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HCG 16: A HIGH CONCENTRATION OF ACTIVE GALAXIES IN THE NEARBY UNIVERSE

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ABSTRACT

In the course of an extensive campaign to measure radial velocities of galaxies in a selected sample of compact groups photometrically studied by de Carvalho et al., we report the discovery of a system very rich in starburst galaxies and active galactic nuclei. This is the system HCG 16 of Hickson's catalog of compact groups. The seven brightest galaxies form a kinematical group with biweighted estimate mean velocity of $V_{\rm BI} = 3959 \pm 66$ km s^{-1}, dispersion $\sigma_{\rm BI} = 86 \pm 55$ km s^{-1}, a median radius $\langle R \rangle = 0.197$ Mpc, a mean density of $\langle D \rangle = 217$ galaxies Mpc^{-3}, and a total absolute magnitude of $M_B = -22.1$. From their spectral characteristics, we have identified one Seyfert 2 galaxy, two LINERs, and three starburst galaxies. Thus, HCG 16 appears to be a dense concentration of active galaxies. In our sample of 17 Hickson groups, HCG 16 is unique in this regard, which suggests that it is an uncommon structure in the nearby universe.

Subject headings: galaxies: compact — galaxies: interactions — galaxies: Seyfert — galaxies: starburst

1. INTRODUCTION

Compact groups (CGs) of galaxies may represent some of the densest concentrations of galaxies known in the universe and so may provide ideal laboratories for studying the effects of strong interactions on the morphology and stellar content of galaxies. This concept has motivated several recent observational programs aimed at establishing the dynamical reality of these structures and signs of galaxy interactions. Whereas most of these works (Rubin, Hunter, & Ford 1991; Pildis, Bregman, & Schombert 1995) have mainly considered objects in which clear morphological signs of interactions are evident, studies made with larger samples have surprisingly shown that the frequency of mergers in CGs is significantly less than that predicted by simple dynamical arguments (Zepf 1993). Confirming this result, in a search for tidal tail–induced dwarf galaxies in 42 of Hickson's (1982) CGs, Hunsberger, Charlton, & Zaritsky (1995) have shown that only seven of them exhibit clear signs of such objects.

Another question that may be addressed by studying CGs refers to the environmental origin of the nuclear activity of galaxies (AGNs) represented by the presence of nuclear emission lines that cannot be explained in terms of normal stellar population. This long-standing question has been debated in the literature with no clear answer. For instance, whereas the studies of Kennicutt & Keel (1984) and Keel et al. (1985) have shown that the AGN phenomenon occurs more often in binary or interacting systems, other studies found no relevant correlations between nuclear activity and interaction parameters (Dahari & De Robertis 1988; Laurikanen & Salo 1995). However, it seems clear from studies of optically selected samples that nearby AGNs avoid systems that are strongly interacting. Activity, if present, seems due rather to intense starburst formation induced by the interaction itself (Bushouse 1986). This may not be true for the ultraluminous infrared galaxies, which are mostly interacting galaxies and show an increasing probability of being Seyferts with increasing infrared luminosity (Veilleux et al. 1995). One may speculate that if AGNs do really prefer interacting systems but avoid those that are strongly interacting, then an ideal place to find them would be the CGs, or at least a subclass of them, which, although apparently very dense as deduced from their radial velocities, show no signs of violent interactions.

In this Letter we spectroscopically revisit one compact group that has been previously noticed as presenting morphological signs of interaction among its galaxies. This is the system HCG 16 of Hickson's (1982) catalog of CGs. We have found this group to be very rich in starburst galaxies and AGNs, since it is a very rare case of such a high concentration of active galaxies in such a dense environment.

