Revista Mexicana de Astronomía y Astrofísica, **44**, 125–136 (2008)

PHOTOMETRIC AND SPECTROSCOPIC STUDY OF SEVEN SHAKHBAZIAN COMPACT GALAXY GROUPS

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Received 2007 October 24; accepted 2007 December 11

RESUMEN

En este artículo presentamos los resultados de un detallado estudio espectroscópico y fotométrico de siete grupos compactos de Shakhbazian (ShCGs), ShCG 285, ShCG 289, ShCG 322, ShCG 323, ShCG 327, ShCG 330, and ShCG 346. Determinamos el corrimiento al rojo de las galaxias miembros y las dispersiones de velocidad radial de los grupos. También estudiamos la distribución del brillo superficial de las galaxias miembros en la banda R y determinamos sus tipos morfológicos. Encontramos, como en otros ShCGs estudiados anteriormente, que algunos miembros de los grupos son galaxias en interacción o incluso están en proceso de fusión. Determinamos los parámetros físicos de los grupos: masas viriales, luminosidades, cocientes de masa-luminosidad y tiempos de cruce. Sobre la base de los resultados obtenidos en este y en trabajos anteriores, se discuten las propiedades generales de 37 ShCGs. Se muestra que alrededor del 75% de las galaxias miembros son de los tipos morfológicos E y S0.

ABSTRACT

The results of the detailed spectroscopic and photometric study of seven Shakhbazian compact groups: ShCG 285, ShCG 289, ShCG 322, ShCG 323, ShCG 327, ShCG 330, and ShCG 346, are presented. We determined redshifts of member galaxies and radial velocity dispersions of groups. We studied also the distribution of the surface brightness of member galaxies in R and determined their morphological types. We found that, as in previously studied ShCGs, some group members are interacting or are even in the process of merging. We determined physical parameters of groups: virial masses, luminosities, mass-to-luminosity ratios, and the crossing times. On the basis of the results obtained in this and our previous works, the general properties of 37 ShCGs are discussed. It is shown that about 75% of member galaxies are of E and S0 type.

Key Words: galaxies: clusters: individual (ShCG 285, ShCG 289, ShCG 322, ShCG 323, ShCG 327, ShCG 330, ShCG 346) — galaxies: photometry — galaxies: distances and redshifts — galaxies: interactions

1. INTRODUCTION

In this paper we continue the presentation of the results of a spectroscopic and photometric study of Shakhbazian Compact groups (ShCGs[3]). ShCGs were selected by an eye inspection of Palomar Sky Survey Prints as dense groups of mainly red galaxies. The groups are very dense formations: the space density in many of them reaches about $10^4 - 10^5$ galaxies per Mpc^3. Possibly due to compactness of the images of member galaxies on the POSS prints, many of which are almost indistinguishable from those of stars, most ShCGs were missed in other compact group lists compiled earlier, e.g. Hickson Compact Groups (HCGs) (Hickson 1982). ShCGs have a "cigar"-like, prolate spheroid configuration (Oleak et al. 1995), like HCGs (Hickson et al. 1984; Malykh & Orlov 1986; Orlov, Petrova, & Tarantaev 2001), and generally like poor groups of galaxies (Plionis, Basilakos, & Tovmassian 2004).

Several years ago we started a program of spectral and detailed photometric studies of ShCGs aiming to collect more data on ShCGs (Tiersch et al.

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[3]In the NED the old nomenclature SHK is used.

2002, Paper 1; Tovmassian et al. (2003a,b, 2004b, 2005a,b,c, 2006a, 2007, Papers 2–9). Particular emphasis was put on the identification of interacting galaxies and on the evaluation of their incidence in CGs. Dynamical friction, tidal interactions between galaxies, and galaxy merging are very likely to occur in the dense environments of ShCGs. Definite signs of interaction were found by Mendes de Oliveira & Hickson (1994) in many HCGs. The different morphological content of ShCGs suggests that these groups span different stages of dynamical and morphological evolution. Therefore, the study of ShCGs may be very helpful for understanding the evolution of compact groups.

Numerical modeling predicted that member galaxies in compact groups may have distorted morphologies, bridges and tails (e.g. Barnes 1985, 1989, 1990; Mihos 1995). However, observations showed that apparent signs of interaction are not always obvious, especially in E/S0 type galaxies. These galaxies are gas poor, and are not expected to produce prominent tidal features during interactions. Nevertheless, as a result of interaction processes, dynamically heated enlarged envelopes may be formed in such galaxies (Barnes 1989). Therefore, in absence of morphological distortions in the member galaxies of ShCGs with predominantly early type population, we inspected contour plots of their optical images to check for the presence of enlarged external isophotes. Earlier we detected galaxies in ShCGs with enlarged halos (e.g. ShCG 154, Paper 1; ShCG 361, ShCG 362, Paper 4). In comparison to the isophotes of galaxies of about the same brightness, the outer isophotes of these galaxies are more widely separated, and their overall sizes are larger. Also emission lines in the spectra may give evidence of the presence of active nuclei or of ongoing starbursts. Both events may be a result of the interaction.

An indirect evidence of interaction and merging processes that occurred in the past is the relative number of E/S0 galaxies. Due to processes of interaction and merging, which may be frequent in ShCGs, the spiral galaxies will convert to S0/E types, as has been suggested by Toomre & Toomre (1972), Barnes & Hernquist (1992) and Mihos (1995). Tovmassian et al. (2004a) concluded that E/S0 galaxies in groups are formed as the result of merging on average of two spiral or E/S0 galaxies with luminosities equal to those of isolated ones. Hence, the morphological content of compact groups is important for understanding their evolution.

In our study of 30 ShCGs (Papers 1–8) we determined the redshifts of many dozens of galaxies in these groups. This allowed us to confirm that the overwhelming majority of them are members of corresponding groups with accordant redshifts. These observations showed also that only a few of the assumed members of ShCGs are stars. We have obtained also the images of these groups mostly in three bands, BVR, or in some cases only in R. We measured the magnitudes of member galaxies in the corresponding bands, and determined their morphological types. Detailed photometry allowed us to study the brightness distribution of member galaxies. We found that some of them are in the process of interaction.

In this paper we present the results of the study of seven further groups: ShCG 285, ShCG 289, ShCG 322, ShCG 323, ShCG 327, ShCG 330 and ShCG 346, and we discuss the general properties of the 37 groups.

