HCG 16 REVISITED: CLUES ABOUT GALAXY EVOLUTION IN GROUPS

REINALDO R. DE CARVALHO¹ AND ROGER COZIOL¹,²

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ABSTRACT

We present new spectroscopic observations of five galaxies, members of the unusually active compact group HCG 16, observed using the Palomar 5 m telescope. The high signal-to-noise ratios (S/N ~ 70) of the spectra allow us to study the variation of the emission-line characteristics and the stellar populations in the nucleus and the circumnuclear regions of the galaxies. The emission-line characteristics of these galaxies are complex, varying between Seyfert 2's and LINERs or between LINERs and starbursts. All of the galaxies show traces of intermediate-age stellar populations, which supports our previous result that poststarburst galaxies are common in compact groups. The galaxies HCG 16-4 and HCG 16-5 show double nuclei and therefore could be two cases of recent merger. Our observations support a scenario in which HCG 16 was formed by the successive merger of metal-poor, low-mass galaxies. The galaxies HCG 16-1 and HCG 16-2, which are more evolved, form the old core of the group. Galaxies HCG 16-4 and HCG 16-5 are two more recent additions that are still in a merging phase. Galaxy HCG 16-5 is a starburst galaxy that is just beginning to fall into the core. If HCG 16 is representative of compact groups in their early stage, the whole set of observations implies that the formation of compact groups is the result of hierarchical galaxy formation. HCG 16 could be one example of this process operating in the local universe.

Key words: galaxies: compact — galaxies: evolution — galaxies: interactions — galaxies: starburst

1. INTRODUCTION

To study the dynamical structure of compact groups of galaxies, de Carvalho et al. (1997) obtained new spectroscopic data on 17 of Hickson's compact groups (HCGs), extending the observations to galaxies that are in the immediate vicinity of the original group members (within 0.35 Mpc, $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$, from the nominal center, on average; Ribeiro et al. 1998). The analysis based on this survey (Ribeiro et al. 1998; Zepf, de Carvalho, & Ribeiro 1997) helped to resolve some of the ambiguities presented by the HCGs. In particular, it revealed that compact groups may be different dynamical stages of evolution of larger structures, where replenishment by galaxies from the halo is always operating. Several other papers have addressed this particular scenario from either the observational or theoretical point of view (e.g., Barton et al. 1996; Ebeling, Voges, & Böhringer 1994; Rood & Struble 1994; Diaferio, Geller, & Ramella 1994, 1995; Governato, Tozzi, & Cavaliere 1996).

Consistent with the dynamical analysis, the classification of the activity types and the study of the stellar populations of the galaxies in these groups suggest that their evolution followed similar paths and that they were largely influenced by their environment (Ribeiro et al. 1998; Mendes de Oliveira et al. 1998). Most of the groups have a core (basically corresponding to the Hickson definition of the group) and halo structure (see Ribeiro et al. 1998 for a definition of the halo population). The core is dominated by AGNs, dwarf AGNs, and galaxies whose spectra do not show any emission, whereas starbursts populate the halo. The AGNs are located in the most early-type, luminous galaxies and are preferentially concentrated toward the central parts of the groups. The starbursts in the halo, on the other hand, appear to be located preferentially in late-type spiral galaxies (Coziol et al. 1998a, 1998b). This last result for the core of the groups was recently confirmed by Coziol et al. (1999b) from a study of a new sample of 58 compact groups in the southern hemisphere (Iovino & Tassi 1998). In this study, we also show that no Seyfert 1's have been found in our sample of compact groups.

In terms of star formation and populations, the galaxies in the core of the groups (the "nonstarburst" galaxies) seem more evolved than those in the outer regions: the galaxies are more massive and more metal rich than the starbursts, and they show little or no star formation. Most of these galaxies have, however, stellar metallicities that are unusually high compared to those of normal galaxies with similar morphologies (Coziol et al. 1998a). They also show unusually narrow equivalent widths of metal absorption lines and relatively strong Balmer absorption lines, which are consistent with the presence of a small (less than 30%) population of intermediate-age stars (Rose 1985). These observations suggest that most of the nonstarburst galaxies in the groups are in a relatively evolved "poststarburst" phase (Coziol et al. 1998a).

HCG 16 is a group composed of seven galaxies with a mean velocity $V = 3959 \pm 66$ km s$^{-1}$ and a dispersion $\sigma = 86 \pm 55$ km s$^{-1}$ (Ribeiro et al. 1998). Although we are keeping Hickson's nomenclature for this group, it is important to note that we are not following specifically Hickson's definition of a group, since this is not a crucial point for our analysis. Besides, there is evidence that HCG 16 is part of a larger and sparser structure (Garcia 1993). Specific studies have been done on HCG 16, covering a broad domain of the electromagnetic spectrum, allowing a thorough exam of its physical properties: radio and infrared (Menon 1995; Allam et al. 1996); CO observations estimating the mass of molecular gas in some of HCG 16's members (Boselli et al. 1996); rotation curves exhibiting abnormal shapes (Rubin, Hunter, & Ford 1991). Hunsberger et al. (1996) detected some dwarf galaxy candidates for HCG 16-a, which is inter-

