The Astrophysical Journal, 497:72–88, 1998 April 10

STRUCTURAL AND DYNAMICAL ANALYSIS OF THE HICKSON COMPACT GROUPS

André L. B. Ribeiro,[1] Reinaldo R. de Carvalho,[2] Hugo V. Capelato,[1] and Stephen E. Zepf[3,4]

Received 1997 May 5; accepted 1997 November 14

ABSTRACT

Based on the spectroscopic survey of de Carvalho et al., we analyze the structural and dynamical properties of 17 Hickson compact groups. This analysis probes a region of $0°.5 \times 0°.5$ around each group and shows that most of them are part of larger structures. Our results also suggest that the Hickson sample is composed of different dynamical stages of the groups" 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.

Subject headings: galaxies: clusters: general — galaxies: interactions

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 a cosmological viewpoint, providing constraints on the density parameter, Ω_0, and on the primordial density fluctuation spectrum (e.g., West, Oemler, & Dekel 1989). Also, the study of groups is important for investigating the relevant processes in the course of galaxy formation and evolution. 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.

Because of their dynamical importance, CGs have been the subject of several observational programs. The first systematic study of these systems was made by Rose (1977), while the best studied sample is that of Hickson (1982). Hickson selected his sample from the Palomar Sky Survey red prints and found exactly 100 compact groups (HCGs) satisfying three selection criteria (see § 2.1). The properties of these groups have been extensively studied over the years. One of the most important conclusions from such studies is that although galaxy mergers are expected to be more common in CGs than in other environments (e.g., Rubin, Hunter, & Ford 1991), the present merging rate is lower than that measured from the observed crossing times in HCGs (Zepf & Whitmore 1991; Zepf 1993). This result indicates that the physical nature of CGs is not completely understood. In fact, it has been suggested that they are mainly the result of chance alignments within loose groups (Mamon 1986, 1992, 1994) or within filaments (Hernquist, Katz, & Weinberg 1994; Ostriker, Lubin, & Hernquist 1995). In such a context, most CGs are just transient configurations. However, it is difficult to support the chance alignment idea after the X-ray survey of HCGs recently published by Ponman et al. (1996). This survey suggests that at least $\sim 75\%$ of the HCGs exhibit X-ray emission from hot intragroup gas. The presence of hot gas associated with a group provides strong evidence for a genuine bound system as well as reveals some aspects of its dynamics and evolutionary history (Ponman et al. 1996).

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 a 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. For instance, Governato, Tozzi, & Cavaliere (1995) suggest that compact groups are bound systems and that the infall of surrounding galaxies onto the groups can regenerate their dynamical state after the first galaxies have merged. Similarly, Diaferio, Geller, & Ramella (1994, 1995) propose that compact groups form continually in a single rich group during its collapse and virialization. These ideas are based on the observational evidence that CGs are located within looser structures or rich neighborhoods (Rose 1977; Sulentic 1987; Rood & Williams 1989; Ramella et al. 1994; de Carvalho, Ribeiro, & Zepf 1994). The presence of galaxies in the surroundings of CGs can redefine the dynamical state of these systems.

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 km s^{-1}. The spectra were taken with the Argus multifiber spectrograph at the prime focus of the Blanco 4 m telescope at Cerro Tololo Inter-American Observatory. The details of the observational setup and data reduction methodology are found in de Carvalho et al. (1997, hereafter Paper I). The survey extends the study of galaxies in CGs down to a magnitude limit of ~ 19.5 in the B band. At this limit it is possible to investigate more properly the compactness and isolation of the Hickson groups. In this work, we analyze the dynamical structure of the

[1] Divisão de Astrofísica, INPE/MCT, C.P. 515, 12201-970, São José dos Campos, Brazil.

[2] Observatório Nacional, CNPq, Departamento de Astrofísica, Brazil.

[3] Department of Astronomy, University of California, Berkeley, Berkeley, CA 94720.

[4] Hubble Fellow.

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 agglomerations and their relation to the large-scale structure are considered. We also discuss the various dynamical stages of the groups revealed by this analysis. (For all distances in this paper, $H_0 = 75$ km s^{-1} Mpc^{-1}.)

2. CRITERIA USED TO DEFINE COMPACT GROUPS

2.1. *Hickson's Criteria*

Groups of galaxies raise important questions concerning the importance of environmental effects on galaxy formation and evolution. In spite of that, 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 neighborhood, especially the faint end of the luminosity function (see de Carvalho, Ribeiro, & Zepf 1994, hereafter dCAZ94; and Ribeiro, de Carvalho, & Zepf 1994). 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 HCGs 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 HCGs. In addition, a recent study made by Barton et al. (1996) concludes that the isolation criterion is not a good indicator of the environment around CGs and contains no information about the physics of the groups. Thus, the Hickson sample may be not representative of real compact systems since the groups can be more extended in both luminosity and radius. This is a clear indication that we need more data, similar to those described here, in the regions around CGs in order to quantify what these systems really are.

2.2. *How to Redefine HCGs*

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. The first catalogs of CGs were published even when the galaxy redshifts were not obtained (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 (as discussed in § 2.1 for the Hickson's case). Particularly, the redshifts for the HCG galaxies were obtained 10 years after the original catalog. This important survey showed that among the 100 HCGs, 92% have $N \geq 3$ and 69% have $N \geq 4$ (Hickson et al. 1992).

Over the years, the methods used to identify physical galaxy groups have evolved significantly with the increasing number of redshift surveys of galaxies (e.g., Huchra & Geller 1982; Giovanelli & Haines 1993). The approach of looking for groups in such catalogs includes the use of different versions of the friends-of-friends algorithm, exploring the quasi–three-dimensional information available. Recently, a new group-finding code from Ramella, Pisani, & Geller (1997) has been used by Barton et al. (1996) to identify CGs as linked sets of "neighboring" galaxies. In this case, the size of the groups is restricted by the limiting parameters ΔD, for the projected separation of each pair of galaxies in a group, and ΔV, for their radial velocity difference. The values of these parameters were selected to produce galaxy systems with properties similar to HCGs. Thus, neighbor galaxies should follow the conditions $\Delta D \leq 67$ kpc and $\Delta V \leq 1000$ km s^{-1}. This search algorithm yields a catalog of 89 groups of three or more galaxies with properties similar to those of HCGs (Barton et al. 1996).

Although automated searches are unquestionably an efficient method to detect structures in large surveys of galaxies, they present some biases introduced by the magnitude-limited nature of the redshift surveys. Naturally, group catalogs defined in this way have a completeness bias in the sense of the most distant groups include only high-luminosity objects, so that the faint end of the luminosity function is not properly probed. At the same time, it appears to be difficult to define specific parameters and criteria that correctly identify all structures. For instance, Mamon (1989) applied the Hickson's criteria to a catalog of galaxies in the Virgo cluster and found a compact group. Likewise, Rood & Struble (1994, hereafter RS94) indicate a great number of spatial coincidences between HCGs and loose groups and clusters, despite the isolation criterion applied by Hickson. As noted by Ebeling, Voges, & Böhringer (1994), about one-third of all HCGs are located within a 30′ distance from an Abell or ACO galaxy cluster, which is about twice the number of coincidences expected if the two samples were uncorrelated. For these reasons, we think that automated searches of galaxy catalogs are best used for an initial search and definition of samples of galaxy groups. A more detailed investigation of each structure is then necessary in order to ascribe a final classification to a galaxy system. In this paper, we study a sample of HCGs both by picking out structures in the velocity space and by looking for the structural extensions of them within a region of $0\overset{\circ}{.}5 \times 0\overset{\circ}{.}5$. Our analysis indicates that a number of surrounding galaxies may be physically attached to the groups. Therefore, it is important to know how such objects modify the HCGs structural and dynamical properties.

The first step toward this goal is to search for kinematical structures in each studied region. Based on the spectroscopic survey (see Paper I), we analyze the velocity distributions in the regions of the 17 HCGs in our sample. This was made through the use of statistical methods proposed by Beers, Flynn, & Gebhardt (1990), using the ROSTAT package (Bird & Beers, 1993). ROSTAT is a statistical package for robust and exploratory analysis of onedimensional data. It includes both canonical estimators of location (median) and scale (dispersion) and robust estimators that do not depend on the parent sample distribution. There are several robust and resistant estimators. The choice of the more adequate ones depend on the size of the sample. For small groups (five to 15 objects), the unbiased estimations of central location and scale of the velocity distribution can be provided by the biweight estimators, $C_{\rm bi}$ and $S_{\rm bi}$, respectively. The confidence intervals (90%) of each estimation correspond to the location and scale errors, $IC_{C_{\rm bi}}$ and $IC_{S_{\rm bi}}$. These were determined using the bootstrap method. The number of bootstrap resamples was set to 1000 in order to obtain accurate percentile intervals (Efron 1987; Beers et al. 1990). The normality of the velocity distribution was studied through the *a*, *u*, and *w* canonical tests (see Yahil & Vidal 1977). In addition, we have employed three other tests based on the empirical velocity distributions: the Cramer–von Mises statistics (W^2), the Watson statistics (U^2), and the Anderson-Darling statistics (A^2) (see details about these tests in D'Agostino 1986). All of these tests quantify the deviation of the velocity distribution from a Gaussian. The null hypothesis that the distributions are drawn from a Gaussian population is rejected at significance levels smaller than 10%.

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' are the measured gaps between the ordered velocities and the w_i' are a set of approximately Gaussian weights. A gap is considered significant if its value is greater than 2.25 (Wainer & Thissen 1976). This value means that random draws from a Gaussian distribution produce weighted gaps this size (or larger) no more than 3% of the time. The presence of big 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. These are foreground and background objects that we have to separate from the main structure. The iterative use of ROSTAT is employed to isolate the sample from interlopers. Thus, the presence of n big gaps divides the data in $n+1$ subsets of galaxies to be individually analyzed with ROSTAT. A kinematical structure is defined only when we have a set of at least three galaxies whose velocity distribution does not present big gaps between the data points. The results of this analysis are summarized in Table 1, where we list the kinematical properties and the most relevant statistical information about the 17 HCGs comprising our sample. Column (1) is the group number; column (2) is the number of objects in the kinematic structure; columns (3) and (4) list the biweight estimate of central location and its associated 90% bootstrap confidence interval; columns (5) and (6) list the biweight scale estimator and its associated 90% bootstrap confidence interval; columns (7)–(14) list the value of the statistics and associated probability for the *a*, *u*, *W*, and A^2 tests, respectively. The results of the Cramer–von Mises and Watson tests are similar to the Anderson-Darling test and are not reported here.

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 behavior of their structural properties as a function of the radius of the systems. This analysis is presented in the next section.

