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On the reality of compact groups of galaxies

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Abstract. The problem of the reality of Compact Groups of galaxies (CGs) is discussed. We separated two classes of groups: elongated, chain-like groups (I), and round ones (II). The number of chain-like groups among Hickson Compact Groups (HCGs) is about twice as large as that of the round ones. In Shakhbazian Compact galaxy Groups (ShCGs) the proportion of chain-like groups is smaller than that of the round ones. It is shown that some parameters of both classes of HCGs are quite different. The radial velocity dispersion (σ_v) is smaller in chain-like groups, and the interaction and merging processes are more efficient in them. The magnitude difference between the brightest and the second brightest galaxies in HCGs is larger in groups of class I, and is smaller in groups with larger number of members. The surface distribution in round CGs is concentrated towards the center.

The above-mentioned differences allow us to conclude that CGs are real physical entities.

Key words: galaxies: clusters: general – galaxies: evolution – galaxies: interactions

1. Introduction

The physical nature of Compact Groups of galaxies (CGs) and their evolution have attracted a lot of attention during recent years. More efforts have been devoted to Hickson Compact Groups (HCGs) (Hickson 1982; Hickson et al. 1989). They generally consist of three to five galaxies, mostly spirals with similar redshifts. Shakhbazian Compact Galaxy Groups (ShCGs) (Shakhbazian 1973, Baier & Tiersch 1979, and references therein) typically contain 5 to 15, mainly elliptical, galaxies (Tiersch et al. 1996).

N-body simulations showed that members of CGs should interact and eventually merge to form a single elliptical galaxy on a time scale of a few orbital periods (Barnes 1985, 1989, 1990; Mamon 1986; Governato et al. 1991). For this reason the very existence of CGs was questioned, and has been debated not only for the discordant redshift members (Burbidge & Burbidge 1961, Burbidge & Sargent 1971, Sulentic 1983), but also for HCGs with homogeneous redshifts. It was argued that CGs are not physical groups of galaxies, but chance alignments in loose groups of galaxies (Rose 1977, Mamon 1986, 1995, Walke & Mamon 1989), or filaments seen end-on (Hernquist et al. 1995, Ostriker et al. 1995). Arguments in favor of HCGs being real physical groups were presented by Hickson & Rood (1988), Mendes de Oliveira & Giraud (1994), Mendes de Oliveira (1995), Ponman et al. (1996), Hickson (1997), Oleak et al. (1995, 1998).

It was shown (Rood & Struble 1994, Ramella et al. 1994, Mamon 1990, 1992, Vennik et al. 1993) that HCGs are usually located within loose galaxy groups. Diaferio et al. (1994, 1995), Governato et al. (1996), Ribeiro et al. (1998) suggested that field galaxies fall from time to time onto CGs, thus keeping the number of groups approximately constant.

Examination of the images of ShCG allowed Vardanian & Melik-Alaverdian (1978) to conclude that most of these groups are flat systems. Later, Oleak et al. (1995, 1998) showed that ShCGs have a prolate spheroidal configuration (“cigars”). Malykh & Orlov (1986) showed that HCGs also have a prolate spheroidal shape. Hickson et al. (1984) stated that randomly oriented *triaxial* spheroids fit best the observed shape distribution.

In this paper, we reconsider the problem of the nature of CGs, and provide new arguments in favor of their physical reality.

2. Two classes of compact groups

The presence of many chain-like groups among CGs is striking. They are more numerous amongst HCGs. It was mentioned by Kodaira et al. (1988) that the group ShCG 202 is located in the bridge between the Coma and A1367 galaxy clusters. Hence, one may suggest that the elongation of this group, and generally of all other groups could be due to the gravitational influence of nearby clusters. However, Palumbo et al. (1993) did not find any evidence for alignment of HCGs in relation to neighboring clusters of galaxies.

Below we concentrate more on the HCGs that have been studied intensively, and use published data on these groups.