¹ Observatório Nacional, Rua General José Cristiano 77, 20921-400 São Cristóvão, Rio de Janeiro, Brazil.
² PRONEX/FINEP—P. 246—41.96.0908.00.
preted as a sign of strong interaction. From the spectral characteristics, Ribeiro et al. (1996) identified one Seyfert 2 galaxy, two LINERs, and three starburst galaxies. Considering the significant amount of information gathered for HCG 16, this group represents a unique opportunity to obtain new clues on the process of formation of the compact groups. Here in this paper we focus on study of the activity of five galaxies belonging to the group: four galaxies originally defined as the Hickson group 16 and the fifth one added from Ribeiro et al. (1998). These authors redefined this structure with seven galaxies (including the original four from Hickson), but we gathered high-quality data for only five of them.

2. OBSERVATIONS AND DATA REDUCTION

Spectroscopic observations were performed at the Palomar 200 inch (5 m) telescope using the Double Spectrograph on UT 1996 October 16. Typical exposure times were 600–900 s depending on the magnitude of the galaxy. Two gratings were used: one for the red side (316 line mm\(^{-1}\), resolution of 4.6 Å), and one for the blue side (300 line mm\(^{-1}\), resolution of 4.9 Å). The wavelength coverage was 3800–5500 Å in the blue and 6000–8500 Å in the red. For calibration, He-Ne arc lines were observed before and after each exposure throughout the night. During the night, the seeing varied around 1.5'. It is important to stress that in this paper we present only a qualitative discussion of the relative rates of star formation since the data were taken under nonphotometric conditions which hampered a proper flux calibration.

The reduction of the spectra was done in IRAF using standard methods. An overscan was subtracted along the dispersion axis, which took care of the bias correction. All the spectra were trimmed and divided by a normalized flat field. Wavelength calibration, done through a polynomial fit to the He-Ne arc lines, gave residuals of ≈0.1 Å.

The relatively high signal-to-noise ratios of the spectra (S/N ≈ 70 on average) allow us to study the variation of the emission-line characteristics and stellar populations as a function of their position in the galaxies. To do so, the reduction to one dimension was done in the case of the red spectra using up to seven apertures of \(0.1\) Å. In galaxies HCG 16-4 and HCG 16-5, the light is slightly more extended (≈3 and 6 kpc, respectively), but this is because each of these two galaxies probably has a double nucleus. The second nucleus in HCG 16-4 corresponds to the second peak 5' east of the primary nucleus, while in HCG 16-5, the second nucleus corresponds to the small peak 7' east of the primary nucleus. It is very unlikely that these structures could be produced by dust because we are using the red part of the spectra, where extinction effects are minimized. In the next section, we will show also that the second nucleus in HCG 16-5 presents a slightly different spectral characteristic compared to the primary nucleus, which is inconsistent with the idea that this is the same

| HCG Number | \(cz\) (km s\(^{-1}\)) | \(M_b\) | \(T\) | Activity Type | Total Galaxy (arcsec) | Ionized Regions (arcsec) | Nucleus (arcsec) | 1 A arcsec (pc) |
|------------|-----------------|-------|----|-------------|----------------------|------------------------|----------------|----------------|
| 16-01      | 4073            | -20.79| 2  | LNR + SBNG  | 36                   | 32                     | 1.8            | 263            |
| 16-02      | 3864            | -20.21| 2  | Seyfert 2 + LNR | 31                   | 21                     | 3.7            | 250            |
| 16-03      | 4001            | -20.29| ...| SBNG       | 34                   | 28                     | 3.7            | 259            |
| 16-04      | 3859            | -19.95| 10 | SBNG       | 45                   | 40                     | 6.0            | 249            |
| 16-05      | 3934            | -19.94| ...| LNR + Seyfert 2 | 40                   | 15                     | 8.3            | 254            |

3. RESULTS

3.1. Distribution of the Light and Ionized Gas in the Spectra

Table 1 gives the basic characteristics of the five galaxies studied in this paper. The numbers in column (1) follow the nomenclature used in Ribeiro et al. (1996). The radial velocities in column (2) and the absolute magnitudes in column (3) were taken from Coziol et al. (1998a). The morphological types listed in column (4) were taken from Mendes de Oliveira & Hickson (1994). The different types of activity in column (5) correspond to our new classification as presented in § 4 and Figure 3. The complexity of the AGNs is obvious from the multiple characteristics of their spectra. The next three columns correspond to the extension of the projected light on the spectra, as deduced from the red part of the spectrum. The total galaxy is measured from the extension until the signal reaches the sky level. The ionized region corresponds to the projected length where emission can be seen. The nucleus corresponds to the extension of light at half-maximum intensity (FWHM). With the exception of HCG 16-1, all the galaxies have a nucleus that is well resolved. The last column gives for each galaxy the equivalent of 1" in parsecs.