2. OBSERVATIONS AND RESULTS

The coordinates of the centers of the studied groups taken from Stoll et al. (1994a, 1994b) and Stoll, Tiersch, & Cordis (1997) are given in Table 1. In the last column of Table 1 the galactic extinction in B, V and R (Schlegel, Finkbeiner, & Davis 1998) is given.

2.1. *Spectroscopy*

Spectroscopic observations of 31 objects in the seven groups studied were made with the Cassegrain spectrograph of the 2.2 m telescope of the DSAZ Calar Alto in 1993–94. The spectrograph is fitted with a TEK CCD with 1024×1024 pixels (24 μm squared) and a 600 lines/mm grating blazed at 5000 Å with a dispersion of 120 Å/mm for the wavelength range of 4900 – 7650 Å. Because of the faintness of some of the observed galaxies, the slit width was set at $\sim 2.5''$. Spectra of 10 objects were obtained with the 2.1 m telescope of the Guillermo Haro Observatory (GHO) in Cananea, México, operated by National Institute of Astrophysics, Optics and Electronics. Observations of five galaxies in ShCG 346 were made in May 1995, of galaxies Nos. 2, 3 and 4 in ShCG 285 in April 1996, and galaxies Nos. 5 and 6 in ShCG 323 in March 1999. The Faint Object Spectrograph and Camera (Zickgraf et al. 1997) with dispersion 8.5 Å/pxl in the spectral range 4000–9000 Å was used. The spectra of galaxies were obtained with an integration time of 60 min; the signal-to-noise ratio is normally about 20. At Calar Alto

TABLE 1

POSITIONS OF THE STUDIED GROUPS AND EXTINCTIONS Q_B, Q_V, Q_R IN CORRESPONDING DIRECTIONS

ShCG	RA (2000)	Dec (2000)	Q_B	Q_V	Q_R
285	$11^h19^m06.9^s$	$-10°23'26''$	$0.^m236$	$0.^m181$	$0.^m146$
289	$13^h58^m08.7^s$	$-12°53'05''$	$0.^m360$	$0.^m277$	$0.^m223$
322	$11^h23^m44.2^s$	$-04°12'48''$	$0.^m153$	$0.^m117$	$0.^m095$
323	$12^h19^m17.8^s$	$-07°24'08''$	$0.^m122$	$0.^m093$	$0.^m075$
327	$14^h11^m51.6^s$	$-09°11'27''$	$0.^m196$	$0.^m150$	$0.^m121$
330	$15^h14^m20.2^s$	$-09°35'29''$	$0.^m462$	$0.^m355$	$0.^m286$
346	$09^h15^m10.4^s$	$+05°14'04''$	$0.^m232$	$0.^m179$	$0.^m144$

TABLE 2

RADIAL VELOCITIES OF MEMBER GALAXIES IN THE STUDIED GROUPS

ShCG 285		ShCG 289		ShCG 322		ShCG 323		ShCG 327		ShCG 330		ShCG 346	
g	RV [km s^{-1}]	g	RV [km s^{-1}]	g	RV [km s^{-1}]	g	RV [km s^{-1}]	g	RV [km s^{-1}]	g	RV [km s^{-1}]	g	RV [km s^{-1}]
1	34800	1	20630	1	15220	1	31065	1	15830	1	31770	1	40650
2	34350	2	20180	2	16040	2	30500	2	15950	2	32130	2	40440
3	34680	3	21050	3	15440	3	29640	3	16010	3	34140	3	40380
4	34890	4	21170	4	15830e	4	30690	4	15890	4	32340	4	40500
5	34950	5	21020	6	15265e	5	29905	5	15740	5	32520	5	star
6	34170	8	star	7	7710	6	28590					7	41852
7	35220			8	16310e							13	40264

the wavelengths were calibrated using a HeAr comparison spectrum, and at GHO the XeNe comparison spectrum was used. The pixel-to-pixel variation of the CCD was calibrated using dome flats. Redshifts of galaxies were generally determined by absorption features of Hβ, MgIb and NaD. Emission lines were detected in the spectra of galaxies 4, 6 and 8 in ShCG 322. The MIDAS package[4] was used for the determination of redshifts, fitting the profile of each observed line by a Gaussian. The redshift of a galaxy was determined as the mean of measurements of individual lines. The accuracy of the measured radial velocities (RV) is between 40 km s^{-1} and 60 km s^{-1} depending on the sharpness and the number of the measured spectral lines. The uncertainties in the case of relatively low signal-to-noise ratios generally do not exceed 100 km s^{-1}. Measured RVs have been corrected for the solar motion according to the expression $\Delta v = 300 sin l \cdot cos b$ km s^{-1} where l and b are the galactic longitude and latitude respectively. The radial velocities of individual galaxies are given in Table 2.

Objects No. 8 in ShCG 289 and No. 5 in ShCG 346 turned out to be stars; Gal. 7 in ShCG 348 is a background object and Gal. 7 in ShCG 322 is a foreground one projected over the group.

2.2. *Direct imaging and photometry*

We obtained high-resolution BVR images of almost all groups. The groups ShCG 285 and ShCG 323 were not observed in V and B, respectively. Observations were made during two observing runs in 1993 and 1994 at the RC focus of the 1.23 m telescope at the DSAZ Calar Alto, Spain. The TEK CCD detector with 512 × 512 pixels of 27 μm squared was used, giving a sky coverage of $4'\ 50'' \times 4'\ 50''$ with an image scale of $0.565''$/pxl. Observations were made at seeing conditions better than $2''$. In total 55 galaxies were photometrically observed.

[4]Munich Image Data Analysis System, which is developed and maintained by the European Southern Observatory.

The images were processed with the MIDAS image processing package. The night sky was eliminated by means of a software program developed by Shergin, Kniazev, & Lipovetski (1996). This program takes into account the complicated conditions in a CG with overlapping galaxy halos. The BVR magnitudes were calibrated in the Kron/Cousins photometric system using the standard star cluster M67. The magnitudes of galaxies in all three bands are estimated within the contour of the surface brightness $\mu = 26\overset{m}{.}5/\mathrm{arcsec}^2$, though in some cases a limit lower than this was reached. The overlapping halos of images of galaxies, which are not rare in compact groups, were separated by extrapolation of the fitted ellipses in the non-overlapping parts down to the mentioned limiting surface brightness. In such cases the last undisturbed isophote (brighter than $\mu = 26\overset{m}{.}5/\mathrm{arcsec}^2$) determines the magnitude. When a galaxy is totally embedded in the common halo we can only estimate its magnitude integrating the emission out to the limit of the common halo. The faint envelope of a such galaxy may not be distinguished from the common halo, and we neglect it. Thus, we overestimate the total magnitude of such galaxy. The measured magnitudes are corrected for extinctions Q_B, Q_V and Q_R within our Galaxy (Columns 4–6 of Table 1). The K-correction is made according to Poggianti (1997). The internal extinction of the individual spiral galaxies is estimated according to $A_i = 0.72 \log(1/\cos i)$. The inclination angle i is deduced by a procedure in MIDAS. The extinction in V and R are calculated by $E_{B-V} = 0.238 Q_B$ and $E_{V-R} = 0.590 Q_B$, respectively. The estimated accuracy of magnitudes of isolated images is about $0\overset{m}{.}06$. The error may be higher in the case of overlapping halos. The diameters and the axial ratios of galaxies are determined by the same contour ($\mu = 26\overset{m}{.}5/\mathrm{arcsec}^2$).

