

Compact groups in the UZC galaxy sample

II. Connections between morphology, luminosity and large-scale density^{*}

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Abstract. The nature of Compact Groups (CGs) is investigated by comparing the luminosities and morphologies of CG galaxies, CG Neighbours and Isolated galaxies. CGs turn out to include more early type galaxies than Isolated galaxies and fewer low-luminosity galaxies. The 33 CGs with a dominant E/S0 and the 30 CGs with a dominant spiral have similar LF parameters. Spiral dominated CGs have fewer galaxies at high and low luminosity in comparison with their Neighbours, while E-S0 dominated CGs seem to lack only faint galaxies when compared to their Neighbours. Ellipticals which are the dominant galaxy of a CG are also brighter than all their Neighbours, while this holds true for only half of the dominant spirals and S0s. Relations linking the number of Neighbours of dominant E-S0s to the luminosity of E-S0s and to the difference between the first and the second ranked CG members do suggest a link between the formation of bright early-type galaxies and the presence of a group-like potential. No similar relations are found for dominant spirals. These tentative results are compatible with the assumption that CG dominant Ellipticals are anomalous galaxies whose formation might have been a secondary outcome during the process of groups formation.

Key words. galaxies: clusters: general – galaxies: interactions – galaxies: luminosity function, mass function – galaxies: evolution

1. Introduction

Because of their high density and relatively low velocity dispersion, Compact Groups (CGs) are predicted to constitute the most probable sites for strong galaxy-galaxy interactions and mergers to occur (Mamon 1992a). If CGs merge into a single galaxy in several Gyr (Barnes 1985, 1989; Mamon 1987), many remnants, possibly resembling bright field ellipticals (Mulchaey & Zabludoff 1999; Vikhlinin et al. 1999; Jones et al. 2003) will be produced in less than a Hubble time.

Indeed, Hickson CGs (HCGs, Hickson 1982, 1997, and references therein) do include an excess of both, early-type galaxies and luminous sources, and they appear as the most likely sites for bright isolated Ellipticals to form. However, the scarce evidence for strongly interacting galaxies (Rubin et al. 1991; Zepf 1993), the underabundance of peculiar or blue early-type galaxies (Zepf et al. 1991; Zepf & Whitmore 1991; Fasano & Bettoni 1994) as well as the non significant difference between galaxies in HCGs and in other environments as far as the fundamental plane is concerned (De La Rosa et al. 2001) do leave open the question of CG evolution. Dynamical N -body

simulations (Mamon 1992b) indicate indeed, that many of the global characteristics of HCGs lying in between those of field galaxies and those of strongly interacting binaries are consistent with the assumption that chance alignments of galaxies in small groups are binary-rich.

Hickson's sample includes CGs spanning a wide range of characteristics, and a relevant fraction of HCGs might not be isolated (Sulentic 1987; Williams & Rood 1987; Rood & Williams 1989; Mamon 1990; Palumbo et al. 1995). In an attempt to produce a larger and more uniform CG sample, Focardi & Kelm (2002) have automatically selected 291 CGs (UZC-CGs) in the Updated Zwicky Catalog (UZC) redshift catalog (Falco et al. 1999). Contrary to HCGs, which represent surface brightness enhancements, UZC-CGs are selected according to compactness criteria (surface number density enhancement) and are thus less biased to compact groups of very luminous galaxies.

Focardi & Kelm have shown that, at variance with galaxies lacking close companions, UZC-CGs are typically non isolated systems displaying an excess of gas-poor galaxies. Further they suggest CGs selected according to compactness criteria to constitute an intrinsically non-homogeneous sample, including two distinct classes of systems which segregate according to morphology and large scale environment.

One class of CGs displays small velocity dispersion, a high fraction of emission-line galaxies and is typically located in

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sparse environments. This class constitute a possibly genuine sample of isolated field-CGs (Ribeiro et al. 1998) probably rich in AGNs (de Carvalho & Coziol 1999; Coziol et al. 2000; Kelm et al. 2004), but its high content in gas-rich galaxies suggests it might be contaminated by non-bound accordant redshift projections.

The other class of CGs, associated with embedded systems, displays large velocity dispersion and includes high fractions of absorption-line galaxies. Since CGs presenting a passive population are embedded in fairly dense environments, a doubt emerges on whether these galaxies can be considered genuine compact group members rather than collapsing cores within large groups (Governato et al. 1996) or transient projections within loose groups (Mamon 1986; Diaferio 2000), clusters (Walke & Mamon 1989) or long cosmological filaments seen end-on (Hernquist et al. 1995). The question is clearly relevant, for the non-reality of CGs would imply that no (or very few) galaxy systems exist on scale intermediate between the scale of galaxies and the scale of groups.

If CGs are real physical structures their local high galaxy density is expected to affect galaxy properties. It can simply act as a particular initial condition, or influence subsequent galaxy evolution or both. In any event, the dominant mechanism acting in CGs is expected to significantly alter the luminosity and the morphology of galaxies within CGs (Carlberg et al. 2001; Helsdon & Ponman 2003a). To determine which characteristics are intrinsic of the galaxies rather than of CGs, we compare galaxies in CGs with a sample of Isolated galaxies. Similarly, to test contamination of the CG sample by transient configuration within loose groups, we compare CGs with their large scale Neighbours.

We will also evaluate the role of a dense environment on the evolution of spirals and early-type galaxies separately, and discuss differences between CGs whose dominant member is a spiral and a E-S0 respectively. This allows addressing the controversial issue of the true nature of spiral rich groups, and to comment on the lack of observed extended X-ray emission in spiral-only groups (Ebeling et al. 1994; Ponman et al. 1996; Mulchaey et al. 1996, 2003; de Carvalho & Coziol 1999). Relative to previous studies addressing similar topics our analysis has the great advantage of comparing samples selected within the same flux-limited catalogue (Falco et al. 1999) and the same redshift range. A Hubble constant of $H_0 = 100 h^{-1} \text{ km s}^{-1} \text{ Mpc}^{-1}$ is used throughout.

2. Isolated galaxies, CGs and Neighbours: The samples

All samples are automatically selected in the UZC, which is 96% complete for northern galaxies with $m_B \leq 15.5$. Magnitudes have been estimated by eye by Zwicky. Bothun & Cornell (1990) estimate the photometric accuracy to be ≈ 0.3 mag.

A galaxy is defined Isolated when no companion galaxies are found within a region of $1 h^{-1} \text{ Mpc}$ projected radius and 1000 km s^{-1} from it. It is worth stressing that our sample of Isolated galaxies is based on a nearly complete catalogue whose limiting magnitude is ≈ 1 mag fainter than those used

in previous investigations (Colbert et al. 2001; Helsdon et al. 2001).

