

Shakhbazian compact galaxy groups

III. Photometric and spectroscopic study of ShCG 181, ShCG 344, ShCG 361, and ShCG 362*

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Abstract. In 1995 we commenced a detailed spectral and photometric study of Shakhbazian compact groups. In this paper the results on groups ShCG 181, ShCG 344, ShCG 361, and ShCG 362 are presented. The redshifts of member galaxies in groups and the radial velocity dispersions, the results of the surface photometry in *BVR*, the profiles of the surface brightness versus semi-major axis a (or $a^{1/4}$) and the twisting position angle versus semi-major axis of galaxies, virial masses, luminosities and mass-to-luminosity ratios, and the crossing times of groups are given. It is shown that some members of groups are in the process of interaction. On the basis of the results obtained in this and previous works, the general properties of thirteen ShCGs are discussed.

Key words. galaxies: clusters: general – galaxies: interactions – galaxies: kinematics and dynamics – galaxies: photometry

1. Introduction

In 1995 we commenced a study of Shakhbazian compact groups (ShCGs). ShCGs are more rich and more dense formations than the well-known HCGs (Hickson 1982; Hickson et al. 1989). The complete list of ShCGs contains 377 groups (Shakhbazian 1973; Shakhbazian & Petrosian 1974; Baier et al. 1974; Baier & Tiersch 1975, 1976a, 1976b, 1978, 1979; Petrosian 1974, 1978). These groups generally consist of 5–15 members; the distances between galaxies are typically 3–5 times the diameter of the galaxies; most of them have a very high density of about 10^4 – 10^5 galaxies per Mpc^3 . The groups have a “cigar”-like, prolate spheroid configuration (Oleak et al. 1995, 1998). At such densities and configurations

the processes of interaction and merging should be common in these groups, in spite of the suggested regular movement of member galaxies and of the members of loose groups (LGs) (Tovmassian & Tiersch 2001) around the gravitational centers of the groups.

The results of the study of 13 ShCGs are presented in Tiersch et al. (2002, Paper I), and in Tovmassian et al. (2003a, Paper II, 2003b). In this paper we present the results of the study of ShCG 181, ShCG 344, ShCG 361, and ShCG 362. We obtained spectra of most galaxies in these groups, and measured their redshifts. We also obtained images of these groups in *BVR*, and determined morphological types and magnitudes of member galaxies in the corresponding bands. The study of the brightness distribution of galaxies allowed us to reveal processes of interaction between some of them.

2. Observations and results

The coordinates of the centers of the studied groups taken from Stoll et al. (1997a, 1997b) and the extinctions Q_B , (Schlegel et al. 1998), are given in Table 1.

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* Figures 2, 3, 5, 6, 8, 9, 11, 12 and Table 2 are only available in electronic form at <http://www.edpsciences.org>

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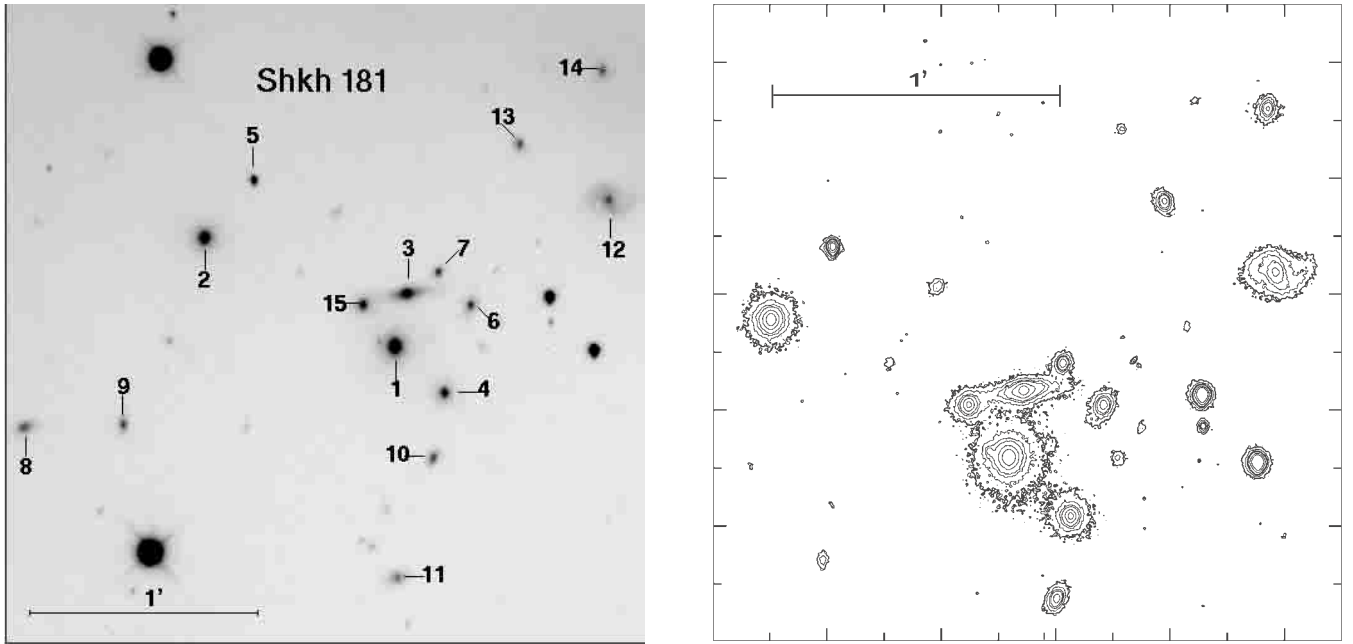


Fig. 1. The image of ShCG 181 in R (left) and the isophotal contour plot (right).