The images of the studied groups in R are presented in the left panels of Figures 1–7. In the right panels of the isophotes of the observed galaxies are shown. The latter are chosen arbitrarily to reveal possible signs of interaction between member galaxies. The units of the isophotes for each group are given in the corresponding figure captions. The galaxy identification numbers are taken from Stoll et al. (1993, 1994a,b, 1997).

The morphological content of groups is important for understanding the history of their dynamical evolution. We determined the morphological types of the group galaxies first by inspection of large scale direct images of groups. When no spiral structure was evident on the image of a galaxy, we determined its morphological type by inspection of the surface brightness profile, μ, versus the semi-major axis a, or $a^{1/4}$. Undisturbed elliptical galaxies have a straight profile on the $\mu - a^{1/4}$ graph (de Vaucouleurs 1948). For galaxies whose $\mu - a^{1/4}$ profile deviates from a straight line, and which thus could be of S0 type or a spiral, we constructed the μ versus a graph. The $\mu - a$ curve may generally be decomposed into the bulge and disc components (Kent 1985; Schombert & Bothun 1987). The bulge of a spiral galaxy is less dominant and its profile is steeper than that of a lenticular S0 galaxy (Kent 1985). Thus, depending on the relative size of the bulge and the steepness of its profile, we differentiated spiral galaxies from S0s. However, as Kent (1985) has mentioned, not all galaxies obey the simple functions for differentiation between S0 and spiral galaxies. Therefore, the identification of spiral galaxies by means of the surface brightness profiles is not very certain. Note also that deviations from ellipticity in both the core and the envelope, as well as deviations from concentric ellipses, are sometimes observed (Pildis, Bregman, & Schomberg 1995). Such deviations, if they are not symmetric, may indicate that a galaxy has undergone an interaction.

The results of the photometry of galaxies in the studied ShCGs are presented in Table 3 in which the following information is given: Column 1 – the galaxy identification number. Column 2 – the magnitude in B. Column 3 – the magnitude in V. Column 4 – the magnitude in R. Column 5 – the position angle of the major axis measured in R. Column 6 – the axial ratio b/a measured in R. Column 7 – the morphological type.

3. DISCUSSION

3.1. *Description of groups*

ShCG 285. The group consists of four bright ellipticals (Nos. 1–4) and about ten fainter galaxies located south of the bright quartet. It may seem that the fainter galaxies are background objects not related to the quartet. However, the redshifts of objects 5 and 7 show that at least these two faint galaxies are members of the group. Note that there are no other galaxies around the group up to distances of about $5' - 6'$. Contour plots (right panel of Figure 1) show that the four bright members have somewhat enlarged halos. Therefore, these four galaxies are probably interacting with each other. Apparently, the un-numbered compact object to the south-east of Galaxy 2 has enlarged contours, and may also be involved in the interaction. On the contrary, a similar object to the south-east

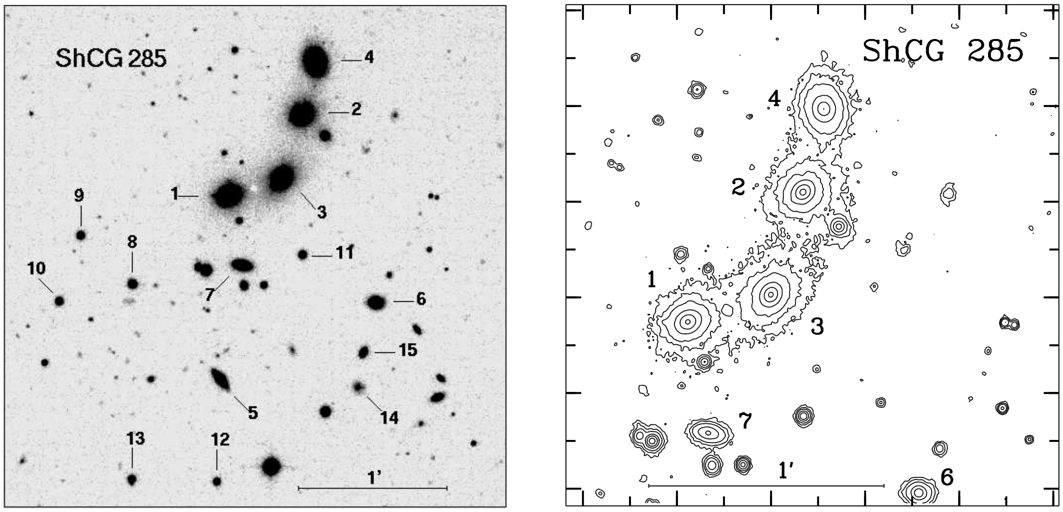

Fig. 1. The images and the isophotal contour plots of galaxies in ShCG 285. The units of surface brightness μ of isophotes starting from the innermost one are: $19^{m}_{.}51$, $20^{m}_{.}49$, $21^{m}_{.}54$, $23^{m}_{.}48$, $24^{m}_{.}55$, and $26^{m}_{.}06$.

