantification of the rate of galaxy encounters in groups is the group crossing time, τ_c, defined by $\tau_c = \bar{a}/\bar{\sigma}_v$, with $\bar{a}$ the median true group major axis and $\bar{\sigma}_v$ the median true (deprojected) group velocity dispersion. The probability of an encounter in a group with a given number of members should be higher in groups with smaller τ_c. However, effective interactions that could alter galaxy morphologies should happen in environments of relatively low-velocity dispersion, which implies a relatively large τ_c for a given group size. Note also that in high σ_v systems that are also extremely elongated, effective galaxy interactions may happen at the apogees of the spatial configuration where the relative velocities of galaxies will be minimal and where the member galaxies will tend to accumulate. Clearly, the dynamics of galaxy mergers in nonspherical structures is a multiparameter problem and not easily quantified.

We attempt to estimate the mean crossing time for groups of different richness (n_m) by taking into account the fact that they are prolate-like (Plionis et al. 2004) and that their member galaxies will probably have mostly radial orbits (moving along the major axis of the prolate spheroid). The *true* median σ_v is estimated using the quasi-spherical groups, i.e., those with axial ratio close to unity, since because of orientation effects the quasi-spherical groups should typically be those elongated groups seen end-on and therefore their velocity dispersion is closer to the true value. We find $\bar{\sigma}_v \simeq 170$ and 360 km s^{-1} for the $n_m = 4$ and 9, 10 groups, respectively. In order to estimate the true size of groups, we rely on a Monte Carlo simulation

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[4] See http://nedwww.ipac.caltech.edu.

[5] See http://www.ipac.caltech.edu/2mass.

[6] See http://leda.univ-lyon1.fr.

TABLE 1

MEAN ABSOLUTE MAGNITUDES $\langle M_K \rangle$ AND $\langle M_B \rangle$ OF E/S0 AND SPIRAL GALAXIES (Sa AND LATER) IN GROUPS AND IN THE FIELD

	E/S0			Spiral		
Galaxy	$\langle M_K \rangle$	$\langle M_B \rangle$	ΔM	$\langle M_K \rangle$	$\langle M_B \rangle$	ΔM
GG	-23.42 ± 1.39 (183)	-19.92 ± 1.17 (194)	-3.47 ± 0.76	-22.51 ± 1.51 (398)	-19.47 ± 1.36 (500)	-2.89 ± 0.89
IG	-22.68 ± 1.64 (43)	-19.44 ± 1.32 (48)	-3.16 ± 0.72	-22.54 ± 1.46 (205)	-19.44 ± 1.40 (269)	-2.82 ± 0.86

NOTE.—The number of corresponding galaxies is given in parentheses.

method, the details of which will be presented elsewhere (M. Plionis & H. M. Tovmassian 2005, in preparation). It is based on searching for the intrinsic group major-axis distribution that once folded through the intrinsic group axial ratio distribution (determined in Plionis et al. 2004) and random orientations with respect to the line of sight, which will produce the projected Monte Carlo group shape parameter (axial ratio, minor and major axis) distributions that are in agreement with the corresponding observed ones. We find $\overline{a}_{3D} \simeq 1.5 \pm 0.3$ and $2 \pm 0.5\, h_{70}^{-1}$ Mpc, respectively, for the $n_m = 4$ and 9, 10 groups, and therefore the group crossing times are $\tau_c \sim 8.6$ and 5.8 Gyr, respectively.

To test the effect of the different values of τ_c on the galaxy encounter and merging rate, disentangling the possible effect of the different group orientations with respect to the line of sight, we determined the mean $f_{\rm E/S0}$ in the most elongated chainlike groups (i.e., those that are preferentially seen perpendicular to the line of sight) for two group categories: those with τ_c higher and smaller than the mean value of the corresponding group subsample. There are 36 groups with axial ratio $q < 0.3$ (all of them with $n_m \leq 6$) and with known morphology of all their members. We find $f_{\rm E/S0} \simeq 0.25 \pm 0.055$ and 0.165 ± 0.045 for groups with τ_c smaller and larger than the corresponding group mean value, respectively. Although the difference is not very significant, it does imply, as expected, that the crossing time is an important parameter in the quantification of the rate of galaxy interactions.

4. ABSOLUTE MAGNITUDES AND COLORS OF GALAXIES

If E/S0 group galaxies are formed as the result of galaxy merging, one should expect them to be more luminous than isolated E/S0 galaxies. We estimated the mean $\langle M_K \rangle$ and $\langle M_B \rangle$ absolute magnitudes of E/S0 and spiral galaxies (Sa and later) in our original group sample ($N = 169$) and IGs (see Table 1). The frequency distribution of the absolute magnitudes of the group and isolated early-type galaxies is shown in Figure 2. We also derived the absolute magnitude difference (ΔM) between GGs and IGs and found $\Delta M_K \approx 0.75$ mag and $\Delta M_B \approx 0.5$ mag for the E/S0 galaxies and $\Delta M_K \approx 0.05$ mag and $\Delta M_B \approx 0.02$ mag for the spiral galaxies (see Table 1).

The K-S test shows that the GG and IG K-band absolute magnitude distributions of early-type galaxies are significantly different, with the probability $\mathcal{P} \simeq 0.05$ of being drawn from the same population. The corresponding M_B distributions do not show a significant difference. Furthermore, no difference in absolute magnitude (neither for M_K nor for M_B) is observed between group and isolated spiral galaxies. The K-S test shows that their distributions have a probability of being drawn from the same population of $\mathcal{P} \simeq 0.7$ and 0.95, respectively, for the K and B bands. We have also found that the values $\langle M_B \rangle$ and $\langle M_K \rangle$ of E/S0 galaxies do not depend on the group richness.