Table 1. Positions of groups ShCG 181, ShCG 344, ShCG 361, and ShCG 362, and the extinction, Q_B .

ShCG	α [h m s] (2000)	δ [$^{\circ}$ ' "] (2000)	Q_B [mag]
181	08 28 00.9	+28 15 49	0.17
344	08 47 30.4	+03 42 08	0.17
361	23 03 17.9	+17 40 22	0.39
362	23 32 37.1	+19 22 33	0.38

2.1. Spectroscopy

Spectroscopic observations of 29 objects in the fields of ShCG 181, ShCG 344, ShCG 361, and ShCG 362 have been carried out with different telescopes. Table 2 lists the telescopes, the sites and dates of observations. We found that one object, No. 10 in ShCG 362, is a star.

Details of spectral observations and reduction are described in Papers I and II. The redshifts were determined using the MIDAS (*standard reduction – long* and *standard reduction – spec with programs therein*) or IRAF packages. Absorption lines of $H\beta$, $MgIb$ and NaD were identified in the spectra of almost all galaxies. In the spectra of some galaxies the KH and G bands were also used. The profile of each observed line was fitted by a Gaussian. The sky lines were removed beforehand. The radial velocities (RV) were measured with an accuracy of about 40–60 km s^{-1} . In the case of very faint galaxies the uncertainties may reach $\approx 100 \text{ km s}^{-1}$. The results of spectral observations are summarized in Table 3 in which the galaxy number in the corresponding group and the measured RV is given. The RV s have been corrected for solar motion according to $\Delta v = 300 \sin l^{\text{II}} \cdot \cos b^{\text{II}} \text{ km s}^{-1}$.

2.2. Direct imaging and photometry

Photometric observations in BVR of ShCG 344 were made with the Danish 1.5 m telescope of ESO at La Silla, Chile, in March 1995. ShCG 181, ShCG 361 and ShCG 362 were observed with the 1.5 m telescope of the Observatorio Astronómico Nacional de San Pedro Mártir (OAN SPM), México, in November 1996 and October 1997. Observations were made at seeing better than $2''$.

The TEK 24 CCD detector installed on the 1.5 m telescope at La Silla had a $0.38''/\text{pxl}$ scale, and a $6'29'' \times 6'29''$ sky coverage. The TEK CCD detector used in observations at the OAN SPM has a 1024×1024 array of $24 \times 24 \mu\text{m}$ pixels. With a $10.54''/\text{mm} = 0.25''/\text{pxl}$ telescope scale it covers a sky area of about 4.3 square arcmin. The twilight images of blank sky areas (Christian et al. 1985) were normally taken after sunset or at dawn to correct images for flat fields.

The images of the four studied groups in R are presented in the left panels of Figs. 1, 4, 7, and 10 (north is up, and east is left)¹. The galaxy identification numbers are from Stoll et al. (1997a, 1997b). The reduction of observational data is described in detail in Papers I and II. The BVR magnitudes were calibrated in the Kron-Cousins photometric system. The star cluster M 67 served as a standard. The instrumental magnitudes were transformed to standard BVR magnitudes using 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 atmospheric extinction coefficient for the zenith distance, t – the instrumental parameter, and zp – the zero point.

¹ The groups in these figures are marked as Shkh according to old designation.

Table 3. Radial velocities of member galaxies in groups ShCG 181, ShCG 344, ShCG 361, and ShCG 362.

ShCG 181		ShCG 344		ShCG 361		ShCG 362	
gal	v_{rad} [km s ⁻¹]	gal	v_{rad} [km s ⁻¹]	gal	v_{rad} [km s ⁻¹]	gal	v_{rad} [km s ⁻¹]
1	28 130	1	23 180	1	24 600	1	26 430
2	27 410	3	23 260	2	23 160	2	26 630
3	28 130	4	23 300	3	24 000	3	26 540
4	28 280	5	8310	4	22 710	4	26 060
7	28 520	6	23 160	5	24 750	5	26 030
9	27 050			6	23 250	10	star
12	27 770			7	17 040		
15	28 070			8	23 940		
				9	24 480		
				10	24 150		

In all three observed bands a limit of the surface brightness generally lower than $\mu = 26^m5/\text{arcsec}^2$ is reached, if images of galaxies are isolated. The isophotes of the observed galaxies in arbitrary units are presented in the right panels of Figs. 1, 4, 7, and 10. The *BVR* magnitudes of galaxies are estimated generally within the $\mu = 26^m5/\text{arcsec}^2$ contour. Using the MIDAS program, the overlapping halos of images of galaxies were separated by extrapolation of fitted ellipses in the undisturbed part down to the surface brightness $\mu = 26^m5/\text{arcsec}^2$. Such a procedure may give somewhat dubious results when the whole galaxy is embedded in the halo of a larger galaxy.

The measured magnitudes in *B* are corrected for the extinction, Q_B , within our Galaxy according to 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 (Strayzis & Sviderskiene 1972). Extinction within spiral galaxies are estimated according to $A_i = 0.72 \log(1/\cos i)$ (de Vaucouleurs et al. 1976). The *K* correction is neglected because the observed groups are relatively nearby. The estimated accuracy of magnitudes is about 0^m06, and could be worse for galaxies with overlapping halos.

