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Compact and Fossil Groups

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Abstract. We present a short review on poor groups of galaxies focusing on the evolution of compact groups and formation of fossil groups. Fossil groups are systems with one dominant luminous elliptical galaxy surrounded by faint companions, in an extended X-ray halo. We will briefly discuss the possibility of fossil groups being the end-products of the merging of compact groups.

Keywords. cosmology: observations–galaxies: clusters: individual: HCG 31, HCG 62, HCG 79, HCG 92, RX J1552.2+2013, RX J1416.4+2315–galaxies: evolution–galaxies: interactions–galaxies: luminosity function, mass function–galaxies: kinematics and dynamics

1. Introduction

Poor groups are structures with typically $\mathbf{3} \leqslant \mathbf{L}^{*} \leqslant \mathbf{7}$ galaxies and velocity dispersions of 100–500 km/s. They are usually classified as loose or compact groups, depending on their typical galaxy-galaxy separations. Loose groups are quite common–our own Local Group is an example of a loose structure. They comprise over half of the nearby structures in the universe (Tully 1987). Compact groups (CGs, hereafter), on the other hand, represent a small fraction of all groups and they are responsible for only 1% of the luminosity density of the universe (Mendes de Oliveira & Hickson 1991). With galaxy-galaxy median separations of the order of one galaxy diameter, the nearby examples of CGs are fairly isolated from rich clusters (by selection) and are often embedded in loose groups (Ribeiro *et al.* 1998). They have a high fraction of interacting galaxies, which makes them important laboratories for the study of galaxy evolution. The most accepted scenario is that CGs evolve through dynamical friction and are expected to merge into one single elliptical galaxy within a fraction of the age of the universe. Compared to all other nearby environments, present-day CGs are the ones which most closely resemble conditions in the high-redshift universe, when galaxy groups must have been combined to form proto clusters and massive elliptical galaxies.

Recently, a new class of groups has been catalogued, the so called *fossil groups* (FG, hereafter). A FG is a system with an extended and luminous X-ray halo ($L_X > 10^{42} h_{50}^{-2}$ erg s^{-1}), optically dominated by one single brighter-than-L* elliptical galaxy, surrounded by low-luminosity companions (where the difference in magnitude between the bright dominant elliptical galaxy and the next brightest companion is > 2 mag in the R-band; Jones *et al.* 2003). It has been suggested that FGs may be the end products of compact groups (Vikhlinin *et al.* 1999, Jones *et al.* 2003). In this paper, we review the properties of compact and fossil groups and investigate the possible connection between these two kinds of systems. For a more complete review on compact groups see Amram *et al.* (2006).

2. Compact Groups

CGs have been largely studied in the past few decades. The best studied sample of nearby CGs is that of Hickson (1982, HCG hereafter), but other nearby samples have also been catalogued and studied in detail – such as the Shakhbazian groups (Tovmassian *et al.* 2005) and the Southern Compact Groups (Prandoni *et al.* 1994, Iovino 2002). Samples of more distant groups ($z = 0.1$ and higher) are only now starting to appear (e.g. Pompei *et al.* 2006, de Carvalho *et al.* 2005).

The HCG sample contains groups in very different evolutionary stages, as can be recognized, for example, from the variety of HI morphologies they display (Verdes-Montenegro *et al.* 2001) and from their very different active-galaxy content (Coziol *et al.* 2004). In general, groups with the lowest velocity dispersions and lowest masses are the ones with greatest activity and largest probability of merging. This is indeed the case of HCG 31, a group which is dominated by a central interacting system in an early stage of merger (Amram *et al.* 2004).

Interactions seem to be very common in CGs (e.g. Mendes de Oliveira & Hickson 1994) while mergers are rare events (Zepf *et al.* 1991). Recent studies of diffuse light in compact groups have revealed that typically 10–20% and up to a fraction of $\sim$ 46% of the total light of the group (in the specific case of HCG 79) can be comprised in the background light of the group, material which presumably comes from stripped stars of previous group members (da Rocha *et al.* 2005). Moreover, the amount of diffuse light in groups seems to correlate with the dynamical evolution of the group: CGs with the largest amounts of diffuse light tend to have more elliptical galaxies (Aguerri *et al.* 2006). This is proof that galaxy-galaxy interactions have taken place and it suggests that the groups may be long lived. On the other hand, diffuse light cannot be created in dynamical processes during the formation of bright elliptical galaxies in major mergers, as Aguirre *et al.* conclude, given that typical elliptical galaxies in compact groups are known to be quite old (Proctor *et al.* 2004, Mendes de Oliveira *et al.* 2005).