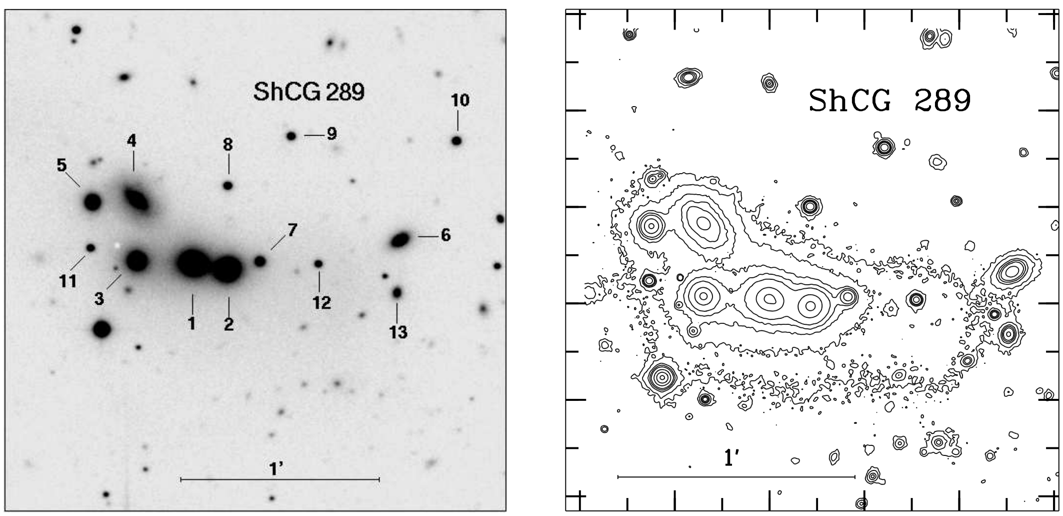

Fig. 2. The same as in Figure 1 for ShCG 289. The units of surface brightness μ of isophotes starting from the innermost one are: $19^{m}_{.}95$, $20^{m}_{.}43$, $21^{m}_{.}80$, $22^{m}_{.}23$, $22^{m}_{.}81$, $24^{m}_{.}15$, and $25^{m}_{.}00$.

of Galaxy 1 is certainly a star. Other supposed members of the group do not show any signs of interaction.

ShCG 289. Baier & Tiersch (1976) mention that the group consists of 13 members. However, spectral observations show that one of the putative members, object 8, is a star. Moreover, photographic observations revealed that objects 9, 10, 11 and 12 are also stars (see right panel of Figure 2). Five bright galaxies 1–5 have accordant redshifts. They seem to be embedded in a common halo. The contour plots of Galaxies 1–4 are somewhat enlarged, while the contour plots of Galaxy No. 5, which is located within the common halo, are not enlarged. This means that Galaxy 5 is located somewhat farther along the line of sight than Galaxies 1–4. It is very possible that the latter galaxies are in the process of interaction. Radio emission of Galaxy 3 (Tovmassian et al. 1999) may possibly be also a result of interaction. The common halo of the group of four bright galaxies is stretched to the west, up to the distance of Galaxy 6. So, probably this galaxy, or Galaxy 13 are also involved in the interaction.

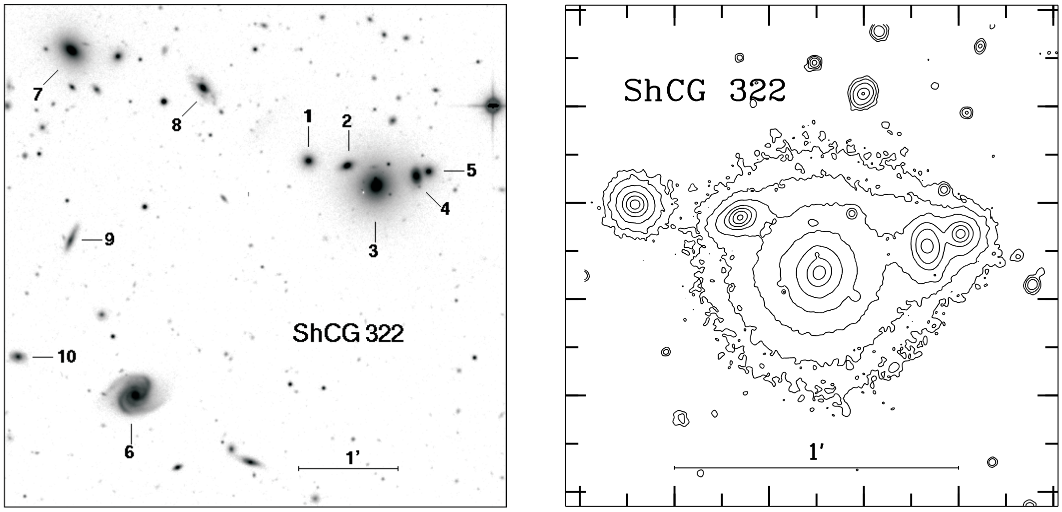

Fig. 3. The same as in Figure 1 for ShCG 322. The units of surface brightness μ of isophotes starting from the innermost one are: $18.^{m}50$, $19.^{m}61$, $20.^{m}96$, $22.^{m}20$, $23.^{m}18$, $23.^{m}71$, and $24.^{m}08$.

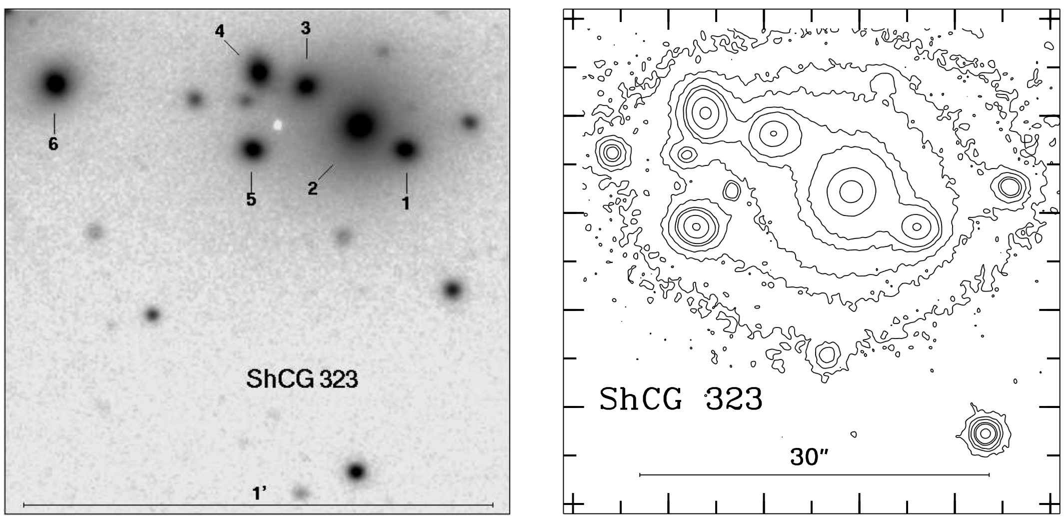

Fig. 4. The same as in Figure 1 for ShCG 323. The units of surface brightness μ of 6 isophotes starting from the innermost one are: $19.^{m}10$, $20.^{m}23$, $20.^{m}78$, $21.^{m}20$, $21.^{m}76$, $22.^{m}05$, $24.^{m}23$.