For a determination of the morphological types of galaxies we constructed first the surface brightness, μ in *R*, versus $a^{1/4}$ profiles, where a is the semi-major axis a . It is known that elliptical galaxies follow the de Vaucouleurs (1948) $a^{1/4}$ law. Hence, if the $\mu - a^{1/4}$ profile is straight, we classify the galaxy as elliptical. If this profile deviates from a straight line, we constructed the μ versus a graph. In the case of S0 and spiral galaxies the $\mu - a$ curve may be decomposed into bulge and disc components (Kent 1985; Schombert & Bothun 1987). Kent (1985) showed that the bulge in spirals is relatively smaller and the profile is steeper than those of lenticulars. Thus, depending on the relative size of the bulge and the steepness of the profile of the bulge, the galaxy was classified as S0 or spiral. However, as Kent (1985) mentioned, not all galaxies can be fitted by these simple functions. Deviations from ellipticity in both the core and envelope, as well as deviations from concentric ellipses, are sometimes observed (Pildis et al. 1995). Such deviations may imply that a galaxy has undergone an interaction, but not in every case is this true. Therefore, the deviations must be interpreted with restraint. The profiles $\mu - a^{1/4}$ and/or

$\mu - a$ for galaxies in ShCG 181, ShCG 344, ShCG 361 and ShCG 362 are presented in Figs. 2, 5, 8 and 11 respectively.

The curves of isophotal twisting of galaxies in the four studied ShCGs are plotted in Figs. 3, 6, 9 and 12. The twisting of the isophotes is considered as a sign of mutual tidal perturbations or galaxy collisions (Kormendy 1982; di Tullio 1979). The boxiness, which is not strictly correlated with interaction and merging (Lima Neto & Combes 1995; Bettoni & Fasano 1993, 1995; Fasano & Bettoni 1994) was not determined.

The diameter of a galaxy in *B*, *V*, and *R* bands was estimated by using the outermost fitted ellipse corresponding to the surface brightness $26^m5/\text{arcsec}^2$. In the case of overlapping halos the diameter of the galaxy was estimated from the fitted ellipse (see above). If a smaller galaxy is embedded in the halo of a nearby bright galaxy, we used for the diameter the last ellipse of the surface brightness profile down to the halo of the brighter galaxy. In such cases the diameter is apparently underestimated. We estimated also the axial ratios b/a , position angles and inclinations i , generally using the $\mu = 26^m5/\text{arcsec}^2$ contour.

The results of the photometry of member galaxies in ShCG 181, ShCG 344, ShCG 361, and ShCG 362 are presented in Tables 4–7 respectively in which the following information is given: Col. 1 – the galaxy identification number, Col. 2 – the magnitude in $B_{26.5}$, Col. 3 – the axial ratio b/a in *B*, Col. 4 – the diameter of the galaxy out to the surface brightness of $26^m5/\text{arcsec}^2$ in *B*; Cols. 5–7 – the latter three parameters in *V*; Cols. 8–10 – the same three parameters in *R*; Col. 11 – the position angle determined in *R*, Col. 12 – the inclination i in *R*, Col. 13 – the morphological type; Col. 14 – the colour $B - V$; Col. 15 – the colour $V - R$.

3. Discussion

We measured *RVs* of 28 galaxies in the four ShCGs studied. Two of them, galaxy 5 in ShCG 344 and galaxy 7 in ShCG 361, turned out to be foreground objects projected over the corresponding group. Their *RVs* differ by more than 1000 km s⁻¹ from the mean *RV* of the corresponding groups, which is accepted as a limiting difference for being a member of a group (Hickson et al. 1992). All the other observed galaxies have accordant redshifts in the corresponding groups.

Interaction between galaxies, which is very probable in dense environments of ShCGs, causes formation of bridges and filaments between them. However, one has to be cautious, since bright galaxies in ShCGs are often very close to each other in projection on the sky, and overlapping emission of their halos may create an impression of bridges. Interaction between galaxies may cause also formation of extended optical halos around galaxies, as demonstrated in Paper I.

Below we discuss in detail each of the studied groups.

ShCG 181. *RVs* of the eight brightest galaxies out of the listed 15 galaxies of the group were measured. The differences of *RVs* of all of them from the mean value are less than 1000 km s⁻¹. Hence, this is a real group. Redshifts of six galaxies, (6, 8, 10, 11, 13, 14) located around the central concentration are not known. They also may be members of the group.