A UZC-CG is defined as a system including at least 3 galaxies within a region of $200 h^{-1} \text{ kpc}$ projected radius and radial velocity within 1000 km s^{-1} from its center (Focardi & Kelm 2002). Cluster subclumps have been excluded from the UZC-CG sample rejecting all CGs found within $1.5 h^{-1} \text{ Mpc}$ from ACO clusters. Samples of Isolated galaxies and CGs at high galactic latitude ($|b^{\text{II}}| \geq 30^\circ$) and $\delta \geq -2^\circ$ are here analysed, covering a solid angle of $\sim \pi$ sr. We do not consider systems at lower galactic latitude because galactic extinction would bias the samples, artificially enlarging the fraction of Isolated galaxies.

We investigate systems in the range of radial velocities between 2500 and 5500 km s^{-1} . The lower cut is adopted to avoid misidentification of group members whose Hubble flows are strongly biased by peculiar velocities. The upper limit is adopted to investigate a galaxy sample which is relatively complete (in flux and volume) also well below M_* . At a distance limit of 5500 km s^{-1} , the UZC extends to $M_B = -18.2 + 5 \log h$ which is roughly 1.5 mag fainter than M_* , the knee of the Schechter (1976) luminosity function.

The Isolated galaxy sample includes 386 galaxies, the CG sample includes 220 galaxies lying in 69 UZC-CGs. Most CG galaxies ($177 = 77\%$) are in Triplets (Ts). The excess of Ts among CGs is partially induced by having rejected subsystems of ACO clusters from the sample, as well as non-symmetric systems (CGs whose galaxies have no univocal membership assignment on a $200 h^{-1} \text{ kpc}$ projected radius scale). In the range of radial velocities between 2500 and 5500 km s^{-1} , we have rejected 43 non-symmetric groups, 26 including 4 or more members.

Neighbours are galaxies at distances between $0.2 h^{-1}$ and $1 h^{-1} \text{ Mpc}$ and at radial velocity within 1000 km s^{-1} from the CG centers. The Neighbour sample includes 278 galaxies. Naked CGs, i.e. with 0 Neighbours are rare (3 out of 69 CGs).

Morphological classification is available (NED) for most galaxies in the samples (82% in CGs, 86% in Neighbours, 71% in the Isolated galaxy sample). Table 1 lists the number of galaxies per morphological class, in the 3 samples. N_{Spir} indicates spirals which cannot be attributed to Sa-Sb or Sc-Sd classes. The last column lists the early type fraction in the samples, normalized to the number of galaxies for which morphological classification is available.

3. Isolated galaxies and galaxies in CGs: Do they constitute two different populations?

Figure 1 shows luminosity functions for the 386 Isolated (open circles) and the 220 CG (filled circles) galaxies. The points are computed with a modified version (Zucca et al. 1997) of the C-method (Lynden-Bell 1971). Schechter function parameters (see Table 2) are derived with the STY method (Sandage et al. 1979). Error bars represent 1σ Poissonian uncertainties. The sample of Isolated galaxies display brighter M_* than CG galaxies, however, one should consider that in the isolated sample there are only 3 galaxies more luminous than $M = -20$, while

Table 1. Morphological content of the samples.

Sample	N_{tot}	N_E	N_{S0}	$N_{\text{Sa-Sb}}$	$N_{\text{Sc-Sd}}$	N_{Spir}	Early-type fraction
CGs	220	25	44	40	39	30	40%
Neighbours	278	15	46	52	65	46	27%
Isolated	386	9	36	62	123	44	16%

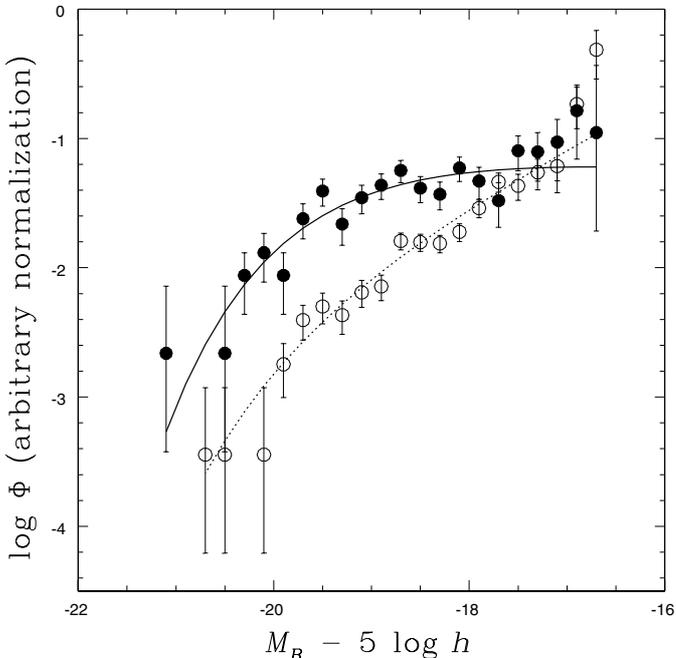


Fig. 1. Luminosity functions for CG galaxies (filled circles) and Isolated galaxies (open circles). The points are computed with a modified version of the C-method. 1σ Poissonian uncertainties are plotted. Best fits are shown, derived with the STY method in the case of a single Schechter function. The relative normalization of the CG versus Isolated samples is arbitrary.

in the CG sample 12 such galaxies are found. Table 2 also indicates that the number of dwarfs in CGs is considerably smaller than the number of dwarfs in the Isolated galaxy sample. The fact that CGs are poor in faint galaxies could imply that CGs are formed without low luminosity galaxies, but it is also consistent with a scenario claiming that they have lost or cannibalized them.

The value of the faint-end slope α has been a matter of debate for HCGs: Mendes de Oliveira & Hickson (1991) find $\alpha = -0.2$, while Sulentic & Rabaca (1994) report $\alpha = -1.13$ (and $\alpha = -1.69$ for the $M < -18$ galaxy subsample). Zepf et al. (1997) use redshifts of faint galaxies around 17 HCGs to replenish the faint end of the HCG luminosity function. The authors find $\alpha = -1$ and state that HCGs are not underabundant of intrinsically faint galaxies. Hunsberger et al. (1998), fit the distribution of 39 HCGs with 2 Schechter functions and interpret the decreasing bright end slope as a deficit of intermediate luminous galaxies.