ShCG 322. We obtained spectra of seven candidate members of this group. We found that one of the galaxies, No. 7, is a foreground one projected over the group. Redshifts of four galaxies, Nos. 3, 6, 7 and 8, were measured by Colless et al. (2003). They are in good agreement with our data. Five galaxies of the group, Nos. 1–5, compose the central condensation of the cluster Abell 1248. De Propris et al. (2003) measured spectra of 44 of the cluster members. The RVD of the cluster is 798 km s^{-1}, while that of the compact group is much smaller, 202 km s^{-1}. We determined the physical parameters of the compact group (see below), which is well isolated from other members of the cluster.

Contour plots (right panel of Figure 3) show that four galaxies (Nos. 2–5) of the compact group are embedded in a common envelope. Contour plots of two of them, Galaxies 3 and 4, are enlarged, hence they are certainly interacting. Interestingly, emission in H_α is observed in Galaxy 4 which is classified by us as of E type. The emission line in this E type galaxy is probably due to activation of a cen-

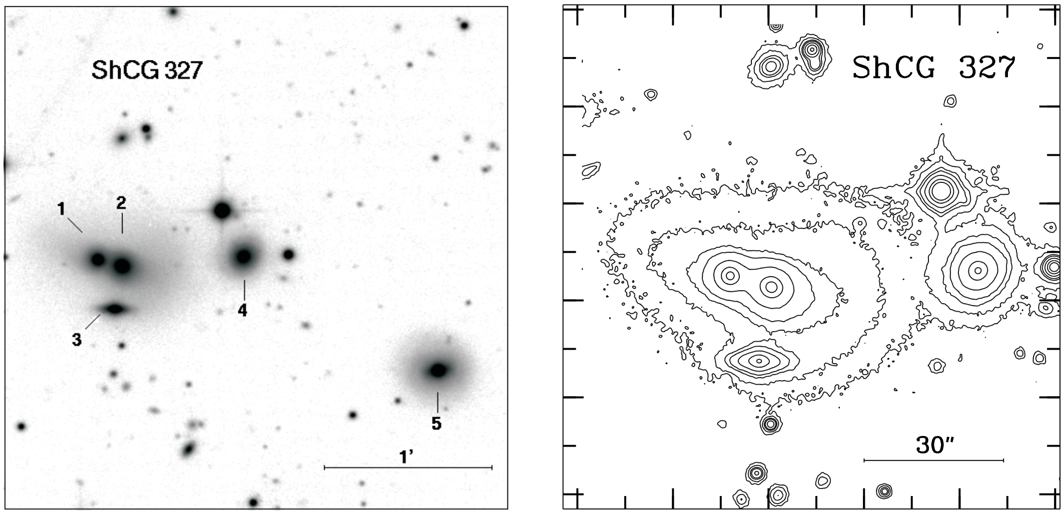

Fig. 5. The same as in Figure 1 for ShCG 327. The units of surface brightness μ of 6 isophotes starting from the innermost one are: $18\overset{m}{.}80$, $20\overset{m}{.}23$, $21\overset{m}{.}19$, $22\overset{m}{.}24$, $22\overset{m}{.}95$, $24\overset{m}{.}20$, $28\overset{m}{.}0$.

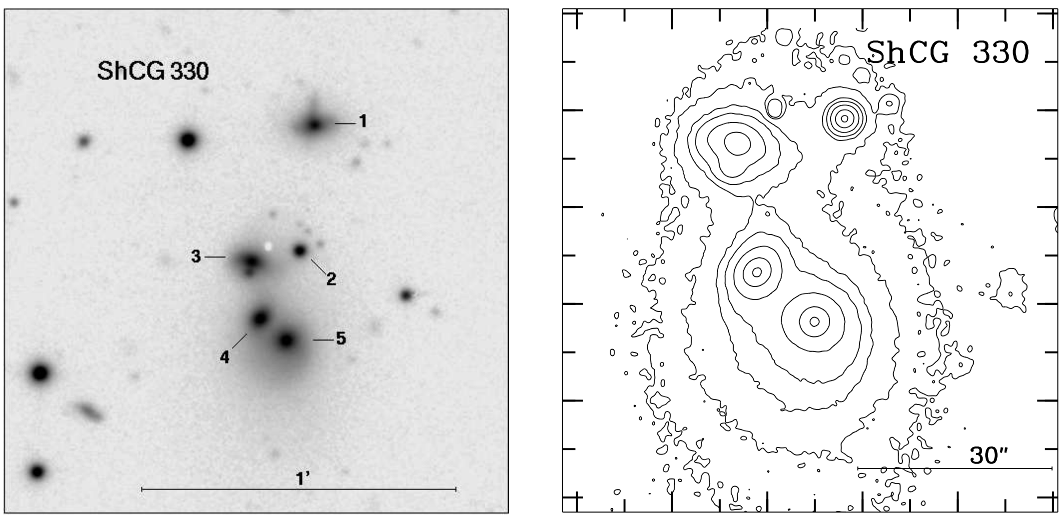

Fig. 6. The same as in Figure 1 for ShCG 330. The units of surface brightness μ of 6 isophotes starting from the innermost one are: $19\overset{m}{.}71$, $20\overset{m}{.}48$, $21\overset{m}{.}20$, $21\overset{m}{.}76$, $22\overset{m}{.}31$, $23\overset{m}{.}23$, $24\overset{m}{.}55$.

tral AGN by a violent interaction process. Contour plots of the compact Galaxy 5 are also somewhat enlarged, so it also may be in interaction with Galaxies 3 and 4. Meanwhile, contour plots of Galaxy 2 are not enlarged, therefore it may be projected over the interacting triplet. Galaxy 1, located on the sky near the interacting galaxies, has an enlarged halo. Therefore, we suggest that it may also be involved in the interaction.

ShCG 323. We obtained spectra of all 6 galaxies of this group. All of them have accordant redshifts. According to contour plots (right panel of Figure 4), all galaxies of the group but one (No. 6) are embedded in a common halo, and apparently are interacting. There are a few faint objects within the large halo. The contour plots of these objects are also enlarged. We suppose that they are also members of the group, and are involved in the interaction.