The data on HCGs are given in Table 1. The following information on each group, taken mostly from Hickson (1994), is presented in the following columns: 1 - HCG designation; 2 - number N of accordant redshift galaxies in the group; 3 - radial velocity dispersion (σ_v); 4 - distance D (H=100 km s^{-1} Mpc^{-1} throughout this paper); 5 - a value; 6 - b value; 7 - ratio b/a; 8 - number of interacting (I) and/or merging (M) galaxies in the

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Send offprint requests to: H.M. Tovmassian group. The data for the last column was taken from Mendes de Oliveira & Hickson (1994).

For a discussion of the problem of the reality of CGs, we consider the dependence of the radial velocity dispersion (σ_v) on the parameter b/a (Rood 1979). The parameter b/a characterizes the elongation of the group. Here *a* is the angular distance between the most widely separated galaxies in the group, and *b* is the sum of the angular distances b_1 and b_2 of the most distant galaxies, on either side of the line *a* joining the most separated galaxies.

We found that in the case of HCGs in spite of a large dispersion there is a certain trend: σ_v increases with b/a.

In order to understand the physical meaning of the dependence of σ_v on the group shape, we separated from HCG and ShCG lists two classes of groups with extreme shapes: chain-like (class I) and round groups (class II), and compared their properties. In the case of HCGs we included into class I the chain-like groups with a ratio $b/a < 0.3$. In the case of ShCGs, that have more member galaxies, we included into class I the groups with $b/a < 0.4$. Groups with a round shape, with $b/a > 0.5$, in both cases form class II. 44 out of 92 accordant–redshift HCGs belong to class I[1]. The number of class II groups among HCGs is 24. Among ShCGs the numbers of chain-like and round groups are 125 and 183 respectively.

3. Discussion

3.1. The radial velocity dispersion

If CGs are real physical entities, and have cigar–like configurations (Oleak et al. 1995, 1998, Hickson et al. 1984, Malykh & Orlov 1986), then their member galaxies should move in elongated orbits. Statistically, the angles between the direction of elongation of many chain–like groups and the line of sight must be small enough ($\leq 45°$). As a consequence, the velocity dispersion of physical chain–like groups should, on average, be smaller than that of round groups, the elongation of which is oriented close to the line of sight.

The comparison of the radial velocity dispersion (σ_v) of chain-like and round HCGs showed that this is the case. The distribution of σ_v for class I and II HCGs is shown on Fig. 1. The curves in this figure are Gaussian fits to the corresponding observed distributions. The mean values of σ_v's for chain-like and round groups are equal to 194.3 and 270.7 km s^{-1} respectively, with standard deviations of ± 119.2 and ± 130.5 km s^{-1} respectively. In order to check the independence of the two distributions, we applied Kolmogorov-Smirnov (K-S), and also Student-*t* and Mann-Whitney two-sample tests. All tests showed that the difference between the mean values of σ_v is statistically significant with a confidence level $> 95\%$.

One may suggest, however, that the dependence of σ_v on the elongation of groups (from the ratio *b/a*) results from a dependence of σ_v on the number of group members. Indeed, round groups of class II have in the mean slightly more members (4.6) than elongated groups of class I (3.9). According to the virial theorem, the more members the group has, the larger is its mass and the higher are the velocities of individual galaxies, hence a larger σ_v.

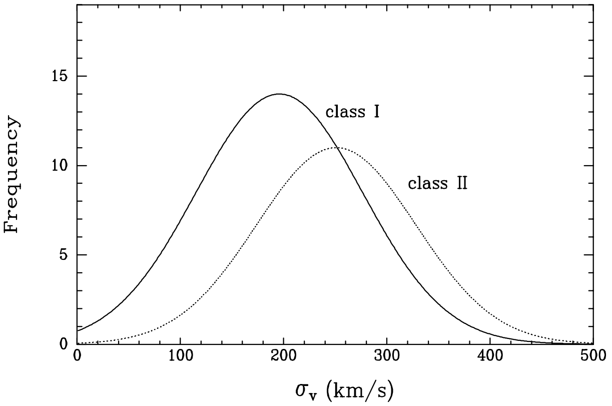

Fig. 1. The distributions of radial velocity dispersions for chain-like (class I), and round (class II) HCGs.