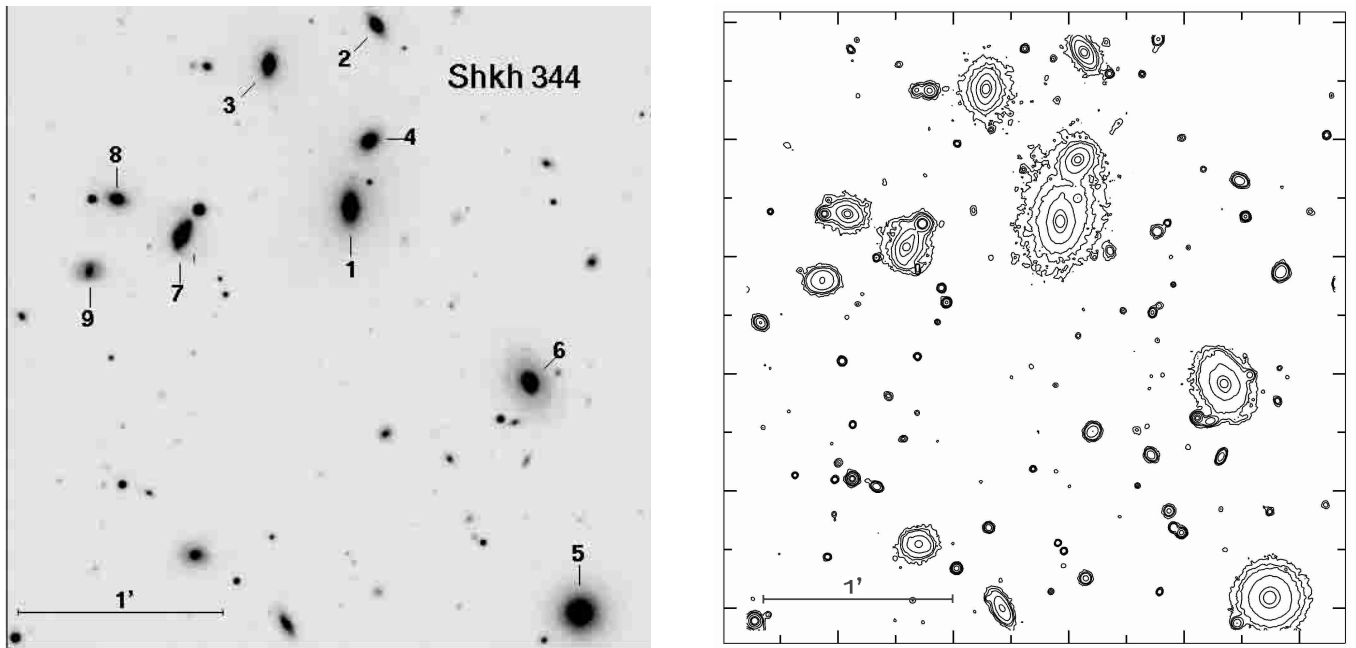


Fig. 4. The image of ShCG 344 in *R* (left) and the isophotal contour plot (right).

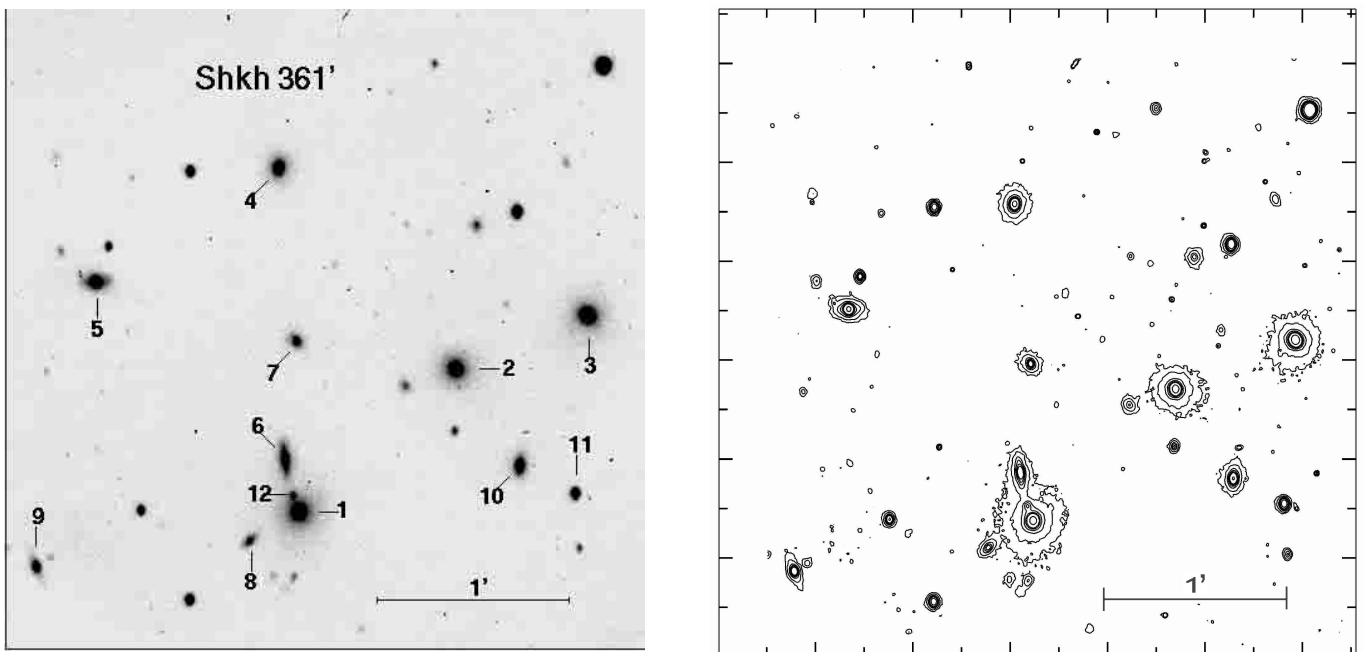


Fig. 7. The image of ShCG 361 in *R* (left) and the isophotal contour plot (right).

The image and the contour plot of object 5 (Fig. 1) show that it is certainly a star.

Two of the central galaxies, 1 and 4, seem to be interacting, since their outermost brightness isophotes are enlarged (Fig. 1), which is a sign of thermal heating (Paper I). Moreover, galaxy 4 has radio emission (Tovmassian et al. 1999). Halos of galaxies 15, 3 and 7 located close to the brightest galaxy 1 seem to overlap the halo of the latter, and also each other. The extension of contour plots between galaxies 3 and 7 is due to a very faint galaxy there. The twisting profiles of these galaxies are normal.

The group ShCG 181 was earlier studied by Bettoni & Fasano (1995) in the red band. There are some differences between our and their morphological classification. Bettoni & Fasano classified galaxies 6–12 as spirals. Figure 2b shows, however, that $\mu - a$ curves of these galaxies, except 9, are less peaked and more shallow than those of spirals (Kent 1985), therefore we conclude that these galaxies are rather lenticular. Most of them are unusually red for spirals. Direct B images of these galaxies do not demonstrate the presence of spiral arms.

