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PHOTOMETRIC AND SPECTROSCOPIC STUDY OF THE SHAKHBAZIAN COMPACT GALAXY GROUPS SHCG 31, SHCG 38, SHCG 43, AND SHCG 282

H. M. Tovmassian,[1] H. Tiersch,[2] S. G. Navarro,[3] V. H. Chavushyan,[1] G. H. Tovmassian,[4], A. S. Amirkhanian,[5] and S. Neizvestny[7]

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RESUMEN

Los grupos compactos de galaxias Shakhbazian son las configuraciones más densas que se conocen. Hace unos pocos años iniciamos un estudio fotométrico y espectroscópico de estos grupos. En este artículo presentamos los resultados de la investigación en los grupos ShCG 31, ShCG 38, ShCG 43 y ShCG 282. Presentamos los corrimientos al rojo de las galaxias miembro, los resultados de la fotometría BVR, las curvas de brillo superficial-radio efectivo, las masas estimadas, luminosidades y las razones masa-luminosidad de los grupos, además de algunos parámetros dinámicos como la dispersión de velocidades radiales y el tiempo de cruce. Los ShCGs estudiados consisten principalmente de galaxias elípticas y lenticulares. Se muestra que algunas galaxias en estos grupos están en proceso de interacción.

ABSTRACT

Shakhbazian compact galaxy groups are the most dense configurations known. A few years ago we commenced a detailed spectral and photometric study of these groups. In this paper we present the investigation results of groups ShCG 31, ShCG 38, ShCG 43, and ShCG 282. The redshifts of member galaxies, the results of the BVR photometry, the surface-brightness profiles, the curves of isophotal twisting, the estimated masses, luminosities, and the mass-to-luminosity ratios of groups, and also some dynamical parameters, as the radial velocity dispersion and the crossing time are presented. The studied ShCGs consist mostly of elliptical and lenticular galaxies. It is shown that some galaxies in groups are in the process of interaction.

Key Words: **GALAXIES: CLUSTERS: INDIVIDUAL (SHCG 31, 38, 43, 282) — GALAXIES: DISTANCES AND REDSHIFTS — GALAXIES: INTERACTIONS — GALAXIES: PHOTOMETRY**

1. INTRODUCTION

Compact groups (CGs) of galaxies are one of the basic structural elements in the world of galaxies. Interest in these groups increased greatly when numerical simulations showed that the best studied sample of CGs, the Hickson compact groups (HCGs) (Hickson 1982) should undergo strong dynamical evolution, and in a few crossing times ($\sim 10^8 - 10^9$ years) member galaxies should merge to one bright cD galaxy (Mamon 1986; Barnes 1985, 1989).

Shakhbazian compact groups (ShCGs) (Shakhbazian 1973; Baier & Tiersch 1979, and references therein) are more rich and more dense formations than HCGs. Oleak et al. (1995;1998) showed that ShCGs have prolate spheroid, "cigar"-like space configurations. Processes of interaction and merging are very likely in such elongated formations, even in the case of a regular rotational movement of member galaxies as proposed by Tovmassian & Tiersch (2001). Therefore, com-

[1]INAOE, México.
[2]Sternwarte Königsleiten, Germany.
[3]IAC, Spain.
[4]OAN, Universidad Nacional Autónoma de México, Ensenada, B. C.
[5]BAO, Armenia.
[6]SAO RAS, Russia.

TABLE 1

THE POSITIONS OF GROUPS SHCG 31, SHCG 38, SHCG 43, AND SHCG 282, AND THE EXTINCTION

ShCG	α h m s (2000)	δ ° ′ ″ (2000)	Q_B mag
31	00 58 17.4	+13 54 45	0.26
38	01 10 52.1	+08 19 21	0.30
43	01 38 26.7	+08 31 08	0.21
282	10 52 52.9	−11 00 28	0.15

pact groups are good laboratories for studying galaxy-galaxy interactions. Due to the small galaxy population in CGs in comparison to galaxy clusters, the analysis of different stages of evolution of the merging process, from the initial tidal interaction to coalescence of member galaxies, is much easier.

We commenced a detailed spectroscopic and photometric study of ShCGs. The results of the study of five groups, ShCG 154, ShCG 166, ShCG 328, ShCG 360, and ShCG 376 are given in Tiersch et al. (2002, Paper 1) and Tovmassian et al. (2003). In this paper, we present the results of the spectroscopic and photometric study of another four groups: ShCG 31, ShCG 38, ShCG 43, and ShCG 282.

2. OBSERVATIONS AND RESULTS

The coordinates of the centers of studied groups and the Galactic extinction Q_B (Schlegel, Finkbeiner, & Davis 1998) are given in Table 1.

2.1. *Spectroscopy*

Spectroscopic observations of galaxies in ShCG 31, ShCG 38, ShCG 43, and ShCG 282 have been carried out with different telescopes. Table 2 lists the galaxy in the group, and the telescopes, the sites and dates of its observations. Spectral resolution, dispersion, and wavelength range for each observation are given in columns 5, 6, and 7, respectively.

With the Cassegrain spectrograph of the 2.2 m telescope of the DSAZ Calar Alto, Spain, a TEK CCD with 1024 × 1024 pxl (24 μm square each) was used in observations. The slit width was set at $\sim 2.5''$. In observations with the 2.1 m telescope of the Guillermo Haro Observatory in Cananea, México, operated by the National Institute of Astrophysics, Optics, and Electronics, the Faint Object Spectrograph and Camera (LFOSC) (Zickgraf et al. 1997) was used. At observations in Calar Alto and La Silla the wavelengths were calibrated using a HeAr, and at GHO observations —a XeNe comparison spectra. The pixel-to-pixel variation of the CCD has been calibrated by means of the dome flats. Absorption lines of Hβ, MgIb, and NaD were identified in the spectra of almost all galaxies. In some cases the KH and G bands were also used. Each line was fitted by a Gaussian profile, after removing sky lines.

The redshifts were determined using the MIDAS (*standard reduction - long* and *standard reduction - spec* with programs therein) or IRAF packages. To minimize the errors due to flexure shifts, a comparison spectrum was taken before and after the exposure of a galaxy. The errors were estimated using the cross-correlation technique (Tonry & Davies 1979). The accuracy of the radial velocity (RV) measurements is $\sim 40 - 60$ km s^{-1}. RVs of faint objects 3, 4, and 5 in ShCG 31 were measured with an accuracy of about 200 km s^{-1}. The measured radial velocities were corrected for solar motion according to $\Delta v = 300 \sin l^{II} \cdot \cos b^{II}$ km s^{-1}. The RVs of the observed galaxies are presented in Table 3. The spectroscopy showed that two of the objects, "galaxy" 3 in ShCG 31 and "galaxy" 6 in ShCG 38, included in original lists of corresponding groups by an eye inspection of the POSS images, turned out to be stars.

2.2. *Direct Imaging and Photometry*

Observations in BVR of ShCG 31 and ShCG 43 were made with the 1.23 m telescope at the DSAZ Calar Alto, Spain. ShCG 282 was observed with the ESO 1.5 Danish telescope at La Silla, Chile, and ShCG 38 with the 1.5 m telescope of the Observatorio Astronómico Nacional de San Pedro Mártir (OAN - SPM), México. The logbook of observations is presented in Table 4.