In order to check whether the dependence of velocity dispersion on b/a is due to differences in the number of galaxies in groups, we compared separately the mean values of σ_v for class I and class II groups consisting of three, four and five members (Table 2). N in this table is the number of accordant redshift galaxies in the group, and the numbers in parentheses refer to the number of groups in each sample.

Consideration of Table 2 shows that in the three samples with different number of members, the mean values of σ_v for round groups exceed that for elongated ones. The Student-*t* test showed that the differences in σ_v between groups of classes I and II with correspondingly three, four and five members are not statistically significant. However the combined probability of having by chance larger σ_v for all three samples of round groups simultaneously is equal to 0.04. This is fairly significant. The Mann-Whitney and the K-S tests also proved the significance of the observed differences in σ_v for all three pairs of groups together, giving a global probability of 4% and 10% respectively that the observed differences are due to chance.

The probabilities given above suppose large sample sizes, whereas for some classes we have small samples (in one case only three groups). Therefore, we applied Monte-Carlo simulations, and got an even lower probability of obtaining by chance larger σ_v for the round groups in all three cases.

Thus, the suggestion that the dependence of σ_v's on *b/a* results from a possible dependence of σ_v's on the number of group members is wrong.

Consideration of Table 2 shows also that σ_v for groups within each of two considered classes also depend on the number of group members: the more member galaxies are in the groups, the larger is their mean σ_v. This finding proves independently (the virial theorem) that the considered groups are gravitationally bound systems, and thus are real physical formations.

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[1] The group HCG 54 with $b/a = 0.08$ was not included in the list of class I groups. It seems to be only a single galaxy, and it was considered as such also by Mendes de Oliveira & Hickson (1994).

