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THE EVOLUTION OF GALAXIES IN COMPACT AND FOSSIL GROUPS

C. Mendes de Oliveira[1]

RESUMEN

Presentamos observaciones en el óptico de algunos de los grupos *compactos* cercanos más evolucionados que se conocen actualmente, HCG 31, HCG 79 y HCG 92, así como las propiedades de dos grupos *fósiles* a z$\sim$ 0.137, RX J1416.4+2315 y RX J1552.2+2013. Aún cuando se sabe poco acerca de las propiedades ópticas de los grupos fósiles, se ha sugerido que éstos podrían ser el producto final de los grupos compactos. En este artículo se discute la posible conexión grupo compacto–grupo fósil. Los grupos compactos de galaxias más evolucionados que se observan, los cuales despliegan una gran variedad de signos de interacción y se piensa que están cercanos a fusionarse (como HCG 31, por ejemplo) son ricos en espirales y probablemente NO son los precursores de grupos fósiles, dada su baja dispersión de velocidades y sus alrededores pobres en galaxias. Grupos compactos con alta dispersión de velocidades, los cuales contienen principalmente galaxias elípticas brillantes y son ricos en compañeros de baja luminosidad (grupos semejantes a HCG 62, por ejemplo) pueden haber sido los precursores de grupos fósiles en épocas más tempranas.

ABSTRACT

We report on optical observations of a few of the most evolved nearby *compact* groups of galaxies known, HCG 31, HCG 79 and HCG 92, and on the properties of two *fossil* groups at z $\sim$ 0.137, RX J1416.4+2315 and RX J1552.2+2013. Although little is known about the optical properties of fossil groups, it has been suggested that they could be the end-products of compact groups. In this paper the possible connection compact group – fossil group is discussed. The most evolved compact groups of galaxies observed, which display a wealth of interacting features and are thought to be about to merge (such as HCG 31, for an example) are spiral rich and are probably NOT the precursors of fossil groups, given their low velocity dispersions and poor neighborhoods. Instead, high velocity dispersion compact groups, which contain mainly bright elliptical galaxies and are rich in low-luminosity companions (groups resembling HCG 62, for an example) may have been the precursors of fossil groups, at early times.

Key Words: **GALAXIES: CLUSTERS — GALAXIES: KINEMATICS AND DYNAMICS — GALAXIES: STRUCTURE**

1. INTRODUCTION

Groups of galaxies are small systems of typically a few L* galaxies, which comprise over 55% of the nearby structures in the universe. A small fraction of galaxy groups are classified as *compact* groups. In these, the projected galaxy-galaxy separations are of the same order of the diameters of the galaxies themselves and, as expected, they contain a high fraction of interacting members. They are commonly believed to evolve through dynamical friction and finally merge to form one single galaxy. Vikhlinin et al. (1999) and Jones et al. (2003) have suggested that the merging of compact groups can lead to the formation of the so called *fossil* groups. A fossil group is a system with an extended and luminous X-ray halo ($L_X > 10^{42} h_{50}^{-2}$ erg s^{-1}), dominated by one single brighter-than-L* elliptical galaxy, surrounded by low-luminosity companions (where the difference in magnitude between the bright dominant elliptical and the next brightest companion is > 2 mag in the R-band; Jones et al. (2003)).

This article reviews some observations of compact and fossil groups which may help understanding the connection between these two types of structures. We focus, in particular, in the question if fossil groups could be the end-products of today's compact groups.

[1]Universidade de São Paulo, Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Departamento de Astronomia, Rua do Matão 1226, Cidade Universitária, 05508-900, São Paulo, SP, Brazil (oliveira@astro.iag.usp.br).

[2]Based on observations obtained at the Gemini Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership: the National Science Foundation (United States), the Particle Physics and Astronomy Research Council (United Kingdom), the National Research Council (Canada), CONICYT (Chile), the Australian Research Council (Australia), CNPq (Brazil) and CONICET (Argentina) – Observing run IDs: GN-2003A-Q-53, GN-2003B-Q-12, GN-2004B-Q-47 and GN-2005A-Q-38, GS-2005B-Q-37.