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 barycenter 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 in Figures 1*a*–1*d* always 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. Table 2 lists the final structural parameters of the groups. Column (1) is the group number;

TABLE 1

KINEMATICAL AND STATISTICAL PROPERTIES OF THE GROUPS

HCG (1)	N (2)	$C_{\rm bi}$ (3)	$IC_{C_{\rm bi}}$ (4)	$S_{\rm bi}$ (5)	$IC_{S_{\rm bi}}$ (6)	a (7)	$p(a)$ (8)	u (9)	$p(u)$ (10)	W (11)	$p(W)$ (12)	A^2 (13)	$p(A^2)$ (14)
4......	5	7345	511	775	585	0.83	...	2.35	0.10	0.91	0.45	0.39	0.39
16......	7	3859	66	86	56	0.79	...	2.75	0.10	0.93	0.60	0.31	0.57
19......	7	4143	263	170	291	0.69	...	2.79	0.10	0.73	0.01	0.97	0.01
22......	4	2629	33	40	28	...	...	...	...	...	...	...	...
23......	8	4873	363	514	414	0.67	...	2.22	0.04	0.85	0.08	0.59	0.13
40......	7	6664	203	280	230	0.71	...	3.15	0.09	0.90	0.37	0.47	0.25
42......	11	3865	160	330	285	0.63	<0.01	3.70	0.09	0.87	0.08	0.66	0.08
62......	13	4594	192	335	174	0.77	0.10	3.62	0.10	0.88	0.06	0.60	0.11
63......	7	9319	271	270	315	0.65	...	3.12	0.10	0.84	0.10	0.67	0.08
64......	4	10694	61	69	55	...	...	...	...	...	...	...	...
67......	14	7435	196	351	193	0.82	0.10	3.46	0.10	0.91	0.15	0.64	0.09
86......	18	6049	259	513	218	0.83	0.10	3.55	0.10	0.93	0.21	0.69	0.07
87......	6	8631	236	249	184	0.87	...	2.26	0.04	0.83	0.10	0.61	0.11
88......	6	6074	58	72	58	0.75	...	2.77	0.10	0.87	0.22	0.51	0.19
90......	9	2590	88	156	81	0.74	...	3.36	0.10	0.97	0.88	0.24	0.77
97......	14	6642	193	424	146	0.78	0.10	3.47	0.10	0.98	0.92	0.18	0.92

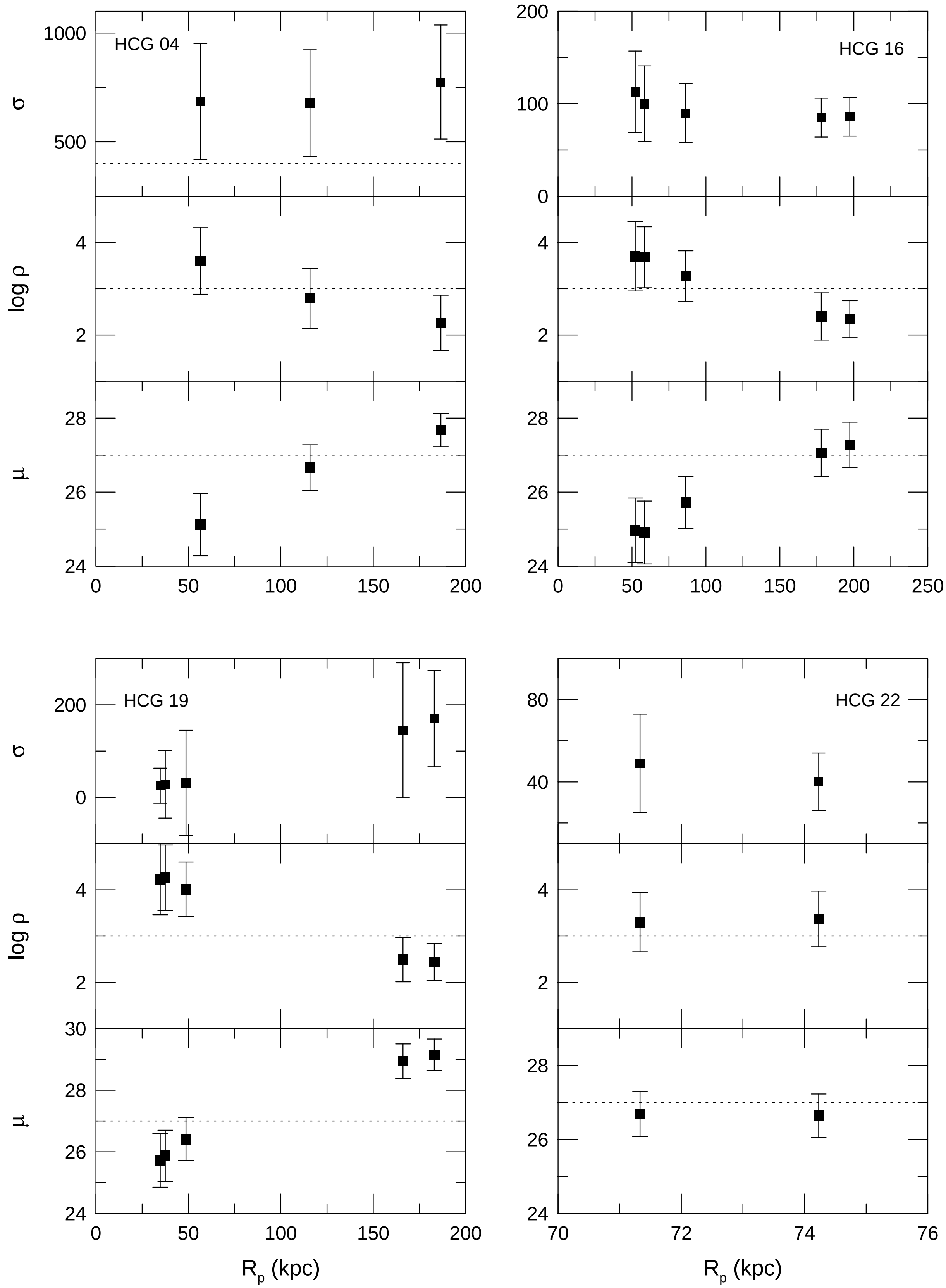

FIG. 1.—Results of our analysis for the groups. The upper panel in each graph is the velocity dispersion (in km s^{-1}). The middle panel is the spatial density (in gal Mpc^{-3}). The lower panel is the surface brightness (in mag $arcsec^{-2}$); the dotted line divides low and bright surface brightness groups. All these quantities are shown as function of the radius (in kpc) of each structure. The radius is estimated from the median projected separation of the galaxies, and the center of the groups correspond to the nominal center of HCGs. The dotted line corresponds to the limiting values for a compact group.

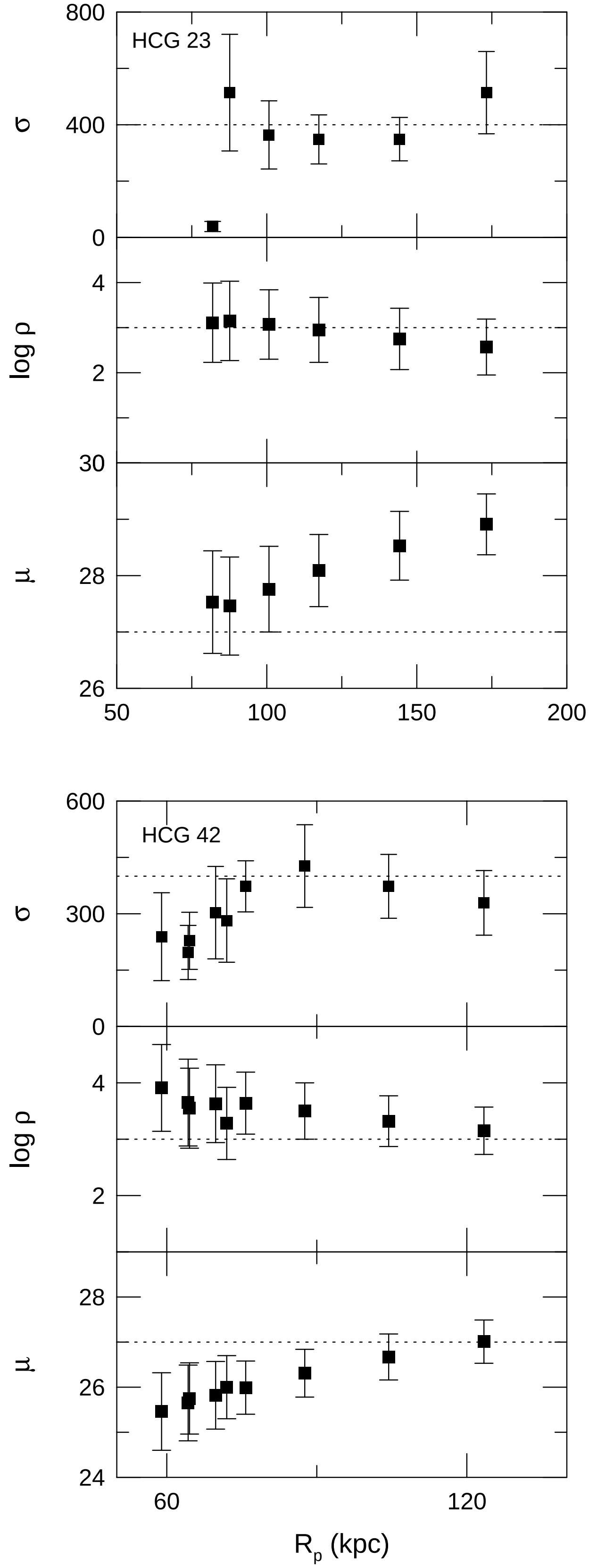

FIG. 1—*Continued*

column (2) lists the number of galaxies in the group; column (3) lists the mean surface brightness of the group (in mag arcsec^{-2}); column (4) is the spatial density of the group (in gal Mpc^{-3}, obtained from $3N/4\pi R^3$); column (5) lists the velocity dispersion (in km s^{-1}) of the galaxies in the group as determined by the biweight estimator of scale; and column (6) is the radius of the group defined as the median pairwise galaxy separations (in kpc).

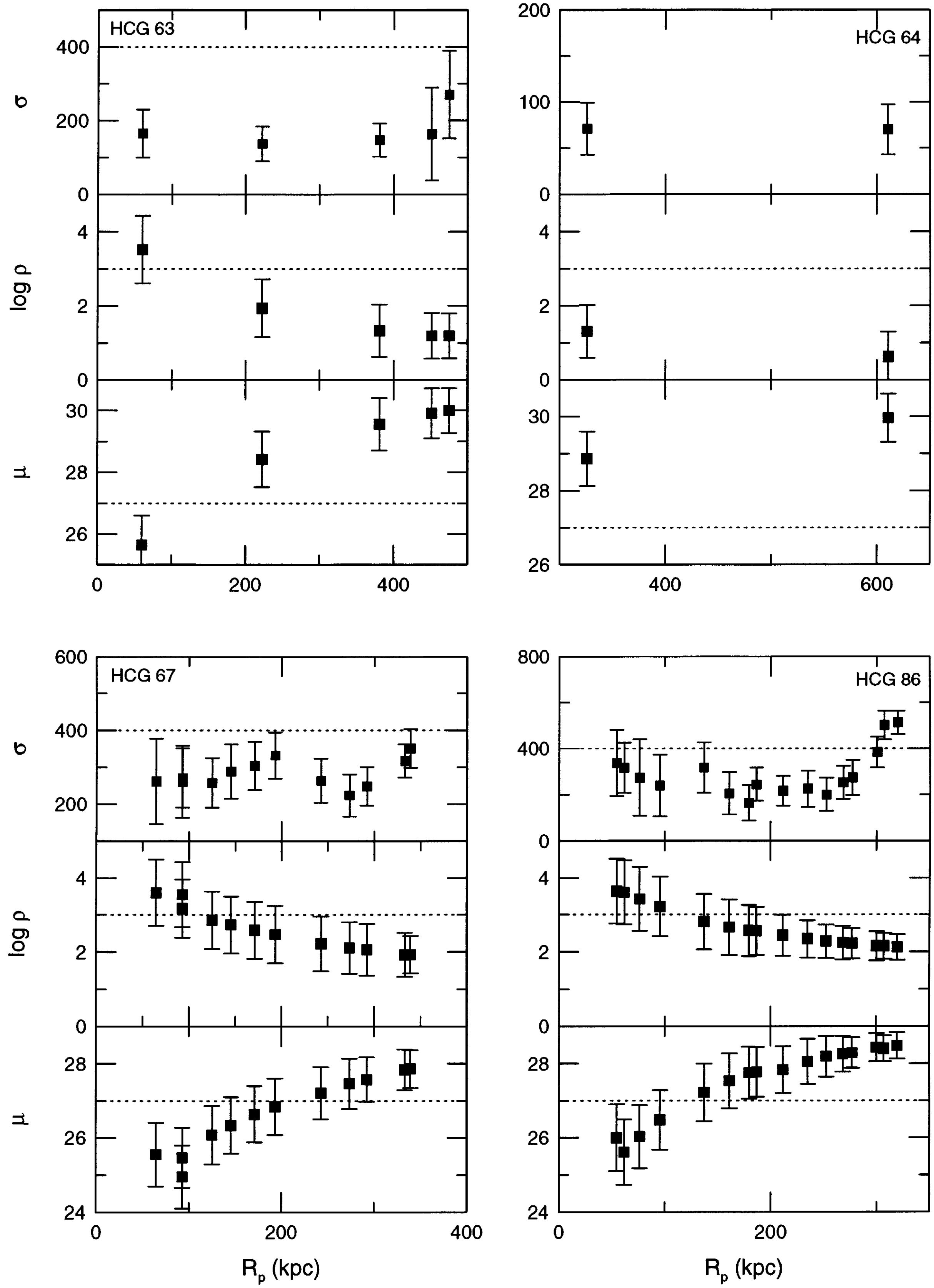

FIG. 1—*Continued*

In Figures 1*a*–1*d* we see that 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. A very simple and illustrative way of investigating the compactness of the groups is to compare the behavior of their structural