Table 1. Some parameters of accordant redshift HCGs

HCG	N	σ_v km s^{-1}	D Mpc	a kpc	b kpc	b/a	$N(I,M)$	HCG	N	σ_v km s^{-1}	D Mpc	a kpc	b kpc	b/a	$N(I,M)$
1	4	85.4	102	84	12	0.14	2	52	3	182.6	128	119	16	0.13	0
2	3	54.8	43	65	11	0.17	3	53	3	82.1	62	73	1	0.01	1
3	3	250.9	78	86	50	0.58	0	55	4	213.8	158	41	3	0.07	0
4	3	336.9	82	86	13	0.15	2	56	5	170.3	81	49	15	0.30	4
5	3	146.9	122	39	6	0.15	3	57	7	271.1	90	145	49	0.34	5
6	4	252.8	114	53	7	0.13	0	58	5	161.9	61	152	89	0.59	3
7	4	89.3	42	66	37	0.56	1	59	4	190.7	41	37	16	0.44	2
8	4	448.2	162	54	22	0.41	2	60	4	427.3	187	123	29	0.24	1
10	4	209.1	48	147	57	0.39	3	61	3	87.3	39	31	15	0.48	3
12	5	238.9	145	108	68	0.63	1	62	4	288.2	42	45	16	0.36	2
13	5	181.0	122	83	49	0.59	2	63	3	132.0	92	50	23	0.46	1
14	3	330.2	56	57	3	0.05	2	64	3	214.0	107	35	1	0.03	2
15	6	424.0	70	155	76	0.49	2	65	5	320.6	142	71	22	0.31	3
16	4	124.3	39	71	17	0.24	4	66	4	305.5	208	57	9	0.16	0
17	5	131.0	181	59	22	0.37	0	67	4	211.2	73	73	32	0.44	3
20	5	273.1	144	57	36	0.63	0	68	5	153.7	24	63	34	0.54	1
21	3	112.4	76	227	42	0.18	0	69	4	222.1	88	51	19	0.37	2
22	3	44.1	27	33	16	0.48	0	70	4	145.7	188	122	59	0.48	0
23	4	167.0	49	99	60	0.61	3	71	3	413.7	93	62	42	0.68	0
24	5	197.5	92	66	16	0.24	1	72	5	265.5	128	78	4	0.05	1
25	4	61.3	64	85	28	0.33	3	73	3	123.3	135	166	37	0.22	1
26	7	198.9	96	63	46	0.73	3	74	5	317.1	121	65	44	0.68	0
27	4	122.5	261	213	28	0.13	0	75	6	292.7	123	78	19	0.24	2
28	3	84.8	115	42	10	0.24	2	76	7	244.5	101	126	70	0.56	2
29	3	409.4	312	52	9	0.17	0	80	4	270.9	93	44	24	0.54	1
30	4	71.7	46	62	50	0.81	1	81	4	176.7	150	37	10	0.27	3
31	3	55.7	41	10	2	0.20	3	82	4	619.8	108	96	48	0.50	1
32	4	211.1	122	116	42	0.36	0	83	5	462.2	156	86	49	0.57	0
33	4	155.5	78	49	14	0.30	3	84	5	204.5	167	105	26	0.25	0
34	4	316.6	92	33	3	0.09	3	85	4	367.1	119	45	27	0.60	0
35	6	319.6	163	103	23	0.22	0	86	4	268.8	60	66	44	0.67	0
37	5	397.6	67	60	24	0.39	3	87	3	120.7	89	39	22	0.56	1
38	3	12.9	88	68	1	0.02	3	88	4	26.7	60	135	20	0.15	2
39	4	198.9	211	60	7	0.12	0	89	4	54.8	89	124	15	0.12	0
40	5	148.5	66	33	11	0.32	3	90	4	99.5	26	57	8	0.14	2
42	4	214.1	40	69	30	0.43	0	91	4	182.3	72	107	15	0.14	2
43	5	221.8	100	123	68	0.55	0	92	4	390.5	66	58	8	0.14	3
44	4	134.9	13	63	22	0.35	4	93	4	206.8	51	124	58	0.47	3
45	3	182.0	218	183	41	0.22	0	94	7	481.2	122	123	25	0.20	3
46	4	326.9	80	83	9	0.11	0	95	4	308.0	118	50	27	0.54	3
47	4	42.6	95	63	15	0.24	2	96	4	133.1	87	59	21	0.35	3
48	3	304.1	30	44	4	0.09	1	97	5	370.3	66	96	66	0.68	1
49	4	34.2	99	24	5	0.19	4	98	3	120.0	80	42	6	0.14	2
50	5	472.4	416	84	48	0.57	0	99	5	265.2	87	56	43	0.77	0
51	5	239.5	77	91	23	0.23	0	100	3	89.1	53	55	13	0.24	3

Table 2. The σ_v's of groups with different number N of members

	$N=3$	$N=4$	$N=5$
Class I	167.1 ± 115.1 (17)	191.9 ± 123.4 (19)	215.5 ± 37.3 (5)
Class II	261.8 ± 146.8 (3)	220.8 ± 112.5 (7)	283.4 ± 111.7 (11)

The correlation between σ_v and b/a obviously cannot be biased by distance (Tikhonov 1990, Mamon 1990 and Whitmore 1991), since the parameters we considered, b/a and σ_v, do not depend on distance. Moreover, the mean distances of groups of class I and II, equal to 112 ± 62 Mpc and 106 ± 74 Mps respectively, practically do not differ from each other. Hence, the dependence of σ_v on b/a is not a distance effect.

Thus, data on radial velocity dispersion of HCGs show that HCGs are *real physical formations*. If CGs were the result of a chance projection of field galaxies, there would be no difference in σ_v between the two classes.

3.2. *Interactions and merging in CGs*

The projected linear widths b of the two classes of groups are different. The mean b value of 44 chain-like groups of class I is equal to 13.6 ± 10.4 kpc, while that of 24 class II groups is equal to 47.5 ± 16.3 kpc. Hence, the mean projected width of the groups in class I is about 3.5 times smaller than that of class II.

The mean width of 14 out of 17 chain-like groups with three members is 6.9 kpc; typically the size of a galaxy. Apparently, this does not result from projection, and the real widths of chain-like groups in the mean are not larger, since, as already shown by Oleak et al. (1995, 1998), Hickson et al. (1984), Malykh & Orlov (1986), CGs have a prolate spheroidal space configuration.