2. DATA AND KINEMATIC PROPERTIES

HCG 16 and its neighboring galaxies were spectroscopically observed in the course of an extensive campaign aimed at measuring radial velocities of galaxies of a selected sample of CGs photometrically studied by de Carvalho, Ribeiro, & Zepf (1994, hereafter dCAZ94). The spectra were taken at the 4 m Cerro Tololo Inter-American Observatory (CTIO) telescope, using the ARGUS fiber feed spectrograph. The details of the instrumental setup and data reduction are discussed by de Carvalho et al. (1996). Table 1 lists the galaxy number as given by dCAZ94 (col. [1]), positions in right ascension and declination (cols. [2] and [3]), magnitudes in *B* (dCAZ94; col. [4]), and heliocentric velocities and errors (cols. [5] and [6]). We list here only the seven galaxies defining the group. A complete list of all the galaxies measured in the field is presented by de Carvalho et al. (1996).

We have used the ROSTAT statistical package (Beers, Flynn, & Gebhardt 1990) in order to analyze the velocity distribution of our sample of galaxies around HCG 16 (0°.5 × 0°.5 around the center), which is complete down to $B = 18.6$ mag. The analysis revealed the presence of a kinematical group consisting of the seven brightest galaxies in the field, with mean velocity (as given by the biweighted estimate) of $V_{\rm BI} = 3959 \pm 66$ km s^{-1} and dispersion $\sigma_{\rm BI} = 86 \pm 55$ km s^{-1} (90% confidence errors). A more detailed study is presented in Ribeiro et al. (1996a).

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TABLE 1

VELOCITY DISTRIBUTION ANALYSIS OF HCG 16

Galaxy 1	R.A. (1950) (2)	Decl. (1950) (3)	B (4)	V (km s^{-1}) (5)	δV (km s^{-1}) (6)
1..........	$2^h6^m57^s.35$	$-10°22'20''.1$	12.88	4073	10
2..........	2 6 53.53	−10 22 10.1	13.35	3864	10
3..........	2 7 50.46	−10 33 24.8	13.35	4001	13
4..........	2 7 11.24	−10 22 58.2	13.61	3859	13
5..........	2 7 15.63	−10 25 11.6	13.66	3934	13
6..........	2 6 38.78	−10 33 23.2	15.56	3972	12
10..........	2 6 09.30	−10 10 28.2	17.52	4000	31

The compact group HCG 16 is a larger group than originally noted by Hickson, being composed of seven galaxies. In Figure 1, we present the distribution of galaxies in HCG 16. The original group described by Hickson is composed of four galaxies: 1, 2, 4, and 5. To these galaxies, we added three others, 3, 6, and 10. Galaxies 3 and 6 are quite luminous, which suggests that this new addition is of great importance for the dynamical structure of the group. The median of the projected separations of the galaxies in the group is $\langle R \rangle = 0.197$ Mpc ($H_0 = 75$ km s^{-1} Mpc^{-1}), and the mean density is $\langle D \rangle = 217$ galaxies Mpc^{-3}. The density is therefore smaller than the density $\langle D \rangle = 10^4$ galaxies Mpc^{-3} originally determined by Hickson. While this density is lower than that in the central part of rich clusters of galaxies, HCG 16 has a density roughly 30 times higher than those found for loose groups of galaxies, as determined by Maia, da Costa, & Latham (1989). The total absolute magnitude of the system is $M_B = -22.1$ (as compared to $M_B = -21.5$ determined by Hickson).