Another indication that interactions are important in CGs comes from the study of the internal dynamics of the galaxy members (e.g. Plana *et al.* 2003, Amram *et al.* 2003). Some apparently normal-looking CGs show galaxies with a number of interaction indicators (e.g. HCG 16c, Mendes de Oliveira *et al.* 1998). From all compact groups perhaps the most well known and best studied one is the Stephan's quintet (or HCG 92), a group at $z = 0.0215$, which also shows a variety of interaction indicators. Most of the gaseous material in Stephan's quintet is in the intragroup medium, suggesting that collisions among group members were frequent. HCG 92 also contains a shock region most probably caused by a high-speed collision of one of the members of the quintet with the intragroup medium (e.g. Trinchieri *et al.* 2003). A number of tidal dwarf galaxies have been identified in this group (e.g. Mendes de Oliveira *et al.* 2001) and more recently also intergalactic HII regions were measured in the HI tidal debris east of the group (Mendes de Oliveira *et al.* 2004, Xu *et al.* 2005).

The presence of diffuse X-ray emission was inferred for 75% of the HCGs, and it was noted that the X-ray emitting CGs are the ones dominated by elliptical galaxies, while the spiral-dominated groups do not seem to show X-rays or they are under the detection limit (e.g. Zabludoff & Mulchaey 1998, with the exception of HCG 16).

N-body simulations of CGs have shown that dynamical friction will cause group members to merge to form a single elliptical galaxy. Some of the first simulations suggested that a CG should merge very quickly (e.g. Barnes 1989). Other authors investigated under which conditions CGs could be long lived given the observational evidence in favor of longer merging timescales. Under certain conditions, such as in the presence of a common massive halo of dark matter around all member galaxies, or when secondary infall is important, or also under some special initial conditions (Ramella *et al.* 1994, Athanassoula *et al.* 1997, Gomez-Flechoso & Dominguez-Tenreiro) CGs could be stable against merging. Nevertheless, there are HCGs that clearly have short dynamical timescales and could evolve to form field elliptical galaxies in less than a Hubble time. It has also been suggested that they could turn into fossil groups (Jones *et al.* 2003).

3. Fossil groups

The first studied FG was RX J1340.6+4018, an apparently isolated elliptical galaxy surrounded by lower luminosity companions within an extended X-ray halo, more typical of groups and clusters (Ponman *et al.* 1994). One other example was shown by Mulchaey & Zabludoff (1999), of a nearby elliptical galaxy NGC 1132 which had no bright companions within a radius of 1 Mpc and a velocity interval of $\pm$ 2000 km/s. In addition, the number density and spatial distribution of dwarf galaxies around NGC 1132 was comparable to that determined for X-ray groups. Other similar groups were studied by Matsushita *et al.* (1998), Matsushita (2001), Vikhlinin *et al.* (1999), Jones *et al.* (2003), and Yoshioka *et al.* (2004). A few individual FGs were also catalogued and studied by Khosroshahi *et al.* (2004), Sun *et al.* (2004) and Ulmer *et al.* (2005). Jones *et al.* (2003) determined that these systems must be quite abundant (density of $\sim 2.4\times 10^{-7}$ Mpc^{-3}) and therefore they may yield an important contribution to the luminosity density and to the baryon budget of the universe.

More recently, the first optical studies of FGs have been completed. Mendes de Oliveira, Cypriano & Sodré Jr. (2006) and Cypriano, Mendes de Oliveira & Sodré Jr. (2006) derived the physical properties of the FGs RX J1552.2+2013 and RX J1416.4+2315, both at redshifts of $z \simeq 0.14$, and computed their luminosity functions. Both systems turned out to be quite massive, with velocity dispersions between 600–700 km/s and masses close to 10^{14} M$\odot$. RX J1552.2+2013 has a cD galaxy in its center and it presented a luminosity function with a lack of intermediate-luminosity ($M'_r = -18$ mag) systems.