A TEK 4 CCD detector was used for observations at Calar Alto. It has 512×512 pixels of 27 μm square giving a sky coverage of $4' \, 50'' \times 4' \, 50''$ with an image scale of $0.565''$/pxl. For observations at the OAN SPM also the TEK CCD, but with 1024×1024 of 24×24 μm pixels was used. With a $10.54''$/mm = $0.25''$/pxl telescope scale it covers a sky area of about $4.3'$. The twilight images of blank sky areas (Christian et al. 1985) were normally taken after sunset or at dawn in order to correct images for flat fields. Dome flat fields were not available at the OAN SPM. The TEK 24 CCD was installed at the 1.5 m telescope at La Silla with $0.38''$/pxl scale. The sky coverage here was $6' \, 29'' \times 6' \, 29''$. All observations were made with a seeing better than $2''$.

The images of the four studied groups in R are presented in the left panels of Figures 1, 4, 7, and 10.

TABLE 2

SPECTROSCOPIC OBSERVATIONS OF SHCG 31, SHCG 38, SHCG 43, AND SHCG 282

G	Telescope	Site	Date	Resolution Å/pxl	Dispersion Åmm	W-Length Range Å
			ShCG 31			
1	2.2 m	DZAS, CA	Nov. 94	2.9	120	4900–7650
2	2.2 m	DZAS, CA	Nov. 94	2.9	120	4900–7650
3	2.1 m	GHO, Cananea	Nov. 99	8.5	380	4200–9000
4	2.1 m	GHO, Cananea	Nov. 99	8.5	380	4200–9000
5	2.1 m	GHO, Cananea	Nov. 99	8.5	380	4200–9000
6	2.2 m	DZAS, CA	Nov. 94	2.9	120	4900–7650
			ShCG 38			
1	2.2 m	DZAS, CA	Nov. 94	2.9	120	4900–7650
2	2.2 m	DZAS, CA	Nov. 94	2.9	120	4900–7650
3	2.2 m	DZAS, CA	Nov. 94	2.9	120	4900–7650
4	2.2 m	DZAS, CA	Nov. 94	2.9	120	4900–7650
5	2.2 m	DZAS, CA	Nov. 94	2.9	120	4900–7650
			ShCG 43			
1	2.2 m	DZAS, CA	Dec. 93	2.9	120	4900–7650
2	2.2 m	DZAS, CA	Dec. 93	2.9	120	4900–7650
3	2.2 m	DZAS, CA	Dec. 93	2.9	120	4900–7650
4	2.2 m	DZAS, CA	Dec. 93	2.9	120	4900–7650
5	1.5 m	ESO, La Silla	Oct. 95	2.9	194	2400–8400
6	1.5 m	ESO, La Silla	Oct. 95	2.9	194	2400–8400
			ShCG 282			
1	1.5 m	ESO, La Silla	March 95	2.9	194	2400–8400
2	2.1 m	GHO, Cananea	Apr. 96	5.5	250	4000–7000
3	2.1 m	GHO, Cananea	Apr. 96	5.5	250	4000–7000
4	2.1 m	GHO, Cananea	Apr. 96	5.5	250	4000–7000
5	1.5 m	ESO, La Silla	March 95	2.9	194	2400–8400
7	1.5 m	ESO, La Silla	March 95	2.9	194	2400–8400

In all images, north is up and east is left. Each image is a superposition of three frames (of one 20 min and two 10 min exposures). The galaxy identification numbers are given from Stoll et al. (1993), Stoll, Tiersch, & Braun (1996)[7]. The images were processed with the MIDAS image processing package. The night sky was eliminated by means of a software program developed by Shergin and Kniazev (SAO, Russia) which takes into account the overlapping of galaxy halos. The BVR magnitudes were calibrated in the Kron/Cousins photometric system using the standard star cluster M67. The instrumental magnitudes were transformed to standard BVR magnitudes using the relations:

$$B = b - k_b M(z) - t_b(B - V) + zp_b \,,$$

$$V = v - k_v M(z) - t_v(B - V) + zp_v \,,$$

$$R = r - k_r M(z) - t_r(V - R) + zp_r \,,$$

where $M(z)$ is the airmass, k—the magnitude correcting coefficient for the zenith distance, t—the instrumental parameter, and zp the zero point.

Though a surface brightness lower than $\mu = 26\overset{m}{.}5/\mathrm{arcsec}^2$ was sometimes reached, the magnitudes of galaxies are estimated down to surface

[7]The groups in figures are marked as Shkh according to old designation.

TABLE 3

RADIAL VELOCITIES OF MEMBER GALAXIES IN SHCG 31, SHCG 38, SHCG 43, AND SHCG 282

	ShCG 31	ShCG 38	ShCG 43	ShCG 282
g	v km s^{-1}	v km s^{-1}	v km s^{-1}	v km s^{-1}
1	56500	26380	37740	42640
2	55600	26740	36430	41770
3	star	26350	37490	42200
4	55780	26050	···	41980
5	56600	star	25350	42640
6	56410	···	37160	···
7	···	···	···	42700

brightness $\mu = 26\overset{m}{.}5/\text{arcsec}^2$. The faintest contour in the contour plots corresponds to this value. Using the MIDAS program the images of overlapping halos of galaxies were fitted by ellipses down to the accepted standard surface brightness of $\mu = 26\overset{m}{.}5/\text{arcsec}^2$. For galaxies embedded in a common halo the magnitudes were determined by the last undisturbed isophote, which is usually brighter than the limiting value $\mu = 26\overset{m}{.}5/\text{arcsec}^2$. The estimated accuracy of magnitudes is about $0\overset{m}{.}06$. Evidently, for galaxies with overlapping halos or galaxies embedded in larger halos of brighter galaxies, the error of the magnitude determination could be worse. The measured magnitude in B was corrected for extinction within our Galaxy, Q_B, (Schlegel et al. 1998). The corrections in V and R are calculated using the color excesses $E_{B-V} = 0.238Q_B$ and $E_{V-R} = 0.590Q_B$, respectively. The individual extinction within a spiral galaxy with inclination i was estimated according to $A_i = 0.72\ log(1/\cos i)$ (de Vaucouleurs, de Vaucouleurs, & Corwin 1976). In the case of E and SO galaxies the extinction within the galaxy was neglected. The K correction was also neglected because the observed groups are relatively nearby. The contour plots in arbitrary units are presented in the right panels of Figures 1, 4, 7, and 10.

The diameter of each galaxy was estimated in B, V, and R using the outer fitted ellipse in cases of undisturbed images. For a galaxy embedded in a common halo the diameter was estimated, if possible, by extrapolation of the surface brightness profile down to the sky level, $26\overset{m}{.}5/\text{arcsec}^2$. The b/a ratios, position angles and inclinations of galaxies are measured from the $\mu = 26\overset{m}{.}5/\text{arcsec}^2$ isophotes, if available.

In Figures 2, 5, 8, and 11 the surface brightness μ in R band vs. $a^{1/4}$, where a is the large semiaxis, and/or μ vs. a is plotted for galaxies in the four studied groups. It is known that elliptical galaxies follow de Vaucouleurs (1948) $a^{1/4}$ law. If the μ vs. $a^{1/4}$ plot is straight, we classify the galaxy as elliptical. If the profile deviates from a straight line, we inspect the $\mu - a$ profile. In the case of SO and spiral galaxies the latter consist of a bulge and a disc components. Kent (1985) showed that the bulge in spirals is relatively smaller and the profile steeper than in lenticulars. Depending on the relative size of bulge and steepness of the profile of bulge, the galaxy was classified as SO or spiral. However, not all galaxies can be fitted by two simple functions. Sometimes deviations from ellipticity in both the core and envelope are observed (Pildis, Bregman, & Schomberg 1995). Such deviations may imply that the galaxy has undergone an interaction.