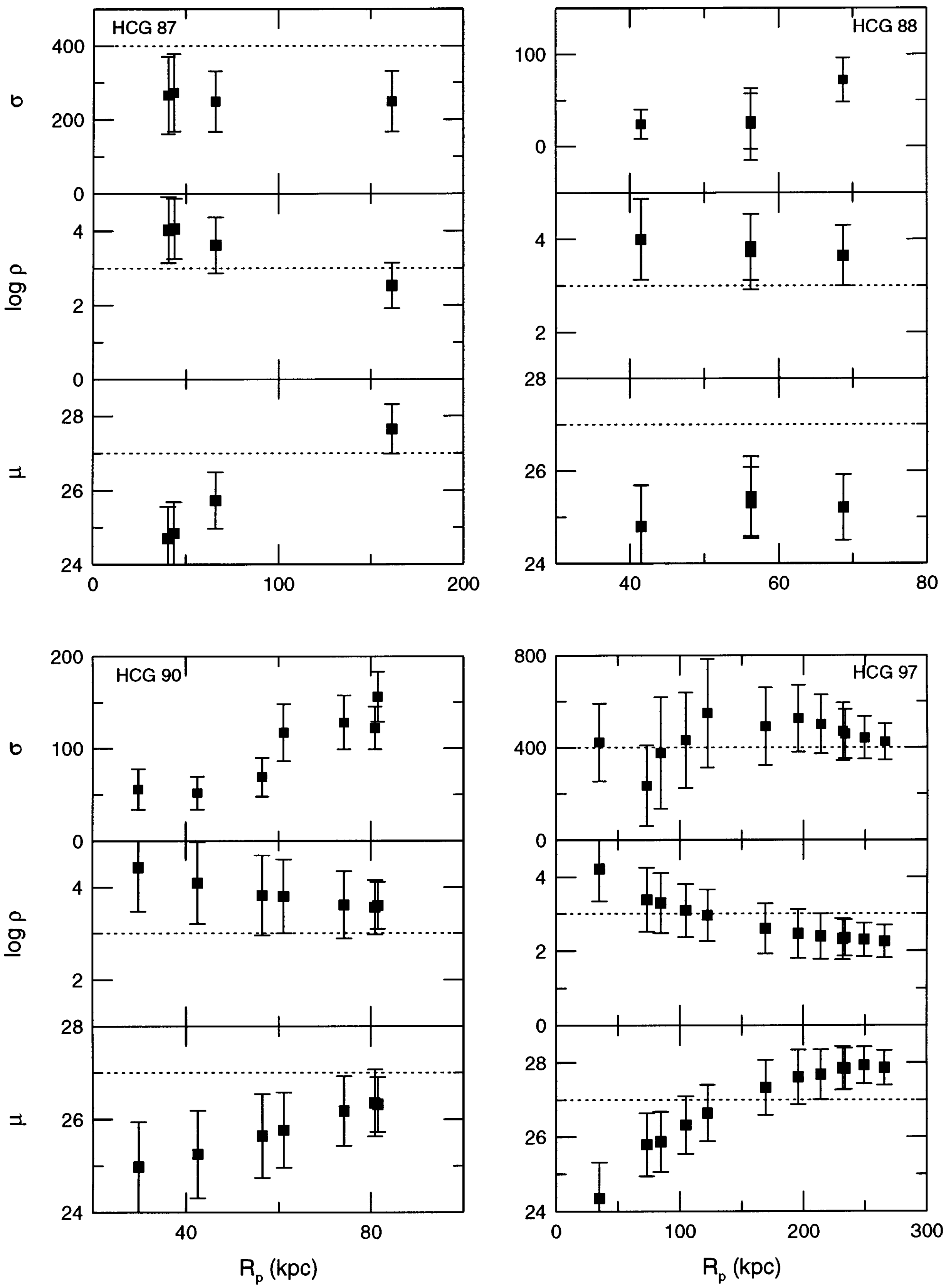

FIG. 1—*Continued*

parameters to the values we would expect from a typical Hickson group. This comparison is plotted in Figures 1*a*–1*d* dotted lines. In the panels displaying the velocity dispersion, the limit 400 km s^{-1} is based on the range (100–400 km s^{-1}) generally found in CGs (Hickson et al. 1992). This means that a compact group with velocity dispersion higher than this limit is probably not compact. A similar argument was used to define the minimum value of the

TABLE 2

STRUCTURAL PROPERTIES OF THE GROUPS

HCG (1)	N (2)	μ (3)	$\log \rho$ (4)	σ (5)	R_P (6)
4......	5	27.68	2.26	775	187
16......	7	27.28	2.34	86	197
19......	7	29.15	2.44	170	183
22......	4	26.64	3.37	40	74
23......	8	28.91	2.57	514	173
40......	7	26.18	3.35	280	91
42......	11	27.01	3.15	329	123
62......	13	27.82	2.54	335	207
63......	7	30.00	1.19	270	475
64......	4	29.96	0.62	69	611
67......	14	27.86	1.93	351	339
86......	18	28.48	2.12	513	320
87......	6	27.65	2.53	249	161
88......	6	25.21	3.65	72	69
90......	9	26.32	3.60	156	82
97......	14	27.86	2.25	425	266

spatial density: 10^3 gal Mpc^{-3}. Groups less dense than this limit are not so compact, since the typical range of densities in compact systems is 10^4–10^6 gal Mpc^{-3} (Hickson 1982; Hickson et al. 1992). Finally, the surface brightness limit is exactly the same used by Hickson (1982), corrected to the B band (see dCAZ94). It means that groups with $\mu > 27$ mag arcsec^{-2} have too low surface brightness to be considered compact.

In the following, we briefly describe the properties of each group in our sample and discuss the dependence of the compactness on the radius and the membership. Some useful parameters for our discussion are listed in Table 3. Column (1) is the group identification; column (2) is the physical scale in Mpc equivalent to 0°.5; column (3) is the absolute magnitude where the completeness is $\sim 90\%$ of the objects sampled in each region; column (4) is the ratio between the radius of the groups and the physical scale of the field; and column (5) is the ratio between the optical radius and the upper limit radius of the X-ray emission detected by *ROSAT* (Ponman et al. 1996). The maps of each studied region can be seen in Paper I.

TABLE 3

PHYSICAL SCALE AND COMPLETENESS

HCG (1)	Scale (Mpc) (2)	M_B (90%) (3)	$\Re_1$ (4)	$\Re_2$ (5)
4......	0.822	−17.22	0.23	...
16......	0.439	−15.58	0.45	1.47
19......	0.472	−14.52	0.39	...
22......	0.302	−15.13	0.25	0.55
23......	0.553	−15.26	0.31	1.29
40......	0.749	−17.66	0.12	0.67
42......	0.441	−15.76	0.28	0.93
48......	0.455	−15.93	...	...
62......	0.522	−16.14	0.40	0.61
63......	1.032	−18.50	0.46	3.58
64......	1.176	−18.92	0.52	4.57
67......	0.832	−18.34	0.41	2.53
86......	0.681	−16.48	0.47	2.38
87......	0.959	−16.97	0.17	1.21
88......	0.684	−19.02	0.10	0.51
90......	0.297	−14.94	0.27	0.61
97......	0.746	−17.66	0.36	0.79

3.1. *HCG 4*

For this field, the main structure identified by the kinematical analysis has a central location at $V = 7345$ km s^{-1} and is composed of galaxies 1a, 2b, and 3d from Hickson's catalog plus two other galaxies, 11 and 23, from our catalog (Paper I). This set of galaxies presents no big gap in the velocity distribution and has normality rejected only by the u test, at a significance level of 10% (see Table 1). First of all, we should note that if we consider only the original Hickson galaxies, we have a median projected separation of 56 kpc, while if we account for all of the galaxies, this value increases to 187 kpc. In the same way, the surface brightness changes from 25.4 to 29.2 mag arcsec^{-2}. Besides, note that only the central triplet presents spatial density higher than the limit of 10^3 gal Mpc^{-3} (see Fig. 1*a*). This suggests that only the central part of the system would be really compact. The two other galaxies could be neighbors orbiting or falling into the triplet. However, we should note that even the central triplet has a velocity dispersion (775 km s^{-1}) significantly higher than that expected for a typical compact group (see Fig. 1*a*). The X-ray emission detected by *ROSAT* seems to be associated with a single source, galaxy 1a (Saracco & Ciliegi 1995; Pildis et al. 1995; and Ponman et al. 1996). For all these considerations, it is not conclusive that we have a compact group here. In fact, we cannot discard a chance alignment case in this field.

We also have the discordant galaxies 4c and 5e plus galaxy 13 forming a group at $V \sim 18{,}400$ km s^{-1}. This set of objects presents no big gap in the velocity distribution and possibly corresponds to a physical structure. However, our data are too incomplete to make any firm conclusion about this system.

3.2. *HCG 16*

The kinematical analysis identifies a group of seven objects at $V = 3859$ km s^{-1} with no big gap in the velocity distribution for this field. Only the u test rejects the normality to this set of objects, at a significance level of 1%. This group corresponds to a core formed by the four Hickson galaxies (1a, 2b, 4c, and 5d) plus galaxies 3, 6, and 10 from Paper I. In Figure 1*a*, we see that the core extends up to 86 kpc while the entire group reaches 197 kpc. At the same time, the surface brightness goes from 25.72 to 27.28 mag arcsec^{-2} and the spatial density goes from 1738 to 217 gal Mpc^{-3}. Such behavior indicates that only the four Hickson galaxies plus the nearest object (galaxy 6) form a compact system. Although the velocity dispersion is lower than the limit of 400 km s^{-1} over the whole extension, our analysis suggests that this group may be composed of a compact and active galactic nucleus–dominated quintet surrounded by a more extended and starburst dominated "halo" (Ribeiro et al. 1996). This halo probably makes part of a larger structure since, according to RS94, this group is associated to the group LGG 49 (Lyon Groups of Galaxies catalog; Garcia 1993). The diffuse X-ray emission detected by Ponman et al. (1996) up to 133 kpc around the Hickson galaxies reinforces the idea that we have a bound structure here. These results support a view that HCG 16 may be a collapsing region within a larger and sparser structure. A prominent and active core is already formed, while the galaxies in the halo will probably replenish it in the future. Since the halo is probably part of a larger system, this scenario agrees well with that proposed by Diaferio, Geller, & Ramella (1994, 1995).