Figure 1 shows, on the left, the extension of the ionized gas, as traced by Hα and the two [N II] lines, and, on the right, the light profile along the slit. In the galaxies HCG 16-1, HCG 16-2 and HCG 16-3, 90% of the light is concentrated in a window ~9" wide, which corresponds to ~2 kpc at the distance of the galaxies. The remaining 10% of the light extends over a region not exceeding 8 kpc. These galaxies look compact compared to normal spiral galaxies.
Fig. 1.—Extension of the ionized gas centered at Hα and light profiles along the slit. The direction of east is indicated. At the left, the extension in kiloparsecs of the region of the spectra with 90% of the light is indicated. This same region is marked in the light profile by a dashed line at the 10% level of intensity. The FWHM and total extension of the galaxies are given in Table 1. The profiles of HCG 16-4 and HCG 16-5 show secondary peaks corresponding to secondary nuclei.

galaxy. HCG 16-4 and HCG 16-5 are probably the product of recent mergers of galaxies. Other studies present strong evidence of central double nuclei (Amram et al. 1992; Hibbard 1995).

In all the galaxies, the ionized gas is more intense and mostly concentrated in the nucleus. H II regions outside the nucleus are clearly visible only in HCG 16-1 and HCG 16-3. It looks as if the activity (star formation or AGN activity) is always concentrated in the center of the galaxies. In HCG 16-5, the second nucleus seems less active (we see less ionized gas) than the primary nucleus, while in HCG 16-4, the two nuclei appear equally active.

3.2. Variation of the Activity Type with the Radius

In Ribeiro et al. (1996) we already determined the activity types of these galaxies. Having in hand spectra with high S/N, we now repeat our analysis of the activity for the five most luminous galaxies, but this time we separate each spectrum in various apertures covering different regions in order to see how activity varies with radius.

In Figure 2, we present the results of our classification of the activity type using the standard diagnostic diagram (Baldwin, Phillips, & Terlevich 1981; Veilleux & Osterbrock 1987). The line ratios correspond to the values obtained after subtraction of the template galaxy NGC 6702. Because of the relatively lower S/N of the blue as compared to the red part of the spectra, we limit our study to only three apertures. In Figure 2, the first apertures, identified by filled symbols, cover the nucleus. The two other apertures cover regions to the east and to the west of the nucleus. The width of these apertures can be found in column (3) of Table 3. Note that these apertures are covering mostly the central part of the galaxies.

Our new classification is similar to the one given in Ribeiro et al. (1996). In particular, the galaxies keep their original classification as an AGN or a starburst. We note, however, some interesting variations. The most obvious of these variations concerns HCG 16-1, which was classified as a luminous Seyfert 2 and now appears as a LINER nucleus with outer regions in a starburst phase. Another difference
with our previous classification is related to the discovery of the second nucleus in HCG 16-5, although we do not find any evidence of difference in excitation state of both nuclei, considering the large error bars (see Fig. 2). We see very little variation in the other three galaxies. The level of excitation for HCG 16-3 is higher, which suggests that the gas in this galaxy is slightly less metal rich than in HCG 16-4 (McCall, Rybski, & Shields 1985; Evans & Dopita 1985).
of the given. The parameters that were measured are the FWHM column (3), the corresponding radius in kiloparsecs is also appended "n" and the circumnuclear regions with "ci". In apertures centered on the nuclei are identified with an identified by a number that increases from east to west. The have divided the spectra in the red into seven equal apertions. The values for the nuclei are identified by filled symbols. The horizontal dotted line separates Seyfert 2 galaxies (and H II galaxies) from LINERs (SBNGs). The solid curve is the empirical separation between AGNs and starbursts as given by Veilleux & Osterbrock (1987).

To study the variation of the activity in greater detail, we have divided the spectra in the red into seven equal apertions of ~ 3′ in width. In Table 2, the different apertures are identified by a number that increases from east to west. The apertures centered on the nuclei are identified with an appended "n" and the circumnuclear regions with "ci". In column (3), the corresponding radius in kiloparsecs is also given. The parameters that were measured are the FWHM of the Hα emission line (col. [4]) and the ratio [N II]/Hα (col. [5]), which allow us to distinguish between starbursts and AGNs (Baldwin et al. 1981; Veilleux & Osterbrock 1987; Ho, Fillipenko, & Sargent 1993; Véron, González, & Véron-Cetty 1997); the equivalent width of Hα (col. [6]), which in a starburst is a good indicator of the strength of star formation (Kennicutt 1983; Kennicutt & Kent 1983; Copetti, Pastoriza, & Dottori 1986; Salzer, MacAlpine, & Boroson 1989; Kennicutt, Keel, & Bihla 1989; Coziol 1996); and the ratio [S II]λ6716 + λ6731/Hα (col. [7]), which we use as a tracer of the level of excitation (Ho et al. 1993; Kennicutt et al. 1989; Lehnert & Heckman 1996; Coziol et al. 1999a). All the lines were measured using the standard routines in SPlot, fitting the continuum by eye. A Gaussian profile was usually assumed, though in some cases, a Lorentzian was used. The uncertainties were determined by comparing values obtained by measuring the same lines in two different spectra of the same object.