Figure 1 shows that the group is elongated in the north-west – south-east direction. Such a configuration fits well with

Table 4. Photometric parameters of galaxies in ShCG 181.

gal	B			V			R					type	B - V	V - R
	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	14	15
1	17.59	0.9	12	16.39	0.9	12	15.13	1.0	20	-2	8	E	1.20	1.26
2	17.91	0.9	10	16.78	1.0	12	15.74	1.0	16	-18	17	E/S0	1.13	1.04
3	17.98	0.7	12	16.86	0.6	7	15.95	0.8	17	-79	60	E/S0	1.49	0.91
4	18.69	1.0	10	17.53	0.8	12	16.32	0.8	16	22	13	S0	1.13	1.21
6	19.37	0.7	8	18.14	0.8	10	17.55	0.7	12	-28	45	S0	1.23	0.59
7	19.60	0.8	8	18.48	0.9	8	17.78	0.8	10	-25	34	S0	1.12	0.70
8	18.55	0.9	10	17.85	0.7	10	17.33	0.8	14	-70	41	S0	0.70	0.52
9	19.08	0.9	10	18.23	0.8	10	17.38	0.7	14	-4	36	S	0.85	0.85
10	19.32	0.7	6	18.33	0.6	10	17.37	0.7	12	-28	43	S0	0.99	0.96
11	19.49	0.8	12	18.24	0.6	12	17.05	0.7	12	-67	46	S0	1.25	1.19
12	17.77	0.7	16	16.97	0.7	16	16.14	0.7	16	-88	47	S0	0.80	0.83
13	19.33	0.8	12	18.39	0.7	11	17.54	0.7	16	26	36	S	0.94	0.85
14	19.30	0.7	12	18.35	0.8	11	17.48	0.9	12	-8	33	S	0.95	0.87
15	18.36	0.9	14	17.44	0.9	13	16.80	1.0	16	-70	34	S	0.92	0.64

Table 5. Photometric parameters of galaxies in ShCG 344.

gal	B			V			R					type	B - V	V - R
	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	14	15
1	17.60	0.6	18	16.23	0.7	32	15.57	0.8	36	-23	52	E	1.37	0.66
2	18.53	0.6	14	17.34	0.6	18	16.59	0.6	21	32	55	S0	1.19	0.75
3	17.98	0.8	16	16.70	0.8	27	15.88	0.8	30	-6	47	E	1.28	0.82
4	18.55	0.7	13	17.28	0.7	18	16.58	0.8	24	-47	39	S0	1.27	0.70
5*	16.61	0.9	22	15.58	1.0	32	15.05	0.9	39	-57	9	S0	1.20	0.53
6	17.56	0.8	24	16.20	0.7	32	15.59	0.8	40	26	38	S	1.36	0.61
7	17.47	0.6	17	16.38	0.6	23	16.08	0.9	25	45	62	S	1.09	0.30
8	18.64	0.8	14	17.37	0.7	19	16.66	0.9	21	82	40	S/S0	1.27	0.71
9	19.20	0.8	10	18.00	0.8	14	17.46	0.8	15	-88	40	S0	1.20	0.54

* Foreground galaxy.

Table 6. Photometric parameters of galaxies in ShCG 361.

gal	B			V			R					type	B - V	V - R
	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	14	15
1	16.10	0.9	23	15.46	0.8	23	14.78	0.9	24	-10	25	E	0.64	0.66
2	16.48	0.9	18	15.76	0.9	18	15.04	0.9	18	-75	25	E	0.72	0.72
3	16.27	0.8	20	15.43	1.0	12	14.66	0.9	26	-30	17	S0	0.84	0.77
4	16.89	0.9	18	16.14	0.8	18	15.33	0.9	18	-10	27	S0	0.75	0.81
5	17.06	0.5	12	16.22	0.6	14	15.51	0.6	14	85	27	S0	0.84	0.71
6	16.88	0.8	16	16.29	0.7	16	15.59	0.7	18	15	72	S0	0.59	0.60
7*	17.87	0.9	11	17.09	0.8	14	16.32	0.8	16	20	29	E	0.78	0.77
8	18.13	0.7	12	17.58	0.6	12	16.81	0.7	12	-50	45	S	0.55	0.77
9	17.91	0.6	14	17.12	0.4	13	16.20	0.8	15	15	51	E	0.79	0.92
10	17.09	0.8	16	16.47	0.8	16	15.69	0.7	16	-8	13	S	0.62	0.88
12	19.23:	0.9	5	18.19:	0.9	5	18.03:	0.9	6	56	16	E:	0.55:	0.80:

* Foreground galaxy.