Fossil groups were suggested to be the end products of merging of L* galaxies in low-density environments (Jones *et al.* 2003). However, the only two FGs studied so far do not constitute low-density environments and, in fact, are more similar to galaxy clusters. The fairly high X-ray emission, the large fraction of elliptical galaxies, as well as the lack of obvious substructures, suggest that both RX J1416.4+2315 and RX J1552.2+2013 are probably fairly massive virialized systems.

While compact groups are very well studied objects, FGs have only now started to be investigated. We do not even have a proper sample of groups yet, the number of known FGs being less than two dozens. For this reason, we decided to make a search for fossil groups in the sloan digital sky survey database (SDSS-DR5). We first checked the profiles and colors of the galaxies to ensure that the first ranked galaxy (taken from the LRG sample, Eisenstein *et al.* 2001) is an early-type object. A cone search was made within 1 Mpc to look for neighbors with accordant photometric redshits, ensuring that the difference in magnitude between the bright dominant elliptical galaxy and the next brightest companion be $\Delta r > 2$. A cross-match with the ROSAT all-sky Survey sources was made to choose optical detections which coincided with X-ray extended sources. Over two dozen new objects were found (Santos Jr. *et al.*, in preparation).

4. The connection compact group-fossil group

Dynamical friction and subsequent merging are the most probable processes responsible for the lack of bright galaxies in fossil groups. Considering the merging scenario, it is possible that the overluminous central galaxy in a fossil group has been formed within a substructure (which resembles a compact group, but is, in general, more massive), within a larger structure. In that case, one could think of a scenario where a compact group was formed within a rich group, which would then have quickly merged and would have left behind the brightest elliptical galaxy of what today is seen as a fossil group.

Matsushita *et al.* (1998) has pointed out that the X-ray luminosity of elliptical galaxies scatter by two orders of magnitude for the same optical luminosity and they speculated that this could be due to the presence or absence of extended emission. Extended emission can also be below the detection limit, which must be the case for some of the fossil groups which may be the end-product of present-day versions of compact groups. We speculate that most of the nearby CGs are not massive enough to be the precursors of fossil groups and they will evolve into isolated elliptical galaxies rather than fossil groups. The most evolved groups, which are about to merge, are also the least massive compact groups known, and these certainly will not end up as massive structures such as the known fossil groups (Mendes de Oliveira 2006). The most massive compact groups known (such as HCG 62), may, on the other hand, have been the precursors of fossil groups, at early times. However, in order to confirm this scenario and to make a firm connection between compact and fossil groups, more fossil systems have to be studied, in a systematic way.

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References

Amram, P., Plana, H., Mendes de Oliveira, C. *et al.* 2003, A&A, 402, 865.
Amram, P., Mendes de Oliveira, C., Plana, H. *et al.* 2004, ApJ, 612, 5.
Amram, P., Balkowski, C., Mendes de Oliveira, C., & Plana, H., in “Mapping the Galaxy and Nearby Galaxies”, Ishigaki Japan, June 2006, eds. K. Wada and F. Combes.
Athanassoula, E., Makino, J., & Bosma, A. 1997, MNRAS, 286, 825.
Barnes, J.E. 1989, Nature, 338, 123.
Cypriano, E.S., Mendes de Oliveira, C.L., & Sodré Jr., L. 2006, astro-ph/0603732.
Coziol, R., Brinks, E., & Bravo-Alfaro, H. 2004, AJ, 128, 68.
Da Rocha, C., & Mendes de Oliveira, C. 2005, MNRAS, 364, 1069.
de Carvalho, R. R., Goncalves, T. S., Iovino A., *et al.* 2005, AJ, 130, 425.
Eisenstein, D.J., Annis, J., Gunn, J.E., *et al.* 2001, AJ, 122, 2267.
Gomez-Flechoso, M. A., & Dominguez-Tenreiro, R. 2001, ApJ, 549, L187.
Hickson, P. 1982, ApJ, 255, 382.
Iovino, A. 2002, AJ, 124, 2471.
Jones, L. R., Ponman, T. J., Horton, A., *et al.* 2003, MNRAS, 343, 627.
Khosroshahi, H.G., Jones, L.R., & Ponman, T.J. 2004, MNRAS, 349, 1240.
Matsushita, K., Makishima, K., Ikebe, Y., *et al.* 1998, ApJ, 499, 13.
Matsushita, K. 2001, ApJ, 547, 693.
Mendes de Oliveira, C. & Hickson, P. 1991, ApJ, 380, 30.
Mendes de Oliveira, C. & Hickson, P. 1994, ApJ, 427, 684.
Mendes de Oliveira, C., Plana, H., Amram, P., Bolte, M., & Boulesteix, J. 1998, ApJ, 507, 691.
Mendes de Oliveira, C., Plana, H., Amram, P., Balkowski, C., & Bolte, M. 2001, AJ, 121, 2524.
Mendes de Oliveira, C., Cypriano, E. S., Sodré., Jr., & Balkowski, C. 2004, ApJ, 605L, 17.
Mendes de Oliveira, C., Coelho, P., González, J.J., & Barbuy, B. 2005, AJ, 130, 55.