In Figure 3, we present the diagrams of the ratio [N II]/Hα as a function of the EW of Hα. The corresponding regions are identified by their number in Table 2. In these diagrams, AGNs usually have a higher [N II]/Hα ratio than starbursts but smaller EW (Coziol et al. 1998a). We now examine each galaxy separately.

In HCG 16-1, the star formation in the outer regions, as noted in Figure 2, appears quite clearly. As compared to HCG 16-4, which is the strongest starburst we have in the group, the relatively lower EW of these H II regions suggests milder star formation. The EW of Hα is a measure of current to past star formation; the relatively lower EW suggests, therefore, an older phase of star formation (Kennicutt et al. 1989; Salzer et al. 1989; Coziol 1996). The star formation is constant on the east side of the galaxy (apertures 1 and 2) but decreases to the west (from aperture 6 to 7). The nucleus and circumnuclear regions do not show any variation, the condition of excitation of the gas staying constant out to a radius of ~ 1.2 kpc.

In HCG 16-2, no star formation is observed. We see a slight variation in the circumnuclear regions, within a 1 kpc radius of the nucleus, and a more significant variation in the outer regions. If we assume that the source of the gas excitation is limited to the nucleus, the variation of the [N II]/Hα and EW in the outer regions can be explained by a simultaneous decrease of the gas excitation (Hα flux goes down) and a change toward older stellar populations (EW Hα decreases). This suggests that HCG 16-2 is an AGN located in a galaxy dominated by intermediate-age and older age stellar populations. In starburst galaxies, the ratio [N II]/Hα is also sensitive to the abundance of nitrogen (Evans & Dopita 1985; Coziol et al. 1999a). The increase of [N II]/Hα in the outer regions, therefore, could also suggest an increase of the abundance of nitrogen (Staufner 1982; Storchi-Bergmann 1991; Storchi-Bergmann & Wilson 1996; Ohyama, Taniguchi, & Terlevich 1997; Coziol et al. 1999a). It may suggest a previous burst of star formation in the recent past of this AGN (Glass & Moorwood 1985; Smith et al. 1999).

HCG 16-3 is a starburst galaxy at the periphery of the four other luminous members of HCG 16 and the only one in our sample that is not an original member of the Hickson group. Comparison with HCG 16-4 indicates that the star formation is at a lower level. Again, no variation is observed within ~ 1.2 kpc of the nucleus, while the [N II]/Hα ratio increases and EW decreases in the outer regions. However, the variation of these two parameters is less severe than in the case of HCG 16-2. Because HCG 16-3 is classified as a starburst, we assume that the source of gas ionization is not limited only to the nucleus but follows the star formation. The variation observed would then mean that the star formation in the outer regions (apertures 2 and 6) is at a more advanced stage of evolution than in the nucleus.

The same behavior as in HCG 16-3 is observed in HCG 16-4. The star formation in this galaxy, however, is at a more intense level. This is probably because HCG 16-4 is in a merger phase since this galaxy has a double nucleus. Contrary to HCG 16-3, we see also some spectral variations in the nucleus, consistent with a double nucleus: apertures 3 and 2 correspond to the second nucleus, while apertures 4 and 5 correspond to the primary nucleus. Again, the outer regions seem to be in a more advanced stage of evolution than in the nucleus.

The variations observed in HCG 16-5 are much more complex than in the other galaxies. The presence of a second nucleus makes the interpretation even more difficult. In Figure 3, the second nucleus corresponds to apertures 6 and 7. It can be seen that the two nuclei have the same

![Figure 2](image_url)

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**Fig. 2.—** Standard diagnostic diagram of line ratios as measured in three different apertures. The values for the nuclei are identified by filled symbols. The horizontal dotted line separates Seyfert 2 galaxies (and H II galaxies) from LINERs (SBNGs). The solid curve is the empirical separation between AGNs and starbursts as given by Veilleux & Osterbrock (1987).
behavior. The variation of the parameters out of the nuclei is similar to what we observed in the two starbursts HCG 16-3 and HCG 16-4, but the range of variation is more similar to that observed in HCG 16-2. Although HCG 16-5 was classified as a LINER, its nature seems ambiguous, showing a mixture of starburst and AGN characteristics. It is important to note the difference with respect to HCG 16-1, which is a central AGN encircled by star-forming regions. In HCG 16-5, on the other hand, the AGN in the nucleus seems to be mixed with intense star formation (Maoz et al. 1998; Larkin et al. 1998). Out of the nucleus, there is no star formation, and the AGNs may be responsible for ionizing the gas (Haniff, Ward, & Wilson 1991; Falcke, Wilson, & Simpson 1998; Contini 1997).