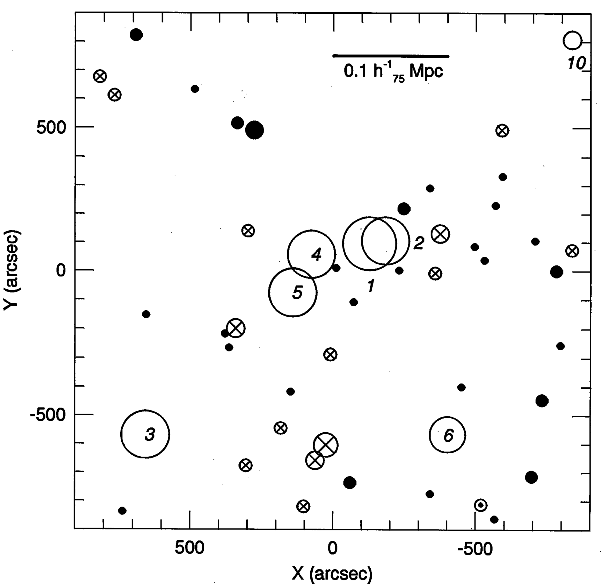

FIG. 1.—Position on the sky of the galaxies in HCG 16. Each circle represents a galaxy, with the diameter being proportional to its magnitude (the greater, the brighter). The nearest four galaxies to the center form the original group, as defined by Hickson. The three new galaxies are within a projected distance of 900″. Symbols are as follows: filled circles, galaxies without measured radial velocity; crossed circles, background galaxies; dotted circle, galaxy at $V = 3167$ km s^{-1}, which has been excluded from the group based on the consistency of the observed distribution being drawn from a single Gaussian parent population.

3. SPECTRAL PROPERTIES

In Figure 2, we present the spectra for the six emission-line galaxies of the seven that constitute HCG 16. The seventh member of the group, galaxy 10, does not show any emission lines. Because the spectra are not flux calibrated, we divided the number counts by their mean values in order to compare the relative intensity of the emission lines in the different galaxies. Galaxy 4 shows the most intense emission lines. Except for the unusually high ratio of [N II]/Hα and the presence of a faint [O I] λ6300 line, this spectrum is very similar to those of disk spiral H II regions. This galaxy is clearly experiencing an intense starburst phase in or near its nucleus. Based on the similarity of the spectra, galaxies 3, 5, and 6 are also starburst galaxies, although at relatively lower intensities than galaxy 4. Galaxies 1 and 2 show a different type of spectrum, both with the high [N II]/Hα ratio typical of AGNs.

The classification of the kind of activity encountered in the galaxies of HCG 16 is based on the different line ratios shown by galaxies of different activity classes. The criteria that we have used for our spectral characterization are explained in detail in Ribeiro et al. (1996b). The presence or absence of a wide Balmer emission-line component allows us to distinguish between a Seyfert 1 and a Seyfert 2. We distinguished between Seyfert 2 and LINERs based on the ratio [O III] λ5007/H$\beta > 2.5$ (Coziol 1996). We adopted this definition because in many cases the [O II] λ3727 line, used by Heckman (1980) to characterize the LINER type, was not available. For the starburst galaxies, we distinguished also between H II galaxies and starburst nucleus galaxies (SBNGs). This distinction is based on a correlation between spectroscopic characteristics and morphologies (Coziol et al. 1994). In general, the H II galaxies are high-excitation ([O III] λ5007/H$\beta > 2.5$), small, metal-poor galaxies, while the SBNGs are low-excitation, massive, metal-rich galaxies. Usually, the spectra of SBNGs indicate a mean excess of 0.2 dex in the [N II]/Hα ratio as compared to normal H II regions (Coziol et al. 1996).

In Figure 3, we present the diagnostic diagram of [O III] λ5007/Hβ versus [N II]/Hα for all the emission-line galaxies in HCG 16. In this diagram, the dotted line represents our criterion to distinguish between high- and low-excitation galaxies. The solid line is the empirical separation established by Veilleux & Osterbrock (1987) between galaxies ionized by an AGN and galaxies ionized by stars. The uncertainties in the line ratios are determined based on Poisson statistics. The high uncertainties in [O III] λ5007/Hβ for galaxies 1 and 2 reflect the weakness of the emission lines. In those galaxies, for Hβ the stellar absorption dominates over the nebular emission. Following our classification, HCG 16 contains three AGNs (two LINERs and one Seyfert 2) and three starbursts. Based on the unusually high intensity of the lines [S II] $\lambda\lambda$6716, 6734 (see Fig. 2), galaxy 2 looks more like a LINER than a Seyfert 2 (Rubin et al. 1991). The starburst nature of galaxy 4 was already suggested by its high emission in the infrared (Sparks et al. 1986). The equivalent widths EW (Hα + [N II]) for galaxies 3, 4, 5, and 6 are 44, 146, 50, and 10 Å, respectively. Except for galaxy 6, those values are comparable to those found in typical starburst galaxies (Kennicutt 1992).