The curves of isophotal twisting of galaxies in the studied four ShCGs are plotted in Figures 3, 6, 9, and 12, respectively. The twisting of the isophotes is considered to be a sign of mutual tidal perturbations or galaxy collisions (Kormendy 1982; di Tullio 1979).

The results of the photometry of galaxies in the studied groups are presented in Tables 5 – 8 in which the following information is given: column l, the galaxy identification number; column 2, the magnitude in $B_{26.5}$; column 3, the axial ratio b/a in B; column 4, the diameter of the galaxy down to the surface brightness of $26\overset{m}{.}5/arcsec^2$ in B; in columns 5 - 7, the latter three parameters in V; in columns 8 - 10, the same parameters in R; in column 11, the position angle determined in R; in column 12, the inclination i in R, and in column 13, the morphological type. Uncertain values of magnitudes of fainter galaxies embedded in a common halo are marked by a colon.

3. DISCUSSION

A galaxy is assumed to be a member of a CG if its RV does not differ from the mean RV of the group by more than $\Delta v \sim 1000$ km s^{-1} (Hickson et al. 1992). The RVs of galaxies in the studied four ShCGs show that almost all galaxies included in the original lists belong to the corresponding groups. We found that only few objects, assumed to be compact galaxies in original lists, were, in reality, stars.

The space density of galaxies in ShCGs is much higher than in galaxy clusters. A possible interaction between galaxies may cause a formation of extended

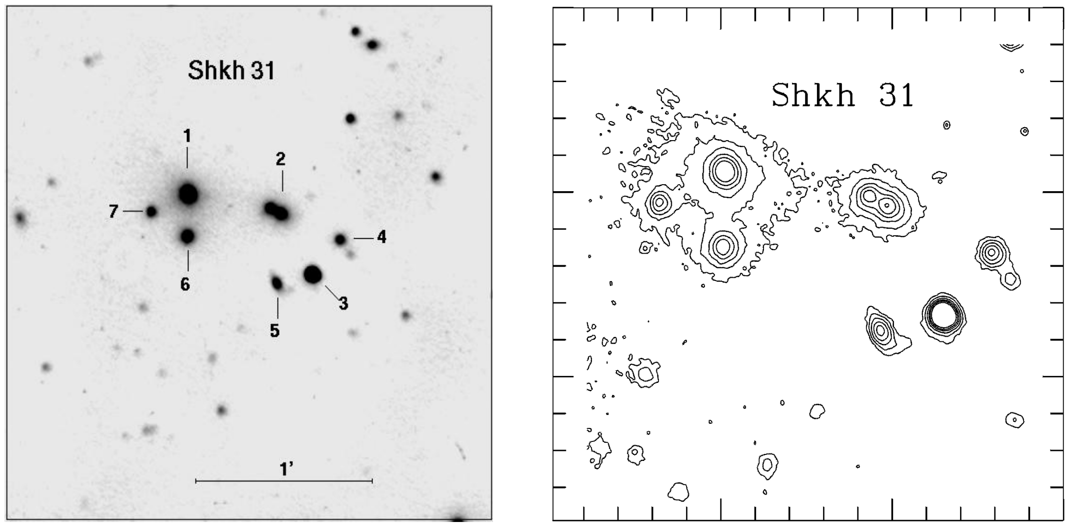


Fig. 1. The image of ShCG 31 in R (left panel) and the isophotal contour plots of galaxies (right panel). North is up, east is left.

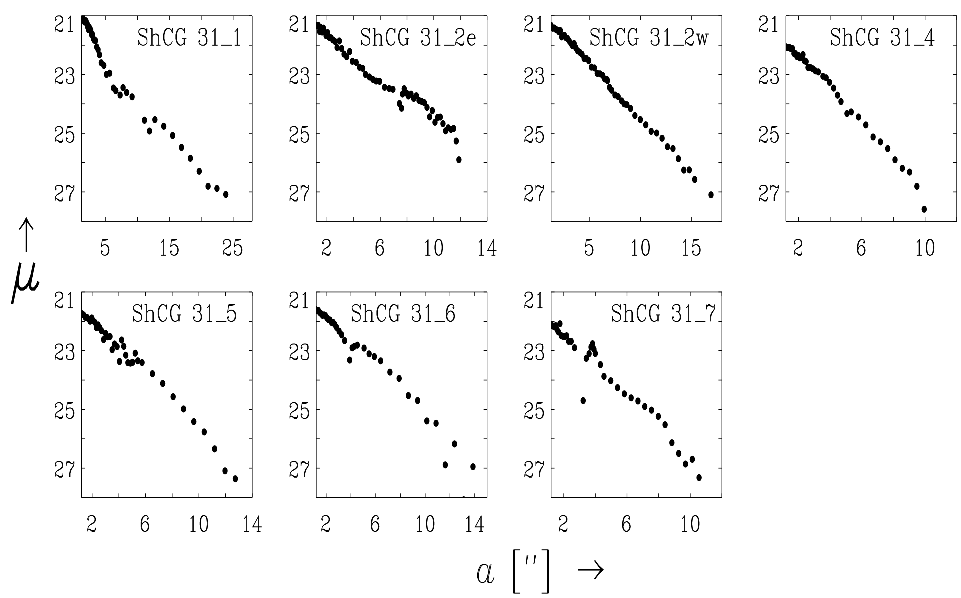


Fig. 2. The surface brightness profiles, μ, in R vs. a for galaxies in ShCG 31.

optical halos around galaxies and bridges between them. One has to be cautious, however. Since bright galaxies in ShCGs are often very close to each other on the sky, the overlapping isophotes may create an impression of physical bridges.

Below, the results on the studied ShCGs are presented.

ShCG 31. We obtained spectra of six objects in ShCG 31. Object 3 turned out to be a star. The mean RV of five galaxies is $\sim 56,000$ km s^{-1}. The dense subgroup of three galaxies, 1, 6, and 7, is certainly interacting (Fig. 1). All three galaxies are embedded in a sufficiently extended common halo. The halo is especially large around the faint galaxy 7.

TABLE 4

PHOTOMETRIC OBSERVATIONS OF SHCG 31, SHCG 38, SHCG 43, AND SHCG 282

ShCG	Telescope, Site	Filter	Date	Filter	Date	Filter	Date
31	1.23 m, CA	B	Dec. 93	V	Dec. 93	R	Dec. 93
38	1.5 m, SPM	B	Oct. 97	V	Oct. 97	R	Nov. 96
43	1.23 m, CA	B	Dec. 93	V	Dec. 93	R	Dec. 93
282	1.5 m, ESO	B	Feb. 95	V	Feb. 95	R	Feb. 95