3.3. Variation of the Excitation with the Radius

Comparing the ratio $[\text{N} \text{II}] \lambda 6548/\text{Hz}$ with the ratio $[\text{S} \text{II}] \lambda 6716 + \lambda 6731/\text{Hz}$ it is possible to distinguish between the different sources of excitation of the gas (Kennicutt et al. 1989; Ho et al. 1993; Lehner & Heckman 1996). Shocks from supernovae remnants in a starburst, for example, produce a $[\text{S} \text{II}] \lambda 6716 + \lambda 6731/\text{Hz}$ ratio higher than 0.6, much higher than the mean value of $\sim 0.25$ usually observed in normal H II regions or in starbursts (Greenawalt & Walterbos 1997; Coziol et al. 1997). In AGNs, however, the effects of shocks are more difficult to distinguish because both of these lines are highly excited (Baldwin et al. 1981; Veilleux & Osterbrock 1987; Ho et al. 1993; Villar-Martín, Tadhunter, & Clark 1997; Coziol et al. 1999a). We will assume here that a typical AGN has $[\text{N} \text{II}] \lambda 6584/\text{Hz} \sim 1$ and $[\text{S} \text{II}] \lambda 6716 + \lambda 6731/\text{Hz} > 0.6$.

In Figure 4, we now examine the behavior of these ratios as a function of the radius for each of the galaxies. In HCG 16-1, although we now classify the nucleus as a LINER, the values of the two ratios are still consistent with those of a typical AGN. The $[\text{N} \text{II}] \lambda 6584/\text{Hz}$ ratio for the outer starbursts are at the lower limit of the value for AGNs, but the $[\text{S} \text{II}] \lambda 6716 + \lambda 6731/\text{Hz}$ ratio is normal for gas ionized by hot stars. On the other hand, the outer region corresponding to aperture 7 has a very unusually high ratio, which suggests that this region could be the location of shocks (Ho et al. 1993; Lehner & Heckman 1996; Contini 1997).

The values observed in the starburst HCG 16-3 are consistent with excitation produced by massive stars. The outer regions, however, show values that could be interpreted as

### Table 2

| HCG Number | Aperture Number | Radius (kpc) | FWHM (km s\(^{-1}\)) | \([\text{N} \text{II}] / \text{Hz}\) | \([\text{S} \text{II}] / \text{Hz}\) |
|------------|-----------------|-------------|---------------------|-----------------------------|-----------------------------|
| 16-01 ...... | 1               | +2.37       | 0.6 ± 0.1           | 14                          | 0.31 ± 0.04                 |
|            | 2               | +1.58       | 0.60 ± 0.01         | 13                          | 0.31 ± 0.01                 |
|            | 3ci             | +0.79       | 118 ± 1             | 1.4 ± 0.2                   | 4 ± 1                       |
|            | 4n              | 0           | 115 ± 6             | 1.4 ± 0.2                   | 4 ± 1                       |
|            | 5ci             | −0.79       | 112 ± 16            | 1.4 ± 0.2                   | 4 ± 1                       |
|            | 6               | −1.58       | 0.52                | 20 ± 1                      | 0.27 ± 0.02                 |
|            | 7               | −2.37       | 126 ± 14            | 1.0 ± 0.2                   | 3 ± 1                       |
| 16-02 ...... | 1               | +2.25       | 2.7 ± 0.2           | 1.2 ± 0.1                   | 1.8 ± 0.8                   |
|            | 2               | +1.50       | 2.1 ± 0.1           | 2.1 ± 0.1                   | 1.0 ± 0.2                   |
|            | 3ci             | +0.75       | 539 ± 3             | 2.1 ± 0.1                   | 3.9 ± 0.3                   |
|            | 4n              | 0           | 522 ± 12            | 1.9 ± 0.2                   | 4.3 ± 0.4                   |
|            | 5ci             | −0.75       | 547 ± 14            | 1.9 ± 0.1                   | 4.5 ± 0.2                   |
|            | 6               | −1.50       | 89 ± 7              | 3.1 ± 0.2                   | 0.89 ± 0.04                 |
| 16-03 ...... | 2               | +1.55       | 0.60 ± 0.03         | 11 ± 2                      | 0.61 ± 0.03                 |
|            | 3ci             | +0.78       | 0.45                | 34.5 ± 0.1                  | 0.4 ± 0.1                   |
|            | 4n              | 0           | 0.45                | 34.5 ± 0.2                  | 0.36                       |
|            | 5ci             | −0.78       | 0.45 ± 0.01         | 34.5 ± 0.2                  | 0.36 ± 0.01                 |
|            | 6               | −1.55       | 0.68 ± 0.02         | 6.9 ± 0.4                   | 0.60 ± 0.04                 |
| 16-04 ...... | 1               | +2.24       | 0.42 ± 0.01         | 55 ± 2                      | 0.36 ± 0.01                 |
|            | 2               | +1.49       | 0.39                | 89 ± 2                      | 0.30                       |
|            | 3ci             | +0.75       | 0.39                | 95 ± 2                      | 0.28 ± 0.01                 |
|            | 4n              | 0           | 0.39                | 126 ± 3                     | 0.25                       |
|            | 5ci             | −0.75       | 0.39                | 122 ± 1                     | 0.24                       |
|            | 6               | −1.49       | 0.46 ± 0.01         | 43 ± 1                      | 0.46                       |
| 16-05 ...... | 1               | +3.05       | 2.49 ± 0.07         | 1                           | 1.41 ± 0.01                 |
|            | 2               | +2.29       | 2.0 ± 0.2           | 1.4 ± 0.3                   | 1.5 ± 0.3                   |
|            | 3               | +1.53       | 1.38 ± 0.02         | 2.9 ± 0.2                   | 0.8 ± 0.1                   |
|            | 4ci             | +0.76       | 0.67 ± 0.01         | 16.6 ± 0.1                  | 0.51 ± 0.01                 |
|            | 5n              | 0           | 0.61                | 46 ± 2                      | 0.38 ± 0.01                 |
|            | 6ci             | −0.76       | 0.61                | 46 ± 1                      | 0.38 ± 0.01                 |
|            | 7               | −1.53       | 1.07 ± 0.07         | 3.4 ± 0.4                   | 1.0 ± 0.1                   |

