Early versus late type galaxies in compact groups

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We find a strong correlation between the effective radius of the largest early-type galaxies in compact groups of galaxies and the velocity dispersion of the groups. The lack of a similar correlation for late type galaxies is supportive of the so called second generation merging scenario which predicts that ellipticals should dominate the internal dynamics of the groups, while late-type galaxies are mainly recent interlopers which are still in an early stage of interaction with the group potential.

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1. Introduction

Compact groups of galaxies (hereafter CGs) have low velocity dispersions (compared to clusters), small size and high spatial density and therefore short crossing and coalescence lifetimes (in the average, \( \tau_{cr} \sim 0.016 \ T_o \) where \( \tau_{cr} \) and \( T_o \) are the crossing and the Hubble time, respectively; Hickson et al. 1992). In the simple assumption that luminous matter is a good tracer of the group potential, these properties call for a high merging rate and turn CGs into putative factories of elliptical galaxies. Short coalescence lifetimes, however, hit against several observational evidences: the relatively large number of CGs observed in the nearby universe leads to an expected number of ongoing or recent mergers which is one order of magnitude higher than what it is actually observed; ellipticals in CGs are on the average very luminous objects (28\% of them is more luminous than M87, Mendes de Oliveira and Hickson 1991) but, in a given group - the sum of the luminosities of the members is too high compared to that of luminous ellipticals; most ellipticals in CGs belong to the so called "bright" family (Capaccioli et al. 1992) which is formed by highly evolved objects which have experienced at least one major (or several minor) merging events (Caon et al. 1994), a fact which seems to be contradicted by the small fraction of E-type galaxies (7\% of the total sample) having the abnormally blue colors which are predicted for recent (age < 5 \ \cdot 10^8 \ years, Zepf et al. 1991) mergers. It needs to be stressed, however, that using the same data but different assumptions, Zepf (1993) and Hickson (1997a) derive completely different estimates for the merging rate (7\% and 23\%, respectively). The latter value is in better agreement with the fact that in several nearby groups faint luminous envelopes encompassing the whole group and thus suggestive of an ongoing merger have been recently detected (Ribeiro et al. 1996, Paramo and Vilchez 1997, Longo et al. in preparation).

These seemingly conflicting results led many authors to suggest that CGs could actually be physically unbound systems: either chance alignments of galaxies in the field (Mamon 1987, 1990) or in filaments (Hernquist et al. 1995, Ostriker et al. 1995), or transient configurations within richer and more dispersed groups of galaxies (Di-aferio et al. 1994). All these models, however fail to explain one or more of the observed properties of CGs (cf. Hickson 1997b) such as: the higher than average frequency of interactions (estimates range from 43\% Mendes de Oliveira and Hickson 1994, to \( \sim 60\% \) Rubin et al. 1991); the different morphological composition of CGs with...
respect to the field and to clusters; the recent X rays surveys which detect diffuse X-ray emission in most groups (e.g. Pildis et al. 1995, Saracco and Ciliegi 1995, Ebeling et al. 1994) with total X-ray luminosity correlating with both the hot gas temperature and the velocity dispersion of the groups (Ponman et al. 1996). A possible way out from this sort of "stall" is the so called "second generation merger scenario" (hereafter SGS) proposed by Governato et al. (1996). Since most groups are found to be not isolated but contained inside larger structures such as loose (or poor) groups and clusters (Vennik et al. 1993), the CGs we see today may be just aggregating from the environment and beginning to interact. The first generation of these groups was destroyed by rapid merging, stripping of dark-matter haloes and subsequent production of a number of early merger remnants which would appear today as early-type galaxies (overluminous and belonging to the "bright" family as it is actually observed) either isolated or in groups (which would explain the concordance of morphological types observed in most groups). These remnants would be surrounded by diffuse haloes both luminous (stripped stars) and dark, and new arrivals would soon begin to interact (high frequency of interaction) but would mostly avoid merging since the collisional cross-sections for individual galaxies are now smaller (Governato et al. 1996). SGS finds also support in the properties of the diffuse X-ray haloes where i) the position angle of the photometric major axis of the central early-type object is aligned to that of the diffuse X halo (Mulchaey and Zabludoff 1997); ii) the position of the dominant early-type galaxies usually coincides with that of the photometric baricenter of the group (as defined in Zabludoff and Mulchaey 1997). In this paper we discuss some additional optical evidences that bright ellipticals and lenticulars largely determine the shape of the galaxy potential as it is predicted by SGS.

The catalogue by Hickson (1982, hereafter HCGs) is so far the most complete, homogeneous and best studied sample of compact groups of galaxies. One of us (AAS) as a part of his Ph.D., has compiled all published photometric (at all wavelengths), morphological and geometrical information on HCG’s in the Hickson’s list, homogenized and reduced (whereas needed) to a standard system. This database will be used in the following discussion and we provide here some information only on the data which are needed for the present work. In what follows, we study the relations between the linear effective radius $R_e$ (for early type objects only), the isophotal diameter for all the objects $D$ and the velocity dispersion $\sigma$ of the groups in the 92 HCGs which have at least three accordant redshift members (Hickson et al. 1992). We rejected from our sample Hickson 54 which is more likely a galaxy shired in pieces rather than a true group (Williams and van Gorkom 1988). Effective radii and morphological types for the early type objects are taken from Bettoni & Fasano (1993), Fasano & Bettoni (1994), Zepf & Whitmore (1993), and were homogenized as in Caon et al. (1994). Among the 91 groups there are 42 for which effective radii for the largest early-type (not necessarily dominant) galaxies (=LEG) are available (H45d was also rejected due to its discordant redshift and H90c is not LEG in its group, Longo et al. in preparation). Isophotal diameters ($\mu_B = 24.5$ mag arcsec$^{-2}$) and asymptotic magnitudes corrected for internal and external extinction for all the galaxies in the 91 HCGs were taken from Hickson et al. (1989). Radial velocity dispersions and average redshifts for the groups are from Hickson (1994). Both effective radii and isophotal diameters were converted in linear sizes by assuming $H_o = 100$ km s$^{-1}$ Mpc$^{-1}$. Our final sample consisted of 91 HCGs (complete sample), 42 of which hosting at least one elliptical galaxy (LEG sample).