3.3. *HCG 19*

The kinematical analysis identifies a group of seven objects at $V = 4143$ km s^{-1} with no big gap in the velocity distribution. For this set of galaxies normality is rejected by three tests at significance levels of 1% (W and A^2 tests) and 10% (u test). This group is formed by the original Hickson galaxies (1a, 2b, and 3c) plus galaxies 9 and 14 from Paper I within a radius of 49 kpc, and a more extended halo (similar to HCG 16) formed by two other objects from Paper I, galaxies 4 and 24. The size of the entire group reaches 183 kpc. This structure seems to contain two different dynamical ranges: the central quintet is very compact and has a density of $\sim 10^4$ gal Mpc^{-3}. The whole structure presents a much lower density, $\sim 10^2$ gal Mpc^{-3}. Like HCG 16, the surface brightness changes when we go from the core to the outer part of the system (26.41–29.15 mag arcsec^{-2}) (see Fig. 1*a*). At the same time, the velocity dispersion increases from 31 to 170 km s^{-1} (a factor of ~ 5), but still remains lower than the limit of 400 km s^{-1}. On the other hand, this group does not present diffuse X-ray emission (Ponman et al. 1996) and does not seem to be related to larger structures (RS94). A possible interpretation of these results is that HCG 19 is a compact quintet plus two neighbors probably orbiting or infalling into the core. This scenario is consistent with that proposed by Governato, Tozzi, & Cavaliere (1996).

3.4. *HCG 22*

The kinematical analysis identifies two sets of objects with no big gap. The compact group, as defined by Hickson (1982), has two objects with discordant redshifts, galaxies 5d and 6e. Indeed, these galaxies are located in the new group we have found, located at $V = 9482$ km s^{-1}. The main group (HCG 22a), located at $V = 2629$ km s^{-1}, is composed of the Hickson galaxies 1a, 4b, and 2c plus galaxy 3 from Paper I. If we consider the just Hickson galaxies, we have a radius of 71 kpc, which extends to 74 kpc if we include galaxy 3 in the structure. In this case, such inclusion does not represent a significant change in density, surface brightness, or velocity dispersion (see Fig. 1*a*). Thus, we conclude that this group is a real compact quartet. However, according to RS94, this group is associated to a larger structure, namely, N1209 or LGG 81. Diffuse X-ray emission is detected up to the upper limit radius of 133 kpc (Ponman et al. 1996). So it is possible that a new survey covering a larger area around this group would reveal some galaxies orbiting HCG 22a and forming a halo similar to those observed in HCGs 16 and 19.

Behind HCG 22a, we found four galaxies that possibly form another group (HCG 22b), galaxies 5d and 6e plus galaxies 7 and 10 from Paper I. The low surface brightness (29 mag arcsec^{-2}) and the low density (20 gal Mpc^{-3}) of this group suggest we have a sparser structure here. However, we should keep in mind that the incompleteness is larger for this background group, and so further investigation is necessary to correctly determine its properties.

3.5. *HCG 23*

The kinematical analysis identifies two groups with no big gap. The main group is located at $V = 4873$ km s^{-1} and corresponds to the original Hickson group (galaxies 1b, 3a, 4d, and 5c) plus four galaxies from Paper I (galaxies 18, 20, 25, and 26). Normality is rejected by the tests u and W at significance levels of 4% and 8%, respectively. The other group is located at a redshift near to the discordant galaxy 6e ($V = 10{,}039$ km s^{-1}). The density of the main group is close to the limit of 10^3 gal Mpc^{-3}, and the radius (173 kpc) is larger than the upper limit radius of the X-ray extension (133 kpc; Ponman et al. 1996). The surface brightness of the group is lower than the limit of 27 mag arcsec^{-2} (see Fig. 1*b*), and the velocity dispersion oscillates around the limit of 400 km s^{-1}. So, a possible scenario for this structure is the beginning of a collapse within a loose group. If this is the case, a prominent core is not completely formed yet. Maybe, we are witnessing the formation of a compact group in HCG 23.

The background group, formed by the galaxies 2, 6e, 7, 8, 12, 16, 17, and 29 and located at $V = 10{,}060$ km s^{-1}, presents low surface brightness (30.57 mag arcsec^{-2}) and the low density (12 gal Mpc^{-3}), and, in contrast to the main group, it does not seem to be a collapsing structure. It more possibly corresponds to a sparser structure.

3.6. *HCG 40*

The kinematical analysis identifies a set of seven objects at $V = 6664$ km s^{-1} with no big gap. The normality is rejected only by the u test at a significance level of 9%. The central part of this group is formed by the original Hickson galaxies (1a, 2b, 3c, 4d, and 5e) plus galaxy 6 from Paper I. Another object from Paper I can be added to the group, galaxy 17. Although the seven galaxies form a high surface brightness and dense structure, the radius of the group increases by a factor of ~ 3 when galaxy 17 is considered (31–91 kpc). However, even including this object, the group presents velocity dispersion lower than the limit of 400 km s^{-1} (see Fig. 1*b*). The group has a poor neighborhood and does not seem to be immersed in a larger structure. In fact, the study of RS94 classifies HCG 40 as an isolated system. Although the X-ray emission of this group extends by a factor of ~ 2 larger than the galaxy distribution, the results suggest that we have in this field a dynamical and compact septet of galaxies.

3.7. *HCG 42*

The kinematical analysis detects a set of 11 objects at $V = 3865$ km s^{-1} presenting no big gap. This set of objects has normality rejected by all the tests at significant levels of $\sim 9\%$ (see Table 1). This is a clear case of a larger structure where the central part was originally classified as a compact group. Now, the group is formed by the Hickson galaxies (1a, 2b, 4c, and 6d) plus galaxies 10, 11, 16 18, 22, 31, and 41 added from Paper I. Although all of its properties are compatible with a compact system (Fig. 1*b*), this group probably extends to a larger radius than we have studied (123 kpc). Although the X-ray emission to 133 kpc (Ponman et al. 1996) is consistent to our optical radius, the X-ray map published by Ebeling et al. (1994) shows a strong and large X-ray emission close to this group. In fact, RS94 found that HCG 42 is associated to N3091 (or LGG 186). In this case, a new survey exploring the surroundings of this group will determine its total extension and will allow us to confirm its final categorization.

3.8. *HCG 48*

In this case, the kinematical analysis divides the original Hickson group into three sets of objects presenting no big gap. The first one is located at $V = 2578$ km s^{-1} and is formed by the Hickson galaxy 3b plus galaxies 10, 15, 17, and 20 from Paper I; the second one is located at $V = 3101$ km s^{-1} and is formed by the Hickson galaxies 1a and 7d plus galaxies 2, 4, and 25 from Paper I; and the third one is located at $V = 4479$ km s^{-1} and is formed by the Hickson galaxy 5c plus galaxies 6, 11, 24, and 34 from Paper I. This is obviously a complex field. Our analysis could not be properly applied in this case. In fact, HCG 48 is not a compact or even a loose group. It is part of the cluster ACO 1060, as shown by RS94 and Ebeling et al. (1994). Maybe it is an example of a group accreting onto the cluster. Gonzales-Casado, Mamon, & Salvador-Sole (1994) show that only compact systems may be robust enough to tidal destruction from the global potential of clusters they are falling into. The study of this possibility in the particular case of the HCG 48 + ACO 1060 system will be explored in future works.

3.9. *HCG 62*

In this case, the kinematical analysis identifies a set of 13 objects at $V = 4594$ km s^{-1} presenting no big gap. The *a*, *u*, and *W* tests reject normality at a significance level of 10% (see Table 1). The group is formed by the four Hickson's galaxies (1a, 2b, 3c, and 6d) plus the galaxies 4, 5, 7, 8, 9, 10, 11, 15, and 22 added from Paper I, reaching a total population of 13 galaxies within a radius of 208 kpc. This is the kinematical group according to our analysis. In this interesting field, while the population and the radius increase, the surface brightness and the density smoothly decrease, crossing the limits of 27 mag arcsec^{-2} and 10^3 gal Mpc^{-3} in the same point, where $N = 8$ and $R_p \sim 120$ kpc (see Fig. 1*b*). At the same time, the velocity dispersion is more stable within the range 300–400 km s^{-1} (except for the first point). Although we have a very compact and central triplet ($\rho > 10^5$ gal Mpc^{-3}) in this structure, it is not dramatically detached from the rest of the galaxy distribution. This result indicates that we have here a sparser group with no clear division between a compact core and a halo. The study of RS94 confirms our analysis and associates HCG 62 to the group LGG 313. The X-ray emission to an upper limit radius of 333 kpc (Ponman et al. 1996) indicates that the group is probably larger and more populated than we have found.

3.10. *HCG 63*

The kinematical analysis detects a set of seven objects at $V = 9319$ km s^{-1} with no big gap. For this set of galaxies, all the normality tests reject normality at significance levels of $\sim 10\%$ (see Table 1). The structure present in this field is 4a compact triplet formed by the Hickson galaxies 1b, 5c, and 12d (galaxy a has discordant redshift, $V = 5228$ km s^{-1}) and a more extended halo with four galaxies 9, 21, 24, and 33 added from Paper I. Figure 1*c* shows a very significant change in the structural properties of the group as the radius increases. The surface brightness goes from 25.65 to 30.00 mag arcsec^{-2}, while the spatial density decreases from $\sim 10^4$ down to ~ 10 gal Mpc^{-3} when we go up to the final radius of the system (475 kpc). This radius is larger than the X-ray extension of 133 kpc detected by *ROSAT* (Ponman et al. 1996). Note that the radius increases by a factor of ~ 8 along the structure. In fact, RS94 associates HCG 63 to the Klemola Cluster 23. Therefore, the halo we observe is probably part of such structure. However, our survey is very incomplete for this field, and so further investigation will be necessary in order to better describe this group.

3.11. *HCG 64*

The kinematical analysis identifies a set of four galaxies at $V = 10{,}694$ km s^{-1} presenting no big gap. This quartet is formed by the original Hickson galaxies 2a and 4b plus the two galaxies 3 and 9 added from Paper I. Galaxy 6c is in the foreground field ($V = 6147$ km s^{-1}) near to three other galaxies (1, 8, and 22), maybe forming a new agglomeration. Galaxy 11d ($V = 11{,}110$ km s^{-1}) is found to be detached from the main group during the kinematical analysis. Although this group presents a velocity dispersion comparable to the typical values found in compact groups, its density and surface brightness are too low (see Fig. 1*c*). In fact, this is the lowest surface brightness group of the sample (30 mag arcsec^{-2}). At the same time, HCG 64 has the largest radius among the 16 groups analyzed (~ 600 kpc). This radius is even larger than the X-ray distribution of 133 kpc (Ponman et al. 1996). On the other hand, this group is an isolated system according to RS94. This information is not conclusive for HCG 64 but suggests that it can hardly be considered a compact group. Indeed, as for HCG 63, our survey is incomplete for this field and further studies will be necessary for a proper categorization of this group.

3.12. *HCG 67*

The kinematical analysis identifies a set of 14 objects at $V = 7435$ km s^{-1} with no big gap. The *a*, *u*, and A^2 tests reject normality to this group at significance levels of $\sim 10\%$. This case is very similar to HCG 62. Now, we have a group formed by 14 galaxies: the original Hickson galaxies (1a, 2b, 4c, and 5d) plus 10 galaxies added from Paper I (galaxies 3, 6, 7, 8, 9, 10, 11, 14, 22, and 23). The structural properties of this group smoothly change as the radius increases (see Fig. 1*c*). At the same time, the velocity distribution oscillates around a value of ~ 280 km s^{-1}. Although the central triplet is very dense ($\rho \sim 10^4$ gal Mpc^{-3}), it does not seem to be significantly detached from the rest of the galaxy distribution. The optical radius of the group (339 kpc) is larger than the upper limit radius of 133 kpc detected by *ROSAT* (Ponman et al. 1996). The conclusion is that HCG 67 is a loose group with an increasing compactness in its inner parts. However, we can not discard the possibility that we have a projection effect causing an apparently dense core within a fairly normal group.