Note.—Apertures spanning the nucleus and the circumnuclear regions are indicated by n and ci, respectively. Radii are positive to the east and negative to the west.
the products of shocks. The same behavior is observed in HCG 16-4, although at a much lower level. This is consistent with the idea that HCG 16-4 is much more active than HCG 16-3. In this galaxy the burst population in the outer regions, though more evolved than in the nucleus, is, however, younger than in the outer regions of HCG 16-3.

Again, the analysis of HCG 16-5 is the most complex. The values for the primary nucleus are at the lower limit for AGNs and starburst and are consistent with shocks. The secondary nucleus has values consistent with shocks and AGNs. All the outer regions show values unusually high, suggesting the presence of shocks or domination by an AGN. This observation supports our previous interpretation that HCG 16-5 is a mixture of two AGNs with starbursts in their nucleus.

3.4. Variation of the Stellar Populations with the Radius

In this section we complete our analysis for our five galaxies by studying the characteristics of their stellar populations, as deduced from the absorption features. For this study, we measured the absorption features in three apertures. The results are presented in Table 3. The three apertures are the same as those used for the activity classification. The corresponding widths in kpc are given in column (3). The absorption features were measured by drawing a pseudo continuum by eye using a region ~100 Å wide on each side of the line. Columns (4)–(8) give the EW of the most prominent absorption features in the spectra. Column (9) gives the ratios of the center of the line intensity of the Ca II H+He lines to the center of the line intensity of the Ca II K, and column (10) gives the Mg$_2$ index. The uncertainties were determined the same way as for the emission line features.

In Figure 5, we show the diagram of the EW of H$\delta$ as a function of the (Ca II H+He)/Ca II K index (Rose 1985). This diagram is useful for identifying poststarburst galaxies (Rose 1985; Leonard & Rose 1996; Poggianti & Barbaro 1996; Zabludoff et al. 1996; Caldwell et al. 1996; Barbaro & Poggianti 1997; Caldwell & Rose 1997). Galaxies with intermediate-age populations have high EW of H$\delta$ and high
Fig. 4—[N II]/Hα ratios as a function of the [S II]/Hα, as measured using seven equal apertures of ~3". The numbers correspond to the different apertures as given in Table 2.

### TABLE 3

| HCG Number | Aperture Number | Width (kpc) | Ca II K (Å) | Ca II H (Å) | Hα (Å) | G-Band (Å) | Hβ (Å) | I(Ca II H)/I(Ca II K) | Mg2 |
|------------|-----------------|-------------|-------------|-------------|--------|------------|--------|----------------------|-----|
| 16-01 ......| 1               | 1.58        | 6.9 ± 0.3   | 4.4 ± 1.0   | 5.0 ± 0.2 | 0.84 ± 0.04 | 0.266 ± 0.004 |
|            | 2n              | 0.50        | 5.1 ± 0.8   | 3.0 ± 0.2   | 3.1 ± 0.2 | 0.08 ± 0.004 | 0.337 ± 0.002 |
| 16-02 ......| 1               | 2.50        | 10.1 ± 1.7  | 4.3 ± 0.9   | 3.2 ± 0.6 | 0.103 ± 0.002 | 0.29 ± 0.01 |
|            | 3               | 2.75        | 14.9 ± 0.5  | 2.4 ± 0.4   | 3.1 ± 0.9 | 0.96 ± 0.007 | 0.3 ± 0.2 |
| 16-03 ......| 1               | 2.50        | 10.8 ± 0.8  | 12.0 ± 0.5  | 11 ± 1  | 0.6 ± 0.04  | 0.19 ± 0.04 |
|            | 2n              | 0.50        | 8 ± 1       | 7 ± 1       | 7 ± 1  | 0.88 ± 0.007 | 0.18 ± 0.03 |
|            | 3               | 1.55        | 3 ± 0.1     | 8 ± 1       | 7 ± 1  | 0.8 ± 0.01  | 0.15 ± 0.01 |
| 16-04 ......| 1               | 2.50        | 3.2 ± 0.6   | 2.5 ± 0.5   | 2.5 ± 0.6 | 1.02 ± 0.003 | 0.125 ± 0.002 |
|            | 2n              | 0.50        | 3.2 ± 1.1   | 3.4 ± 0.4   | 3.0 ± 0.1 | 0.98 ± 0.003 | 0.114 ± 0.004 |
|            | 3               | 2.24        | 3.9 ± 0.4   | 3.4 ± 0.7   | 3.0 ± 0.1 | 0.72 ± 0.007 | 0.13 ± 0.02 |
| 16-05 ......| 1n2             | 2.79        | 12 ± 1      | 9.3 ± 1.2   | 9.3 ± 0.7 | 0.82 ± 0.002 | 0.166 ± 0.003 |
|            | 2n1             | 1.02        | 3.75 ± 0.01 | 8.4 ± 1.2   | 7.7 ± 0.5 | 0.79 ± 0.003 | 0.16 ± 0.01 |
|            | 3               | 1.78        | 4.1 ± 0.8   | 7.7 ± 0.2   | 7.9 ± 0.3 | 0.79 ± 0.003 | 0.16 ± 0.01 |
values of the \((\text{Ca} \,\text{II} \,\text{H} + \text{He})/\text{Ca} \,\text{II} \,\text{K})\) ratios. From this diagram, it can be seen that the five galaxies in HCG 16 show the presence of intermediate age stellar populations.