4. X-RAY CHARACTERISTICS

X-ray emission from HCG 16 was first detected by Bahcall, Harris, & Rood (1984). An analysis of *ROSAT* observations by Saracco & Ciliegi (1995) suggests that in general the emission

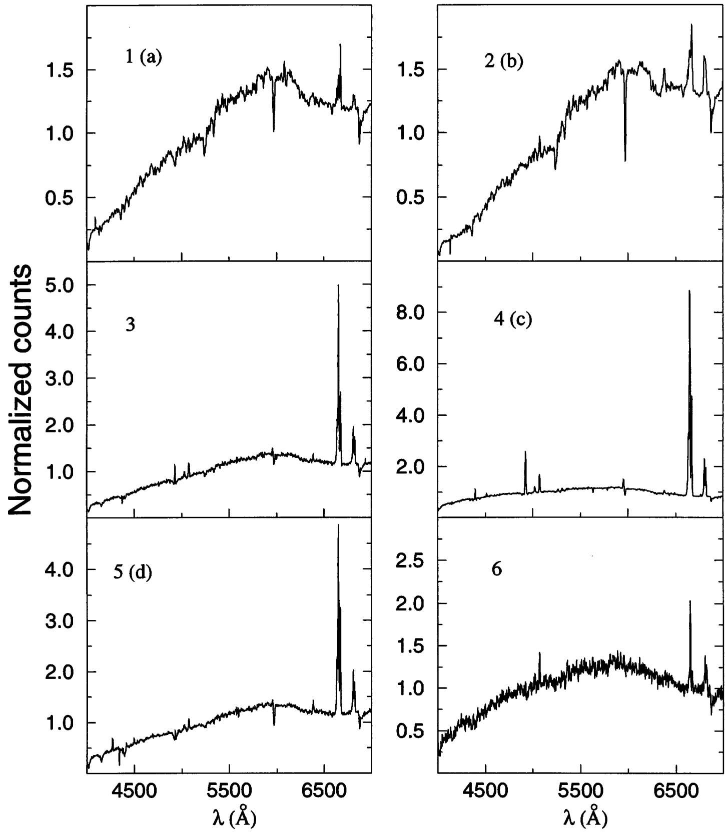

FIG. 2.—Optical spectra for the six emission-line galaxies of HCG 16. For each spectrum, the counts were divided by the mean value to facilitate the comparison between the galaxies. Each galaxy is identified by a running number (see Table 1). The letter in parentheses refers to the original notation by Hickson (1982).

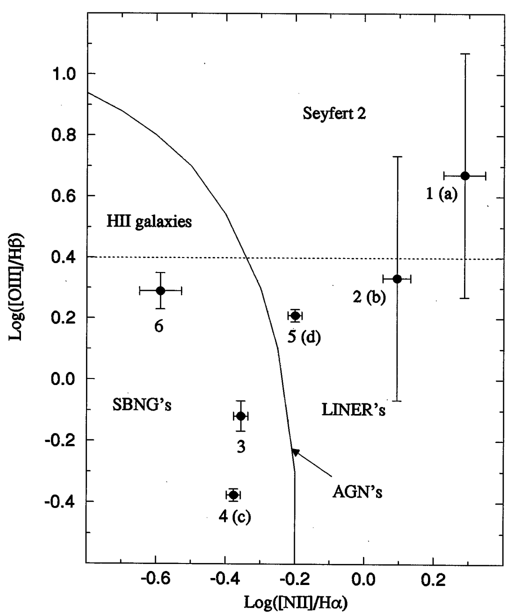

FIG. 3.—Diagnostic diagram of emission-line ratio and classification of the different activity of the galaxies of HCG 16. The dotted line at log([O III]/Hβ) = 0.4 establishes a distinction between high-excitation and low-excitation galaxies (Coziol 1996). The solid line indicates the empirical separation between starburst galaxies and AGNs as determined by Veilleux & Osterbrock (1987).

