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HICKSON COMPACT GROUPS: THE CORES OF ELONGATED LOOSE GROUPS

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RESUMEN

Se presenta evidencia la cual indica que casi todos los HCGs están asociados dinámicamente con grupos de galaxias dispersos, generalmente alargados, y que son los núcleos compactos de estos últimos. Para muchos de estos grupos dispersos, el ángulo entre la dirección de elongamiento y la línea de visión es cercano a 45°, lo cual ya había sido encontrado en investigaciones anteriores. Los HCGs tienen probables tiempos de vida más largos de los que se deducen de simulaciones de N-cuerpos y, por lo tanto, son configuraciones más estables. Los miembros más alejados de los HCGs (los miembros de los grupos dispersos) están gravitacionalmente ligados con ellos.

ABSTRACT

Evidence is presented which indicates that almost all HCGs are dynamically associated with generally elongated loose groups of galaxies, and are compact cores of the latter. Most of those loose groups, the direction of elongation of which lies at angles close to 45° with the line of sight, were revealed by previous investigations.

Hence, HCGs have, probably, longer life-times than it has been deduced from N-body simulations, and thus are more stable configurations. The remote members of HCGs (the members of loose groups) are gravitationally bound with them.

Key Words: **GALAXIES: CLUSTERS: GENERAL — GALAXIES: INTERACTIONS — GALAXIES: KINEMATICS AND DYNAMICS**

1. INTRODUCTION

The physical nature of compact groups (CG)[1] of galaxies and their evolution have attracted much attention during recent years. The very existence of CGs is puzzling. According to N-body simulations the merging activity begins after a small number of crossing times. The members of CGs should finally merge to one giant elliptical galaxy on a time scale of $\sim 10^8 - 10^9$ years (Barnes 1985, 1989, 1990; Mamon 1986). However, a surprisingly large spiral fraction and an unexpected lack of blue elliptical galaxies were found, which means that the present merging rate in HCGs is lower than is estimated from the observed crossing times (Zepf & Whitmore 1991; Zepf 1993; Pildis, Bregman, & Schombert 1995). Moreover, Menon (1995) mentioned that if interactions play a major role in the origin of luminous radio sources, then the lack of luminous radio sources in HCGs, which would have undergone many interactions in their lifetime, is indeed a puzzle. Sulentic & de Mello Rabaça (1993) and Hickson et al. (1989) mentioned a curious absence of strong far-infrared sources in HCGs. Therefore, the very existence of the best studied sample of CGs, HCGs, was questioned. Mamon (1986, 1995) and Walke & Mamon

[1]Two large lists of CGs were published in recent years: Shakhbazian Compact Groups (ShCG) (Shakhbazian 1973; Baier, & Tiersch 1979, and references therein), and Hickson Compact Groups (HCGs) (Hickson 1982; Hickson, Kindl, & Auman 1989).

(1989) suggested that HCGs are not real physical groups, but chance alignments of galaxies in loose groups (LG). Hernquist, Katz, & Weinberg (1995) and Ostriker, Lubin, & Hernquist (1995) put forward another version: CGs are filaments seen end-on. Arguments in favor of HCGs being real physical groups were presented by Hickson & Rood (1988), Mendes de Oliveira & Giraud (1994), Mendes de Oliveira (1995), Ponman et al. (1996).

There is another strong argument for the reality of compact groups. Oleak et al. (1995, 1998) investigated the average "flatness" of nearly 300 compact galaxy groups of the Shakhbazian survey (which are obviously of the same nature as the HCGs) and found that the distribution of the axial ratios of these groups could be represented solely by a population of prolate spheroids with low intrinsic axial ratios, i.e., these groups have a cigar-like shape. This result provides confirmation that these groups are real physical entities. Earlier Hickson et al. (1984), Malykh & Orlov (1986) showed that HCGs have the shape of a prolate spheroid.