We conclude that indeed there is strong evidence that the group E/S0 galaxies are brighter, especially in K with respect to the IGs of either type, E/S0 or spiral. The fact that absolute magnitudes of the group E/S0 galaxies are on average brighter than those of IGs by ≈0.75 mag is consistent with the idea that E/S0 group galaxies are formed by the merging of two spiral galaxies of about the same luminosity. The latter is in general agreement with the environmental dependence of the IR luminosity function found by Balogh et al. (2001).

Finally, we compare the $M_B - M_K$ colors of the considered subsamples. We find that the mean color of the E/S0 galaxies in groups is redder by about 0.30 mag than that of the IGs, and the corresponding color distributions are significantly different, having a K-S probability of consistency of only $\mathcal{P} \simeq 0.006$. A redder color of the group E/S0 galaxies may be due to the shedding of gas during merging. As expected, we find that both group and isolated spiral galaxies are bluer on average in comparison to the group and isolated E/S0 galaxies (see Fig. 3 and Table 1). Figure 3 also shows the presence of a few relatively blue galaxies ($M_B - M_K \leq 1$) among the group E/S0 galaxies, for which weak starburst processes, induced by interactions, could be responsible (Zepf et al. 1991).

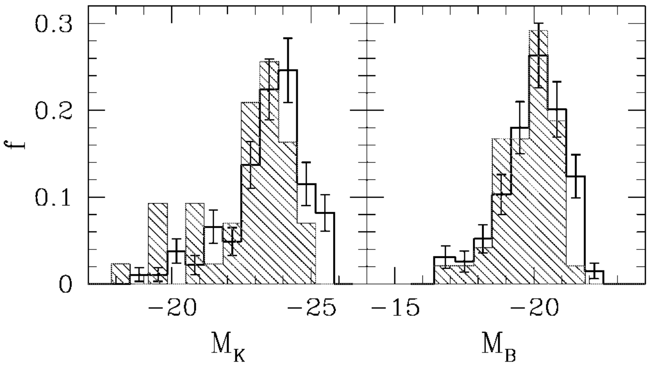

FIG. 2.—Normalized frequency distribution of the M_K (*left*) and M_B (*right*) magnitudes for early-type galaxies in groups (*line with error bars*) and isolated (*hatched histogram*). The galaxy numbers involved are listed in Table 1.

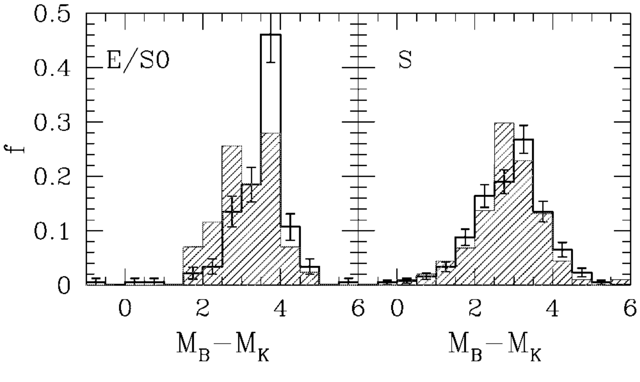

FIG. 3.—Normalized frequency distribution of the $M_B - M_K$ colors of the group (*line with error bars*) and isolated (*hatched*) galaxies for early types (*left*) and spiral galaxies (*right*). The galaxy numbers involved are listed in Table 1.

5. CONCLUSIONS

We have found that the mean fraction of early-type galaxies, $f_{\rm E/S0}$, in poor USGC groups of galaxies (with $1000\ {\rm km\ s^{-1}} < cz < 5500\ {\rm km\ s^{-1}}$ and galaxy members $4 \le n_m \le 10$) is ~0.23 ± 0.04, which is ~65% higher than that of the field galaxies. This fraction is a weakly increasing function of group richness and thus of group mass. This trend is also confirmed from the statistically significant, although weak, increase of $f_{\rm E/S0}$ with group velocity dispersion.

We have also found that the mean near-infrared absolute magnitude of E/S0 galaxies in our groups ($\langle M_K \rangle \approx -23.4$ mag) does not depend on the number of the group members and is ~0.75 mag brighter than that of isolated E/S0 galaxies, while the mean blue absolute magnitude, $\langle M_B \rangle$, of E/S0 galaxies in these groups is brighter by 0.5 mag than the isolated ones. No such differences are found in the corresponding spiral galaxy samples. We conclude that E/S0 galaxies in groups may be the result of the merging of two galaxies of about the same luminosity. The $M_B - M_K$ colors of the group E/S0 galaxies are redder, by about 0.30 mag on average, than those of isolated E/S0 galaxies.

These results are in agreement with the paradigm in which the early-type galaxies, in relatively dense environments, are formed by merging. The redder $M_B - M_K$ colors of the group E/S0 galaxies in comparison to the isolated ones show that the formation processes of the former somehow differ from that of IGs. An open question remains: how are the isolated E/S0 galaxies formed? Various authors have found signs of disturbed morphologies in field E/S0 galaxies (e.g., Colbert et al. 2001; Kuntschner et al. 2002; Marcum et al. 2004). Although the bright isolated E/S0 galaxies may also be remnants of merged groups or pairs of galaxies, the isolated faint E/S0 galaxies probably are not (e.g., Marcum et al. 2004); their origin may be primordial and thus different from those in groups.

This research has made use of the NASA/IPAC Extragalactic Database, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration and the Lyon-Meudon Extragalactik Database (Leda, now Hyper-Leda) maintained at Observatoire de Lyon (see footnote 6). M. P. acknowledges support by the Mexican CONACYT grant 2002-C01-39679 and H. A. by CONACYT grant 40094-F. We thank the anonymous referee for comments that led to a clearer presentation of our results.

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