Small Galaxy Groups
ASP Conference Series, Vol. 209, 2000
M. Valtonen and C. Flynn, eds.

On the Nature of Compact Groups of Galaxies

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Abstract. Based on the spectroscopic survey of de Carvalho et al. (1997), we analyse the structural and dynamical properties of 17 Hickson Compact Groups (HCG). This analysis probes a region of 0.5° × 0.5° around each group and shows that most are part of larger structures. Our results also suggest that the Hickson sample is composed of different dynamical stages of the group's evolution. Specifically, we identify three possible evolutionary phases among groups in the sample: loose groups, [core+halo] systems and compact groups, each one presenting a distinct surface density profile. This sequence is consistent with the replenishment scenario for the formation and evolution of compact groups within larger and less dense systems.

1. Introduction

A large fraction of all galaxies in the universe lie in groups (Nolthenius & White 1987). These structures probe intermediate scales between isolated galaxies and rich clusters and therefore are important from the cosmological viewpoint. In particular, the study of compact groups (CGs) can reveal how the environment affects the intrinsic properties of galaxies. The main reason for this is that compact groups combine high spatial densities and moderate velocity dispersions. This combination suggests that CGs are the most probable sites for interactions and mergers in the nearby universe.

Working on the hypothesis that CGs are real dynamical entities with short lifetimes ($\sim$0.1 H_0^{-1}), White (1990) raised a fundamental point about the nature of these systems: primordial groups should have merged long time ago and a number of progenitors and descendants of them should exist in the universe. The descendants would contribute to the field population of early-type galaxies. At the same time, some mechanism would be responsible for the replenishment of the number of observable CGs. The replenishment idea is present in most of the recent scenarios for CGs evolution (Governato, Tozzy & Cavaliere 1995, Diaferio, Geller & Ramella 1994, 1995). Observational evidence that CGs are located within looser structures or rich neighbourhoods comes primarily from the following contributions: (Rose 1977, Sulentic 1987, Rood & Williams 1989, Ramella et al. 1994, de Carvalho, Ribeiro & Zepf 1994, Coziol et al. 1998a, 1998b, de Carvalho & Coziol 1998).

A recent spectroscopic survey of galaxies in the regions of a selected sample of Hickson compact groups (Hickson 1982) was carried out by de Carvalho et al. (1997). The galaxies observed in this survey lie in the surroundings of 17 Hickson groups located in the southern hemisphere and nearer than ~ 9000 $\mathrm{km\,s^{-1}}$. In this work, we analyse the dynamical structure of the groups observed during this survey. The use of statistical methods applied to the radial velocity distribution allows us to detect structures in it. The physical properties of these systems and their relation to the large-scale structure are considered. We use $H_0 = 75$ $\mathrm{km\,s^{-1}\,Mpc^{-1}}$ throughout this paper.

2. How to Select CGs

Groups of galaxies raise important questions concerning the importance of environmental effects on galaxy formation and evolution. Nevertheless, groups have been studied much less than rich clusters. This is because groups suffer from small number statistics and their properties are a strong function of the algorithm used to define them (Mamon 1994). In particular, Hickson (1982) defined a sample of CGs based on three selection criteria: membership, compactness and isolation. The membership criterion is a very restrictive one because it limits CGs to those ensembles with four or more galaxies within the interval $[m_1, m_1 + 3]$, where m_1 is the magnitude of the brightest galaxy in the group. It clearly impairs any deep investigation of the group and its neighbourhood, especially the faint end of the luminosity function (see de Carvalho, Ribeiro & Zepf 1994, hereafter dCAZ94, Ribeiro, de Carvalho & Zepf 1994, and Zepf et al. 1997). The compactness criterion says that CGs should have a mean surface brightness brighter than 26 $mag\ arcsec^{-2}$ in the E band. It requires that groups correspond to a significant surface density enhancement of bright galaxies over the field. Finally, the isolation criterion detaches CGs from the nearby field by a ring between θ_G and $3\theta_G$ containing no galaxies with magnitudes brighter than $m_1 + 3$ (θ_G is the smallest circle encompassing the centers of the galaxies in the group). This criterion introduces a strong bias on the nature of the compact groups since it artificially detaches them from their surroundings. For example, dCAZ94 extended the limiting magnitude of the HCG's to $m_B \simeq 19.5$ and verified that nearly all of the groups failed the null ring criterion. Indeed, dCAZ94 used only the compactness criterion to study the structural extensions of the HCG's (See also Barton et al. 1996, Barton et al. 1998). Thus, the Hickson sample may be not representative of real compact systems since the groups can be more extended both in luminosity and radius. This is a clear indication that we need more data, similar to the one described here, in the regions around CGs in order to quantify what these systems really are.

2.1. How to Redefine CGs

It is always a difficult task to define a small and compact structure. The search for more proper and physical criteria is a continuous and iterative process. Different authors have used various selection criteria to define groups. Unfortunately, all the suggested criteria are not completely objective, as they involve the use of subjective critical values of selection parameters (e.g. Shakhbazyan 1973, Rose 1977, Hickson 1982). These groups were defined using criteria of compactness and isolation of possible members from the field galaxies. Particularly, the redshifts for the HCG galaxies were obtained ten years after the original catalog.