2. Discussion

As already mentioned before, one obvious implication of the SGS is the existence of a dichotomy of properties between early and late type objects in the groups: most Es in CGs must be highly evolved objects (i.e. relics from first generation mergers) shaping the potential well of the groups, while late type members are just now infalling, are not yet virialized and do not affect much the dynamics of the groups. By comparing the properties of galaxies in the complete sample and in the LEG sample we do not find any systematic differences between the average velocity dispersions for the early and late type objects. The absence of a systematic difference between the two groups, however, is likely due to the fact that groups have different total luminosities (hence masses) and the distances from the centers of the groups of individual galaxies should be rescaled. This normalization, however is prevented by the small number statistics.

A possible evidence in favor of SGS comes instead from the linear sizes of the brightest galaxies.

In Fig.1 we plot the Log of the effective radii of the early-type objects in our LEG sample versus the velocity dispersion of the group; ellipticals are shown as filled symbols and lenticulars as asterisks; symbols encircled denote that the object belongs to an E-type group (i.e. early type dominated group, Hickson 1982), while symbols surrounded by a square mark objects belonging to S-type (late type dominated) groups. The existence of a strong correlation (confidence level larger than 99.5 %) between the two quantities is apparent and a simple bisector fit gives the following equation:
Figure 1: Plot of the log of the linear effective radius for the galaxies in the LEG sample versus the velocity dispersion of the group. Symbols are as follows: filled = ellipticals, asterisks = lenticulars. Encircled and “in squared” symbols denote galaxies which belong to E-type and S-type groups, respectively. The solid line gives the best fit.

\[ \log \sigma = 0.97(\pm 0.12) \log R_e + 1.65(\pm 0.10) \]  

The existence of a correlation between an individual \((R_e)\) and a global \((\sigma)\) property confirms that at least the groups in the LEG sample are physically bound systems. When coupled to the well known correlation between \(\log R_e\) and the total luminosity (hence the mass) for early type galaxies (Hamabe and Kormendy 1987, Capaccioli et al. 1992) Eq. 1 implies that the gravity potential of the groups in the LEG sample is dominated by the early type objects. For what late-type objects were concerned, since effective radii are poorly defined, we preferred to use isophotal diameters which are expected to be shortened by the effects of tidal stripping which truncates the disks of late type galaxies which move into high spatial density environments (e.g. Boselli et al. 1996).

Previous attempts to detect such an effect in CGs were made by Hickson et al. (1977), who using a non-homogeneous sample of 18 groups measured on POSS-I plates, found a correlation between the size of the largest galaxies and the mean separation of galaxies within the group; by Whitmore (1990, 1992) who found a weak correlation between the size of the largest galaxy and the spatial number density of the group, and by Maia and da Costa (1990) who also found a correlation between size and spatial density but explained it as partially due to distance dependent selection effects. In our sample we do not find any correlation between \(\sigma\) and the logarithm of the linear isophotal diameter \(D\) for late type galaxies in the complete sample (see Fig.2).

These different behaviors of early and late type objects can have different explanations. One could argue that spiral dominated groups are more likely than early-type ones to be chance alignments in filaments or clusters (e.g. Hernquist et al. 1995, Pildis 1995). This, however, is not the case since we do not find any correlation between \(\log D\) and \(\log \sigma\) even if we restrict our late type sample to the 14 which belong to groups in the LEG sample (Fig.3). A second possible explanation is that isophotal diameters are not as good “physical” tracers of the evolutionary history as the effective radii are for the early type objects but this objection can be ruled out on the basis that almost all late type galaxies in CGs show signs of ongoing strong interactions and, therefore, should be truncated by tidal stripping. A third, more likely explanation comes in a rather straightforward way from the SGS: late type objects are mainly just now infalling and are therefore poor tracers of the gravity potential.

One more word of caution: when dealing with HCGs, distance dependent selection effect need always to be checked (Whitmore 1990). However: 1) if we take into account such correlation and detrend our data for the
distance effects we still find a strong correlation (confidence level larger than 99.5%); ii) distance dependent selection effects should work in the same way on both effective radii and isophotal diameters and we do not find any correlation for the 14 late type galaxies in the LEG sample. Since this may be related to the use of $D$ instead of $R_e$, we checked the dependence of $\log(D)-\log(\sigma)$ for the LEG finding a correlation similar to that in Eq1.

Furthermore, the link between an individual property of the LEG (namely the effective radius) which is related to the total luminosity and hence the mass of the galaxy (Caon et al. 1994) and the velocity dispersion of the groups which is instead a parameter related to the total mass of the groups, confirms both the physical reality of these groups and the fact that ellipticals dominate the dynamics of the groups.

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