Tovmassian, Martínez, & Tiersch (1999, hereafter TMT) provided new arguments in favor of the physical reality of CGs. They found that the radial velocity dispersion (RVD) of groups is correlated with their elongation, characterized by the ratio b/a, where b is the width of a group, and a is its length. This correlation shows that galaxies in CGs are gravitationally bound. Elongated, chain-like groups are oriented nearly perpendicular to the line of sight, and we measure smaller components of velocities of member galaxies directed along the chain. Therefore, RVDs of such groups are small. More round groups are oriented close to the line of sight. The velocities of the observed movements within the group are large, and consequently RVDs are large as well.

Diaferio, Geller, & Ramella (1994, 1995) and Governato, Tozzy, & Cavaliere (1996) suggested that CGs are being formed within denser environment of LGs. This scenario seems plausible since, as was shown by Rose (1977), Sulentic (1987), Rood & Williams (1989, hereafter RW) and Ramella et al. (1994, hereafter RDGH), some HCGs are associated with LGs of galaxies.

On the basis of the detailed structural and dynamical study of 17 HCGs Ribeiro et al. (1998) suggested that the Hickson sample is composed of groups which are at different dynamical stages of evolution: LGs, core+halo systems, and CGs.

Consideration of redshifts of galaxies in the environment of some HCGs and poor groups of galaxies showed that the RVDs of the faint galaxies with accordant redshifts in the environment of these groups are also correlated with the elongation of the whole system, as is the case of the CGs (Tovmassian & Chavushyan 2000). It means that the fainter members of LGs are distributed along the elongation determined by the principal members of CGs.

In this paper we reconsider the problem of the association of HCGs with LGs, and present evidence which favors the idea that galaxies in LGs in the environment of HCGs are not just field galaxies, gravitationally unrelated to corresponding groups, but are *physically associated with them.*

2. DISCUSSION

If LG galaxies around CGs are just field galaxies, which do not have any dynamical association with CGs, then they should obviously be randomly distributed around the latter. If members of LGs are, however, dynamically associated with CGs, then one may expect a certain correlation of the number of the detected LGs with the ratio b/a, which characterizes the CG elongation. In the discussion below we take into account that HCGs have cigar-like shapes, and that member galaxies in them move along the elongation of the group (TMT).

To see whether there is a dynamical association of HCGs with galaxies in their neighborhood, we used two lists of LGs around HCGs compiled by RW and RDGH.

RW looked for LGs of galaxies in an area within ten HCG radius. They assumed that there is an extra number of neighbors in comparison with the density of field galaxies in the neighborhood of a HCG if the ratio of the signal to Poisson noise, $S/N = (N_{observed} - N_{field})/(N_{field})^{1/2} > 1$. For pure Poisson noise from superposition of field galaxies, S/N has an average of 0 and a standard deviation of 1. Groups with $S/N > 1$ were assumed to have statistically detected neighborhood.

RDGH examined the relationship between HCGs and their neighborhoods in the area with a characteristic radius 1.5 h^{-1}, and within a velocity range of 1500 km s^{-1} from the median radial velocity of the group. Two areas, within and outside of the complete CfA survey, were searched. Below we consider the data related to the region of the complete CfA survey. RDGH assumed that the presence of LG is certain, if $N_n \gg N_{int}$, where N_n is the number of neighbors in the redshift space, and N_{int} is the number of expected interlopers. It should be mentioned that RDGH found a relatively larger number of LGs than RW. Apparently, the use of the redshift space helps to detect more galaxies associated with CGs.