The probability for a chain-like group to be observed end-on, i.e. aligned along the line of sight, is very small. Such narrow chain-like groups observed end-on should have the size of a single galaxy. In some cases, it would be very difficult to distinguish such a group from the image of a single, non-regular galaxy. The group HCG 54 is an example. Some of the "nests" of galaxies in Vorontsov-Veliaminov's Catalogue of Interacting Galaxies (1959) could possibly be just chain-like CGs seen end-on.

If CGs are real physical entities then tidal interactions and merging should take place more often in very narrow chain-like groups, where conditions are favorable for interaction.

Below we consider the morphological content of class I and II groups using data from Mendes de Oliveira & Hickson (1994), who showed that 43% of the HCGs member galaxies have morphological and/or kinematical distortions, indicating interactions and/or mergers.

Groups HCG 27, 29, 39, 45 and 50 were excluded from the sample, since Mendes de Oliveira & Hickson mentioned that they are too faint to find I/M galaxies. Hence, for the morphological content we consider 62 groups taken from the Hickson's Atlas (1994). We find that 70 out of 171 galaxies in chain-like groups, i.e. 41% show signs of interaction and/or merging, while in class II groups only 27 out of 110, i.e. 24%, show such signs[2]. Thus, as predicted, the relative number of galaxies with signs of interaction and/or merging in class I groups is twice larger than that in round groups.

The relative number of groups with three or more I/M members is larger by a factor ~ 2 in class I: it is ~ 0.32 in class I, and ~ 0.17 in class II. The relative number of groups without I/M galaxies is on the contrary smaller in class I: $\sim 23\%$ in class I, and $\sim 29\%$ in class II. The corresponding mean percentage found by Mendes de Oliveira & Hickson for all 92 groups is 25%. The fraction of groups without I/M galaxies is larger in groups with large velocity dispersion. 3 out of 12 (25%) class I HCGs with $\sigma_v > 250\,\mathrm{km\,s^{-1}}$ do not contain I/M members. This proportion is even larger in class II groups: 9 out of 13 groups (69%). The larger proportion of groups without I/M galaxies among groups with larger σ_v, i.e. with higher velocities, is apparently due to the lower efficiency of interaction and/or merging processes.

The correlation of CG properties with distance (Tikhonov 1990, Mamon 1990 and Whitmore 1991) could possibly influence the differences in the fractions of I/M galaxies in the considered CGs. But since groups of both classes are practically at the same distance, there cannot be any influence of distance *per se* on the relative quantity of I/M galaxies in groups of the two classes.

The fraction of E and S0 galaxies in groups of both classes that do not contain I/M members is 71%. It is larger than for the groups containing I/M members, 52%. The corresponding percentage for elliptical galaxies only are equal to 35% and 21% respectively.

One may suggest that in groups without I/M galaxies the dynamical evolution is much more advanced. When the merging process is advanced or completed, we see a higher proportion of elliptical and spherical galaxies. It should be taken into account, however, that the tidal disturbances should produce more dramatic effects in spirals than in the more amorphous ellipticals.

Hence, the differences in fractions of I/M and E, S0 galaxies in groups of classes I and II shows that, *as we predicted*, interaction and merging processes are more efficient in elongated, chain-like groups.

3.3. *The magnitude difference between the brightest and the second broghtest galaxies*

Galaxies in physical CGs should interact and eventually merge into a single galaxy. In some ShCGs there are very bright galaxies that may be considered as the merging products of a few galaxies in groups. A common halo in the central region of such groups and multiple cores can be interpreted in the same way. In the case of ShCG 16, 331, 351, 376, etc., the membership of very bright, dominant galaxies to the groups has been proved spectroscopically (Tiersch et al., in preparation).

It is noteworthy that the difference in magnitudes between the brightest and the second brightest galaxy in the group, $m_1 - m_2$, decreases systematically with increasing number of member galaxies in HGs. For groups of both classes with three, four, five, and six/seven members this difference is equal to $1.05{\pm}0.7\,(20)$, $0.71{\pm}0.5\,(27)$, $0.61{\pm}0.5\,(15)$, and $0.4{\pm}0.2\,(5)$ respectively. The corresponding numbers of groups are shown in parenthesis.