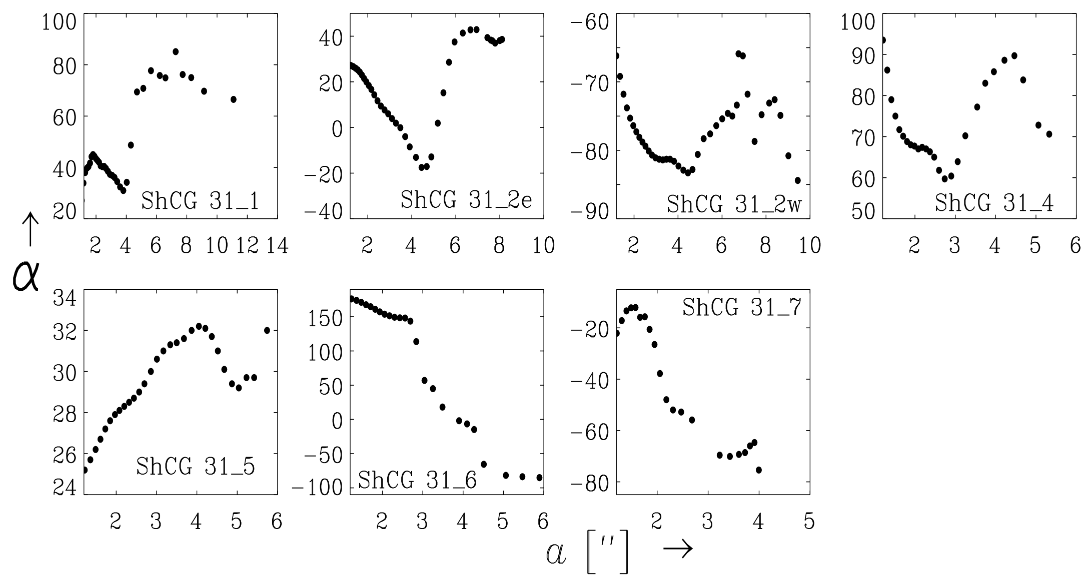


Fig. 3. The position angle α, vs. large semiaxis a, for galaxies in ShCG 31.

As Barnes (1985;1989) showed, interaction between galaxies may cause formation of extended optical halos around galaxies. The twisting profiles of galaxy 6 undergoes sufficiently high variation of about 150^o (Fig. 3). Galaxy 2 in the original list is in fact a close pair of interacting galaxies. Their common halo is apparently enlarged. The profile $\mu - a^{1/4}$ of galaxy 2w is not straight, though the profile $\mu - a$ (Fig. 2) of it is straight. Probably this is a result of thermal heating.

According to $\mu - a$ graphs (Fig. 2), all galaxies of the group are of E or SO types.

ShCG 38. The spectra of five objects in this group were obtained. Four galaxies, 1 to 4, have concordant redshifts. The highest difference of the RV from the mean value of the group, 360 km s^{-1}, has the galaxy 2. Object 5 turned out to be a star, as it was supposed by Bettoni & Fasano (1995) on the basis of the direct R image of the group. Four galaxies of this group compose almost a straight chain (Fig. 4) and are embedded in a common, enlarged halo. Hence, they are certainly in interaction. The halo of galaxy 4 which is by about 1^m brighter in R than that of the undisturbed galaxy 6, is quite small. Bettoni & Fasano (1995) supposed that galaxy 4 may be a secondary nucleus of galaxy 1. However, the projected distance between them is about 10 kpc. Therefore, this can hardly be the case. It seems more probable that due to a strong interaction, galaxy 4 lost its outer envelope, and is merging with galaxy 1. Its twisting profile rotates by about 60^o (Fig. 6). Bettoni & Fasano (1995) classified galaxies 3 and 6 as spirals. The surface brightness-large semiaxis curves (Fig. 5) show that these two galaxies may be spirals, though it is not certain. The sufficiently red color

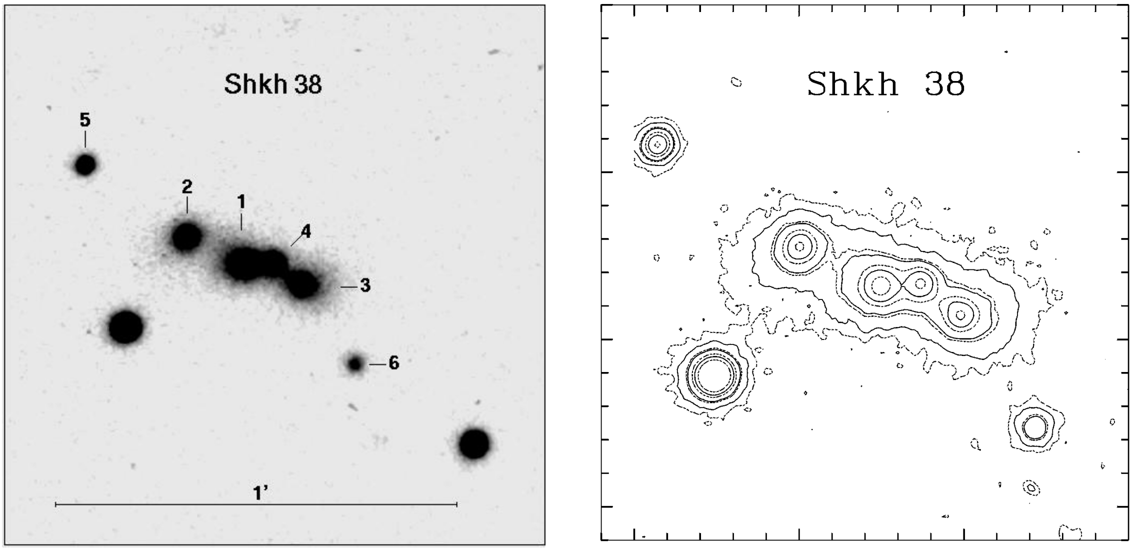


Fig. 4. The image of ShCG 38 in R (left) and the isophotal contour plot (right).

TABLE 5

PHOTOMETRIC PARAMETERS OF GALAXIES IN SHCG 31

g-xy	B			V			R					Type
	m	b/a	D $''$	m	b/a	D $''$	m	b/a	D $''$	α $\circ$	i $\circ$	
1	2	3	4	5	6	7	8	9	10	11	12	13
1	18.59	0.8	10	17.26	0.9	11	16.56	0.8	14	−21	−44	S0
2e	18.40:	0.8	5	17.45:	0.9	5	17.00:	0.8	5	46	24	S0
2w	18.40:	0.8	6	17.25:	0.7	6	16.70:	0.6	6	−60	31	S0/E
4	19.67	0.9	7	18.68	0.9	8	18.12	0.7	8	−39	−70	S0/E
5	19.33	0.5	7	18.28	0.7	7	17.77	0.7	10	−36	−80	S0/E
6	19.02	0.8	9	18.10	0.8	9	17.34	0.8	9	3	20	S0
7	19.65:	0.7	8	18.65:	0.8	8	18.12:	0.9	8	25	38	S0

$B - V = 1\overset{m}{.}31$ of galaxy 3 shows that it may rather be a lenticular. The redshift of galaxy 6 is unknown. Its angular diameter is small in comparison to other galaxies of the group, and it may be projected over the group. Inspection of the surface brightness-large semiaxis curves (Fig. 5) shows that the other three galaxies of the group are of SO types.

ShCG 43. In this group of nine objects we obtained spectra of the five central brightest ones which compose a chain. Galaxy 5 is a foreground galaxy with $\Delta v \approx 12,000$ km s^{-1}, unrelated to the group. Inspection of prime images (Fig. 7) shows that objects 4 and 7 are stars. Hence, the group consists of at least four concordant redshift galaxies, 1, 2, 3, and 6, with a mean $RV \approx 37,100$ km s^{-1}. The redshift of galaxy 8, considered as a member of the group in the original list, was not measured. The isophotes of galaxies of this group (Fig. 7) do not show any certain signs of interaction between member galaxies.

All five member galaxies are of E or S0 type (Fig. 8). The foreground galaxy 5 is a lenticular.