While results concerning HCGs are inevitably biased because of the magnitude concordance criterion ($\Delta m \leq 3$) applied to select the groups, in the UZC-CG sample the lack of faint galaxies relative to the Isolated sample is real, as the

Table 2. Schechter best fit parameters for CGs, Neighbours and for the Isolated galaxy sample.

Sample	N_{tot}	M_*	α
CGs (all)	220	-19.3	-0.93
CGs (E-S0)	69	-18.7	+0.56
CGs (Spirals)	110	-19.1	-0.79
Iso (all)	386	-19.7	-2.08
Iso (E-S0)	45	-18.2	+0.38
Iso (Spirals)	229	-19.5	-1.65
Neigh (all)	278	-20.1	-1.82
Neigh (E-S0s)	61	-19.0	-0.49
Neigh (Spirals)	176	-20.1	-1.84

redshift range and the magnitude depth of the CG and Isolated galaxy samples are the same. It has been suggested (Zabludoff & Mulchaey 1998) that the deficiency of faint galaxies in CGs might reflect the enhanced rate of dynamical friction for luminous (massive) galaxies, bringing high luminous galaxies into the compact core of loose groups, and leaving low luminosity galaxies outside the loose group cores.

4. The influence of local density on morphology and luminosity

CG galaxies are expected to display significant differences in morphological content compared to Isolated galaxies. Figure 2 shows the morphological content of Isolated galaxies, CGs and Neighbours. This figure indicates that CGs display a significant excess of early-type galaxies, along with a clear deficiency of late ($>Sb$) spirals when compared to Isolated galaxies. That CGs contain a relatively higher fraction of elliptical galaxies relative to the field has also been found in the SDSS-CG sample (Lee et al. 2003). Neighbours display a distribution intermediate between CGs and Isolated galaxies, suggesting galaxies surrounding CGs are neither typical CG members nor typical Isolated galaxies. The relative content of early-spirals is the same in the 3 samples indicating that the fraction of Sa-Sb galaxies is a poor tracer of environmental density.

In Fig. 3, the fraction of E-S0s over the total number of galaxies with assigned morphological type in each of the 3 samples is plotted. As one can reasonably expect from the morphology-density relation (Postman & Geller 1984), the early-type fraction does increase with global density, ranging from 16% in the Isolated galaxy sample to 39% in the CG sample. The fraction of early-type galaxies we find in UZC-CGs is identical to the fraction found in HCGs, when limiting Hickson's sample to groups lying between 2500 and 5500 km s^{-1} . Mergers could be responsible for the fact

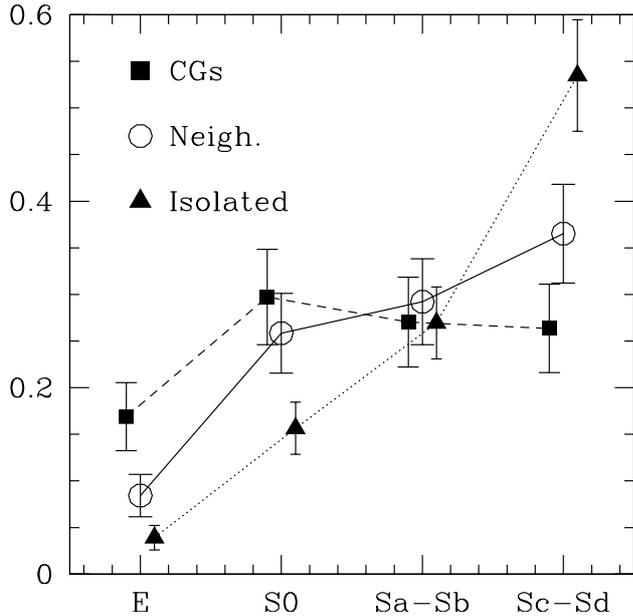


Fig. 2. Morphological distribution of CGs, Neighbours and Isolated galaxies. Error bars are multinomial, points are slightly shifted for clarity. CGs display an excess of ellipticals and a deficiency of late spirals compared to Isolated galaxies. Neighbours display a morphological distribution intermediate between the distributions of Isolated and CG galaxies.

that Neighbours display an intermediate global fraction of E/S0s (27%) between those of CGs and Isolated galaxies (see Mamon 2000). Alternatively, Fig. 3 could indicate that CGs are typically born in environments which are already evolved compared to the low density field, suggesting that whatever the enhancement of early-type galaxies in CGs, it is partially due to initial conditions.

Because the early type fraction increases in more luminous samples, we also show in Fig. 3 the early-type fractions computed for the faintest and more luminous thirds of each sample. The early-type fraction increases with environmental density in the brightest subsample, but not in the faintest one. Figure 3 indicates that only the morphologies of high luminosity CG galaxies are affected, and might suggest that the CG environment enhances the luminosity of early-type galaxies only, while leaving the luminosity of the spiral population quite unaffected. And indeed, while early-type galaxies do constitute only 30% of the whole CG galaxy population (when including also galaxies with no morphological type assigned), they represent roughly half of the CG dominant members.

5. Spirals and E-S0s: Type specific luminosity distributions

The analysis performed so far suggests the CG environment is a favourable one for bright E-S0s and could imply that the high luminosity of E-S0s is (or has been) triggered by the CG. It remains then to be seen whether spirals are triggered similarly: to investigate this point, type specific luminosity distributions of CGs and Isolated galaxies are to be compared.

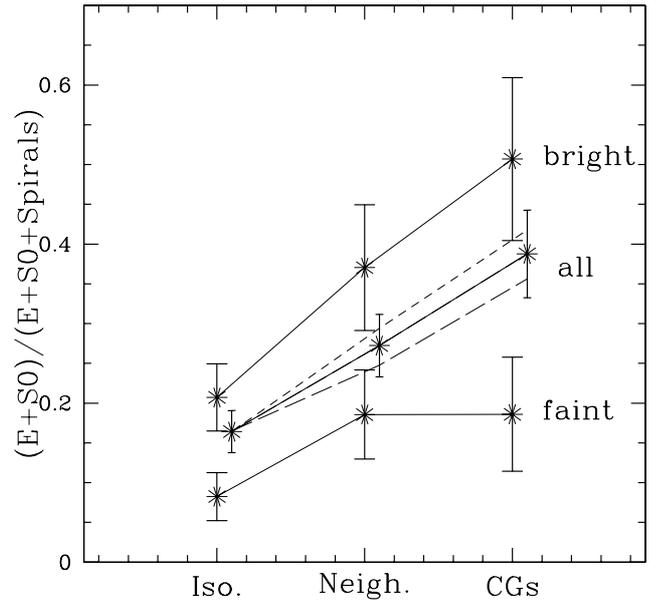


Fig. 3. Global morphology-density relation for Isolated galaxies, CGs and Neighbours. The fraction of early-type galaxies (E-S0s) normalized to the number of galaxies with assigned morphological type, for each of the 3 samples is plotted. Points are shifted for clarity, error bars are multinomial. Fractions have been computed for the total samples (central) and for the faintest and more luminous thirds of each sample. The early-type fraction appears to increase as a function of both, galaxy density and luminosity.