TMT showed that member galaxies in HCGs are generally moving along elongated orbits. If galaxies of the LG are dynamically associated with corresponding CG then they should move in analogous orbits with the same orientations. RW looked for the neighbor galaxies in areas within ten times the radius of HCG's. In the case of a chain-like HCG which is oriented almost perpendicular to the line of sight, i.e., when its b/a is close to zero, the probable members of a LG located farther than ten CG radii would be out of the searched area, and apparently would not be detected. The relative number of such HCGs with associated LGs would be small. If the angle θ between the direction of the orientation of the CG and the line of sight decreases, then the ten CG radii on the sky would correspond to a larger linear distance from the CG in space. At angles θ of 45° to 60° the searched distance from the group is 1.4–2 times larger. Hence, galaxies located at larger linear distances from CG would be found. The number of detected distant members of the HCG, and hence the relative number of detected LGs, should be large at angles θ close to 45°, i.e., at values of b/a close to 0.7. However, when the orientation of the HCG approaches $\sim 45°$, some of its distant members would be projected on the CG itself, and would be considered as proper members. Therefore, the relative number of CGs with detected LGs should decrease. Thus, the largest value of the relative number of detected LGs would be reached at values of b/a somewhat less than 0.7. When the angle θ approaches zero, i.e., the orientation of a CG approaches the line of sight, almost all distant galaxies physically associated with it would be projected on it. Then the group may not be recognized as CG. As a result, some CGs which are dynamically associated with LGs would not be detected. Hence, the relative number of round HCGs with associated LGs would be small.

A similar variation of the number of the LGs found around CGs should be observed for the RDGH sample as well. As in the case of RW sample, some of the LGs around chain-like HCGs, those oriented close to the perpendicular to the line of sight, may not be detected. The same would be true for LGs around almost round groups oriented close to the line of sight. In the latter case the neighbor galaxies of LGs with velocities in excess of the accepted limiting value of ~ 1500 km s^{-1} were not considered as members of CGs. Thus, the relative number of LGs associated with HCGs oriented, as in the case of RW LGs, at angles θ close to $\sim 45°$, would be larger.

Hence, if galaxies of LGs around CGs are really dynamically associated with the latter, then the relative number of detected LGs should be small at small b/a values, should increase with increasing values of b/a until ~ 0.7, and should decrease for higher values of b/a, i.e., the distribution of relative number of LGs around CGs would be similar to a normal distribution. The dependence of the relative numbers of CGs associated with LGs on the value of b/a is presented in Figure 1. The ratios b/a were determined using only accordant redshift members of groups. For the construction of Fig. 1 we used the RW data of 88 accordant redshift HCGs. Three groups out of 92 with $b/a > 0.8$ were deleted from the sample because of poor statistics in this range. The group HCG 54 was omitted, since it is considered as a single galaxy (Mendes de Oliveira & Hickson 1994). The RDGH sample contains 38 HCGs located in the region of the complete CfA survey. Twenty nine RDGH groups have associated LGs. We excluded the group HCG 54 here too. Because of the smaller number of groups in this case, we considered the relative numbers of HCGs with associated LGs in bins of the b/a values twice as large.

There are 29 common CGs and only 14 LGs in the two lists used. Thus, the LGs samples of RW and RDGH are practically independent.

Fig. 1 shows that the observed regular variation of the relative number of HCGs with associated LGs for both samples is just that what we expected. The RW distribution fits a normal distribution with a mean value $\mu = 0.49 \pm 0.18$, and the RDGH sample fits a normal distribution with $\mu = 0.45 \pm 0.21$.

The similarity of the observed distributions of the relative numbers of detected LGs around HCGs of both samples with the expected one is not accidental. We ran the Kolmogorov-Smirnov goodness-of-fit test to check whether the observed RW and RDGH distributions are due to chance. The hypothesis that both samples are normally distributed is not rejected at a 1% significance level. Hence, we conclude that both the RW and RDGH samples are consistent with a normal distribution. The applied two-sample Mann-Whitney rank sum test showed that both distributions are consistent with each other, with a probability $> 99\%$.

It is noteworthy that RW found LGs in 60% of 38 HCGs with median values of $0.3 < b/a < 0.6$, that, as we saw, are in favorable conditions for finding the associated LG. Meanwhile, LGs were found only in 33% of 54 HCGs with $0.6 < b/a < 0.3$, which have orientations not favorable for detection of LGs.