3.13. *HCG 86*

This is the most numerous and complex group. In fact, the kinematical analysis distinguishes two kinematical structures in this field. HCG 86a (located at $V = 5845$ km s^{-1}) is formed by 12 galaxies (1a, 2, 3b, 4c, 6d, 8, 10, 11, 12, 14, 19, 26) and HCG 86b (located at $V = 6682$ km s^{-1}) formed by six galaxies (5, 7, 9, 15, 18, and 21). HCG 86a seems to be a typical case of core + halo structure, where the core is a compact quartet and the halo extends to a distance of ~ 300 kpc from the nominal center of the group. Similarly, HCG 86b is a quartet + two structure but showing a lower surface brightness ($\mu > 27$ mag arcsec^{-2}) even in the central quartet. Two possible scenarios for the system HCG 86 (a + b) are that (1) we are looking at a bimodal structure, maybe in a merging process, or that (2) HCG 86 (a + b) is a single group, not relaxed, where HCG 86b is an extension of HCG 86a in the velocity space. Exploring this second case, we would have an 18 galaxy group, located at $V = 6049$ km s^{-1}, with the following properties: $\mu = 28.48$ mag arcsec^{-2}, $\sigma = 513$ km s^{-1}, $\rho = 132$ gal Mpc^{-3}, and $R = 319$ kpc (this radius is larger by a factor of 2.4 than the X-ray emission of 133 kpc; Ponman et al. 1996). The behavior of these properties are very similar to that found in HCGs 62 and 67: a smooth variation of the surface brightness and density as the radius increases (see Fig. 1*c*). The core is very dense and luminous, but not detached from the rest of the structure. RS94 indicates that exists an association of HCG 86 to a nonidentified cluster of galaxies. So, our conclusion about HCG 86 is that we are looking at a piece of a loose and larger structure, possibly not dynamically relaxed and with an increasing compactness in its inner parts.

3.14. *HCG 87*

The kinematical analysis detects a set of six objects at $V = 8631$ km s^{-1} presenting no big gap in this field. The normality to this set is rejected by the W and A^2 normality tests at significance levels of $\sim 10\%$. This region seems to contain a core + halo structure, where the core is a compact quintet composed by the Hickson galaxies 1a, 3b, and 4c (galaxy 9d has discordant redshift) plus galaxies 11 and 21 and the halo object, galaxy 13, added from Paper I (see Fig. 1*d*). For comparison, the quintet and the final sextet have a difference in density by a factor larger than 10. In the same way, the radius increases by a factor of 2 and the surface brightness goes from 25.73 to 27.65 mag arcsec^{-2} along the structure (Fig. 1*d*). The total radius, 161 kpc, is comparable to the X-ray distribution detected by *ROSAT*, 133 kpc (Ponman et al. 1996). However, the velocity dispersion is exactly the same in the quintet and in the sextet, and the neighborhood of the system is poor. The analysis of RS94 classifies this group as isolated. Thus, it indicates a categorization of HCG 87 as a compact quintet accompanied by one neighbor, possibly orbiting or falling into the group.

3.15. *HCG 88*

This field is severely contaminated by stars. The catalog for this group is only 90% complete at $M_B = -19.0$. Despite of that, this group seems to be very similar to HCG 22. The kinematical analysis detects a set of six galaxies at $V = 6074$ km s^{-1} with no big gap. Only the u test rejects normality to this set at a significance level of $\sim 10\%$ (see Table 1). The group is composed of the Hickson galaxies 1a, 2b, 4c, and 7d plus the galaxies 24 and 25 from Paper I. It has the following structural properties $R = 69$ kpc , $\sigma = 72$ km s^{-1}, $\mu = 25.21$ mag arcsec^{-2}, and $\rho = 4.5 \times 10^3$ gal Mpc^{-3}. All of these properties are typical of a compact system and do not change significantly along the structure (see Fig. 1*d*). The X-ray extension goes to the upper limit of 133 kpc (Ponman et al. 1996) and suggests that the galaxy distribution of this group can be larger. RS94 classify this group as isolated and so reinforce our categorization of HCG 88 as a real compact group. However, a more complete survey of this field will be necessary in order to confirm this conclusion.

3.16. *HCG 90*

The kinematical analysis identifies a set of nine galaxies at $V = 2590$ km s^{-1} with no big gap in the velocity distribution. Only the u test rejects normality at a significance level of 10% (see Table 1). The objects that compose the system are galaxies 1a, 2b, 3c, and 4d from the Hickson catalog, plus galaxies 5, 6, 7, 9, and 18 from Paper I. Figure 1*d* shows the behavior of the structural properties along the system. Note that the spatial density is very high and the group presents high surface brightness. In fact, the behavior of these properties are smooth and the changes remain within the typical range for a compact system. At the same time, the velocity dispersion is lower than the limit of 400 km s^{-1}, with a significant change along the structure. In the literature, HCG 90 is associated to larger structures: M59, N7172, LGG 450, and Klemola Cluster 34 (RS94). In fact, the X-ray emission is detected up to the upper limit of 133 kpc (Ponman et al. 1996), which is a factor of 1.7 larger than the optical radius analyzed (80 kpc). This suggests that the galaxy distribution should be larger than that we observed. Although only a new survey covering a larger area around HCG 90 will say what its nature is, the present data indicate that it probably corresponds to a compact system within a loose group.

3.17. *HCG 97*

The kinematical analysis identifies a set of 14 galaxies at $V = 6642$ km s^{-1} with no big gap. The a and u tests reject normality at significance levels of 10%. This case is very similar to HCGs 62 and 67. Here, the system assembles 14 objects: the Hickson galaxies 1a, 6b, 4c, 3d, and 9e plus the galaxies 2, 5, 7, 10, 11, 13, 17, 19, and 31, added from Paper I. Although the group presents a very luminous and dense central triplet, it is not significantly detached from the rest of the galaxy distribution. In Figure 1*d*, we can see the structural properties of this group smoothly changing as the radius increases. The curves for density and surface brightness cross the limits of 10^3 gal Mpc^{-3} and 27 mag arcsec^{-2} at the same point, $N = 6$, and $R_p \sim 120$ kpc. At the same time, the velocity dispersion oscillates around the limit of 400 km s^{-1}. The final configuration has surface brightness of 27.86 mag arcsec^{-1}, spatial density of 178 gal Mpc^{-3}, velocity dispersion of 425 km s^{-1} and radius of 266 kpc. In this case, the X-ray emission is detected up to a radius of 333 kpc (Ponman et al. 1996), suggesting that HCG 97 is probably more extended than we have found. In fact, RS94 associate this group to a nonidentified cluster of galaxies. All these results indicate that HCG 97 is a larger and loose group whose central parts are increasingly compact. A new survey exploring a larger area around this group will allow us to confirm this categorization.

4. GENERAL CHARACTERISTICS OF THE SAMPLE

4.1. *A Tentative Classification of the Groups*

From the previous section we conclude that the Hickson sample is not completely homogeneous. In fact, 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 struc-

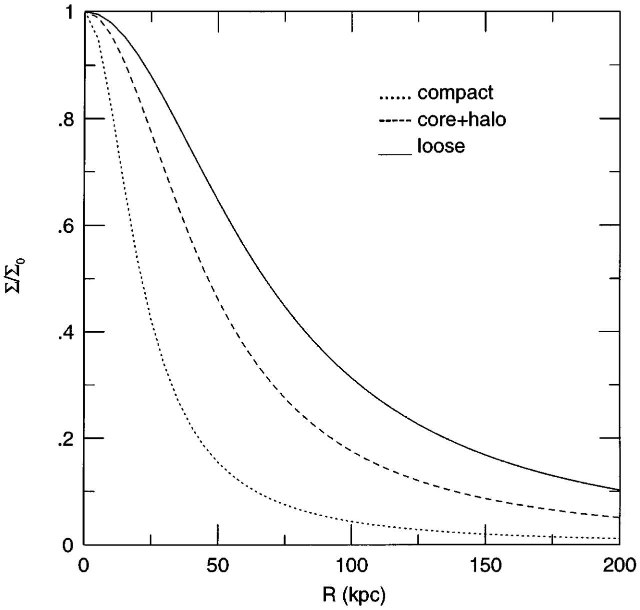

FIG. 2.—Surface density profiles of the groups

ture. 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 leads us to three different "families" in this sample: (1) real CGs, like HCGs 22, 40, and 88; (2) core + halo systems, like HCGs 16, 19, 63, and 87; and (3) loose groups (or at least part of loose groups), like HCGs 23, 42, 62, 67, 86, 90, and 97. HCG 4 has contradictions in its properties and could be a chance alignment case, HCG 64 is a too low surface brightness group, and HCG 48 is part of the cluster ACO 1060. None of them can be included in the three categories we have found.

4.2. *The Surface Density Profile of the 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. Mendes de Oliveira & Giraud (1994, hereafter MG94) rescaled HCGs to a common size and showed that they are consistent with a King surface density profile, with typical core radius of 20 kpc. Montoya et al. (1996) developed a statistical method to infer the density profile of poor galaxy systems without assuming a given center. They applied the method to HCGs quartets and found that the data are consistent with both a Hubble surface density profile ($r_c = 24$ kpc) and a King profile ($r_c = 8$ kpc).

In order to study the surface density profiles of our sample, we have proceeded similarly to MG94, 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. As discussed in Capelato et al. (1980), this distance is a reliable estimator of the size of the projected galaxy distribution. 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 isothermal profile for each "family" is showed in Figure 2. Note that the core radius for our CGs is approximately the same as that found by MG94, although less concentrated than that obtained by Montoya et al. (1996). This is somewhat expected since the use of the galaxy barycenter probably washes out inner concentrations of the galaxy distribution (Beers & Tonry 1986). Indeed, using the Hickson's center instead of the barycenter of the whole distribution, we find that the resultant density profiles are roughly unchanged for the outer part while significantly sharper at the center of the galaxy distribution. Despite of this effect, 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). On the other hand, the two other families present profiles clearly distinct of that for compact groups. 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.