In Figure 5, we compare the five galaxies in HCG 16 with the sample of HCG galaxies previously studied by Coziol et al. (1998a). It can be seen that the five galaxies in HCG 16 have characteristics that indicate younger poststarburst phases than in most of the galaxies in Coziol et al. (1998a). This observation is consistent with our scenario for the formation of the groups, which suggests that HCG 16 is an example of a young group.

In Figure 5, it is interesting to compare the position of the two starburst galaxies HCG 16-3 and HCG 16-4. The position of HCG 16-3 suggests that it contains more intermediate-age stars than HCG 16-4. But at the same time we deduce from Figure 3 that HCG 16-4 has a younger burst than HCG 16-3. How can we understand this apparent contradiction? One possibility is to assume that the EW(Hδ) in HCG 16-4 is contaminated by emission, explaining the low EW observed for this galaxy. For the \((\text{Ca} \,\text{II} \,\text{H} + \text{He})/\text{Ca} \,\text{II} \,\text{K})\) indices we note also that these values are comparable with those produced by very massive stars (Rose 1985). Another alternative, however, would be to suppose that the stellar populations are from another generation, suggesting multiple bursts of star formation in HCG 16-4 (Coziol 1996; Moore, Lake, & Katz 1998; Smith et al. 1999; Taniguchi & Shioya 1998).

In Figure 5, the position of HCG 16-2 is consistent with no star formation in its nucleus. It could have been higher in the outer regions in the recent past, which is consistent with our interpretation of Figures 3 and 5 for this galaxy. We also note the very interesting position of HCG 16-5, which shows a strong poststarburst phase in the two nuclei and in the outer regions. This observation supports our previous interpretation of these two LINERs as a mixture of AGNs with starbursts in their nuclei.

Finally, we examine the stellar metallicities of our galaxies, as deduced from the Mg index (Burstein et al. 1984; Brodie & Huchra 1990; Worthey, Faber, & González 1992; Bender, Burstein, & Faber 1993). In Figure 6, the stellar metallicity is shown as a function of the ratio \(\text{EW(\text{Ca} \,\text{II} \,\text{K} + \epsilon)}/\text{EW(\text{Ca} \,\text{II} \,\text{H})}\), which increases as the stellar population gets younger (Rose 1985; Dressler & Schectman 1987). For our study, we assume that a high value of the Mg index indicates a high stellar metallicity. In Figure 6, the range of Mg generally observed in late-type spirals is indicated by two dotted lines. The upper limit for the early-type galaxies is marked by a dashed line.

Figure 6 suggests that the stellar populations are generally more metal rich in the nuclei than in the circumnuclear regions. The two AGNs, HCG 16-1 and HCG 16-2, are more metal rich and, therefore, more evolved. HCG 16-3 and HCG 16-4 have, on the other hand, typical values for starburst galaxies (Coziol et al. 1998a). In terms of stellar population and metallicity, HCG 16-5 is more similar to HCG 16-3 and HCG 16-4, which suggests a similar level of evolution.

4. DISCUSSION

Our observations are consistent with the existence of a close relation between AGNs and starbursts. In our sample the most obvious case is HCG 16-1, which has a LINER nucleus and star formation in its outer regions. A similar
situation was probably present in HCG 16-2, in the recent past. HCG 16-5, on the other hand, shows a very complicated case in which we cannot clearly distinguish between star formation and AGN activity. The question then is what is the exact relation between these two phenomena?

One possibility would be to assume that AGNs and starbursts are, in fact, the same phenomenon (Terlevich et al. 1991): the AGN characteristics are produced by the evolution of a massive starbursts in the center of the galaxies. HCG 16-5 could be a good example of this. However, nothing in our observations of this galaxy allows us to identify the mechanism producing the LINER with only star formation. In fact, the similarity of HCG 16-5 to HCG 16-2 suggests that what we see is more a mixture of the two phenomena, where an AGN coexists in the nucleus with a starburst (Maoz et al. 1998; Larkin et al. 1998; Gonzalez-Delgado et al. 1997; Serlemitsos, Ptak, & Yaqoob 1997).