ShCG 327. Redshifts of five members of this group were measured. The difference of redshifts is very small, the RVD is only 87 km s^{-1}. Galaxies 1,

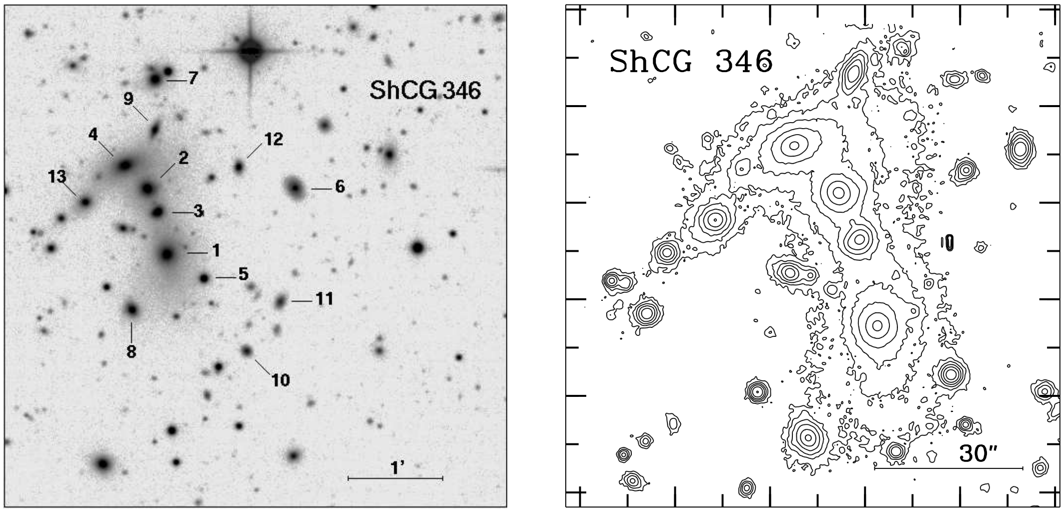

Fig. 7. The same as in Figure 1 for ShCG 346. The units of surface brightness μ of 6 isophotes starting from the innermost one are: $20^{\mathrm{m}}.28$, $21^{\mathrm{m}}.76$, $22^{\mathrm{m}}.82$, $24^{\mathrm{m}}.00$, $25^{\mathrm{m}}.45$, $28^{\mathrm{m}}.10$.

2 and 4 have enlarged halos (right panel of Figure 5), and are apparently interacting. Galaxy 5 located relatively far from this triplet also has a large halo, well seen on the prime image (left panel of Figure 5), and is apparently interacting with the latter. The contour plots of Galaxy 3, which is located on projection very close to the pair of interacting Galaxies 1 and 2, are not enlarged. Hence, this member of the group is located relatively far along the line of sight from interacting Galaxies 1, 2 and 4.

ShCG 330. We measured redshifts of all five candidate member galaxies of the group. Four of them, Galaxies 1, 2, 4 and 5 have accordant redshifts. Galaxy 3 is located farther and is projected over the group. The right panel of Figure 6 shows that Galaxies 2–5 are embedded in a common envelope. The contour plots of Galaxies 4 and 5 are enlarged. Moreover, the halo of Galaxy 5 is asymmetric, and is stretched towards the south-west. Hence, these two galaxies are certainly interacting with each other. Contour plots of Galaxy 3 seem also to be somewhat enlarged. However, since the galaxy is farther than the group, the observed enlargement of countour plots could be due to photographic superposition of the common large envelope of Galaxies 4 and 5. Note that the contour plots of Galaxy 2, which seems to be embedded in the common halo, are not enlarged. This means that, being a member of the group, Galaxy 2 is a back- or foreground object in relation to interacting Galaxies 4 and 5. The galaxy is very compact, and the projection of the envelope of Galaxies 4 and 5 does not affect its contour plots. There is an ejection-like feature on the north side of Galaxy 1. However, since it is not directed strictly to the galactic nucleus, it may be an object projected over Galaxy 1.

ShCG 346. We obtained spectra of seven objects of this group. Galaxies 1, 2 , 3 , 4, 13 have accordant redshifts with a small velocity dispersion of about 100 km s^{-1}. The redshift of Galaxy 7, which is not a member of the group but a background object, was measured also in the Sloan Digital Sky Survey; it is 41889 km s^{-1} (Adelman-McCarthy et al. 2007). Object 5 is a star.

Contour plots (right panel of Figure 7) show that Galaxies 1–4, and possibly also No. 9 are involved in interaction with each other. All of them have enlarged contour plots. A common halo stretches also from Galaxy 4 toward Galaxy 13 and farther to the unnumbered object south-east from Galaxy 13. All these galaxies seem to be interacting with each other. Galaxy 13 is also a NVSS radio source.

In Tovmassian et al. (1999) Galaxy 8 was tentatively identified with the radio source NVSS J0915112+051426. If this galaxy is indeed the radio source, its radio emission may evidence that it probably participates in the interaction as well. However, since the accuracy of the radio position is not very high, the radio source could be the object located 15 arcsec north-east of Galaxy 8.