Mendes de Oliveira, 2006, RMxAC, 26, 105.
Mendes de Oliveira, C.L., Cypriano, E.S., & Sodré Jr., L. 2006, AJ, 131, 158.
Mulchaey, J.S., & Zabludoff, A.I. 1999, ApJ, 514, 133.
Plana, H., Amram, P., Mendes de Oliveira, C. *et al.* 2003, ApJ, 125, 1736.
Pompei, E., de Carvalho, R.R., & Iovino, A. 2006, A&A, 445, 857.
Ponman, T.J., Allan, D.J., Jones, L.R., *et al.* 1994, Nature, 369, 462.
Prandoni, I., Iovino, A., & MacGillivray, H. T. 1994, AJ, 107, 1235.
Proctor, R.N., Forbes, D.A., Hau, G.K.T., *et al.* 2004, MNRAS, 349, 1381.
Ramella, M., Diaferio, A., Geller, M.J., & Huchra, J.P. 1994, AJ, 107, 1623.
Ribeiro, A.L.B., de Carvalho, R.R., Capelato, H.V., & Zepf, S.E. 1998, ApJ, 497, 72.
Sun, M., Forman, W., Vikhlinin, A., *et al.* 2004, ApJ, 612, 805.
Tovmassian, H., Tiersch, H., Chavushyan, V.H., *et al.* 2005, A&A, 439, 973.
Tully, R. B. 1987, ApJ, 321, 280.
Ulmer, M. P., Adami, C., Covone, G., *et al.* 2005, ApJ, 624, 124.
Verdes-Montenegro, L., Yun, M. S., Williams, B.A., *et al.* 2001, A&A, 377, 812.
Vikhlinin, A., McNamara, B. R., Hornstrup, A. *et al.*, 1999, ApJ, 520, L1.
Trinchieri, G., Sulentic, J., Breitschwerdt, Pietsch, W., 2003, AA, 401, 173.
Xu, C. K., Iglesias-Pramo, J., Burgarella, D., *et al.* 2005, ApJ, 619, L95.
Yoshioka, T., Furuzawa, A., Takahashi, S., *et al.* 2004, AdSpR, 34, 2525.
Zabludoff, A. I., & Mulchaey, J. S. 1998, ApJ, 498, L5.
Zepf, S.E., Whitmore, B.C., & Levison, H.F. 1991, ApJ, 383, 524.

Discussion

D. Forbes: Do the studied fossil clusters follow the L_X-sigma relation for clusters?

C. Mendes de Oliveira: Yes, the two fossil groups for which we have a secure determination of sigma, RX J1416.4+1615 and RX J1552.2+2013, do follow the L_X-sigma relation for clusters.

I. Salamanca: Is there any information on the ages, metallicties and overabundances from the absorption line studies for fossil group first ranked galaxies?

C. Mendes de Oliveira: A preliminary study indicates that first ranked galaxies of fossil groups make a heterogeneous sample with varied values of ages, metallicties and overabundances. Although, half of the galaxies in our sample show old ages, this result should be taken with caution due to the presence of emission-line contamination. On the contrary, the overabundance seems to be consistently high for the whole sample.

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