5. DYNAMICAL ANALYSIS OF THE GROUPS

A possible starting point to study the dynamical evolution of HCGs is to consider such systems as real dynamical entities that evolve from loose groups and in the present epoch are sufficiently detached from their surroundings in order to satisfy the Hickson's criteria (see § 2.1). Also, we generally suppose that HCGs will be destroyed by mergers after of $\sim 0.1 H_0^{-1}$ (Barnes 1985, 1989, 1990; White 1990). However, our analysis suggests that part of the groups are not completely detached from the neighboring galaxy distribution. Besides, we have identified 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 comparison like that is carried out in this section. The dynamical parameters we have used are listed in Table 4. In this table, column (1) is the group identification; column (2) is the mass of the group computed under the hypothesis that the galaxies are orbiting around a central mass (Bahcall & Tremaine 1981: "satellite mass") in units of $10^{14}\ M_\odot$; column (3) is the mass of the group obtained assuming that the galaxies form a self-gravitating system (Heisler, Tremaine, & Bahcall 1985: "self-gravitating mass") in units of $10^{14}\ M_\odot$; column (4) is the crossing time of the groups, computed as $t_{cr} = (4/\pi)(R/V)$ in H_0^{-1} units (here V is the three-dimensional velocity dispersion, calculated as $V = [3(\langle v^2\rangle - \langle v\rangle^2 - \langle \delta v^2\rangle)]^{1/2}$, where v is the measured radial velocity of the galaxy, δv is the estimated velocity error, and angle brackets denote the average over all galaxies in the group); column (5) lists the median absolute magnitude that divides the group in bright and faint galaxies; column (6) is the spiral fraction of the group (see definition below); column (7) lists the group blue luminosity in ergs^{-1}; column (8) lists the X-ray luminosity from Ponman et al. (1996) in ergs^{-1}; column (9) is the intragroup gas temperature from Ponman et al. (1996) in keV; and columns (10) and (11) list the mass-to-light ratios

TABLE 4

DYNAMICAL PROPERTIES OF THE GROUPS

HCG (1)	M_{SG} (2)	M_{SAT} (3)	T_{cr} (4)	$M_B(1/2)$ (5)	SpF (6)	L_B (7)	L_X (8)	T (9)	M/L (SG) (10)	M/L (SAT) (11)
4......	0.536	0.990	0.018	−19.23	0.40	44.42	...	...	780	1441
16......	0.011	0.040	0.195	−19.95	0.86	44.58	41.68	0.30	11	40
19......	0.034	0.050	0.089	−17.68	0.29	43.81	...	...	201	296
22......	0.004	0.014	0.123	−18.33	0.25	44.01	<41.15	...	15	52
23......	0.320	0.117	0.012	−18.14	0.50	43.84	<41.72	...	1768	646
40......	0.021	0.008	0.011	−19.44	0.57	44.39	<41.73	...	33	12
42......	0.152	0.061	0.012	−16.90	0.09	44.30	42.16	0.82	292	117
62......	0.224	0.080	0.023	−17.91	0.31	44.43	43.04	0.96	319	114
63......	0.326	0.134	0.148	−17.88	0.43	44.30	<42.49	...	626	257
64......	0.055	0.014	0.821	−20.20	0.50	44.54	<42.48	...	61	15
67......	0.741	0.338	0.062	−19.09	0.50	44.85	41.69	0.82	401	183
86......	1.183	0.488	0.041	−17.82	0.33	44.52	42.32	...	1367	564
87......	0.155	0.075	0.043	−19.61	0.33	44.30	<42.36	...	298	144
88......	0.012	0.008	0.075	−18.96	0.50	44.52	<42.18	...	14	10
90......	0.014	0.035	0.033	−17.67	0.33	44.21	41.48	0.68	33	83
97......	0.727	0.215	0.037	−18.16	0.21	44.64	42.78	0.87	638	189

NOTE.—SG: self-gravitating mass. SAT: satellite.

(in solar units), computed using the satellite and self-gravitating masses, respectively.

For the following analysis, the sample is examined as a whole. It would be very difficult to study the general dynamical trends dividing the sample according to the categorization we made in the previous section. Such an examination will be carried out in future works, when we have a larger sample of compact groups.

5.1. *Galaxy Morphology*

In order to investigate how the new population of galaxies added to HCGs changed their morphological type distribution, we carried out a study of the environmental correlations found by Hickson, Kindl, & Huchra (1988, hereafter HKH). But here, images are not available for most of the objects, and so our morphological classification is based on the spectra instead of the galaxy appearance. In this work, a spectrum presenting EW(Hα) > 6 Å indicates a late-type object. According to this criterion, Figure 3 shows a plot of spiral fraction versus spatial density. Points represent means of groups in each density bin, and the error bars are the standard error (1 σ) for each point. HKH conclude from their data that there is no correlation between spiral fraction and galaxy space density in CGs. The behavior found by HKH is reproduced by our data only when we plot the original Hickson galaxies and the brighter galaxies of the sample. This result shows that groups in our sample are representative of the Hickson sample and that the bright population is not much different from the Hickson galaxies. On the other hand, when we include the faint population the result is quite different, indicating that the spiral fraction in HCGs is lower than that found previously. However, the general result is the same: there is no correlation between spiral fraction and spatial density. This is contrary to the results found in other environments, where a clear density-morphology correlation is seen (e.g., Dressler 1980). However, we can not discard the possibility that the morphological type distribution in CGs is strongly determined at the time of galaxy formation.

Figure 4 shows a spiral fraction plotted against the total blue luminosity of the groups. Note that while HKH found a strong correlation, our data do not confirm the trend that high-luminosity groups contain fewer spirals. In fact, if we exclude the bright end of the distribution ($L > 44.5$ ergs^{-1}), we see that the correlation found by HKH is not so strong. Thus, the only trend we clearly see in the graph is that, for a specific luminosity bin, our sample has a lower spiral fraction. Such a discrepancy can be explained by the fact we have a dynamical mixture in our sample and by the low-luminosity population widely dominated by non–emission-line galaxies we added to the groups. On the other hand, in Figure 5 we see the spiral fraction as a function of galaxy luminosity. The solid line shows data from a sample of 836 field galaxies studied by Meisels & Ostriker (1984). Note that the shape of the distributions are similar. However, at the bright end, our points are nearer to the field curve. This effect may be a result of our morphological classification based on the spectra. In fact, ∼20% of the early-type Hickson galaxies are classified here as emission-line objects. On the contrary, there is a slight decreasing of the spiral fraction in both samples at the faint end of the distributions. This behavior is clearer for our points, since we have more objects with $L < 42.75$ ergs^{-1}. For the intermediate points

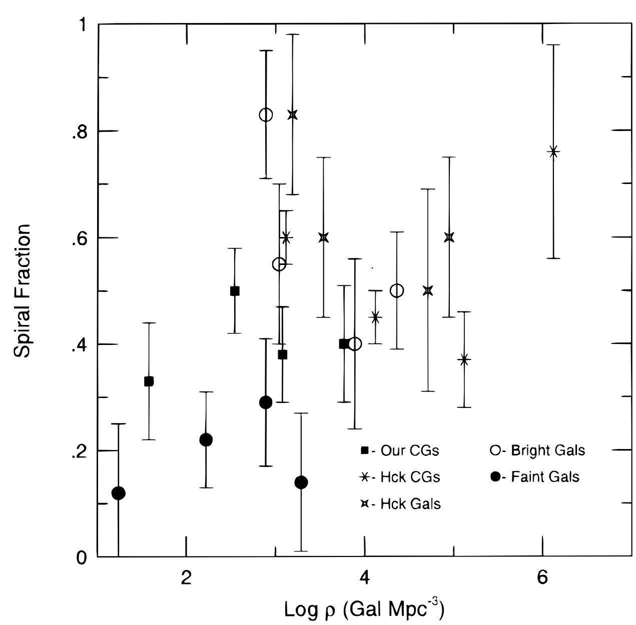

FIG. 3.—Spiral fraction against the spatial number density of the mean groups.

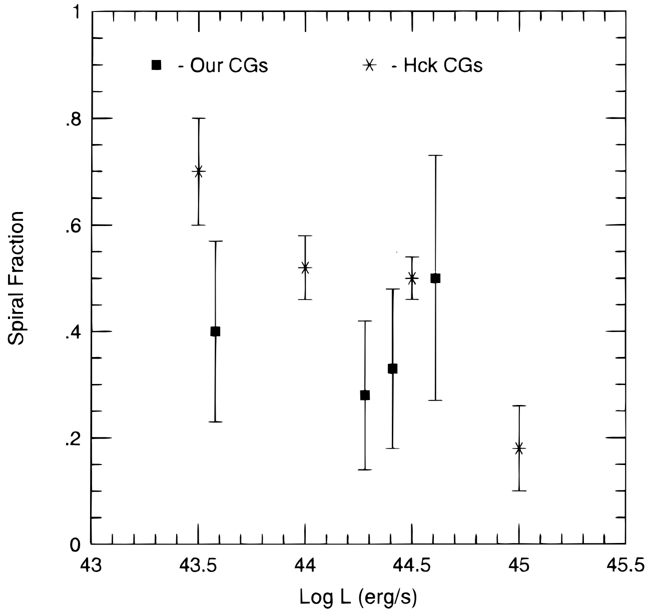

FIG. 4.—Spiral fraction against the group blue luminosity of the mean groups.

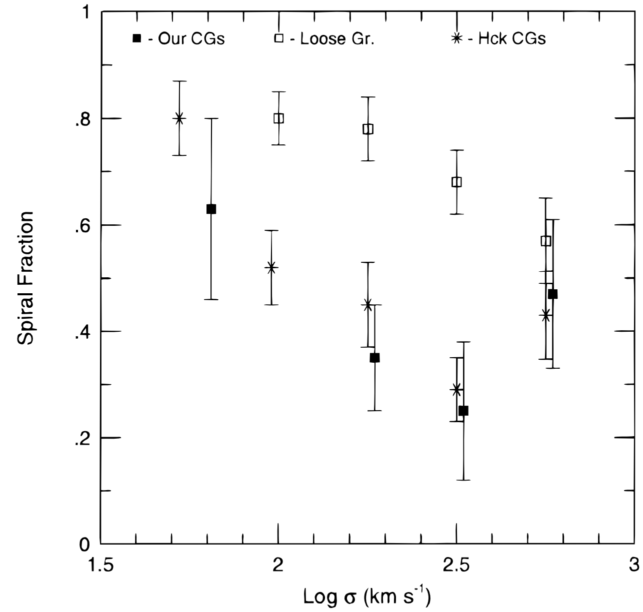

FIG. 6.—Spiral fraction against the velocity dispersion of the mean groups.

($42.75 < L < 43.75$ ergs^{-1}), our data confirm the result found by HKH: there is a lower spiral fraction in CGs than in the field. This result suggests that the morphology of galaxies in CGs is somewhat affected by the environment, either at the formation time or during their evolution.

Figure 6 shows a spiral fraction against group velocity dispersion. The result found by HKH is confirmed by our data: groups with higher velocity dispersion contain a lower spiral fraction. Note that the behavior for a sample of typical loose groups (Maia, da Costa, & Latham 1989) displays a similar trend (although less steep) compared with that of the CGs. Also, note that at the highest velocity dispersion bin the spiral fraction is almost the same of that found in CGs. For HKH, the upturn in $\log \sigma = 2.5$ km s^{-1} is due to contamination by unrelated field galaxies. In our sample, the upturn is due to the richer groups that present higher velocity dispersions, as we can see in Figure 7. This result reinforces the idea that our sample includes groups that are dynamically different from CGs and that are very similar to loose groups.

A further correlation is shown in Figure 8, where the spiral fraction is plotted against the crossing time of the groups. Hickson et al. (1992) found the following trend: groups with smaller crossing times contain fewer late-type galaxies. This result is exactly what one could expect, since the evolution through interactions and mergers should be more intense in groups with small crossing times. This result is roughly reproduced by our data. Note, however, that our points are within a range significantly smaller than those of Hickson et al. (1992).