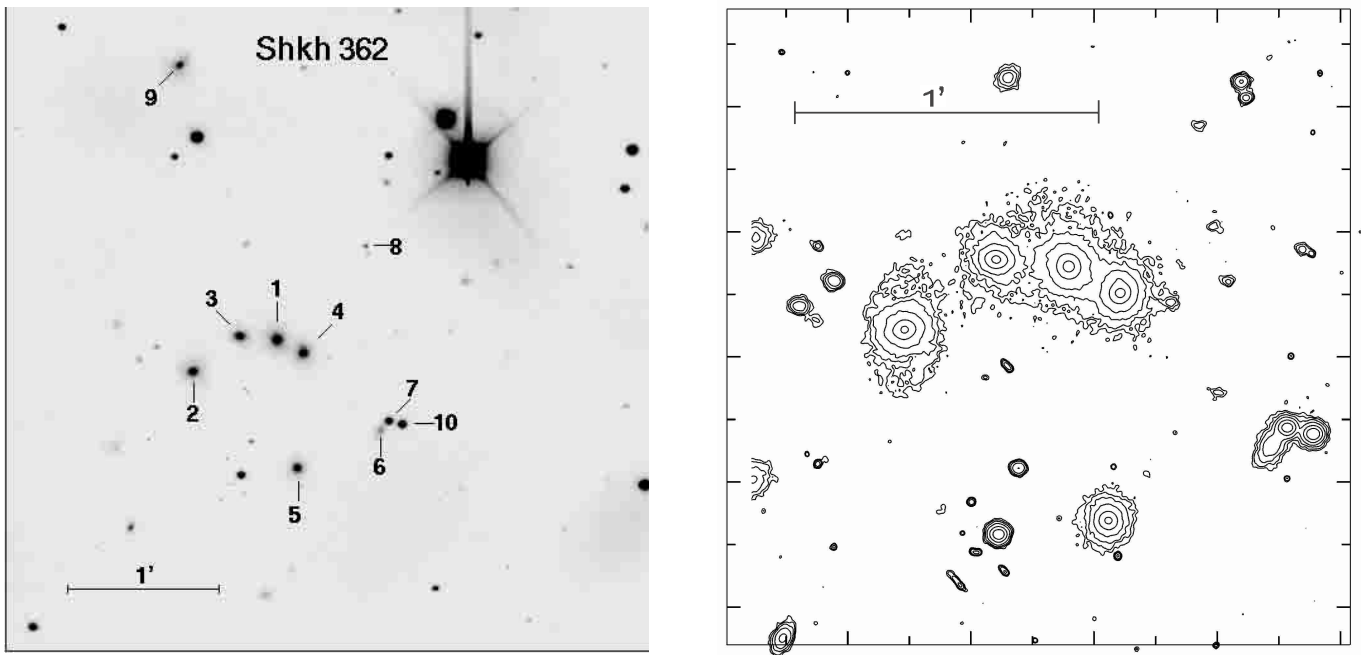


Fig. 10. The image of ShCG 362 in R (left) and the isophotal contour plot (right).

Table 7. Photometric parameters of galaxies in ShCG 362.

gal	B			V			R			α	i	type	$B - V$	$V - R$
	m	b/a	D	m	b/a	D	m	b/a	D					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	17.78	0.8	17	17.12	0.9	14	16.44	0.8	18	45	31	E	0.66	0.68
2	18.17	0.8	15	17.38	0.8	16	16.50	0.9	19	-85	23	S	0.79	0.88
3	18.38	0.9	13	17.60	1.0	14	16.77	0.9	17	80	28	S0	0.78	0.83
4	18.00	0.8	20	17.26	0.8	16	16.43	0.8	18	0	30	E	0.74	0.83
5	18.38	0.9	14	17.60	0.9	14	16.74	0.8	20	-0	11	E	0.78	0.86

the interpretation given by Tovmassian & Tiersch (2001) that ShCGs are elongated poor clusters of galaxies, the brightest members of which happen to be close to each other during assumed rotation around the gravitational center of the group. The presence of spirals is atypical for Shakhbazian groups. The space density of ShCG 181 (assuming that it consists of 15 galaxies) is about 500 Mpc^{-3} , and also is not characteristic for ShCGs which generally have a much higher spatial density.

ShCG 344. Spectra of five galaxies, 1, 3, 4, 5, and 6, of this group of eight galaxies were obtained. Four of them have accordant redshifts. The brightest galaxy 5 with a much smaller RV is a foreground galaxy, projected over the outskirts of the group.

Consideration of the contour plots (right panel of Fig. 4) shows that two galaxies in this group, the brightest galaxy 1 and galaxy 4, are possibly interacting, since the halo of galaxy 1 is apparently enlarged in comparison with halos of the other galaxies. The FIR emission at $60 \mu\text{m}$ and $100 \mu\text{m}$ identified with galaxies 1 and/or 4 (Tovmassian et al. 1998) may also be considered as evidence of interaction. Moreover, in the halo of galaxy 1 there are a few relatively bright knots. The brightness

concentration of the latter is smaller than those of a large number of faint objects in the area (right panel of Fig. 4). Therefore, the former are less likely to be objects projected over the halo of galaxy 1. The mentioned knots may be dwarf galaxies formed as a result of interaction with galaxy 4 (e.g. Barnes & Hernquist 1992; Elmegreen et al. 1993; Hunsberger et al. 1996).

The radio source NVSS J233236+192215 was identified with galaxy 7 or with its close faint neighbour (Tovmassian et al. 1999). The spiral arms of galaxy 7 are undisturbed (Fig. 4). Thus, it is not interacting with the very compact and faint neighbour. Most probably this faint object is projected over galaxy 7, and is the radio emitter. The radial velocity of this faint object is unknown. Its knowledge would clarify the situation.

There are two spiral galaxies in this group, 6 and 7. The morphological type of galaxy 8 is uncertain. It also may be a spiral.

ShCG 361. Nine galaxies have accordant RV s. Galaxy 7 has a discordant redshift and, thus, is projected over the central region of this group.

Contour plots of galaxies (right panel of Fig. 7) show that halos of the brightest galaxies 1, 2 and 3 are apparently enlarged. The unusual $\mu - a^{1/4}$ profile of galaxy 2 (Fig. 8) also shows an enlarged halo. These three galaxies may be interacting. This suggestion becomes more convincing when one compares the halos of galaxies 2 and 3 with R magnitudes of 15^m04 and 14^m66 respectively, with the halo of the obviously isolated galaxy 4 with about the same R magnitude, 15^m33 . It is remarkable that the halo of galaxy 3 is slightly extended towards galaxy 1. Also the twisting profiles of these three galaxies (Fig. 10) are not smooth. The projected distance between galaxies 1 and 3 is relatively small, only ≈ 200 kpc. At the same time, the difference between RV s of these three galaxies is ≈ 1400 km s $^{-1}$. The difference between space velocities may be higher. In such conditions galaxies may shed gas and dust by thermal heating. Galaxy 12 appears to be located very close to galaxy 1 and, if confirmed as a group member, is possibly strongly affected by interaction, having completely lost its halo (Fig. 7). It looks somewhat similar to the ultra compact dwarf galaxies found by Drinkwater et al. (2000) and Phillipps et al. (2001) in the Fornax cluster, but it is larger; its diameter is 5 kpc. The halo of galaxy 6 is undisturbed. Its twisting angle is practically unchanged (Fig. 9). Most probably, this galaxy is just projected near galaxy 1.