TABLE 3

PHOTOMETRIC PARAMETERS OF GALAXIES

Gal.	B	V	R	PA	b/a	Type
			ShCG 285			
1	18.38	-	16.24	25	0.85	E
2	18.24	-	16.19	45	0.90	E
3	18.45	-	16.39	54	0.74	E
4	18.36	-	16.35	−79	0.68	E
5	19.53	-	17.15	−61	0.65	E
6	19.47	-	17.42	−1	0.79	E
7	19.46	-	17.58	−12	0.71	S0
14	19.92	-	17.07	64	0.76	E
15	20.81	-	18.66	64	0.76	E
			ShCG 289			
1	16.62	15.85	15.17	−13	0.85	S0
2	16.91	15.86	15.17	37	0.69	E
3	17.42	16.18	15.78	−17	0.90	S0
4	17.85	16.88	16.36	−47	0.65	S0
5	17.82	16.82	16.22	−4	0.86	E
6	18.33	17.11	16.50	28	0.66	S0
7	19.00	18.09	17.22	−31	0.96	E
13	19.58	18.57	18.18	70	0.72	S0
			ShCG 322			
1	18.58	17.37	16.53	−22	0.95	E
2	18.22	17.01	15.93	17	0.76	E
3	16.43	15.09	14.06	56	0.91	S0
4	17.87	16.71	15.80	−85	0.54	E
5	18.75	17.53	16.81	19	0.76	S0
6	16.19	15.18	14.19	14	0.62	S
7*	16.87	15.79	14.88	−44	0.82	S0
8	17.85	16.93	16.13	−48	0.54	S
9	19.10	18.20	17.13	64	0.36	S
10	18.73	17.98	17.39	−6	0.74	S0
			ShCG 323			
1	-	17.56	16.73	12	0.90	E
2	-	16.1720	15.71	26	0.97	S0
3	-	17.40	16.31	14	0.92	S0
4	-	17.66	16.71	−70	0.77	S0
5	-	18.01	16.97	−13	0.80	S0
6	-	17.22	16.48	26	0.88	S0
			ShCG 327			
1	17.24	16.49	15.78	−13	0.79	S0
2	16.76	15.89	15.28	−21	0.75	E
3	17.85	16.83	16.00	−1	0.50	S
4	16.98	16.33	15.34	50	0.92	S0
5	16.79	16.00	14.82	3	0.92	S0
			ShCG 330			
1	18.41	17.34	16.56	4	0.79	E
2	18.29	17.00	16.03	−6	0.81	S0
3	18.09	17.72	17.37	8	0.97	S0
4	18.20	16.86	16.03	76	0.79	S0
5	17.35	16.47	15.63	−36	0.76	S0
			ShCG 346			
1	18.32	17.30	16.65	−65	0.99	E
2	18.35	17.22	16.70	−5	0.80	E/S0
3	18.94	17.66	17.00	29	0.70	S0
4	18.94	17.50	16.67	18	0.82	S0
6	18.96	18.00	17.49	−57	0.73	S0
7	18.36	17.55	16.89	60	0.81	E
8	18.96	17.89	17.45	−47	0.78	S0
9	19.38	18.48	17.93	77	0.71	S
10	19.48	19.04	18.84	−24	0.81	S0
11	19.76	19.16	18.68	62	0.72	S0
12	19.61	18.67	18.11	−79	0.71	S0
13	19.91	18.43	17.62	9	0.65	E

*Foreground galaxy.

3.2. *Physical properties of groups*

Knowing the distances of the member galaxies in the observed groups ($H_0 = 74$ km s^{-1} Mpc^{-1}) and using the results of their photometry, we determined, as in other papers of this series (Papers 1–9), some important physical parameters of the groups, presented in Table 4. In Table 4 the following information is given: Line 1 – the number of galaxies with measured redshifts. Line 2 – the redshift z (weighted by masses of member galaxies). Line 3 – the length a of the group determined by the two members of the group with the largest mutual separation on the sky. Line 4 – the RVD (weighted by the masses of the galaxies). Line 5 – the virial radius, R_{vir}, of the group (weighted by the masses of the galaxies). Line 6 – the virial mass, $\mathcal{M}_{vir}$. Line 7 – the luminosity of the group, L, in solar units. Line 8 – the mass-to-luminosity ratio, $\mathcal{M}/L$, in solar units. Line 9 – the crossing time, τ_c. For details on the determination of the above mentioned parameters see Paper 1.

3.3. *Summary of results of the study of ShCGs*

The total number of the studied ShCGs is 37 (this paper and Papers 1–8). One of the studied ShCGs (Tovmassian et al. 2005c) is identical to cluster Abell 1097, and we will not consider it below.

In the area of the 37 compact groups we obtained in total spectra of 222 candidate members. Only 14 of them turned out to be stars. Twelve galaxies have discordant redshift and thus are projected over the corresponding groups. Hence, though the groups have been selected by an eye search on the Palomar Sky Survey Prints without knowledge of the redshifts of the galaxies, they are real physical entities. The total number of member galaxies with accordant redshifts in these groups is 196, i.e. about 90% of the putative member galaxies are confirmed. If ShCGs were selected by an automated search, some of their members located at relatively large angular distance from the main concentration of galaxies, like Galaxies 2 and 12 in ShCG 181 (Paper 4), Galaxy 9 in ShCG 376 (Paper 2), Galaxy 4 in ShCG 257 (Paper 8), Galaxy 6 in ShCG 245 (Paper 9), would be missed as group members, since in the compact group selection algorithms the accepted limiting projected distance between galaxies is smaller than in the examples just given. Also, some groups, like ShCG 188 (Paper 5) would not be recognized as a CG. Hence, though eye search is very time consuming, for some cases it is more effective than the automated search with an arbitrary algorithm.

TABLE 4

PHYSICAL PARAMETERS OF THE STUDIED SHCGS

Parameter	ShCG 285	ShCG 289	ShCG 322	ShCG 323	ShCG 327	ShCG 330	ShCG 346
n_m	7	5	4	6	6	4	4
z	0.1157	0.0693	0.0518	0.1011	0.0529	0.1076	0.1351
a [kpc]	430	130	240?	92	140	92	510
RVD [km s^{-1}]	276	360	202	606	87	270	107
R_{vir} [kpc]	93	27	28	25	39	30	46
$\mathcal{M}_{vir}$ [$10^{11}\mathcal{M}_\odot$]	78	38	13	101	33	24	6
L [$10^{11}[L_\odot$]	4.9	0.4	0.3	0.8	0.5	0.43	1.5
$\mathcal{M}/L$ [$\mathcal{M}_\odot/L_\odot$]	16	99	37	132	7	54	4
τ_c [10^6 years]	139	30	57	17	184	46	183

Detailed photometric data have been obtained for 279 candidate members in the studied groups, and also for nine galaxies projected over the groups. Photometric data and the knowledge of distances of groups allowed us to determine such physical parameters of ShCGs as their masses, luminosities, mass-to-luminosity ratios, and crossing times. The summary of the physical parameters of the studied ShCGs is presented below. Note that in Papers 1–6 the physical parameters were determined adopting the Hubble constant $H_0 = 55$ km s^{-1} Mpc^{-1}, whereas $H_0 = 74$ km s^{-1} Mpc^{-1} was used in Papers 7 and 8. For comparison of the physical parameters and for deducing corresponding mean values, we recalculated the parameters presented in Papers 1–6 for $H_0 = 74$ km s^{-1} Mpc^{-1}. In some of the studied groups the redshifts of some faint members were not measured. Therefore, it may seem that the derived physical parameters of such groups may not be correct. However, only one parameter, the mass-to-luminosity ratio, may differ slightly from the real value. Indeed, the determined mass is the virial mass, which is estimated using RVD. The latter depends on the total mass of the group which in turn is determined mainly by the group brightest members (see Paper 1). Note that the derived mass of a group with few members may have some uncertainty for the unknown projection effect. Faint galaxies located at the outskirts of a group do not play a significant role in the determination of the RVD. Meanwhile, the total luminosity has been determined using only galaxies with measured redshifts. Since the contribution of possible group members with unknown redshift was not taken into account, in some cases the estimated luminosity is actually a lower limit to the group luminosity. In such cases the mass/luminosity ratio is overestimated. Therefore, the estimated mass/luminosity ratio in such cases will be smaller than the real value. However, deviation may not be very high because most of the galaxies in the outskirts of a group are generally much fainter than the central galaxies, and their contribution to the total group luminosity will be negligible.