This fact also helps to understand the nature of CGs. We suggest that several merging processes have already occurred in groups with smaller number of members, and that for this reason the central (cannibal) galaxy became brighter. If this is true, the more galaxies there are in a group, the less number of mergings have occurred in it, and hence the smaller should be the difference in magnitude between the brightest (cannibal) galaxy and the other galaxies in the group.

Hence, the differences in $m_1 - m_2$ in groups with different number of members allow us to suggest that interaction and merging processes are actually going on in CGs. It follows that

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[2] The actual percentages could be slightly different, since they were calculated on the basis of 340 brighter galaxies classified by Mendes de Oliveira & Hickson (1994) out of 389 galaxies contained in the 92 groups.

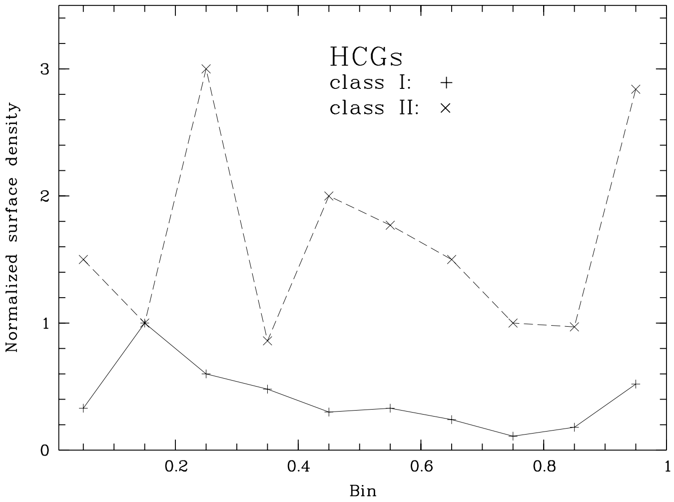

Fig. 2. Normalized density profiles for the class I, and class II HCGs.

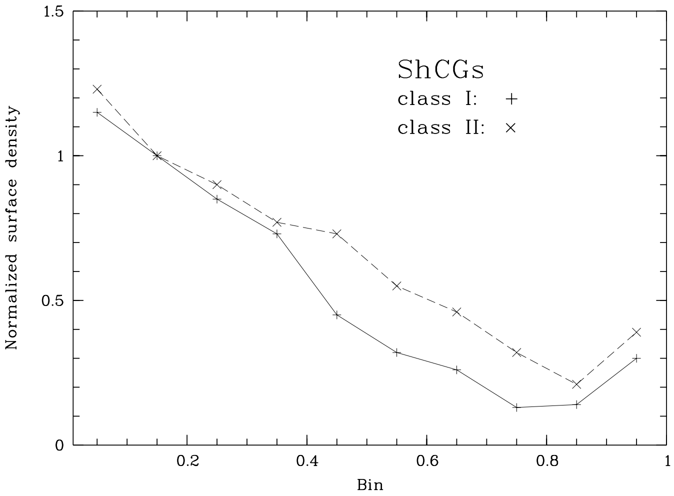

Fig. 3. Normalized density profiles for chain-like (I), and round (II) ShCGs.

groups with smaller number of members are in more evolved stages.

3.4. *Surface density*

In the case of a random two-dimensional distribution of galaxies the probability of having by chance a galaxy at radius r, $P(r) \sim r$, and surface number density $\Sigma(r)$ is constant. Therefore, in round groups no central concentration should be observed. In chain-like groups the distribution of galaxies is almost one-dimensional, so that $P(r) \sim const$, and $\Sigma(r) = P(r)/(2\pi r) \sim 1/r$. It follows that optical chain-like groups should exhibit a central concentration in surface density.