Figure 4 shows the luminosity functions for E-S0 and spirals separately in the CG and in the Isolated sample. In CGs, spirals display steeper faint-end slopes (α) than do E-S0s (see Table 2 and Fig. 5 for contour plots). The same result is found when comparing spirals and E-S0s in the Isolated galaxy sample. This confirms, for CGs and for the isolated environment separately, the results by Lin et al. (1996), Zucca et al. (1997) and Madgwick et al. (2002) all claiming emission line galaxies have a steeper faint end slope than galaxies without emission lines.

The faint-end luminosity functions are steeper for isolated galaxies than for CG galaxies in the spiral samples. In the E-S0s samples the difference is small, suggesting that the lack of dwarf galaxies in CGs might be related to their higher fraction of early-type galaxies (de Lapparent et al. 2003). The values of the parameter M_* for E-S0s and spirals in the isolated sample indicate that bright isolated galaxies are typically spirals. In CGs the values of M_* for E-S0s and spirals are roughly similar: among the brightest CG galaxies ($M < -20$) 7 E/S0 and 5 spirals are found, suggesting that in general luminous galaxies are more likely associated to early-type hosts.

6. Galaxies in CGs and CG Neighbours

It has been shown in Fig. 3 that CG Neighbours display a fraction of early-type galaxies intermediate between CGs and isolated galaxies. It has also been shown that the fraction of luminous galaxies among the E-S0s is somewhat larger in CGs than among their Neighbours. To test whether CG Neighbours present a deficit of bright E-S0s compared to CGs, we next

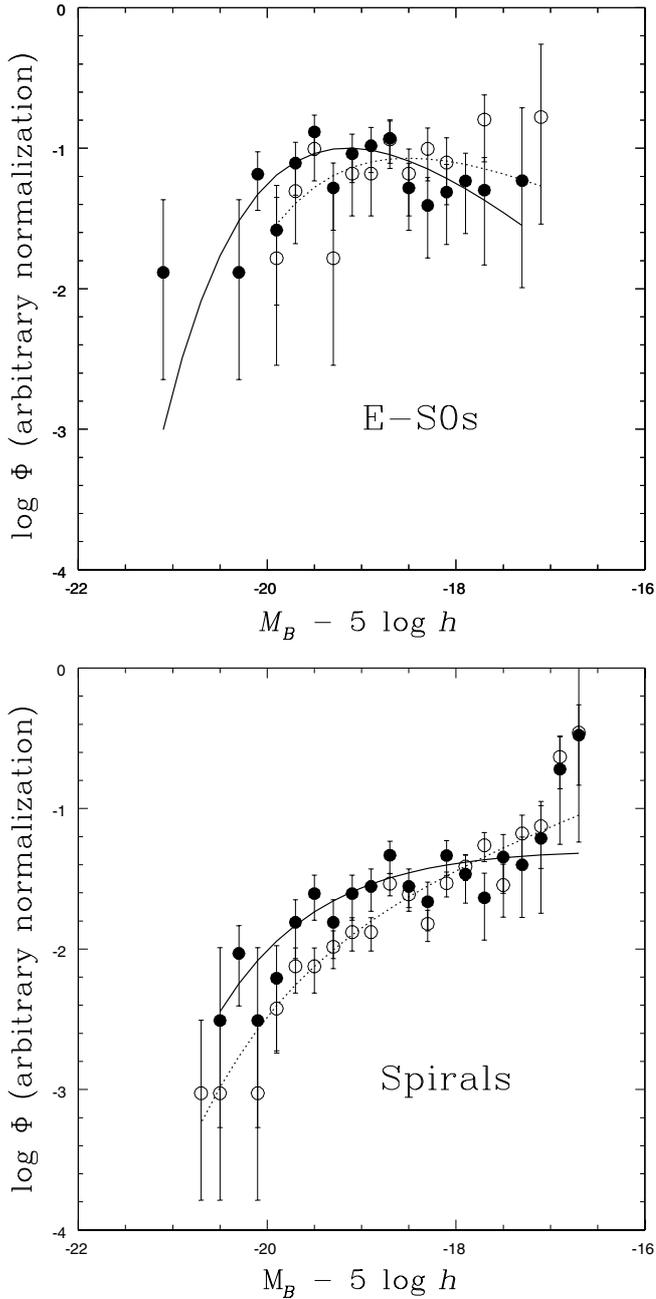


Fig. 4. Luminosity functions for E-S0 and spiral galaxies in the isolated galaxy sample (open circles) and in CGs (filled circles). The points are computed with a modified version of the C-method. 1σ Poissonian uncertainties are plotted. Best fits are shown, derived with the STY method in the case of a single Schechter function. The relative normalization of the CG versus Isolated samples is arbitrary.

compare E-S0s in the Neighbour and CG samples. In Fig. 5 we show confidence ellipses (at 1σ) for the parameters α and M_* for CGs (solid), Neighbours (dashed) and Isolated galaxies (dotted).

Figure 5 shows that LF parameters are strongly dependent on morphological type, regardless of environment. But it also indicates that CGs have fewer low-luminosity E-S0s than their Neighbours, and definitely fewer low-luminosity spirals. Figure 5 suggests that the lack of faint galaxies in CGs is not a