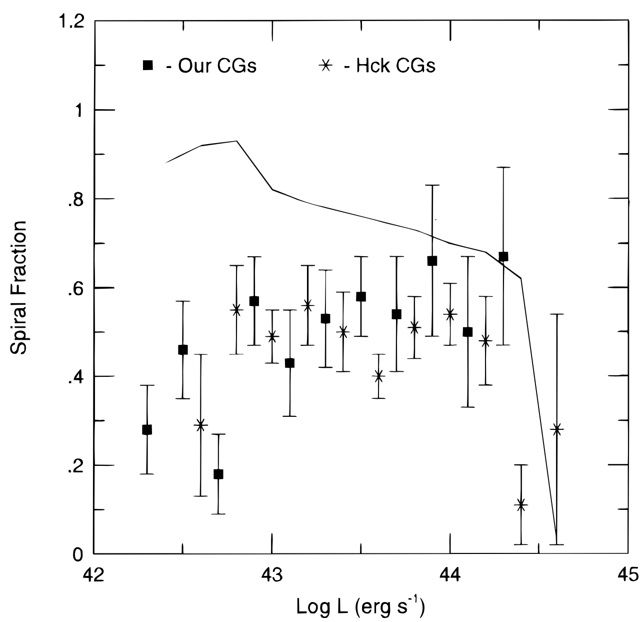

FIG. 5.—Spiral fraction against the galaxy blue luminosity

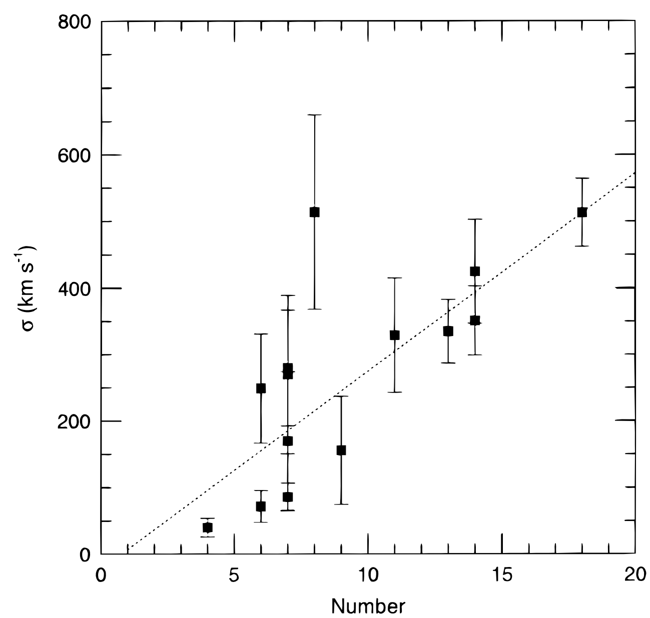

FIG. 7.—Velocity dispersion against the membership of the groups. The dotted line is the best-fitting regression line.

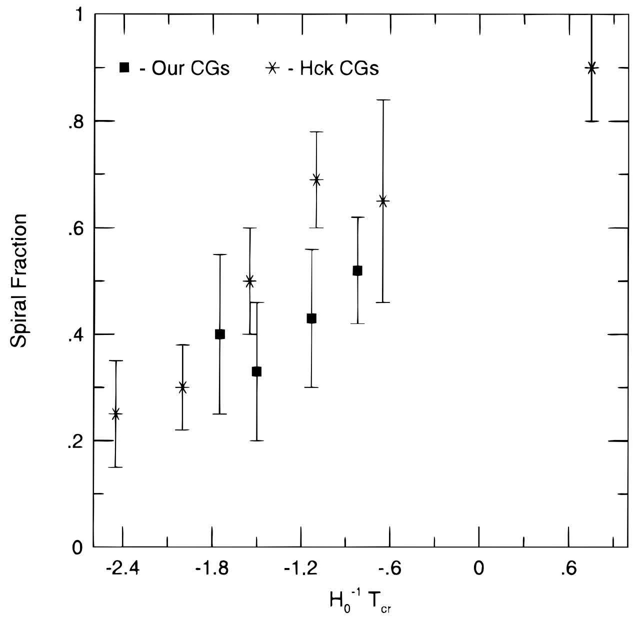

FIG. 8.—Spiral fraction against the crossing time of the mean groups

5.2. *X-Ray Correlations*

The detection of X-ray emission from a gas halo around the Hickson groups gives evidence that most of them are physically bound (Ponman et al. 1996). Besides, as we have seen in the previous sections, the galaxy distribution of CGs extends to a larger radius than that found by Hickson (1982). Consequently, it is important to know if the correlations found between the optical and X-ray properties of the groups are still valid.

One of the strongest correlations found by Ponman et al. (1996) is that between total X-ray luminosity of the groups and galaxy velocity dispersion. The general trend is that groups with higher X-ray luminosity have higher velocity dispersion. Figure 9 shows the comparison between our data and those of Ponman et al. (1996). The comparison is made between the 22 groups that present well-determined X-ray properties against our groups (six of them with upper limits for the X-ray luminosity). Note that the behavior is very similar, and, except for the lowest velocity dispersion groups (HCGs 16, 22, and 88), our points follow the fit found by Ponman et al. (1996). This is a very important verification, since such correlation suggests that most of the groups are probably in virial equilibrium. HCGs 16, 22, and 88 may be suffering dynamical instabilities and should not correspond to strictly virialized systems. Remember that HCGs 22 and 88 were classified as true CGs in § 4.1 and that HCG 16 is an uncommon high concentration of active galaxies (Ribeiro et al. 1996).

If most of the systems really are in dynamical equilibrium, a correlation between the gas temperature and the velocity dispersion should exist as well. In fact, Ponman et al. (1996) verified this correlation, and by comparing it to that found in clusters, they showed that compact groups follow a steeper behavior. Figure 10 shows the regression lines that fit groups and groups + clusters points according to Ponman et al. (1996), and the regression line for our data. Note that groups follow a steeper curve than that of the groups + clusters fitting. As discussed in Ponman et al. (1996), this result is a consequence of systems with low mass having $\beta < 1$. This means that the specific energy in the gas is higher than that in the galaxies for these groups. Using only our data, this behavior is even more pronounced than that found by Ponman et al. (1996). The action of galaxy winds raising the gas temperature and the reduction in the velocity dispersion due to dynamical friction may be responsible for the systematically lower value of β in low-mass systems like CGs (Bird, Mushotzky, & Metzler 1995). Therefore, the steeper curves for groups in Figure 10 probably indicate that CGs are suffering the action of environmental effects.

A further correlation is shown in Figure 11, where we plot X-ray luminosity against spiral fraction. The general trend

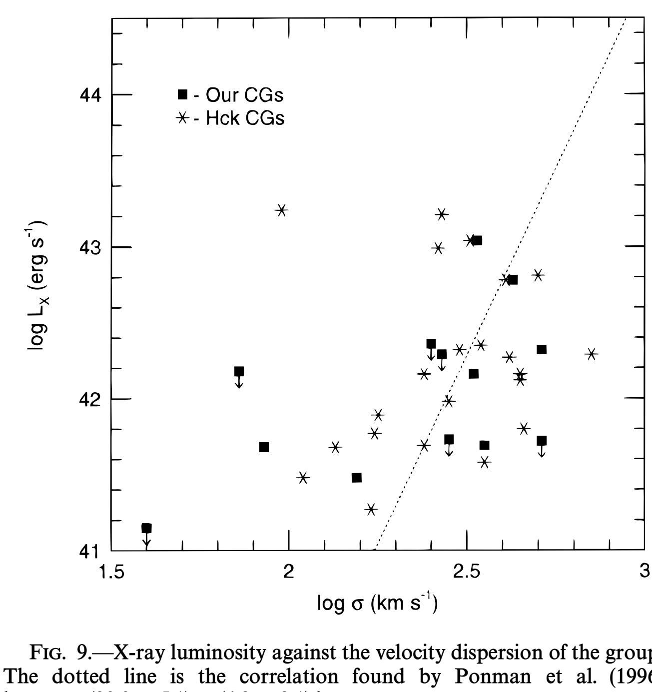

FIG. 9.—X-ray luminosity against the velocity dispersion of the groups. The dotted line is the correlation found by Ponman et al. (1996): $\log L_X = (30.0 \pm 5.1) + (4.9 \pm 2.1) \log \sigma$.

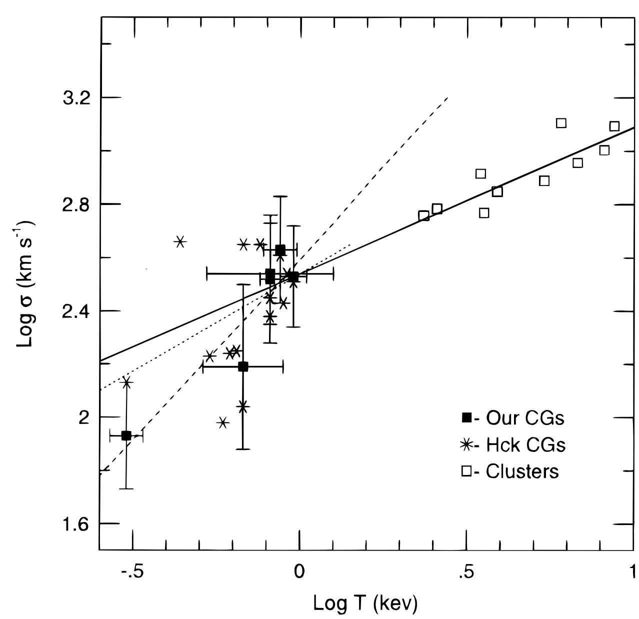

FIG. 10.—Velocity dispersion against the gas temperature of the groups. The solid line is the correlation found by Ponman et al. (1996) for the group + cluster sample: $\log \sigma = (2.54 \pm 0.04) + (0.55 \pm 0.05) \log T$; while the dotted is the best-fitting regression line of Ponman et al. (1996) and the dashed line is the best-fitting regression line for our data.

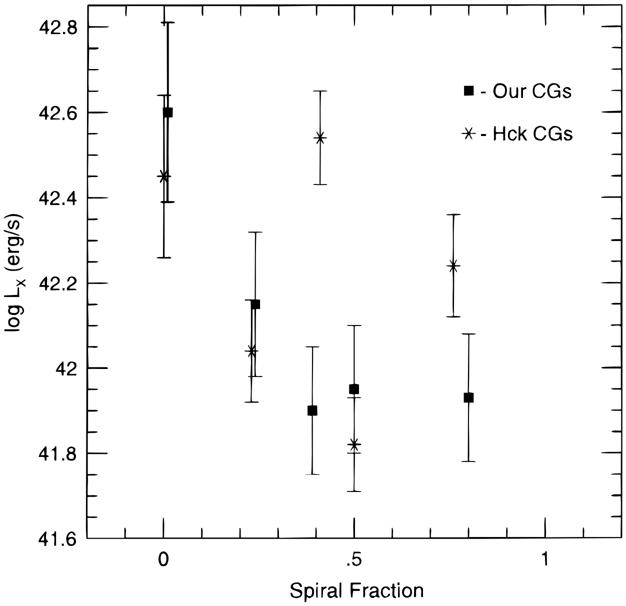

FIG. 11.—X-ray luminosity against the spiral fraction of the mean groups.

is true for both samples: groups with higher X-ray luminosity present fewer late-type galaxies. A possible explanation for this effect is that groups dominated by elliptical galaxies are the most evolved ones with the deepest potential wells, where the dominant galaxies and the diffuse gas would be the result of merging process, as suggested by the N-body simulation of Barnes (1989).

5.3. *Dark Matter and* Ω_0

The comparisons of our data to those from Ponman et al. (1996) suggest that within the physical extension we have examined most of the CGs seem to be close to the virial equilibrium. Therefore, our estimations of virial mass should be roughly correct for the extensions analyzed. Consequently, we can compute the mass-to-light ratios and the density parameter for this sample from the data listed in Table 3. The M/L distribution is shown in Figure 12. In this figure we see that there is a wide range of mass-to-light ratios in the groups. Note that the median values of M/L is 131 (using the satellite mass) and 294 (using the self-gravitating mass) if we use all the groups. This range is comparable to the values of M/L quoted for loose groups (for instance, $\sim$191: Rood & Dickel 1978; $\sim$135: Ramella, Geller, & Huchra 1989). On the other hand, if we consider only the most compact groups of the sample (HCGs 22, 40, and 88), the median value of M/L would be $\sim$15. This value is comparable to that obtained by Hickson et al. (1992), $\sim$38.