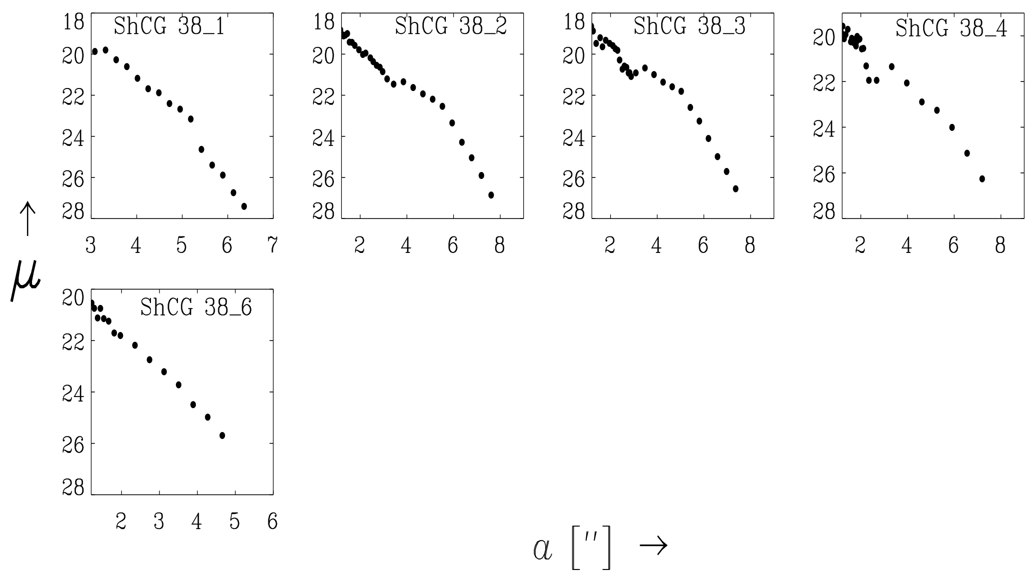


Fig. 5. The surface brightness profiles, μ, in R vs. a for galaxies in ShCG 38.

TABLE 6

PHOTOMETRIC PARAMETERS OF GALAXIES IN SHCG 38

g-xy	B			V			R					Type
	m	b/a	D $''$	m	b/a	D $''$	m	b/a	D $''$	α $\circ$	i $\circ$	
1	2	3	4	5	6	7	8	9	10	11	12	13
1	17.66	0.5	14	16.58	0.7	12	15.64	0.7	11	86	11	S0
2	18.11	0.9	10	16.59	0.9	17	15.73	0.9	14	60	30	S0
3	17.96	0.7	10	16.64	0.7	12	15.71	0.9	15	−72	33	S/S0
4	18.46:	0.6:	8:	17.56:	0.7:	10:	16.707	0.8:	13:	−65	35	S0
6	19.62	0.8	9	18.54	0.9	11	17.86	0.9	10	−51	12	S/S0

ShCG 282. Six out of eight galaxies were observed spectroscopically. All have concordant redshifts. The most discrepant value from the mean RV of the group, ≈ 550 km s^{-1} is that of galaxy 2. The central four galaxies of this group (1, 2, 3, and 4) are clearly interacting (Fig. 10). They all are embedded in a common, large halo. Galaxy 4 has radio emission (Tovmassian et al. 1999), which is a clear sign of interaction. The large axis of this galaxy rotates by about 60° and that of the galaxy 1 by about 80° (Fig. 12). Galaxy 7 seems also to be involved in interaction. The length of the halo of galaxy 1 is larger in the direction toward galaxy 7 than in the orthogonal direction. Moreover, galaxy 7 has an extension towards galaxy 1. The galaxy located to the northeast of the chain of galaxies 1 – 4, and not numbered in the original list, also has a large halo. Apparently, it belongs to the group, and it is in interaction with other galaxies in the core of the group. The halo of galaxy 6 also seems to be enlarged. In the halo of this galaxy, and also in the halo of galaxy 7, there are relatively bright concentrations which may

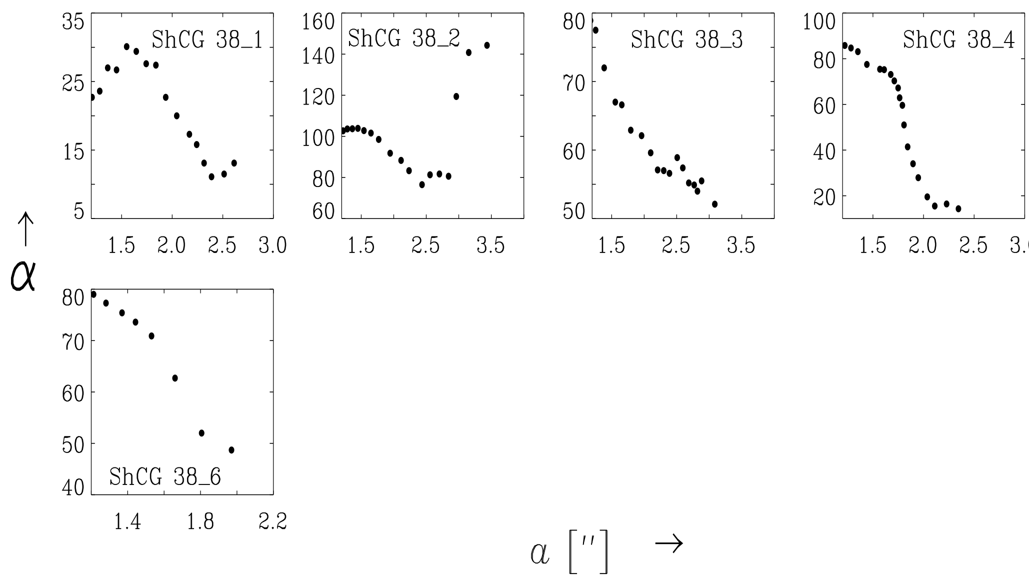


Fig. 6. The position angle α, vs. large semiaxis a, for galaxies in ShCG 38.

TABLE 7

PHOTOMETRIC PARAMETERS OF GALAXIES IN SHCG 43

g-xy	B			V			R					Type
	m	b/a	D ″	m	b/a	D ″	m	b/a	D ″	α °	i °	
1	2	3	4	5	6	7	8	9	10	11	12	13
1	17.60	0.8	15	16.38	0.8	19	15.93	0.8	20	64	34	E
2	18.20	0.8	11	17.00	0.8	15	16.45	0.8	16	31	13	E
3	18.08	0.8	12	16.66	0.9	14	16.08	0.9	17	−55	28	E
5[a]	18.07	0.7	14	17.43	0.8	14	17.25	0.8	15	− 9	33	S0
6	19.06	0.9	7	17.83	1.0	6	17.38	0.9	8	87	25	E
8	19.20	0.8	13	18.19	0.8	14	17.59	0.8	14	−53	26	S0/E

[a]Foreground galaxy.

be dwarf galaxies in the process of merging or in the process of formation as a result of interaction (Barnes & Hernquist 1992; Elmegreen, Kaufman, & Thomasson 1993; Hunsberger, Charlton, & Zaritsky 1996).

The $\mu - a^{1/4}$ profiles (Fig. 11a) show that galaxies 3 and 4 are ellipticals. According to $\mu - a$ profiles (Fig. 11b) galaxies 2 and 6 may be spirals, though both are quite red. All other galaxies of the group are of E/S0 type.