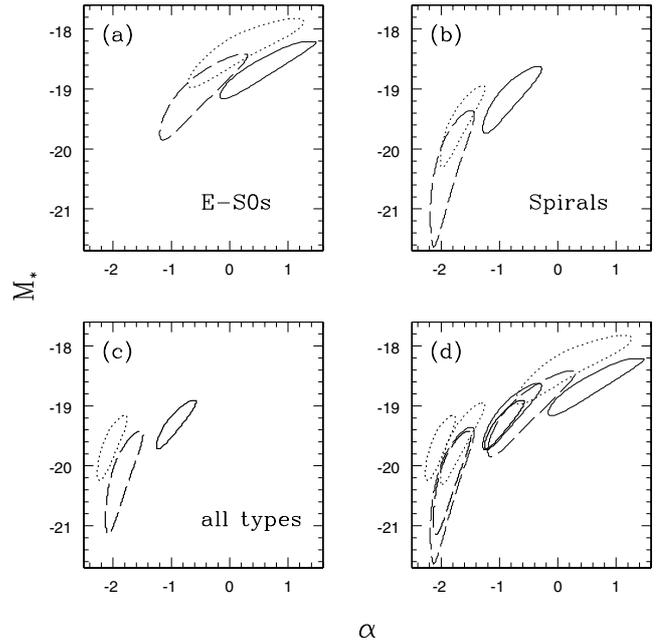


Fig. 5. Confidence ellipses for the parameters α and M_* , for CG galaxies (solid), Neighbours (dashed) and Isolated galaxies (dotted). 1σ contours are plotted. Panels **a)** and **b)** refer to E-S0s and spirals subsamples, panel **c)** to full samples. Panel **d)** shows all samples together. CGs appear to have fewer low-luminosity galaxies than Neighbours and than Isolated galaxies, and no excess of bright galaxies.

characteristic shared by their neighbour galaxies. Hence, it appears that a segregation (Zabludoff & Mulchaey 1998) between bright and faint galaxies occurs, separating CG galaxies from their neighbours.

LF contour plots indicate marginal brighter M_* for Neighbour E-S0s relative to E-S0s in CGs, and significant brighter M_* for Neighbour spirals relative to spirals in CGs. No excess of bright E-S0s is associated to CGs in terms of their M_* parameter. Along with the deficit in dwarf E-S0s, this suggests that CGs include an excess of E-S0s of intermediate luminosity relative to E-S0s in their Neighbour sample. The excess of E-S0s of intermediate luminosity in CGs appears to contradict the finding of Hunsberger et al. (1998) that HCGs show a deficit of intermediate luminous galaxies relative to the field.

The lack of bright spirals in CGs in comparison with spirals in the Neighbour sample confirms that dense CGs are not a preferred environment for bright spirals. Differences between late and early type galaxies are also seen in loose group samples of bright galaxies (Girardi et al. 2003) with early-type galaxies lying closer to the group center than late type galaxies.

Results drawn from CG type specific analysis deserve some caution, however, because real CGs and their Neighbours are never E-S0-only (spiral-only) systems.

7. Dominant CG galaxies, non-dominant CG galaxies and Neighbours

We next investigate whether differences between CG and Neighbour samples are equally likely induced by CGs which are dominated by early-type galaxies and by spirals.

Table 3. Morphological content of E-S0 and Spiral dominated CGs and of their Neighbour samples.

Sample	N_E	N_{S0}	N_{Sa-Sb}	N_{Sc-Sd}	N_{Spir}	Early-type fraction with/without dom.
E-S0 dom. CGs	19	30	14	15	15	53%/27%
E-S0 dom. Neigh.	7	21	23	29	20	28%
Spiral dom. CGs	5	12	28	22	15	21%/33%
Spiral dom. Neigh.	6	23	26	31	24	26%

Table 4. Schechter best fit parameters for CGs with (without) a dominant E-S0 or Spiral and for their Neighbours.

Sample	N_{tot}	M_*	α
CG (dom. E-S0)	110	-19.4	-0.91
CG (dom. Spir.)	92	-19.1	-0.72
CG (without dom. E-S0)	77	-18.5	-1.02
CG (without dom. Spir.)	62	-18.6	-1.07
Neigh (E-S0 dom. CGs)	130	-19.7	-1.59
Neigh (Spir. dom. CGs)	129	-20.7	-2.10

In comparison with the global type-dependent luminosity function, the analysis of luminosity functions according to the morphological type of the dominant member seems more meaningful. Dynamical simulations of similar mass merging spirals lead to ellipticals for binary mergers and for multiple mergers within dense groups (Barnes 1988, 1989). Spiral dominated and E-S0 dominated CGs also display a very different behaviour in the X-ray domain: E-S0s dominated CGs are likely associated to extended X-ray emission (Mulchaey et al. 2003) and E-S0 dominated CGs might constitute an artificial subsample of E-S0 dominated loose groups (Zabludoff & Mulchaey 1998; Helsdon & Ponman 2000). At variance with this, it is still uncertain whether spiral dominated (or spiral rich) CGs do exist presenting diffuse X-ray emission (Burstein & Blumenthal 2002; Mulchaey et al. 2003) as AGNs seem to contaminate the X-ray properties of these systems (de Carvalho & Coziol 1999). The one case of an X-ray group with only spiral galaxies is HCG 16, whose X-ray morphology appears clumpy (Dos Santos & Mamon 1999), although this is not evident in recent XMM-Newton data (Belsole et al. 2003).

Out of 69 CGs, we find 33 E-S0 dominated, and 30 Spiral dominated (6 CGs present a dominant member whose morphological type could not be assigned). For comparison, among HCGs (between 2500 and 5500 km s⁻¹) there are 10 Spiral dominated and 8 E-S0 dominated groups. The morphological content of CGs with a dominant E-S0 (Spiral) is listed in Table 3, along with the morphological content of their Neighbours. In Table 4, we list the best fit STY parameters for these sample. The fraction of early-type galaxies is 53% among E-S0s dominated CGs, while being 21% among Spiral dominated CGs. The early-type fraction in E-S0 dominated and Spiral dominated CGs are \approx typical of groups and of the field (Bahcall 1999), which could be used to argue that only CGs with a dominant early-type galaxy are dense and physical (e.g. mergers should build up the early-type fraction). However, when dominant galaxies are excluded from the computation the

fraction of early-type galaxies in the two samples becomes similar (27% in E-S0 dominated and 33% in Spiral dominated). This could imply that densities in systems with a dominant E-S0 and a dominant Spiral are similar and that both type of systems are physical. Alternatively, assuming only E-S0 dominated CGs are physical, the result might suggest no global morphology-density relation to hold in CGs, where the morphology of the dominant galaxy alone traces the real underlying potential.

The early-type fraction in samples of Neighbours of E-S0 and Spiral dominated CGs are similar (see Table 3) and it is noteworthy that the early-type fraction in both Neighbour samples tend to be comparable to fractions derived for the non-dominant CG population. This may imply that, for small groups, the characteristics of the brightest member are possibly a more fundamental parameter than general CG properties such as the total fraction of early-type (or late-type) galaxies, or the velocity dispersion (Zabludoff & Mulchaey 1998; Helsdon & Ponman 2003a). Whether (and how many) CGs exist in which all members have their morphology modified by a locally dense environment remains an open question which could be checked investigating CG samples selected according to different criteria (Prandoni et al. 1994; Iovino 2002; Barton et al. 1996; Giuricin et al. 2000; Zandivarez et al. 2003; Lee et al. 2003).