ShCG 362. We obtained spectra of all five members of the group listed in Baier & Tiersch (1979). They all have accor-dant RV s with a small dispersion of ~ 280 km s $^{-1}$. The spectrum shows that object 10 is a star. The contour-plot shows that objects 7 and 8 are also stars. A faint galaxy 6 is nearby. However, its membership of the group of five brighter galaxies is not confirmed spectroscopically. The spiral galaxy 9 is relatively far from the central concentration. Its redshift is also unknown. It is remarkable that in the area of the group (within about 4.5 square arcmin) there are about a dozen sufficiently faint galaxies distributed along the north-west south-east direction.

The contour plots of galaxies (right panel of Fig. 10) shows that galaxies 1, 3, 4 and probably also galaxy 2 seem to be interacting. The outer isophotes of galaxies 1, 3 and 4 are sufficiently enlarged in comparison to that of the apparently isolated galaxy 5, which has the same magnitude as galaxy 3. The large extent of galaxy 2 in the north-south direction is due to its spirals, but the central body of this galaxy shows extended isophotes. The enlargement of isophotes may be due to thermal heating. Twisting profiles of galaxies 1 and 4 (Fig. 12) also show that interaction is indeed taking place.

The physical parameters of ShCGs. The results of the photometry of member galaxies in the observed cores of the studied groups and knowledge of distances of groups allowed us to deduce, as in Paper I, the physical parameters of groups presented in Table 8, in which the the following information is given: line 1 – the redshift z (weighted by masses of member galaxies); line 2 – the projected diameter D of the group ($H = 55$ km s $^{-1}$ Mpc $^{-1}$); line 3 – the RVD (weighted by the masses of galaxies); line 4 – the virial radius, R_{vir} , of the group (weighted by the masses of galaxies); line 5 – the virial mass; line 6 – the luminosity of the group, L , in solar units; line 7 – the mass-to-luminosity ratio M/L in solar units; and line 8 – the crossing time, τ_c .

Table 8. Physical parameters of the studied ShCGs.

Parameter	ShCG 181	ShCG 344	ShCG 361	ShCG 362
z	0.0930	0.0774	0.0800	0.0870
D [kpc]	440	270	400	470
RVD [km s $^{-1}$]	140	40	220	160
R_{vir} [kpc]	80	110	160	54
M_{vir} [$10^{11} M_{\odot}$]	17.8	1.8	83.0	15.4
L [$10^{11} L_{\odot}$]	13.0	5.0	21.2	5.7
M/L [M_{\odot}/L_{\odot}]	1.4	0.4	3.9	2.7
τ_c [10^6 years]	230	1220	310	140

Below we discuss the physical parameters of all thirteen ShCGs, including those presented in Papers I, II and in Tovmassian et al. (2003b).

The RVD of the thirteen groups studied is much smaller than the typical value of ≈ 1000 km s $^{-1}$ for rich galaxy clusters (Zabludoff et al. 1990). The highest RVD is that of the group ShCG 43, 284 km s $^{-1}$.

The derived virial masses of groups reach $\approx 130 \times 10^{11} M_{\odot}$. The smallest mass of $1.8 \times 10^{11} M_{\odot}$ deduced for the group ShCG 344 may in reality be twice as high, since it was deduced on the basis of four members (galaxies 1, 3, 4, and 6). The other four possible members (galaxies 2, 7, 8, and 9) of comparable luminosities are not taken into account, since their redshifts are not measured. For the unknown projection effect, the derived mass of an individual group with fewer members has, however, some uncertainty. The obtained values are typical for galaxy groups. Taking into account that ShCGs are larger systems with a number of fainter members (Tovmassian & Tiersch 2001), their real masses could be higher.

The mean value of mass-to-luminosity ratios for thirteen of the studied groups is 4.8 ± 4.2 , and is much smaller than the mean value for HCGs, ≈ 30 (Hickson et al. 1992). ShCG 43 has the highest value, $M/L = 28.5$. The mass-to-luminosity ratios for these thirteen ShCGs are somewhat smaller than the dynamical mass-to-light ratio for ellipticals, ≈ 8 (Karachentsev 1987). This is possibly due to the uncertainty of the estimated virial mass.

The crossing time, τ_c , of nine out of the thirteen ShCGs is smaller than the mean τ_c of HCGs, $\approx 260 \times 10^6$ years (Hickson et al. 1992). The mean τ_c of these nine groups is $163 \pm 49 \times 10^6$ years. The very high value, $\approx 1.2 \times 10^9$ years, of τ_c deduced for the group ShCG 344 may not be reliable, since we have spectra of only four galaxies of this group, and the RVD is very small, only ≈ 38 km s $^{-1}$. One has to take into account that the real crossing times of groups in both samples (HCGs and ShCGs) may in reality differ from the deduced values. It was shown that ShCGs and HCGs are, most probably, the cores of larger elongated systems (Tovmassian et al. 2001; Tovmassian & Tiersch 2001; Tovmassian 2001, 2002). We observe such a system as a CG if its orientation is close to the line of sight, or otherwise if its bright members happen to be close to each other during supposed rotation around the common gravitational center of the whole system. This means that the deduced τ_c of the groups oriented end-on, and seen as round, will be smaller than the real values, since their sizes will be underestimated. On the

other hand, the deduced τ_c will be overestimated for the elongated chain-like groups, since their deduced *RVDs* would be smaller than the real values.