We consider separately the variation in surface density for groups of both classes. The area of each group was divided into 10 circular bins starting from the geometric center of the group. The number of galaxies in each bin was divided by the corresponding area of the bin. Then, the mean values of surface density in the corresponding bins of all groups were determined for both classes. The radius of the groups was normalized, and the surface density was normalized based on the second bin.

The normalized density profiles for classes I and II of HCGs and ShCGs are presented in Figs. 2 and 3 respectively.

Fig. 3 shows a strong central concentration of density in both classes of ShCGs. The same tendency is also seen for the HCGs of class I, whereas in groups of class II, the central concentration is not clear (Fig. 2). This may be due to the small number of groups (24 in total).

The increase in surface density in the last bins on Figs. 2 and 3 is due to the presence of two galaxies that determine the edge of the group.

Previously, Mendes de Oliveira & Giraud (1994) showed that all HCGs can be described as isothermal spheres with surface density at the center about five times larger, on average, than in the outskirts.

Montoya et al. (1996) showed that the results of surface density distribution studies in CGs that contain small numbers of members, suffer from the poor definition of the center of the system. They claim that more correct results can be obtained relying upon the distribution of projected galaxy separation, and showed that their fitted surface density profiles are even more concentrated than those obtained by Mendes de Oliveira & Giraud (1994). Hence, the surface density curves obtained in this paper could be steeper.

Thus, the central concentration of density profiles of class II round groups shows undoubtedly that galaxies in groups are not distributed at random. The reason for the concentrated surface density distribution may be genetic.

3.5. *The false, optical groups*

However, it cannot be excluded that some groups, especially those with very large σ_v, may not be real physical groups, but result from optical projection. If we assume arbitrarily that groups with σ_v's exceeding 400 km s^{-1} result from chance projection, then at most 3 out of 43 groups of class I (about 7%), and 4 out of 23 groups of class II (about 17%) may be false optical groups. Hence, false groups may be more common by a factor 2 in round groups.

Two groups among chain-like HCGs, HCG 94 and HCG 60, have the largest σ_v. Data on HCG 94 (Hickson et al. 1982) suggest that 4 of its galaxies, *a*, *b*, *c*, and *e*, with radial velocities 12 040, 11 974, 12 120 and 12 250 km s^{-1} respectively, form most probably one group. The other three galaxies, *d*, *f*, and *g*, with radial velocities of 13 009, 12 920, and 13 200 km s^{-1} seem to form another group. The diffuse light and an X-ray emission reported by Pildis (1995) seems to be associated with the group of 4 galaxies. Data on HCG 60 (Hickson et al. 1982) suggest that it could well result from a chance projection of two pairs of galaxies: *a* and *c* with radial velocities of 19 007 and 19 277 km s^{-1}, and *b* and *d* with radial velocities 18 318 and 18 300 km s^{-1}. Thus this group is probably a false one.

4. Conclusions

Among CGs we distinguish two classes, chain-like groups of galaxies (class I), and round groups (class II).

We find that:

- The mean values of the radial velocity dispersion of chain–like and round HCGs are equal to 194 km s^{-1} and 271 km s^{-1} respectively. The K-S, Student-*t* and Mann-Whitney two–sample tests proved that the difference in σ_v is statistically significant.
- The dependence of σ_v's on the group elongation is not related to the number of group members.
- The number of I/M galaxies is ~ 2 times larger in chain-like HCGs, where conditions are more favorable for I/M processes.
- The number of HCGs without I/M members is smaller in round groups with large σ_v.
- The percentage of E and S0 galaxies is larger in HCGs that do not contain I/M galaxies.
- The $m_1 - m_2$ difference is systematically larger in groups with smaller number of members.
- ShCGs exhibit a strong concentration of surface density towards group centers (Fig. 3). The central concentration is also apparent in chain-like HCGs (Fig. 2).

All this leads to the conclusion that CGs do not result from chance projection of field galaxies or filaments seen end-on, but are *real physical formations*.

Since interaction processes are more efficient in chain-like groups, they must have shorter life–times.

It is not excluded, however, that some groups with large σ_v are not real physical groups. The relative amount of false groups ($\sim 7\% - 15\%$) could be about twice larger in round groups.

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