Figure 6 shows confidence ellipses for the parameters α and M_* for CGs with a dominant E-S0 (solid) and a dominant Spiral (dotted). The parameters are the same for E-S0s dominated and Spiral dominated CGs. E-S0 and Spiral dominated CGs present similar numbers of bright and faint galaxies and they both appear to lack faint galaxies relative to isolated galaxies, which display a much steeper faint-end LF slope. As expected, the exclusion of dominant members (light contours) moves the ellipses towards less luminous M_* and steeper faint-end slopes; but again, no difference is found between LF parameters of Spiral and E-S0 dominated CGs.

In Fig. 6 we have also plotted the contour plots of Neighbours of E-S0s dominated CGs (short dashed) and Spiral dominated CGs (long dashed). Neighbours of Spiral dominated CGs appear rich in faint and bright galaxies in comparison with Spiral dominated CGs. E-S0 dominated CGs have Neighbours which are moderately richer in faint and in bright galaxies. The presence of many luminous (massive) galaxies among CG Neighbours might indicate that dynamical friction has not operated efficiently in bringing bright galaxies into the center of a large group. Or, that bright Neighbours have an initial position so distant from the group centre that they had not enough time to decay by dynamical friction to the core of the group.

Table 5. Tremaine-Richstone statistic for brightest CG galaxies.

Sample	N	$\langle M_1 - M_2 \rangle$	$\sigma(M_1)$	t_1	t_1^{random}	$P(t_1^{\text{random}} < t_1)$
CGs (all)	69	0.71	0.60	0.85	0.90 ± 0.10	32.3%
CGs E-S0. dom.	33	0.78	0.52	0.67	0.90 ± 0.11	0.6%
CGs Spir. dom.	30	0.72	0.57	0.80	0.88 ± 0.11	20.6%

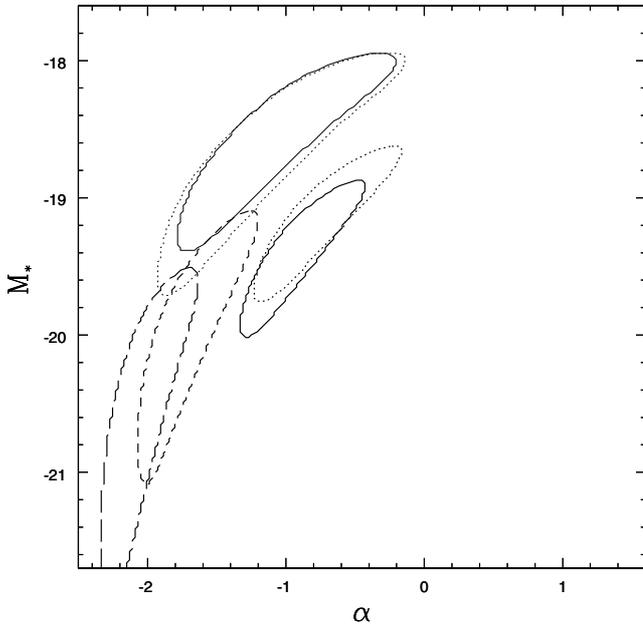


Fig. 6. Confidence ellipses for the parameters α and M_* for E-S0 dominated CGs (solid) and Spiral dominated CGs (dotted). Heavy contours are for the whole samples, light contours for CGs without their dominant members. 1σ contours are plotted. Confidence ellipses for neighbours of CGs with a dominant E-S0 (short dashed) and a dominant Spiral (long dashed) are also shown. E-S0 dominated CGs appear to have fewer low-luminosity galaxies than their Neighbours. Spiral dominated CGs appear to have significantly fewer dwarfs and bright galaxies in comparison with their Neighbours.

Figures 5 and 6 indicate that CGs are poor in dwarfs relative to their Neighbours when applying a morphological segregation as well as when separating samples according to the morphological type of the CG dominant galaxy. More significant differences between CGs and their Neighbours emerge when the comparison involves spirals or Spiral dominated CGs, but spirals are more numerous in both samples and small number statistics might affect results concerning the early-type galaxy population.

8. Spiral and E-S0 dominated CGs

Both bright spirals and bright E-S0s are found in optically selected CGs. This agrees with the results by Norberg et al. (2002) indicating that (below L_*) both early and late types have approximately the same dependence of clustering strength on luminosity and with the finding by Cappi et al. (2003) that (very) bright spirals are often the brightest members of systems which escape standard group finding methods. Bright E-S0s and bright spirals in groups actually display different X-ray

emission properties and we therefore next investigate whether an analogous difference might emerge from the analysis of optical data alone.

We have applied the Tremaine-Richstone statistic (1977) to see if the brightest CG members are indeed anomalous members. The test is based on two parameters t_1 and t_2 defined by

$$t_1 = \frac{\sigma(M_1)}{\langle M_2 - M_1 \rangle}$$

$$t_2 = \frac{\sigma(M_2 - M_1)}{(0.677)^{1/2} \langle M_2 - M_1 \rangle}$$

where $\sigma(M_1)$ and $\sigma(M_2 - M_1)$ are the standard deviations of the absolute magnitude M_1 and of the difference in absolute magnitude ($M_2 - M_1$). Values of t_1 and t_2 below 1 indicate that the first-ranked group galaxies are abnormally bright. Table 5 lists the value for t_1 (which appears to be a better estimator than the parameter t_2) for the whole sample of brightest CG galaxies and for the E-S0 and spiral dominated subsamples. Given the small number of galaxies in the CGs and the small number of CGs in the sample the T-R statistic t_1 is biased to low values (Mamon 1987). Monte-Carlo simulations (1000 random trials) for a given slope of the Schechter luminosity function show that the expected value of t_1 is ≈ 0.90 in all samples (Mamon, priv. comm.). So the distribution of $(M_1 - M_2)$ from the galaxies in the E-S0 dominated CGs has less than 1% probability of being randomly drawn from a parent LF, implying that the brightest group member is abnormally luminous. On the contrary, the dominant Spirals are not abnormally luminous. This is just a tentative result that should be checked on larger and complete CG samples. We stress that the significantly low t_1 for the E-S0 sample is partially caused by a fairly low (but not significant) $\sigma(M_1)$.