Using the median values of M/L, and assuming that groups represent a fair sample of the universe, we can estimate the density parameter, Ω_0. The standard method for estimating Ω_0 from bound virialized systems is to assume that all galaxies have the same mass-to-light ratio M/L, given by the median M/L of the groups, then to integrate over the luminosity function to get the mass density (Kirschner, Oemler, & Schechter 1979). For a Schechter luminosity function this means

$$\Omega_0 = \frac{8\pi G}{3H_0^2}\left\langle\frac{M}{L}\right\rangle \phi^* L^* \Gamma(\alpha + 2) . \qquad (2)$$

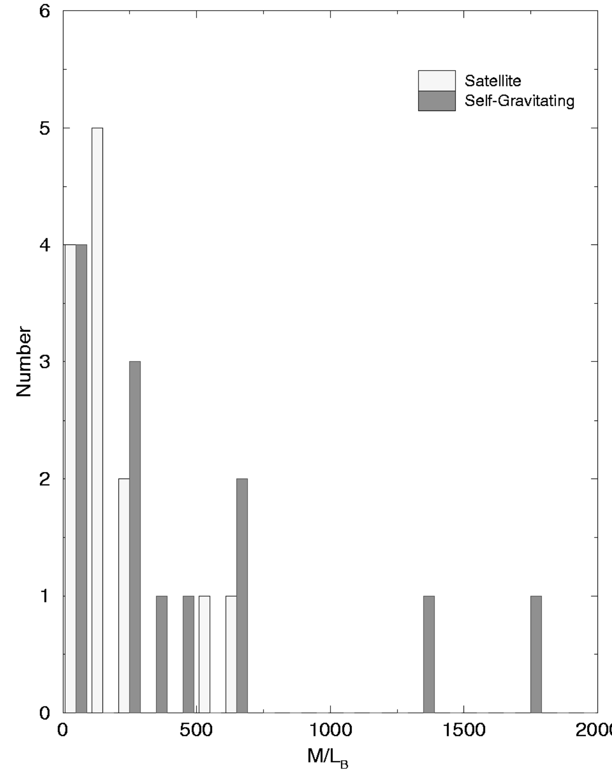

FIG. 12.—Mass-to-light distributions

From Zepf, de Carvalho, & Ribeiro (1997) we know that $\phi^* = 1.89 \times 10^{-4}$ gal Mpc^{-3}, log $L^* = 43.83$ ergs^{-1}, and $\alpha = -0.98$. Introducing these values in equation (2) we obtain the results summarized in Table 5. In this table, column (1) is the sample we are using, column (2) is the $\langle M/L \rangle$ range, and column (3) is the respective Ω_0 range. Note that $\langle M/L \rangle$ increases from the more compact to the loose groups and, consequently, so does Ω_0. This result agrees well with the study made by Bahcall, Lubin, & Dorman (1995), which indicated the existence of an increasing luminosity segregation in small and dense systems like individual galaxies and small groups. We also should note that taking all the groups in this sample, our Ω_0 range is the same of that found for different samples of clusters, $\Omega_0 \sim$ 0.2–0.4 (e.g., Fisher et al. 1994; Davis et al. 1996). This range is also compatible with the recent value obtained by Carlberg et al. (1996) for the Canadian Network for Observational Cosmology cluster survey, $\Omega_0 \simeq 0.23$.

6. SUMMARY AND CONCLUSION

1. HCGs form a nonhomogeneous 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.

TABLE 5

DENSITY PARAMETER: Ω_0

Sample (1)	$\langle M/L \rangle$ (2)	Ω_0 (3)
Compact	15–40	0.02–0.05
Core + halo......	201–250	0.25–0.31
Loose	183–401	0.23–0.50
All groups........	131–294	0.16–0.37

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 and work done by Ponman et al. (1996) suggest that most of the groups are probably in virial equilibrium. This result is reinforced by the fact that $\sim 75\%$ of the groups have a Gaussian velocity distribution indicated by at least one of the normality tests we have used.

5. Comparisons between our data and that of HKH 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 $\langle M/L \rangle$ for this sample is comparable to the values found in samples of loose groups and implies that $0.16 < \Omega_0 < 0.37$.

The most important conclusion of this work is that although the Hickson sample is not representative of strictly CGs, it is very useful for investigating the probable ways a compact system forms and evolves. Possibly, the three families identified in our analysis correspond to dynamical snapshots showing three different dynamical stages. Groups like HCGs 23, 42, 62, 67, 86, 90, and 97 are probably the central parts of larger and loose groups. The luminous (but not strongly detached) cores of these systems would be the seed of new CGs. This scenario is consistent with the N-body simulations made by Diaferio, Geller, & Ramella (1994) that show that compact configurations form continually within rich collapsing groups. Core + halo systems like HCGs 16, 19, 63, and 87 would be more evolved groups, where the compact cores are already formed and some surrounding galaxies are possibly orbiting or falling into them. In particular, HCGs 19 and 87 do not seem to be related to larger structures. For these groups, the replenishment mechanism could be the secondary infall of field galaxies, as suggested by Governato, Tozzi, & Cavaliere (1996). Finally, the isolated and very dense systems like HCGs 22, 40, and 88 would represent the real CGs of this sample. In this case, there is no visible influence of the neighborhood, and the groups are expected to evolve through strong merging on a timescale of a few crossing times.

We thank the CTIO for the good working conditions during our observations runs. We also thank the anonymous referee for the useful suggestions. A. L. B. Ribeiro acknowledges the support of the CAPES, and S. E. Zepf acknowledges support from NASA through grant HF-1055.01-93A awarded by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., for NASA under contract NAS5-26555.

REFERENCES

Bahcall, N. A., Lubin, L. M., & Dorman, V. 1995, ApJ, 447, L81
Bahcall, J., & Tremaine, S. 1981, ApJ, 244, 80
Barnes, J. 1985, MNRAS, 215, 517
———. 1989, Nature, 338, 123
———. 1990, in Dynamics and Interaction of Galaxies, ed. R. Weilen (Heidelberg: Springer), 186
Barton, E., Geller, M. J., Ramella, M., Marzke, R. O., & da Costa, L. N. 1996, AJ, 112, 871
Beers, T. C., Flynn, K., & Gebhardt, K. 1990, AJ, 100, 32
Beers, T. C., & Tonry, J. L. 1986, ApJ, 300, 557
Bird, C. M., & Beers, T. C. 1993, AJ, 105, 159
Bird, C. M., Mushotzky, R. F., & Metzler, C. A. 1995, ApJ, 453, 40
Capelato, H. V., Gerbal, D., Mathez, G., Mazure, A., Salvador-Solé, E., & Sol, H. 1980, ApJ, 241, 521
Carlberg, R. G., Yee, H. K., Ellingson, E., Abraham, R., Gravel, P., Morris, S. L., & Prichet, C. J. 1996, ApJ, 462, 32
D'Agostino, R. B. 1986, in Goodness-of-Fit Techniques, ed. R. B. D'Agostino & M. A. Stephens (New York: Marcel Dekker), 367
Davis, M., Nusser, A., & Willick, J. A. 1996, ApJ, 473, 22
de Carvalho, R. R., Ribeiro, A. L. B., Capelato, H. V., & Zepf, S. 1997, ApJS, 110, 1 (Paper I)
de Carvalho, R. R., Ribeiro, A. L. B., & Zepf, S. E. 1994, ApJS, 93, 47 (dCAZ94)
Diaferio, A., Geller, M. J., & Ramella, M. 1994, AJ, 107, 868
———. 1995, AJ, 109, 2293
Dressler, A. 1980, ApJ, 236, 351
Ebeling, H., Voges, W., & Böringer, H. 1994, ApJ, 436, 44
Efron, B. 1987, J. Am. Stat. Assoc., 82, 171
Fisher, K. B., Davis, M., Strauss, M., Yahil, A., & Huchra, J. 1994, MNRAS, 267, 927
Garcia, A. M. 1993, A&AS, 100, 47
Giovanelli, R., & Haynes, M. P. 1993, AJ, 105, 1271
Gonzales-Casado, G., Mamon, G. A., & Salvador-Sole, E. 1994, ApJ, 433, L61
Governato, F., Tozzi, P., & Cavaliere, A. 1996, ApJ, 458, 18
Hernquist, L., Katz, N., & Weinberg, D. H. 1995, ApJ, 442, 57
Heisler, J., Tremaine, S., & Bahcall, J. 1985, ApJ, 298, 8
Hickson, P. 1982, ApJ, 255, 382
Hickson, P., Kindl, E., & Huchra, J. P. 1988, ApJ, 331, 64 (HKH)
Hickson, P., Mendes de Oliveira, C., Huchra, J. P., & Palumbo, G. G. C. 1992, ApJ, 399, 353
Huchra, J., & Geller, M. 1982, ApJ, 257, 423
Kirschner, R. P., Oemler, A., & Schechter, P. 1979, AJ, 84, 951
Maia, M. A. G., da Costa, L. N., & Latham, D. W. 1989, ApJS, 69, 809
Mamon, G. A. 1986, ApJ, 307, 426
———. 1989, A&A, 219, 98
———. 1992, ApJ, 401, L3
———. 1994, in Clusters of Galaxies, ed. F. Durret, A. Mazure, & J. Tran Thanh Van (Paris: Editions Frontieres), 297
Meisels, A., & Ostriker, J. P. 1984, AJ, 89, 1451
Mendes de Oliveira, C., & Giraud, E. 1994, ApJ, 437, L103 (MG94)
Montoya, M. L., Dominguex-Tenreiro, R., Gonzalez-Casado, G., Mamon, G. A., & Salvador-Solé, E. 1996, ApJ, 473, 83
Mulchaey, J. S., Davis, D., Mushotzky, R. F., & Burstein, D. 1996, ApJ, 456, 80
Nolthenius, R., & White, S. D. M. 1987, MNRAS, 235, 505
Ostriker, J. P., Lubin, L. M., & Hernquist, L. 1995, ApJ, 444, L61
Pildis, R. A., Bregman, J. N., & Schombert, J. M. 1995, AJ, 110, 149
Ponman, T. J., Bourner, P. D. J., Ebeling, H., & Böringer, H. 1996, MNRAS, 283, 690
Ramella, M., Diaferio, A., Geller, M. J., & Huchra, J. P. 1994, AJ, 107, 1623
Ramella, M., Geller, M., & Huchra, J. 1989, ApJ, 344, 57
Ramella, M., Pisani, A., & Geller, M. J. 1997, AJ, 113, 483
Ribeiro, A. L. B., de Carvalho, R. R., Coziol, R., Capelato, H. V., & Zepf, S. 1996, ApJ, 463, L5
Ribeiro, A. L. B., de Carvalho, R. R., & Zepf, S. 1994, MNRAS, 267, L13
Rood, H. J., & Dickel, J. R. 1978, ApJ, 224, 724
Rood, H. J., & Struble, M. F. 1994, PASP, 106, 413 (RS94)
Rood, H. J., & Williams, B. A. 1989, ApJ, 339, 772
Rose, J. A. 1977, ApJ, 211, 311
Rubin, V. C., Hunter, D. A., & Ford, W. K., Jr. 1991, ApJS, 76, 153
Saracco, P., & Ciliegi, P. 1995, A&A, 301, 348
Shakhbazyan, R. K. 1973, Astrofizika, 9, 495
Sulentic, J. W. 1987, ApJ, 322, 605
Wainer, H., & Thissen, D. 1976, Psychometrika, 41, 9
West, M., Oemler, A., & Dekel, A. 1989, ApJ, 346, 539
White, S. D. M. 1990, in Dynamics and Interactions of Galaxies, ed. R. Wielen (Heidelberg: Springer), 380
Yahil, A., & Vidal, N. V. 1977, ApJ, 214, 347
Zepf, S. E. 1993, ApJ, 407, 448
Zepf, S. E., de Carvalho, R. R., & Ribeiro, A. L. B. 1997, ApJ, 488, L11
Zepf, S. E., & Whitmore, B. C. 1991, ApJ, 383, 542