Therefore, we may conclude that *almost each HCG has an associated LG*, members of which are distributed along the elongation of the correspond-

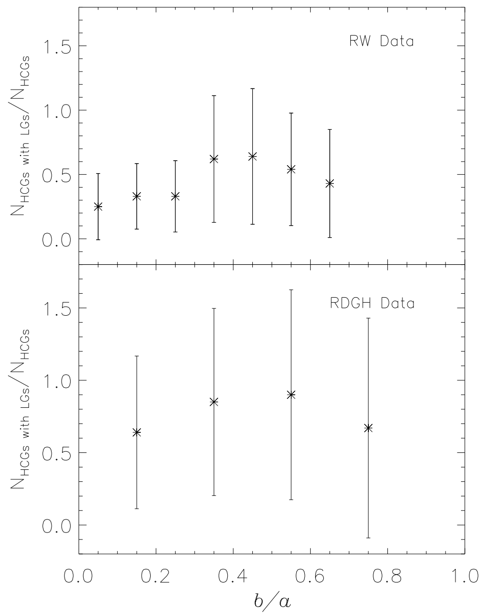

Fig. 1. The dependence of the relative number of HCGs with associated loose groups on the ratio b/a for RW (top) and RDGH (bottom) samples. Vertical bars are errors determined by Poissonian noise.

ing group. Many LGs were not found because of limitations of the search, that are conditioned by orientation reasons. The dependence of the relative numbers of HCGs associated with LGs on the ratio b/a is presented as further evidence that suggests a physical association of the galaxies of LGs with corresponding HCGs.

Two more observed facts are also explained by the suggested scenario. As the result of the increasing number of projected galaxies over the corresponding CG with a decrease of the angle θ, the number of members of round CGs would increase. Indeed, the average number of members of round HCGs is 4.6, while that of the chain-like groups is 3.9 (TMT). At the same time, if a large number of LG members are projected on the CG, then it may not satisfy the compactness criterion (Hickson 1982), and it would be missed. Thus, there should be fewer round HCGs than chain-like ones. As was shown by TMT, the number of round HCGs is, indeed, about one half that of the chain-like groups.

Tovmassian (2001) made counts of faint galaxies in two orthogonal narrow strips passing through the center of elongated HCGs, and found that field galaxies in the strip oriented along the elongation of corresponding HCG outnumber those in the orthogonal strip. Hence, members of LGs associated with CG are indeed distributed along the same direction as the principal members of the CG.

If member galaxies of LGs are gravitationally bound with HCGs, then the physical conditions of the supposed CGs should be essentially reconsidered. The masses must be larger than it has been assumed. The RVDs should also be larger, since for those groups, whose elongation is close to the perpendicular to the line of sight, the measured values are smaller than the real ones. The velocities of galaxies near the center of the elongated system would be sufficiently large. In these conditions the merging rate may be lower. The absence of luminous radio and far-infrared sources, mentioned by Menon (1995), Sulentic & de Mello Rabaça (1993), Hickson et al. (1989) may be natural.

It follows then that the results of N-body simulations involving 5 to 10 galaxies which do not have regular movement around the common center (Barnes 1985, 1989; Bode, Cohn, & Lugger 1993), and constraining the life-time of CGs (Sulentic & Rabaça 1994), should be reconsidered. The N-body simulations that assume a low central concentration and substantial angular momentum (Athanassoula, Makino, & Bosma 1997) seem to be closer to reality. In this case, the group lifetimes may exceed a Hubble time.

3. CONCLUSIONS

It is found that the rate of detection of LGs in the environment of HCGs with prolate spheroid shapes (Hickson et al. 1984; Malykh & Orlov 1986; Oleak et al. 1995, 1998) depends on the elongation of HCGs, which is characterized by the ratio b/a. This allows us to conclude:

1. LGs probably exist around almost every HCG.
2. LGs are elongated formations.
3. Members of LGs are not just field galaxies that fall from time to time onto the CGs, and thus maintain their existence. Neighbor galaxies are constituent members of HCGs, most probably *gravitationally bound* with them.
4. HCGs are more stable configurations than it has been supposed.

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