Bright spirals in CGs appear therefore different compared to bright E-S0s in CGs. Menon & Hickson (1985) were the first to point out that dominant elliptical galaxies in HCGs were special: indeed they found that among HCG galaxies that were radio continuum emitters, those that were ellipticals were always the dominant group member, while those that were spirals had random group rank. Dominant Spirals and dominant E-S0s possibly show a different behaviour also in the $(m_1 - m_f)$ parameter (Δmag between the brightest and the faintest CG galaxy) distribution. Figure 7 shows the absolute magnitude of the brightest (triangles) and the faintest (squares) member of each CG, plotted against radial velocity for CGs with a dominant E-S0 and Spiral respectively.

Bright Spiral dominant galaxies are preferentially hosted in nearby CGs, a trend which bright dominant E-S0s do not seem to follow. The statistical significance of the different distribution of $(M_B \leq -19.5)$ dominant E-S0s and dominant Spirals

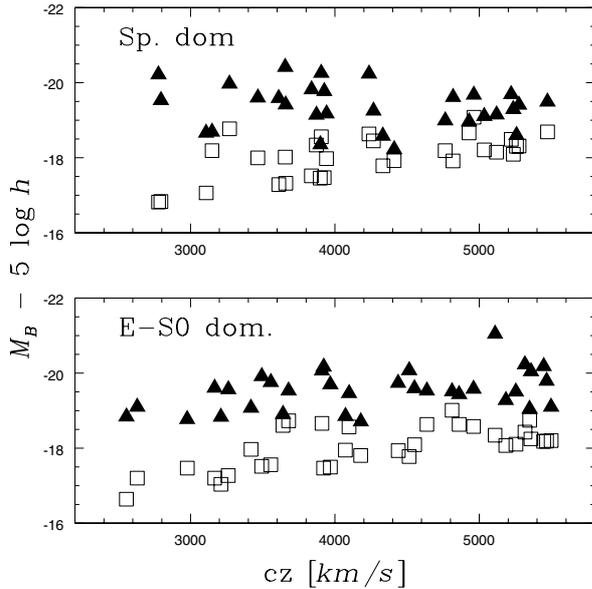


Fig. 7. Absolute magnitude of the brightest (triangles) and faintest (empty squares) member of each CG as a function of radial velocity for CGs whose dominant galaxy is a Spiral (*upper panel*) and an E-S0 (*lower panel*) respectively.

in this diagram emerges when comparing the different fractions of Spiral dominant galaxies in the $cz \leq 4000$ and the $cz > 4000 \text{ km s}^{-1}$ subsamples. Below 4000 km s^{-1} 17 bright dominant galaxies are seen, with 8 E-S0s and 9 Spirals. Above 4000 km s^{-1} 16 bright dominant galaxies are seen, 12 E-S0s and 4 Spirals. The most nearby dominant Spirals typically present a larger gap between the brightest and the faintest CG member than dominant E-S0s.

The MW+LMC+SMC system is actually compact, and it would pass the flux limit if SMC did (which for $M_B(\text{SMC}) = -16$ translates to $cz < 2000 \text{ km s}^{-1}$). Any CG selection criterion imposing an upper limit on the difference in magnitude between the brightest and the faintest group galaxy will certainly be biased against systems including bright spirals. And indeed, of the 10 dominant Spirals in Hickson’s sample (in the $2500\text{--}5500 \text{ km s}^{-1}$ range) only one (HCG 90) is below 4000 km s^{-1} , while 4 (out of 8) dominant E-S0s are.

Figure 7 also shows that faint-galaxy-only CGs are rare. Bright galaxies ($M_B \lesssim -19$) are nearly always included in CGs whatever the magnitude of the faintest galaxies seen (ranging from ≈ -17 at $cz = 3000 \text{ km s}^{-1}$ to ≈ -18 at $cz = 5000 \text{ km s}^{-1}$).

9. First-ranked Spirals and E-S0s: Differences in large scale properties

We have shown that in UZC-CGs, dominant E-S0s are possibly anomalous CG members, while spirals do not share this characteristic. We have also shown that Spiral dominated CGs present a neighbourhood rich in luminous galaxies while in E-S0 dominated CGs and their Neighbour sample the values of M_* are similar. These trends suggest that E-S0 dominant galaxies are more likely than dominant Spirals to be more luminous than their Neighbours. To test this hypothesis we next compare each CG with its own Neighbours. We find that among

the 30 dominant Spirals, 14 ($\approx 50\%$) display a more luminous neighbour, while among the 33 dominant early-type galaxies, only 8 (25%) do so. It is noteworthy that these 8 galaxies all are S0s, whose more luminous companions are generally spirals. We thus find that all 14 dominant Ellipticals in the CG sample are the (optically) brightest sources and possibly the center of the potential well, in a region $2 h^{-1} \text{ Mpc}$ across.

This indicates that dominant Ellipticals in CGs are typically the dominant member of a much larger system, while the same is true for only roughly half of the dominant Spirals and S0s. That CGs and loose groups with a dominant Elliptical and diffuse X-ray emission display similar X-ray properties (Helsdon & Ponman 2000) can be used to indirectly support our result. That only half of the S0s are dominant galaxies in large groups might be attributed to morphological misclassification (Andreon 1998), or could imply that the evolution of Ellipticals and S0s is differently linked to their large scale properties.

Concerning dominant Spirals with a more luminous companion on large scale (in principle similar to MW+M31), their potential well is possibly rather shallow, which could justify why they lack a diffuse X-ray halo (Mulchaey et al. 2003). HI observations (at the GMRT) will tell whether the 16 dominant Spirals with no more luminous companion present a large unperturbed cold gas disk rather than a truncated one, thereby discriminating between projected and interacting spirals.

In Fig. 8, we show another result which is consistent with the picture in which E-S0 dominant galaxies are formed in denser and more massive groups, while dominant spirals are formed in lower mass, less dense environments. Figure 8 shows that the 25 E-S0s displaying no more luminous neighbour present a correlation between the density of the large scale environment and both, the luminosity of the galaxy and the difference between the magnitude of the first and second ranked galaxy. Spearman-rank test coefficients indicate that correlations exist for E-S0s ($\rho = 0.50$ in M_B vs. Neighbours and $\rho = 0.51$ in Δmag_{12} vs. Neighbours) but not for spirals (0.05 and 0.17). For E-S0s, the correlations are 99% significant.