is pointlike and centered on the galaxies, although Ponman et al. (1996) have recently presented evidence for diffuse intragroup X-ray emission from this group. The two dominant galaxies, 1 and 2, appear to be in a common X-ray envelope, for which Saracco & Ciliegi give a total luminosity of L_X (0.5–2.3 keV) = 4.3×10^{40} ergs s^{-1}. The fainter galaxies, 4 and 5, have resolved emission with luminosities 4.6×10^{40} ergs s^{-2} and 1.9×10^{40} ergs s^{-1}, respectively. In the X-ray contour map presented by Saracco & Ciliegi (1995), we found a pointlike emission at the southeast that exactly coincides with galaxy 3. A crude estimate of the X-ray luminosity of this source gives $\sim 0.5 \times 10^{40}$ ergs s^{-1}.

For comparison, mean values found by Green, Scott, & Ward (1992) give L_X (0.5–4.5 keV) = 1.8×10^{41} ergs s^{-1} for Seyfert 2, 2.2×10^{40} ergs s^{-1} for LINERs, and 7.0×10^{39} ergs s^{-1} for starburst galaxies. In general, therefore, the X-ray luminosities of the galaxies in HCG 16 are comparable to those found in LINERs, and their X-ray emission intensities decrease with the decreasing intensity of the starburst activity.

5. DISCUSSION

HCG 16 is a clear example of recent and multiple interacting galaxies. As suggested by the spectroscopy, these interactions have triggered a new phase of star formation in galaxies 3, 4, and 5, while in galaxies 1 and 2, it is likely that only the nuclei were activated. The fact that galaxies 1 and 2 do not exhibit a starburst seems to be in contradiction with the description of their morphologies by Rubin et al. (1991), who reported signs of interactions in the forms of weak antennas (in galaxy 1), tidal tails (galaxy 2), and a faint bridge between galaxies 1 and 2. Indeed, following models of interacting galaxies, the development of such structures, especially the very long tails, requires a few $\times 10^8$ yr (Barnes 1990), which is also comparable to the fading timescale of an induced starburst due to gas depletion (Mihos, Bothun, & Richardson 1993).

Based on the absence of tidal features in galaxies 3, 4, and 5, we could suppose that those galaxies are examples of a more recent interaction (starbursts much younger than 10^8 yr) than galaxies 1 and 2, which are at a more advanced stage of interaction. In favor of this scenario, we note that galaxies 1 and 2 may have a common X-ray envelope. The hot diffuse component could have been formed from gas that was stripped from the individual galaxies following their close encounter (Sulentic, Pietsch, & Arp 1995). As judged from the remnant traces of interaction in the morphologies of these two AGNs, galaxies 1 and 2 could have experienced a very strong starburst in their recent past (but surely older than a few times 10^8 yr). Since then, the burst has faded, and only low activity in the nuclei remains. More observations are needed to look for possible traces of poststarburst activity near the nuclei of galaxies 1 and 2. It is not clear, however, if any direct relation exists between the starburst event and the AGNs. In particular, galaxies 1 and 2 could already have possessed a well-formed black hole in their nuclei that was rejuvenated by a new infall of matter provided by the interaction.