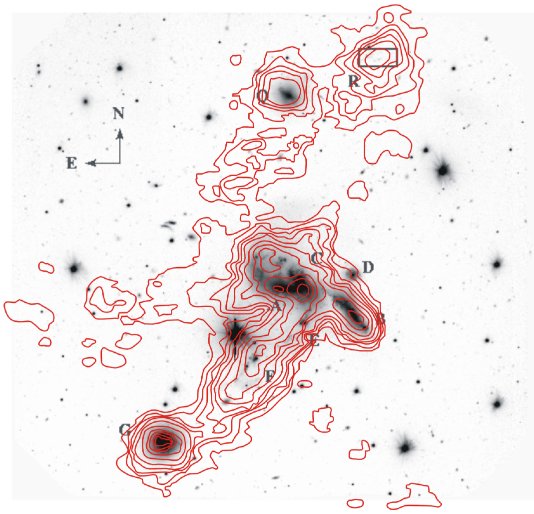

Fig. 1. r-band image of HCG 31 obtained with Gemini+GMOS and HI profiles overlaid onto it. The contours are from the VLA CnB array data from Verdes-Montenegro et al. (2005), at column densities of 1.0, 2.4, 3.8, 5.2, 6.9, 9.6, 13.0, 16.5, 19.9 and 23.3 $\times$ 10^{20} atoms cm^{-2}. The field is 5.5 arcmin on a side or $\sim$ 90 kpc.

2. INTERACTING COMPACT GROUPS: HCG 31, HCG 79 AND HCG 92

There is evidence from both observations and simulations that groups evolve through dynamical friction and coalesce to form more compact structures as the universe ages. A few of the most compact, and therefore most evolved groups known, from Hickson's catalogue (Hickson et al. 1992) are HCG 31, HCG 79 (or Seyfert Sextet) and HCG 92 (or Stephan's quintet). The study of these groups is very important to help understanding processes common in merging systems, environments that may occur often in the high-redshift universe.

HCG 31 is a group at $z \sim 0.013$ and with a velocity dispersion of $\sigma \sim 60$ km s^{-1}. This is a gas-rich group with intense star forming activity (e.g. Mendes de Oliveira et al. 2006), dominated by a central pair of interacting galaxies A+C (see Fig. 1). HCG 31 is thought to be in a pre-merging phase (Amram et al. 2004; Verdes-Montenegro et al. 2005) and it has well developed tidal tails seen in Hα and HI. The group hosts two excellent candidates for tidal dwarf galaxies, namely member F, in the southern tail and member R, 40 kpc to the north of the group (for an assumed distance to the group of 54.8 Mpc). Fig. 1 shows an r-band image of the group obtained with the Gemini-N telescope and the Gemini Multi-Object Spectrograph (GMOS), with HI contours overlaid onto it.

HCG 79, also known as "Seyfert Sextet", was originally identified as a sextet of galaxies but it is now known to be a quartet at $z = 0.0145$ (the 5th object turned out to be in the background and the 6th is a luminous tidal debris to the northeast of the group). This is the most compact group in Hickson's catalogue with a galaxy-galaxy distance below 10 *kpc* (for an adopted distance of the group of $\sim$ 60 Mpc) and a velocity dispersion of $\sigma = 138$ km s^{-1}. The four galaxies present morphological distortions and increased activity (tidal debris, bar in HCG 79B, dust lane in HCG 79A, radio and infrared emission, disturbed rotation curves and nuclear activity). The group presents a prominent intra-group light envelope which contains 45% of the total light of the group (Da Rocha and Mendes de Oliveira 2005) and irregular envelopes of HI (Williams, McMahon & van Gorkom 1991) and X–rays (Pildis et al. 1995). These suggest that recent or on-going interaction is taking place within this system.