This suggests that the formation/evolution of dominant E-S0s and the properties of their large scale environment are possibly linked. Luminous passive galaxies in the 2dF (Colless et al. 2003) have already been shown (Kelm et al. 2003b) to display an excess of large scale neighbours compared to luminous emission-line galaxies. The location of CG dominant E-S0s at the centre of their systems to a much greater extent than implied by our CG selection criteria is in agreement with observations in the X-ray domain, showing that the center of diffuse X-ray emission is nearly always overlapping the optically brightest (early-type) galaxy of an underlying group. The relation between the large scale galaxy density and the difference between the first and second ranked galaxy could further indicate that, in accordance with predictions, dynamical friction has more efficiently operated in systems with a larger potential, where the fraction of group mass associated with individual galaxies is low (Zabludoff & Mulchaey 1998). This tentative result possibly extends to groups Sandage’s (1976) conclusion that the luminosity of brightest cluster galaxies is determined by some special processes. Whether the formation of a group dominant

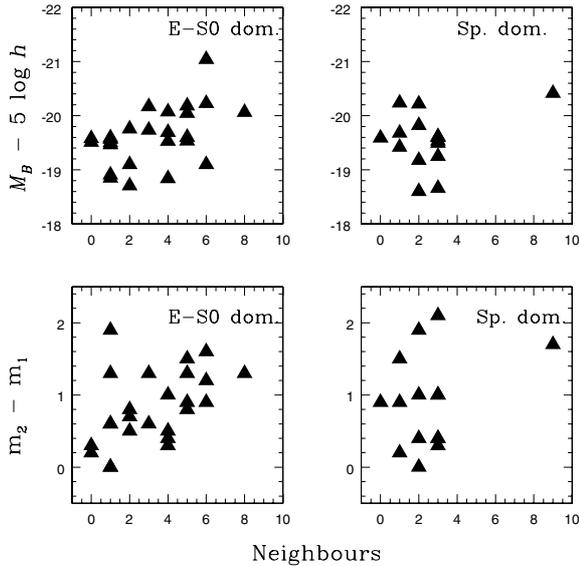


Fig. 8. Absolute magnitude of CG dominant galaxies (*upper panels*) as a function of the large scale density (number of Neighbours) for E-S0s (*left*) and Spirals (*right*) with no more luminous neighbour. The lower panel show the difference in magnitude ($m_2 - m_1$) between the first and the second ranked galaxy vs. large scale density.

Elliptical occurs during the formation of the group potential or later, when progenitor galaxies merge, is still an open question.

No relation exists between the number of CG Neighbours and the luminosity of CG dominant Spirals, which might suggest that luminous spirals in CGs are the dominant member of a small system whose mass is mainly associated with the dominant member itself rather than with a massive halo. Therefore it seems rather unlikely for these systems to evolve directly into an E-S0 dominated CG. The alternative scenario predicts luminous spirals in CGs are contaminated by accordant redshift projections. The search within $\pm 1000 \text{ km s}^{-1}$ from the CG center translate to a search within $\pm 10 h^{-1} \text{ Mpc}$, so that truly isolated galaxies, aligned along the line of sight of the CG will end up in the “wrong” sample. Contamination is stronger in a filamentary universe (Hernquist et al. 1995). Contamination of Spiral dominated CGs by Isolated galaxies could explain why HCGs and UZC-CGs, which should be triggered by interactions, do not display enhanced IR temperature nor IR luminosity (Zepf 1993; Verdes-Montenegro et al. 1998; Kelm et al. 2003a).

10. Conclusions

The morphological content and the luminosity of CGs and Isolated galaxies have been compared. Galaxies in the samples are selected from the same flux limited ($m_B \leq 15.5$) catalogue and within the same redshift range ($2500\text{--}5500 \text{ km s}^{-1}$). We find that galaxies in CGs display an excess of early-type galaxies and a lack of faint galaxies compared to isolated galaxies. It is mainly the spiral CG population that appears poor in faint galaxies suggesting that the lack of dwarf galaxies in CGs relative to Isolated galaxies might be related to their high content in ellipticals.

We have also compared CG galaxies with their Neighbours to explore whether CGs are compatible with being real

condensations rather than temporary non physical projections within loose groups. CGs include more early-type galaxies than their Neighbours and they also have fewer low luminosity and high luminosity galaxies. The lack in dwarfs also emerges when E-S0s in CGs are compared with E-S0s in the Neighbour sample indicating that the lack of dwarfs in CGs is not solely induced by a high content in E-S0. The lack of bright galaxies in CGs in comparison with their Neighbours is due to the presence of many bright spirals among Neighbours.

In our sample, Spirals and E-S0s are equally likely to be first-ranked CG galaxies. It is interesting that the fraction of early type galaxies in E-S0 dominated and Spiral dominated CGs tends to become the same ($\sim 30\%$) when CG dominant galaxies are excluded from computation.

Comparing the 33 CGs with an E-S0 dominant galaxy with their Neighbours (and the 30 CG with a Spiral dominant galaxy with their Neighbours) confirms a lack of low-luminosity galaxies in CGs. Spiral dominated CGs appear to be deficient in bright members relative to their Neighbours and the Tremaine-Richstone test indicates that dominant Spirals are not anomalous CG members. E-S0s in optically selected CGs are however anomalous luminous members, which might relate with the observation that the brightest member in X-ray emitting groups is an elliptical and that this elliptical is special (Helsdon et al. 2001; Helsdon & Ponman 2003b).

All 14 dominant Ellipticals in CGs are the brightest galaxies in a region of redshift space $2 h^{-1} \text{ Mpc}$ across, while the same is true for only half of the dominant Spirals and dominant S0s. When considering only CGs whose dominant member is the brightest galaxy in a $1 h^{-1} \text{ Mpc}$ projected radius region (25 E-S0s and 16 Spirals) we also find a relation to link the number of neighbours of dominant E-S0 to 1) the luminosity of the galaxy and 2) the difference in magnitude between the first and second ranked galaxy. No such relation holds for dominant spirals.

First ranked ellipticals appear to gain luminosity as they gain large scale companions implying a direct causal relationship between the group formation process and the formation of the first ranked galaxy therein. No relation exists between the luminosity of first ranked spirals and the number of their large scale neighbours suggesting that the formation of a bright spiral at the center of a large potential well is unlikely. The presence of many neighbours around dominant ellipticals is possibly accompanied by large quantities of infalling gas, implying that X-ray emission is likely associated to elliptical-dominated groups (Zabludoff & Mulchaey 1998; Mulchaey et al. 2003).

In summary a clear distinction appears between CGs with a dominant E-S0 and CGs with a dominant Spiral. The former closely resemble small clusters. The latter are likely systems of 1 giant + several faint galaxies, often presenting a bright companion within a $1 h^{-1} \text{ Mpc}$ distance, a configuration remindful of our Local Group. The above results are based on a small sample, and are just tentative. But they all support a scenario in which the formation of bright Ellipticals (but not of bright spirals) and the presence of large group-scale potentials are linked. And dominant CG Ellipticals could just represent a secondary outcome during the process of formation of group size systems.

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