Perhaps the two phenomena are different but still related via evolution. In one of their recent papers, Gonzalez-Delgado et al. (1997) proposed a continuous sequence in which a starburst is related to a Seyfert 2, which, at the end, transforms into a Seyfert 1. Following our observations, it is interesting to see that in terms of stellar populations, HCG 16-1 and HCG 16-2 are the most evolved galaxies of the group. In Coziol et al. (1998a) we also noted that this is usually the case for the luminous AGN and low-luminosity AGN galaxies in the groups. The AGNs in the samples of Gonzalez-Delgado et al. (1998) and in Hunt et al. (1997) all look like evolved galaxies. However, as we noted in the Introduction, we have not found any Seyfert 1's in the 60 compact groups we have investigated (Coziol et al. 1998b). Following the scenario of Gonzalez-Delgado et al. (1998), this would simply mean that the groups are not evolved enough. This is difficult to believe as it would suggest that we observe all these galaxies in a very special moment of their existence. In Coziol et al. (1998a), the observations suggests that the end product of the evolution of the starburst–Seyfert 2 connection in the groups is a low-luminosity AGN or a galaxy without emission lines.

Perhaps there are no Seyfert 1's in the groups because the conditions for the formation of these luminous AGNs are not satisfied in the groups. On this matter, it is interesting to find two mergers in HCG 16: HCG 16-4 and HCG 16-5. But galaxy HCG 16-4 is a strong starburst, while HCG 16-5 is, at most, a LINER or a Seyfert 2. Could it be then that the masses of these two mergers were not sufficient to produce a Seyfert 1? Maybe the mass of the merging galaxies and/or the details on how the merging took place are the important parameters (Moles, Sulentic, & Marquez 1997; Moore, Lake, & Katz 1998; Lake, Katz, & Moore 1998; Taniguchi 1998; Taniguchi & Shioya 1998).

An evolutionary scenario for the starburst-AGN connection is probably not the only possible alternative. It could also be that the presence of a massive black hole (MBH) in the nucleus of an AGN influences the evolution of the star formation (Perry 1992; Lake et al. 1998; Taniguchi 1998). One can imagine, for instance, that a MBH is competing with the starburst for the available gas. Once the interstellar gas has become significantly concentrated within the central region of the galaxy, it could accumulate in an extended accretion disk to fuel the MBH. Assuming 10% efficiency, accretion representing only $7 M_\odot$ yr$^{-1}$ will easily yield $10^{13} L_\odot$, while astration rates of 10–100 $M_\odot$ yr$^{-1}$ are necessary to produce $10^{11–10}{12} L_\odot$ (Norman & Scoville 1988). Obviously the gas that goes into the nucleus to feed the MBH will not be available to form stars; hence, the star formation phase will have a shorter lifetime. Other phenomena also related to AGNs, such as jets, ejection of gas, or even just a very extended ionized region, could stimulate or inhibit star formation in the circumnuclear regions (Dey et al. 1997; Falcke 1998; Quillen & Bower 1999). Obviously, the more active the AGN, the greater its influence should be. Therefore, the fact that most of the AGNs in the compact groups are of the shallower types (Seyfert 2, LINER and low-luminosity AGN) suggests that these phenomena probably were not so important in the groups.

Another interesting aspect of our observations concerns the origin of the compact groups. In Coziol et al. (1998a) and Ribeiro et al. (1998), we suggest that the cores of the groups are old collapsing structures embedded in more extended systems, where they are replenished in galaxies (Governato et al. 1996). We have also proposed an evolutionary scenario for the formation of the galaxies in the group. Following this scenario, HCG 16 would be an example of a group at an early stage of its evolution. Our present observations support this scenario and give us further insights on how the groups could have formed.

The original core of HCG 16 is formed of the galaxies HCG 16-1, HCG 16-2, HCG 16-4, and HCG 16-5 (Ribeiro et al. 1998). Our observations now suggest that HCG 16-1 and HCG 16-2 form the evolved core of HCG 16, while HCG 16-4 and HCG 16-5 are more recent additions. The fact that we see traces of mergers in these two last galaxies suggests that HCG 16-4 and HCG 16-5 originally were not two massive galaxies but four smaller mass, metal-poor galaxies. The remnant star formation activity in HCG 16-1 and HCG 16-2 could also indicate that they too were formed by mergers, but a much longer time ago. This scenario may resolve the paradox of why galaxies in the cores of the HCGs have not already merged to form one big galaxy (Zepf & Whitmore 1991; Zepf 1993). If HCG 16 is typical of what happened in the other groups, then originally the number of galaxies was higher and their mass lower and hence the dynamic of the groups was much different. HCG 16-3 looks, on this matter, like a more recent addition and suggests that the process of formation of the group is still going on today.

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