HCG 92, also known as Stephan's quintet, is in reality a quartet with $z = 0.0215$ and a foreground galaxy. It is the most well studied compact group – multi wavelength data are available from radio to X-rays. Most of the gaseous material in Stephan's quintet is concentrated not around the bright galaxies but in the intragroup medium, suggesting that collisions among group members may have happened frequently. 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).

These three spiral-rich groups are thought to be in their final stages of evolution – they are, in fact, some of the most compact systems found in the Hickson's catalogue. Yet, they have members that can be clearly identified as individual galaxies, suggesting that once merging starts, it may proceed quite quickly, and the groups may no longer be recognized as such. The bright members of these groups will almost certainly end up as a single galaxy pile. But will these systems end up as fossil groups, or as single isolated elliptical galaxies? Before answering this question we review, in the next section, some of the properties of the fossil groups studied so far.

A list of about a dozen fossil systems known to date are summarized in Table 4[3] of Mendes de

[3]We note that that table needs to be updated by removing objects RX J1256.0+2556 and CL 1205+44. The brightest galaxy of RX J1256.0+2556 is now known to host at least three luminous nuclei (Mendes de Oliveira, unpublished) and CL 1205+44 was found to have a member, previously thought

Oliveira, Cypriano and Sodré Jr. (2006). Only two fossil groups in this list have been studied in detail in the optical (imaging and spectroscopy). The results are described below.

3. THE OPTICAL PROPERTIES OF TWO FOSSIL *CLUSTERS*: RX J1416.4+2315 AND RX J1552.2+2013

Mendes de Oliveira, Cypriano and Sodré Jr. (2006) derived the physical properties of the fossil group RX J1552.2+2013, at a redshift of z=0.136, and computed its luminosity function, based on the spectroscopy for 36 member galaxies. The results were: (1) the system was not a fossil group but a fossil cluster, given its high number of members and high velocity dispersion (close to 700 km/s) and (2) the luminosity function not only had a lack of bright galaxies (as expected, since they were selected this way) but also had a lack of intermediate-luminosity ($M_r' = -18$ mag) systems. This was a surprise, since the general case for systems of similar velocity dispersion is to *not* have dips in their luminosity functions at intermediate luminosities (de Propris et al. 2003; Popesso et al. 2005).

Cypriano, Mendes de Oliveira and Sodré Jr. (2006) studied a second fossil group, RX J1416.4+2315, at a similar redshift of z=0.137. For this system also a fairly high velocity dispersion was measured (584 km s^{-1}), for 25 members located in the inner 542 kpc ($\sim$ 0.45 of the virial radius) of the system. Similar results were found by Khosroshahi et al. (2006).

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 fossil groups 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, distribution, 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.

Not all fossil groups are such large and massive systems as these two observed so far. From Table 4 of Mendes de Oliveira, Cypriano and Sodré Jr. (2006), several of the groups have lower X-ray luminosities and some of them are also quite nearby (at z< 0.03). An image of a fossil group at z=0.03 is shown in Fig. 2, with the X-ray contours overlaid onto it.

to be a star, which is only 1.6 mag fainter than the central object (Durret, 2005, private communication). These, therefore, do not fulfill the strict definition of a fossil group.

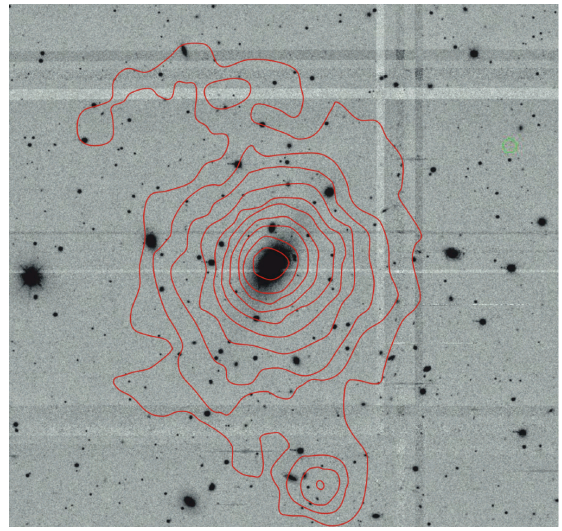

Fig. 2. Fossil group RXJ 0454.8-1806, at $z = 0.0314$. The B image (14.5 arcmin or 530 kpc on a side, for $H_0 = 70$ km/s/Mpc) was taken with the mosaic camera on the Blanco Telescope, at the Cerro Tololo Interamerican Observatory and the contours are ASCA data taken from the work of Yoshioka et al. (2004). The contours are logarithmically spaced by a factor of 1.19, with the lowest one at 4.27×10^{-4} counts s^{-1} $arcmin^{-2}$.