Therefore, it is important to know how such objects modify the HCG's structural and dynamical properties. The first step toward this goal is to search for kinematical structures in each studied region. We analyse the velocity distributions in the regions of the 17 HCG's in our sample through the use of statistical methods proposed by Beers, Flynn and Gebhardt (1990), using the ROSTAT package (Bird and Beers, 1993). The unbiased estimations of central location and scale of the velocity distribution can be provided by the biweight estimators.

The process of identifying kinematical structures in the velocity distributions was made through a weighted gap analysis. A weighted gap is defined by

$$y_i = (w_i g_i)^{-1/2} \qquad (1)$$

where the g_i's are the measured gaps between the ordered velocities and the w_i's are a set of approximately Gaussian weights (Wainer & Thissen 1976). The presence of large gaps in the velocity distribution indicates that we are not sampling a single structure. Naturally, there are a number of unrelated galaxies in each studied field. The procedure employed to isolate the sample from interlopers is the iterative use of ROSTAT. Thus, the presence of n large gaps divides the data in $n + 1$ subsets of galaxies to be individually analysed with ROSTAT. A kinematical structure is defined only when we have a set of at least three galaxies whose velocity distribution does not present large gaps between the data points.

The second step to redefine the groups is to verify if the structures picked out by the kinematical analysis still correspond to our expectation about physically compact systems. Indeed, two fundamental properties are expected from compact groups: high spatial density and low velocity dispersion. A possible way to investigate the compactness of the groups is through the behaviour of their structural properties as a function of the radius of the systems.

3. Structural Properties of the Compact Groups

In the following we study how the structural properties of the groups depend on the characteristic length scale. This is defined as the median projected separation of the galaxies that constitute the systems. The kinematical catalogs of each group is ordered in terms of the distance from the nominal center given by Hickson (1982), which roughly corresponds to the baricenter of the most luminous galaxies and so it is a good choice for the dynamical center of the structure. The structural properties considered here are: velocity dispersion, spatial density and surface brightness of the groups. These properties were studied in a cumulative way. The first point corresponds to the triplet formed by the three galaxies nearer to the nominal center of the groups. The radius of this triplet is given by the median pairwise galaxy separations. In the same way, the second point corresponds to the central quartet, and so on. The structural parameters of the groups suffer significant changes as the radius and the membership increase. In general, such changes produce an attenuation of the compactness of the groups. So, it is important to know if the groups still belong to the class of compact systems at the end of our analysis (Ribeiro et al. 1996, 1998).

An important point we verified from the individual analysis of the groups is that there is a significant change in their structural properties as the radius and membership increase. In some cases, the limits that define the range for typical compact systems suggest a natural division between two dynamical regions of the groups: a more central, luminous and compact "core" and an extended and lower surface brightness "halo". In other cases, the groups smoothly decrease both in surface brightness and spatial density and probably correspond to the central parts of larger and looser structures. In such cases, there is no prominent separation between the core and the more external parts of the structure. Finally, there are groups that seem to be really isolated and compact, with no visible extension. According to this analysis, a tentative way to classify the systems lead us to three different "families" in this sample: 1) Real CGs ; 2) Systems [core+halo] type ; and 3) Loose groups (or at least part of loose groups).

The nature of the "families" we have identified can be investigated through the characterization of their surface density profiles. Although the number of groups in each category is small, if they really correspond to different dynamical stages, their surface density profiles should exhibit some signs of that difference. In order to study the surface density profiles of our sample, we have proceeded similarly to Mendes de Oliveira and Giraud (1994), but instead of using the maximum radius of each structure to normalize the galaxy distribution, we rescaled the groups to a common size through the median interpairs distance. By applying this method to our data we found the following core radii: $r_c = 21 \pm 9$ kpc, for the compact groups; $r_c = 46 \pm 17$ kpc, for the [core+halo] systems; and $r_c = 68 \pm 16$ kpc, for the loose groups. The value we obtained for the more compact systems is completely within the range of the core radius for the X-ray gas distribution found by Mulchaey et al. (1996), which goes from 5 to 40 kpc (depending on the β_{gas} value). The core radius increases by $\sim 2\sigma$ between each family. This result supports the idea that the families we have previously identified probably correspond to three different dynamical stages of groups, each one presenting distinct surface density profile for the galaxy distribution.