The physical parameters of groups. The results of the photometry of member galaxies in the studied groups and a knowledge of distances to the groups allowed us to deduce their physical parameters, presented in Table 9. In the consecutive lines of this table the following information is given: line 1, the mean redshift z (weighted by the masses of member galaxies); line 2, the projected diameter of the group, D (H = 55 km s^{-1} Mpc^{-1}); line 3, the σ_v (weighted by the masses of member galaxies);

TABLE 8

PHOTOMETRIC PARAMETERS OF GALAXIES IN SHCG 282

g-xy	B			V			R					Type
	m	b/a	D $''$	m	b/a	D $''$	m	b/a	D $''$	α $\circ$	i $\circ$	
1	2	3	4	5	6	7	8	9	10	11	12	13
1	18.57	0.8	15	17.12	1.0	27	16.67	0.8	30	− 2	23	S0
2	18.97	0.9	11	17.63	0.8	16	16.67	0.6	26	−60	31	S/S0
3	19.25:	0.8	12	18.05:	0.9	16	16.95:	0.8	26	−47	24	E
4	19.35:	0.8	10	18.15:	0.8	14	17.05:	0.8	23	− 4	36	E
5	19.73	0.8	8	18.29	0.7	13	17.38	0.7	22	58	29	S0
6	19.67	0.7	13	18.39	0.7	14	17.36	0.8	23	−87	31	S/S0
7	20.00	0.9	8	18.63	0.8	13	17.48	0.8	21	71	19	S0
8	20.24	0.8	8	18.65	0.8	15	18.01	0.8	17	67	32	S0

TABLE 9

PHYSICAL PARAMETERS OF THE STUDIED SHCGS

Parameter	ShCG 31	ShCG 38	ShCG 43	ShCG 282
z	0.1868	0.0878	0.1242	0.1416
D (kpc)	320	75	500	240
σ_v (km s^{-1})	230	135	284	166
R_{vir} (kpc)	120	30	150	70
M_{vir} (10^{11} $M_\odot$)	67.5	5.4	131.8	20.0
L ($10^{11}/L_\odot$)	5.1	2.7	4.6	22.3
M/L ($M_\odot/L_\odot$)	13.3	2.0	28.5	0.9
τ_c (10^6 years)	200	82	216	164

line 4, virial radius R_{vir} of the group (weighted by the masses of galaxies); line 5, the virial mass, M_{vir}; line 6, the luminosity L of the group in solar units; line 7, the mass-to-luminosity ratio in solar units, $M_\odot/L_\odot$, and line 8, the crossing time, τ_c.

In the case of the considered groups with small number of members, the weighting is important because the differences between weighted and unweighted RVDs may be as high as a factor of ~ 2. The weighting of RVDs (σ_v's) by masses of galaxies is done according to:

$$\sigma_v^2 = M_{tot}^{-1} \sum (M \Delta v_i^2).$$

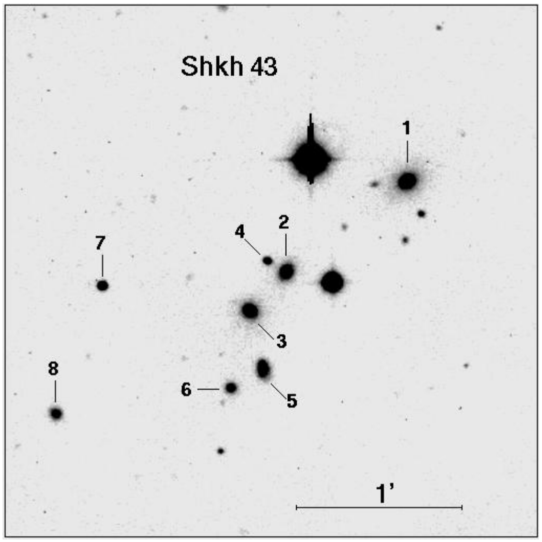
Masses of galaxies were estimated by using the V magnitudes, and adopting a mass-to-luminosity ratio equal to 4 for spirals, and 8 for ellipticals (Karachentsev 1987). The masses of groups are deduced from the virial theorem assuming that they are gravitationally bound:

$$M_{vir} = 3\pi\sigma_v^2 R_{vir} G^{-1},$$

where

$$R_{vir} = M_{tot}^2 [\sum M_i M_j / R_{ij}]^{-1}.$$

Since only galaxies with measured redshifts are used for estimating the group virial mass, the real value of the mass may be higher if a group contains more galaxies. The mass-to-luminosity ratios were deduced by using the estimated virial masses and total luminosities of the corresponding groups. The



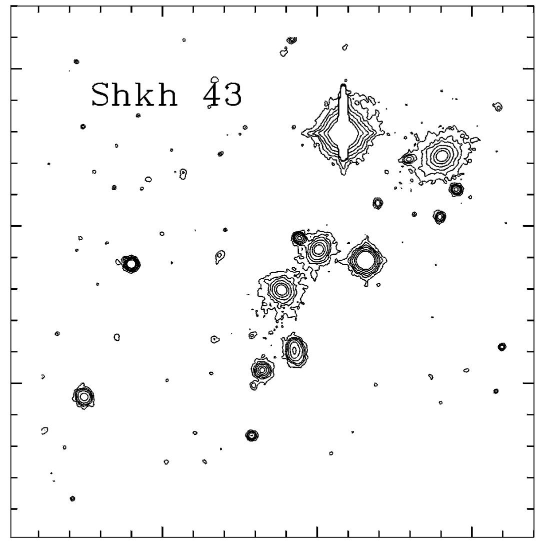


Fig. 7. The image of ShCG 43 in R (left) and the isophotal contour plot (right).

crossing time was determined according to the formula of Gott, Wrixon, & Wannier (1973):

$$\tau_c = (3/5)\pi R_{vir}(2\sqrt{3}\sigma_v)^{-1}.$$

Below we discuss the physical parameters of all nine groups, including those presented in Paper 1 and in Tovmassian et al. (2003).

The mean RVD of the nine groups is $\approx$ 200 km s^{-1}. It is the same as that of HCGs and loose groups (LGs) (Hickson et al. 1992; Geller & Huchra 1983). The RVDs of CGs are smaller than those of rich galaxy clusters, the typical value for which is $\sim$ 1000 km s^{-1} (Zabludoff, Huchra, & Geller 1990).

The total luminosities of eight groups are smaller than 5.5×10^{11} $L_\odot$. Only one group, ShCG 282, has a higher luminosity, 22.3×10^{11} $L_\odot$.

The derived virial masses of groups are different, ranging from 7×10^{11} $M_\odot$ to 130×10^{11} $M_\odot$. These values are typical for galaxy groups. However, the estimated mass of an individual group may be somewhat uncertain because of the unknown projection effect which becomes important in the case of groups with a small number of galaxies. The estimated masses should be considered as lower limits, since there could be more members in each group (Tovmassian & Tiersch 2001).

For only one group, ShCG 43, the mass-to-luminosity ratio is equal to 28.5, and is close to the median value, $\approx$ 30, for HCGs (Hickson et al. 1992). For the eight other groups this ratio is much smaller. For ShCG 154 the mass-to-luminosity ratio, equal to 8.9, is very close to the dynamical mass-to-light ratio for ellipticals, which is about 8 (Karachentsev 1987), and for five groups (ShCG 38, ShCG 166, ShCG 282, ShCG 328, and ShCG 376) it is even smaller. This means that the amount of dark matter in the intergalactic space of most ShCGs is even smaller than that of the dark matter within individual galaxies.