The virial masses of the studied groups span a wide range of values within $(5 - 270) \cdot 10^{11}\mathcal{M}_\odot$ with a mean value $74 \pm 72 \cdot 10^{11}\mathcal{M}_\odot$. The smallest virial mass is that of the group ShCG 104 with three confirmed members, while the highest mass is that of the group ShCG 360 with eight members. The obtained values are typical for galaxy groups. Total luminosities also vary in a wide range, from $0.3 \cdot 10^{11}\mathcal{L}_\odot$ for ShCG 322 with 6 members to $5.9 \cdot 10^{11}\mathcal{L}_\odot$ for ShCG 223 with 9 members. Note that variations in both the virial mass and the total luminosity are much larger than the difference in the number of the group members. The mean mass-to-luminosity ratio for 37 groups is 44 ± 44. The highest mass-to-luminosity ratio, $\mathcal{M}/L = 161$, is that of the ShCG 257 ($n = 3$), and the group ShCG 371 ($n = 4$) has the smallest mass-to-luminosity ratio, $\mathcal{M}/L = 2$. The mean RVD of the 37 studied groups is 322 ± 158 km s^{-1}. The RVDs of ShCG 74W and ShCG 327 consisting of 3 and 5 members respectively are very small, 88 km s^{-1} and 87 km s^{-1} respectively. The three groups, ShCG 323, ShCG 360 and ShCG 361, with the highest RVD (over 600 km s^{-1}) are comparable to those of clusters (Zabludoff, Huchra, & Geller 1990). The mean crossing time τ_c of 36 ShCGs (excluding ShCG 74W which consists of only three members, and has very high $\tau_c = 60 \cdot 10^7$), is $\approx (90 \pm 62) \cdot 10^6\ y$.

If ShCGs were completely isolated systems, their members would traverse the parent group is major axis more than hundred times, on average, in a Hubble time. Note, however, that CGs are generally embedded in loose groups (Sulentic 1987; Rood & Williams 1989; Rood & Struble 1994). In a series of papers (Tovmassian, Yam, & Tiersch 2001; Tovmassian 2001, 2002; Tovmassian & Chavushyan 2000; Tovmassian & Tiersch 2001; Tovmassian, Plionis, & Torres-Papaqui 2006b) it has been shown that HCGs and ShCGs are the cores of larger, elongated groups whose members are gravitationally bound with the central condensation. Therefore, the number of crossings in reality will be somewhat smaller. The smaller the crossing time, the higher the number of revolutions that the member galaxies will make within the group, and the higher the chances that these galaxies will encounter and merge to form E/S0 galaxies (Toomre & Toomre 1972; Barnes & Hernquist 1992; Mihos 1995). Tovmassian, Plionis, & Andernach (2004) showed that E/S0 galaxies are formed by merging of two spiral or E/S0 type galaxies of about the same luminosity. It follows that the fraction of early type galaxies will be high in compact groups. The loss of interstellar gas by galaxies caused by tidal forces and/or ram pressure may also explain the lack of spirals. Hickson, Kindle, & Aumann (1989) showed that about half of the member galaxies in HCGs are of early types.

Detailed photometry of galaxies in ShCGs (this paper and Papers 1–8) helped us to determine their morphological types. As it was expected, ShCGs consist mostly of early type galaxies. Within 37 ShCGs we found 57 elliptical galaxies, 38 of intermediate E/S0 type and 110 S0 lenticulars (including the candidate members without spectroscopic confirmation). Among the studied 287 member galaxies we found only 56 spirals. For 26 galaxies the spectral type is indefinite – S/S0. If we assume that half of the latter are of S0 type, then the relative number of early type galaxies (E and S0) in ShCGs is about 76%. If we assume that all 26 galaxies with indefinite morphological type are early type galaxies, then the number of E/S0s will be 231, i.e. 80%. If all galaxies with indefinite morphological type are spirals, then 71% of member galaxies are of early type. This is higher than in HCGs in which only about half of member galaxies are of E/S0 types (Hickson et al. 1989). Note that redshifts of 85 candidate member galaxies are not known. Some of them may be field galaxies unrelated to corresponding groups. And since field galaxies are mainly spirals, their exclusion will only increase the relative number of early type galaxies in groups. Hence, most of the studied groups consist preferentially of early type galaxies. The groups ShCG 8, ShCG 251, ShCG 344 and ShCG 376 are exceptions. About 84% of members in these groups are spiral galaxies.

Detailed photometry of ShCGs showed that interaction processes occur in almost each of them. In many groups (ShCG 19, ShCG 31, ShCG 38, ShCG 154, ShCG 223, ShCG 245, ShCG 285, ShCG 289, ShCG 322, ShCG 323, ShCG 327, ShCG 328, ShCG 330, ShCG 346, ShCG 360, ShCG 362, ShCG 371) two or more galaxies are embedded in a common halo. In the spectra of 25 spiral galaxies we detected emission lines. Some emission line spectra are presented in Papers 2 and 6. Eight of them are in groups consisting mainly of spiral galaxies.

4. CONCLUSIONS

In this paper we present the results of the study of seven ShCGs (ShCG 285, ShCG 289, ShCG 322, ShCG 323, ShCG 327, ShCG 330 and ShCG 346). We determined redshifts of 40 supposed members in these groups. One of them (ShCG 322-7) is a foreground galaxy, and another one (ShCG 289-8) turned out to be a star. We measured stellar magnitudes in BVR of 38 confirmed members of these groups and of 16 supposed members not spectroscopically confirmed. (Note that ShCG 285 was not observed in V and ShCG 323 in B).

The general properties of the 37 studied groups are discussed. It is prominent that the fraction of elliptical and lenticular galaxies in ShCGs is $\approx 75\%$, which is higher than in HCGs. It means that ShCGs are dynamically more evolved.

We are grateful to our anonymous referee for a very careful reading of the manuscript and many comments. H. Tiersch is grateful to the Government of the Land Brandenburg for the support of this work (Az 24-19/003; 2000), to the DFG for Grants TI 215/6-2, TI 215/6-3, MEX 111/1/98, and to Mr. O. Beck for private financial support.

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