A possible starting point to study the dynamical evolution of HCG's is to consider such systems as real dynamical entities which evolve from loose groups and in the present epoch are sufficiently detached from their surroundings in order to satisfy the Hickson's criteria. Also, we generally suppose that HCG's will be destroyed by mergers after $\sim 0.1\,H_0^{-1}$ (Barnes, 1985, 1989, 1990; White 1990). However, our analysis suggests that part of the groups are not completely detached from the neighbouring galaxy distribution. Besides, we have indentified three possible dynamical stages of the structures. So, in order to investigate the dynamical properties of the groups we have to proceed carefully. First of all, it is necessary to make a direct comparison between the dynamical trends found in our sample and those found in previous works. It is important to know if the dynamical mixture we have identified produce significant changes in the well known correlations found in the Hickson sample. A detailed analysis is presented in Ribeiro et al. (1998). In the following section we present the main results obtained with the data we have analysed so far.

4. Results

1. HCG's form a non-homogeneous sample from the dynamical point of view.
2. We have identified three possible families or three different dynamical stages of the groups: compact, [core + halo] and larger (maybe loose) systems.
3. Although our categorization of the groups is only tentative, the families present distinct surface density profiles, with core radius increasing significantly from compact to loose groups.
4. Comparisons between our data to the work made by Ponman et al. (1996) suggest that most of the groups are probably in virial equilibrium. This result is reinforced by the fact of $\sim$ 75% of the groups have Gaussian velocity distribution indicated by at least one of the normality tests we have used.
5. Comparisons between our data to Hickson, Kindl, and Huchra (1988) suggest that the merging evolution has modified the morphological type distribution in groups. The differences we have found are probably due to our morphological classification based on the galaxy spectra.
6. The $< M/L >$ for this sample is comparable to the values found in samples of loose groups and implies that $0.16 < \Omega_0 < 0.37$.

References

Barnes, J. 1985, MNRAS, 215, 517

Barnes, J. 1989, Nature, 338, 123

Barnes, J. 1990, in Dynamics and Interaction of Galaxies, R. Weilen, ed., (Springer, Heidelberg p. 186

Barton, E., Geller, M. J., Ramella M., Marzke, R. O. and da Costa, L. N. 1996, AJ, 112, 871

Barton, E., de Carvalho, R. R., and Geller, M. J. 1998, AJ116, 1573

Beers, T. C., Flynn, K. and Gebhardt, K. 1990, AJ, 100, 32

Bird, C. M. and Beers, T. C. 1993, AJ, 105, 159

Coziol, R., Ribeiro, A. L. B., Capelato, H. V. and de Carvalho, R. R. 1998a, ApJ, 493, 563

Coziol, R., Ribeiro, A. L. B., de Carvalho, R. R. and Capelato, H. V. 1998b, ApJ, 506, 545

de Carvalho, R. R., Ribeiro, A. L. B. and Zepf, S. E. 1994, ApJS, 93, 47 (dCAZ94)

de Carvalho, R. R., Ribeiro, A. L. B., Capelato, H. V. and Zepf, S. 1997, ApJS, 110, 1.

de Carvalho, R. R. and Coziol, R. 1998, AJ, 117, 1657

Diaferio, A., Geller, M. J. and Ramella M. 1994, AJ, 107, 868

Diaferio, A., Geller, M. J. and Ramella M. 1995, AJ, 109, 2293

Governato, F., Tozzi P. and Cavalieri A. 1996, ApJ, 458, 18

Hickson, P. 1982, ApJ, 255, 382

Hickson, P., Kindl, E., & Huchra, J.P. 1988, ApJ, 331, 64

Mamon, G. A. 1994, *in "Clusters of Galaxies"*, ed. F. Durret, A. Mazure and J. Tran Thanh Van (Editions Frontieres), p. 297

Mendes de Oliveira, C. and Giraud 1994, ApJ, 437, L103

Mulchaey, J. S., Davis, D., Mushotzky, R. F., and Burstein, D. 1996, ApJ, 456, 80

Nolthenius, R. and White, S. D. M. 1987, MNRAS, 235, 505

Ponman, T. J., Bourner, P. D. J., Ebeling, H. and Böringer, H. 1996, MNRAS, 283, 690

Ramella, M., Diaferio, A., Geller, M. J. and Huchra J. P. 1994, AJ107, 1623

Ribeiro, A. L. B., de Carvalho, R. R. and Zepf, S. 1994, MNRAS, 267, L13

Ribeiro, A. L. B., de Carvalho, R. R., Coziol, R., Capelato, H. V. and Zepf, S. 1996, ApJ, 463, L5

Ribeiro, A. L. B., de Carvalho, R. R., Capelato, H. V. and Zepf, S. 1998, ApJ497, 72

Rood, H. J. and Williams, B. A. 1989, ApJ, 339, 772

Rood, H. J. and Struble, M. F. PASP, 106, 413, 1994

Rose, J. A. 1977, ApJ, 211, 311

Shakhbazyan, R. K., 1973, Astrofiz., 9, 495

Sulentic, J.W., 1987, ApJ, 322, 605

Wainer, H. and Thissen, D. 1976, *Psychometrika*, 41, 9

White, S. D. M 1990, "Dynamics and Interactions of Galaxies", ed. R. Wielen (Heidelberg: Springer), 380

Zepf, S. E., de Carvalho, R. R. and Ribeiro A. L. B. 1997, ApJL, in press.