Interaction and merging of galaxies alter their morphology (Toomre & Toomre 1972). The spirals in CGs may be converted to S0/E galaxies during dynamical evolution. The smaller the crossing time, the more efficient is this process. Hickson et al. (1992) showed that groups with crossing times smaller than $\approx$ $3\,H_o^{-1}$ are, indeed, spiral-poor. The crossing times of seven out of the studied nine ShCGs (with exception of ShCG 166 and ShCG 376) are smaller than the mean value for HCGs which is $\sim$ 260×10^6 years[8] (Hickson et al. 1992). The scarcity of late type galaxies in ShCGs is remarkable. The spiral fraction here is only $\approx$ 20%. The group ShCG 376, which almost completely consists of spirals (Tovmassian et al. 2003), is an exception. Hence, ShCGs are more evolved than HCGs. However, one has to take into account that the crossing time deduced from the estimated virial radius and σ_v may differ from the real value. Indeed, since ShCGs have very elongated "cigar"-like configurations (Oleak et al. 1995, 1998), the measured σ_v of a group seen almost orthogonal to the line of sight would be smaller than the real

[8] H = 55 km s^{-1} Mpc^{-1}.

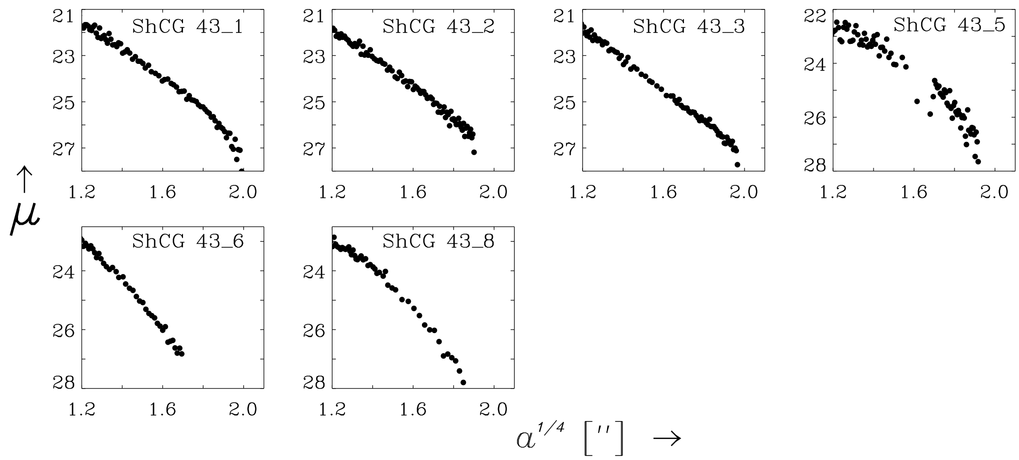


Fig. 8. The surface brightness profiles, μ, in R vs. $a^{1/4}$ for galaxies in ShCG 43.

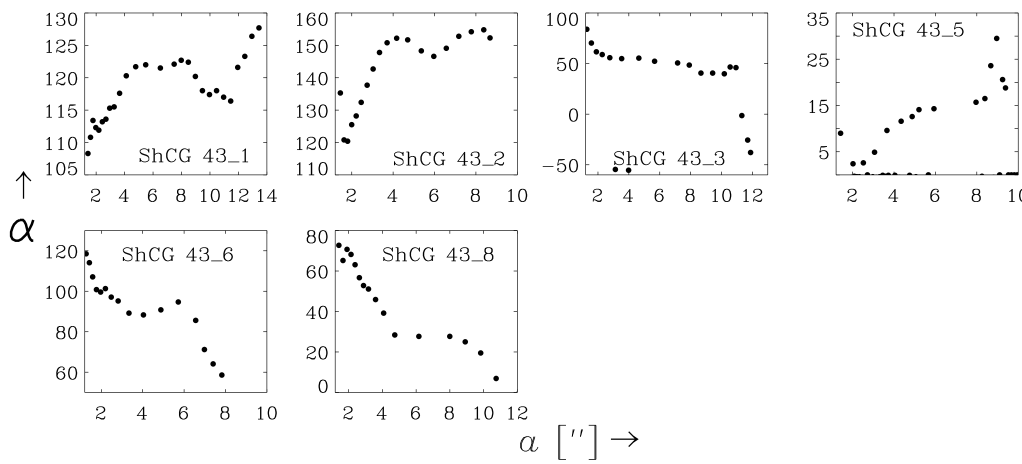


Fig. 9. The position angle α, vs. large semiaxis a, for galaxies in ShCG 43.

value, while the observed linear size of such a group would, on average, be larger. As a result, the deduced crossing times of elongated groups may, on average, be higher than those of the round ones. This means that the latter groups, with smaller estimated crossing times, may not always be more evolved than elongated, chain-like groups.

Most elliptical and lenticular galaxies in the studied groups are very red. Their $B-V$ colors are about one, or even more. Hence, they are comparable to the reddest galaxies of RC2 and RC3 (Buta et al. 1995). It is remarkable that no bright blue elliptical galaxies which are predicted by models of evolution of galaxies were detected. This result agrees with the finding of Zepf, Whitmore, & Levison (1991) with a very small number of blue ellipticals in CGs, and disagrees with the environment-dominated models, according to which there should be a high number of blue ellipticals in CGs due to interactions and merging. Though there are some galaxies that are certainly interacting in the nine groups studied, the FIR emission was detected only in one of them (the irregular or disturbed spiral galaxy 4 in ShCG 376, Tovmassian et al. 2003). This shows that early type galaxies in ShCGs have very little dust.

The linear dimensions of groups vary from 75 kpc to 500 kpc. It was shown by Tovmassian & Tiersch

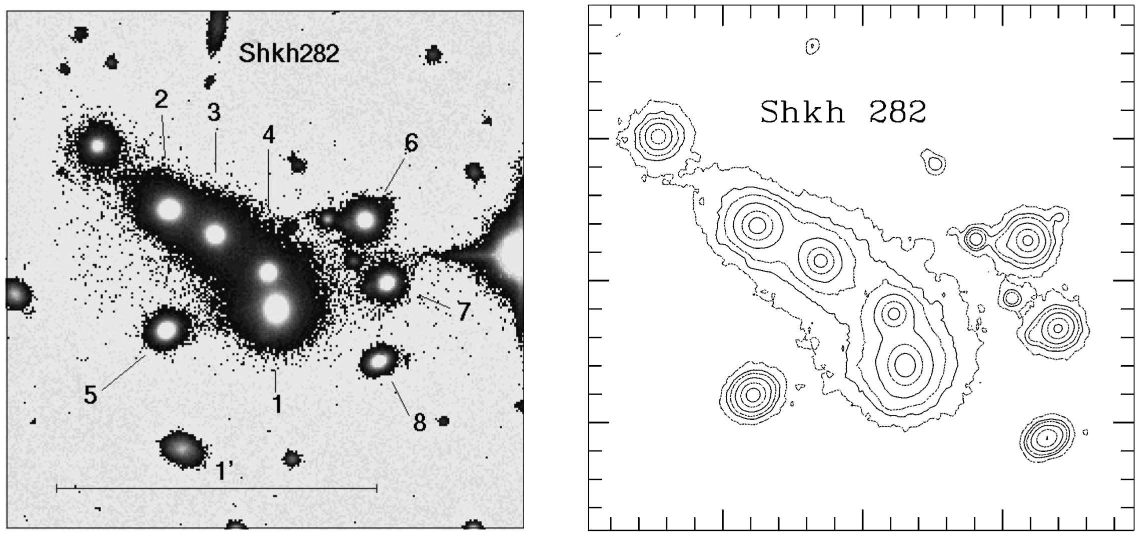


Fig. 10. The image of ShCG 282 in R (left) and the isophotal contour plot (right).