4. THE COMPACT GROUP – FOSSIL GROUP CONNECTION

Dynamical friction and subsequent merging are probably the processes responsible for the lack of bright galaxies in the luminosity function of 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 some of the known nearby compact groups), 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. One weak argument against this scenario is that the nearby examples of compact groups are not usually found within such massive structures, but instead are more often surrounded by very sparse structures. There are, however, a number of groups in Hickson's catalogue surrounded by large numbers of lower-luminosity galaxies (Zabludoff & Mulchaey 1998).

We should stress, however, that the precursors of fossil groups could *not* be compact groups such as those described in Section 2, some of which are

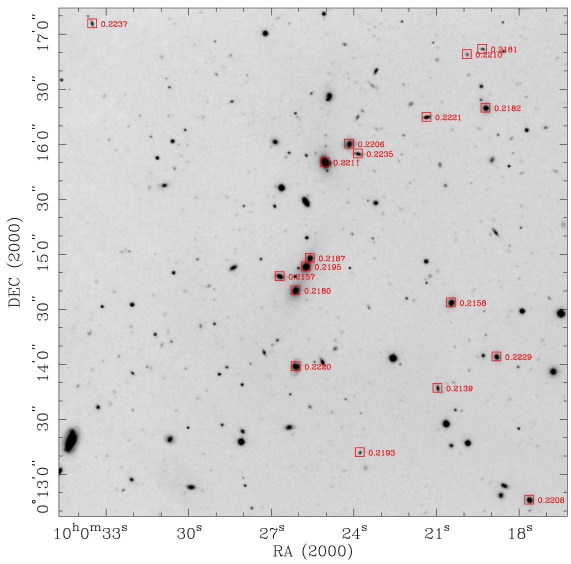

Fig. 3. System CG 6, from the list of Lee et al. (2004). Compact group at z=0.22 and with velocity dispersion $\sigma \sim 700$ km s^{-1}. Image in the i band, taken with Gemini+GMOS. A total of 18 galaxies within 2000 km s^{-1} from the mean radial velocity of the group are marked with squares and their redshifts are given. The image is 4.7 arcmin on a side or 1 Mpc (H_0 = 70 km/s/Mpc). Details can be found in Mendes de Oliveira, Carrasco and Infante (2006), in preparation.

in the pre-merging phase. These are clearly different kinds of objects than the observed fossil groups studied so far (described in Section 3). In particular, these groups have much lower masses, as indicated by their sparse environments and lack of bright X-rays. More probable precursors of fossil groups could be systems such as HCG 42 or HCG 62, both at z=0.013, which have fairly high velocity dispersions (between 300–400 km s^{-1}), contain a wealth of dwarf galaxies (more than 30 members each), and are involved in bright and extended X-ray halos (Mulchaey and Zabludoff 1998). Both HCG 42 and HCG 62 are elliptical-galaxy dominated groups.

It is interesting to note that there may be other such examples of compact groups embedded in larger structures among higher redshift counterparts. In fact, we have recently obtained images and spectroscopy with Gemini+GMOS for one such compact group, CG 6, at z=0.22, from the list of Lee et al. (2004), and have found a velocity dispersion for the compact group+environment, from 20 members, of close to 700 km/s. An i-band image of the group, with 18 members marked with squares, is shown in Fig. 3.

The main conclusion of this review is then that *massive* versions of today's compact groups may have been the best candidate precursors of fossil groups.

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