A fundamental point we want to stress in this Letter is that our spectroscopic data support the identification of HCG 16 as a real compact group. Both the kinematical parameters and the spectral classification of the six brightest galaxies as active are easily understood if HCG 16 is a bound, dense system. In contrast, our observations are difficult to understand if the enhanced activity and density in HCGs is explained by projections along filaments incorporating a true pair (see, e.g., Hernquist, Katz, & Weinberg 1995; Mamon 1995). At the same time, HCG 16 is unique among our sample of 17 groups as a clear case of compact structure, and groups like it may be very rare, at least in the nearby universe (Ribeiro et al. 1996a). The other structures have a wide variety of projections and dynamical configurations. This variety demonstrates how difficult it is to define small groups of galaxies and how useful spectroscopy is for detecting groups, both by picking out structures in velocity space and by testing for nuclear activity.

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REFERENCES

Bahcall, N. A., Harris, D. E., & Rood, H. J. 1984, ApJ, 284, 29
Barnes, J. E. 1990, in Dynamics and Interaction of Galaxies, ed. R. Weilen (Heidelberg: Springer), 186
Beers, T. C., Flynn, K., & Gebhardt, K. 1990, AJ, 100, 32
Bushouse, H. A. 1986, AJ, 91, 255
Coziol, R. 1996, A&A, in press
Coziol, R., Demers, S., Barnéoud, R., & Peña, M. 1996, AJ, submitted
Coziol, R., Demers, S., Peña, M., & Barnéoud, R. 1994, AJ, 108, 405
Dahari, O., & De Robertis, M. M. 1988, ApJ, 331, 727
de Carvalho, R. R., Ribeiro, A. L. B., Capelato, H. V., & Zepf, S. E. 1996, in preparation
de Carvalho, R. R., Ribeiro, A. L. B., & Zepf, S. E. 1994, ApJS, 93, 47 (dCAZ94)
Green, P. J., Scott, F., & Ward, M. J. 1992, MNRAS, 254, 30
Heckman, T. M. 1980, A&A, 87, 152
Hernquist, L., Katz, N., & Weinberg, D. H. 1995, ApJ, 442, 57
Hickson, P. 1982, ApJ, 255, 382
Hunsberger, S. D., Charlton, J. C., & Zaritsky, D. 1995, preprint
Keel, W. C., Kennicutt, R. C., Hummel, E., & van der Hulst, J. M. 1985, AJ, 90, 708
Kennicutt, R. C. 1992, ApJ, 388, 310
Kennicutt, R. C., & Keel, W. C. 1984, ApJ, 279, L5
Laurikanen, E., & Salo, H. 1995, A&A, 293, 683
Maia, M. A. G., da Costa, L. N., & Latham, D. W. 1989, ApJS, 69, 809
Mamon, G. A. 1995, in ASP Conf. Proc. 70, Groups of Galaxies, ed. O.-G. Richter & K. Borne (San Francisco: ASP), 83
Mihos, J. C., Bothun, G. D., & Richstone, D. O. 1993, ApJ, 418, 82
Pildis, R. A., Bregman, J. N., & Schombert, J. M. 1995, AJ, 110, 149
Ponman, T. J., Bourner, P. D. J., Ebeling, H., & Böhringer, H. 1996, preprint
Ribeiro, A. L. B., de Carvalho, R. R., Capelato, H. V., & Zepf, S. E. 1996a, in preparation
Ribeiro, A. L. B., de Carvalho, R. R., Coziol, R., Capelato, H. V., & Zepf, S. E. 1996b, in preparation
Rubin, V. C., Hunter, D. A., & Ford, W. Kent, Jr. 1991, ApJS, 76, 153
Saracco, P., & Ciliegi, P. 1995, A&A, 301, 348
Sparks, W. B., Hough, J. H., Axon, D. J., & Bailey, J. 1986, MNRAS, 218, 429
Sulentic, J. W., Pietsch, H. W., & Arp, M. 1995, A & A, 298, 420
Veilleux, S., Kim, D. C., Sanders, D. B., Mazzarella, J. M., & Soifer, B. T. 1995, ApJS, 98, 171
Veilleux, S., & Osterbrock, D. E. 1987, ApJS, 63, 295
Zepf, S. E. 1993, ApJ, 407, 448