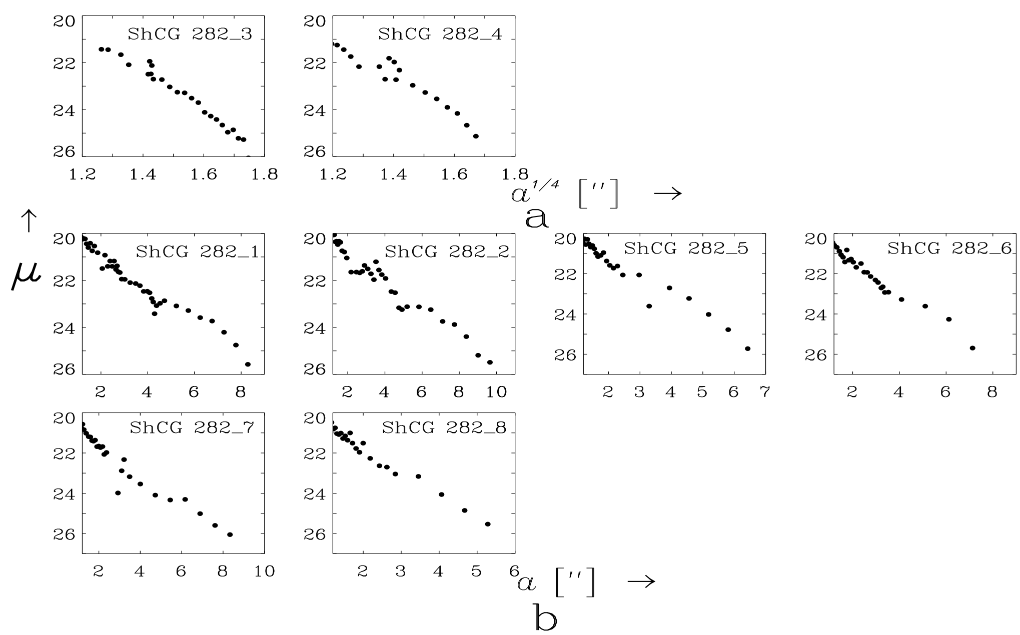


Fig. 11. The surface brightness profiles, μ, in R vs. : a. $a^{1/4}$, b. a for galaxies in ShCG 282.

(2001) that ShCGs are generally embedded in elongated poor groups of galaxies. We see such group as a CG if it is observed nearly end-on. When it is oriented almost orthogonal to the line of sight we see it as a CG if its bright members happen to be close to each other on the sky. Faint members of such elongated poor clusters are detected up to distances of about 1 Mpc. Therefore, it is not strange that the studied ShCGs have appreciably different linear sizes.

4. CONCLUSIONS

Twenty galaxies (one of them turned to be a foreground one) were investigated spectroscopically and 26 galaxies were observed in BVR in four Shakhbazian groups, ShCG 31, ShCG 38, ShCG 43,

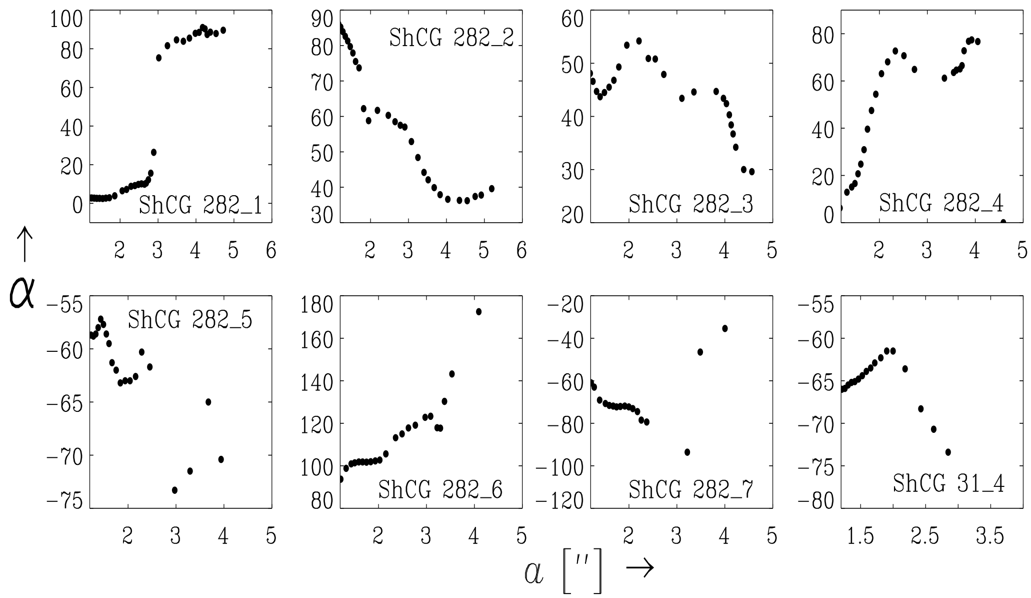


Fig. 12. The position angle α, vs. large semiaxis a, for galaxies in ShCG 282.

and ShCG 282. The important physical parameters of these groups were deduced (Table 9).

Consideration of the results of the study of nine groups, including those presented in Paper 1 and in Tovmassian et al. (2003), shows that:

1. The measured RVs of galaxies prove that these groups are real physical formations and not chance projections of field galaxies.

2. The redshifts of nine of the studied ShCGs are in the range from 0.0396 to 0.1868, i.e., they all are located well beyond the Local Supercluster.

3. The mass-weighted radial velocity dispersions of ShCGs are in the range of 130 – 285 km s^{-1}, comparable to those of HCGs and LGs.

4. The virial radii are in the range of 30 – 150 kpc.

5. The virial masses of the groups range from 5×10^{11} $M_\odot$ to 132×10^{12} $M_\odot$, values typical for galaxy groups.

6. The mass-to-luminosity ratio of ShCGs ranges from 0.9 to 28.5. It is smaller than the median value, ≈ 30, for HCGs (Hickson et al. 1992). This values are comparable to the M/L of individual galaxies. They mean that these compact groups (except for ShCG 43) have almost no dark matter.

7. The crossing time for Shakhbazian groups ranges from 82×10^6 to 380×10^6 years. It is smaller than the Hubble age.

8. The percentage of E and S0 galaxies is high ($\approx 75\%$) in ShCGs. The very small relative number of spirals is apparently due to the ejection of interstellar gas from galaxies by ram pressure and/or tidal forces.

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A. S. Amirkhanian: Byurakan Astrophysical Observatory, Aragatsotn, 378433 Armenia (amirkhanian@bao.sci.am).
V. H. Chavushyan and Hrant M. Tovmassian: Instituto Nacional de Astrofísica, Óptica y Electrónica, Apdo. Postal 51 and 216, 72000, Puebla, Pue., México (vahram@inaoep.mx, hrant@inaoep.mx).
Silvana G. Navarro: Instituto de Astrofísica de Canarias, Vía Láctea s/n, 38200 La Laguna, Tenerife, Spain (silvana@ll.iac.es).
S. Neizvestny: Special Astrophysical Observatory RAS, Nizhnij Arkhyz, Karachai-Cherkessia, 357147 Russia (neiz@sao.ru).
H. Tiersch: Sternwarte Königsleiten, 81477, München, Leimbachstr. 1a, Germany (htiersch@uni.de).
Gaghik H. Tovmassian: Observatorio Astronómico Nacional, Instituto de Astronomía, UNAM, Apdo. Postal 877, 22830 Ensenada, B. C., México (gag@astrosen.unam.mx).