Due to processes of interaction which may be frequent in the central areas of the considered groups, the spirals should be converted to *S0/E* types. This explains the low rate of the former in ShCGs, $\approx 25\%$ on average. Two groups, ShCG 344 and ShCG 376, are exceptions. Six out of eight members of ShCG 344 and all nine members of ShCG 376 are spirals. Elliptical galaxies in all studied ShCGs are very red, the $B - V$ of many of them are of about 1 or more. Such colour have the reddest ellipticals in the sample studied by Buta et al. (1995). In agreement with the finding of Zepf et al. (1991) we have not detected a population of bright blue elliptical galaxies predicted by the environment-dominated models of evolution of galaxies, according to which the frequency of blue ellipticals in CGs should be higher.

4. Conclusions

We investigated spectroscopically 28 galaxies in the regions of four Shakhbazian groups, ShCG 181, ShCG 344, ShCG 361, and ShCG 362. Thirty nine galaxies of these groups were observed in *BVR*. Important physical parameters of these groups are deduced (Table 8). The results of the detailed study of these four groups and another nine groups presented in Papers I and II and in Tovmassian et al. (2003b) can be summarized as follows:

1. In the thirteen studied ShCGs we obtained spectra of 88 objects. Three of them turned out to be stars. One more star was revealed by the detailed photometry of 121 supposed members. Hence, the overwhelming majority of objects in the selected groups are, indeed, galaxies, although ShCGs have been selected by eye from the POSS prints as compact groups of *compact*, red galaxies, and it could not be excluded that some of the objects included in the groups may in reality be stars.

2. The measured *RVs* of galaxies in the thirteen groups prove they are real physical entities and not a chance projection of field galaxies. Out of 66 spectroscopically observed objects, only three or possibly four (galaxy 6 in ShCG 376) turned out to be foreground galaxies.

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

4. The majority of galaxies in ShCGs are *E* and *S0* galaxies. Of 120 member galaxies observed in *BVR* only 18 or 30 are spirals (if all dubious *S/S0* classifications are spirals) i.e. at most 25%. The low relative number of spirals could be due to the loss of interstellar gas by galaxies caused by tidal forces and/or ram pressure due to the expected frequent processes of interaction between member galaxies. Detailed photometry showed that in almost each group there are interacting galaxies.

5. The mass-weighted *RVDs* of most of the studied ShCGs are between 40 km s^{-1} and 280 km s^{-1} , comparable to that of HCGs and LGs.

6. The virial radii are small enough; they do not exceed 160 kpc.

7. The derived virial masses of the groups range from $\sim 2 \times 10^{11} M_\odot$ to $\sim 130 \times 10^{11} M_\odot$. These values are typical for galaxy groups. However, one has to take, into account that the real masses may be higher, since, as it was shown by Tovmassian & Tiersch (2001), ShCGs are the cores of larger, elongated systems.

8. The mass-to-luminosity ratio M/L of eleven of the studied ShCGs is within $\sim 0.5-10$, with an average value $M/L = 4.8 \pm 4.4$. These ratios are smaller than the mean value, ~ 30 , for HCGs (Hickson et al. 1992), and are comparable to those of individual galaxies. This means that these compact groups, except ShCG 43 for which $M/L \sim 30$, have nearly no dark matter.

9. The crossing time for eleven out of twelve ShCGs ranges from $\sim 80 \times 10^6$ to 380×10^6 years. It is generally shorter than the Hubble age. The high value of τ_c for the group ShCG 344, $\sim 1.2 \times 10^9$, may be due to the very small value of *RVD* (38 km s^{-1}) deduced by using *RVs* of only four out of, at least, eight galaxies.

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Online Material

Table 2. Spectroscopic observations of ShCG 181, ShCG 344, ShCG 361, and ShCG 362.

G	Telescope	Site	Date	Resolution lines/mm	Dispersion Å/mm	W-length range Å
ShCG 181						
1	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
2	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
3	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
4	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
7	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
9	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
12	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
15	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
ShCG 344						
1	1.5 m	ESO, La Silla	March 95	2.9	194	2400–8400
	2.1 m	GHO, Cananea	Apr. 96	5.5	250	4000–7000
3	1.5 m	ESO, La Silla	March 95	2.9	194	2400–8400
	2.1 m	GHO, Cananea	Apr. 96	5.5	250	4000–7000
4	1.5 m	ESO, La Silla	March 95	2.9	194	2400–8400
5	1.5 m	ESO, La Silla	March 95	2.9	194	2400–8400
	2.1 m	GHO, Cananea	Apr. 96	5.5	250	4000–7000
6	1.5 m	ESO, La Silla	March 95	2.9	194	2400–8400
ShCG 361						
1	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
	2.1 m	GHO, Cananea	May 95	5.5	250	4000–7000
2	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
	2.1 m	GHO, Cananea	May 95	5.5	250	4000–7000
3	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
	2.1 m	GHO, Cananea	May 95	5.5	250	4000–7000
4	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
5	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
6	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
	2.1 m	GHO, Cananea	May. 95	5.5	250	4000–7000
7	2.1 m	GHO, Cananea	Nov. 99	18	8.2	4200–9000
8	2.1 m	GHO, Cananea	Nov. 99	18	8.2	4200–9000
9	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
	2.1 m	GHO, Cananea	May 95	5.5	250	4000–7000
10	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
	2.1 m	GHO, Cananea	May 95	5.5	250	4000–7000
ShCG 362						
1	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
	2.1 m	GHO, Cananea	May 95	5.5	250	4000–7000
2	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
3	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
4	2.2 m	DSAZ, CA	Nov. 94	2.9	120	4900–7650
	2.1 m	GHO, Cananea	May 95	5.5	250	4000–7000
5	2.1 m	GHO, Cananea	May 95	5.5	250	4000–7000
	2.1 m	GHO, Cananea	Nov. 99	8.5	380	4200–9000

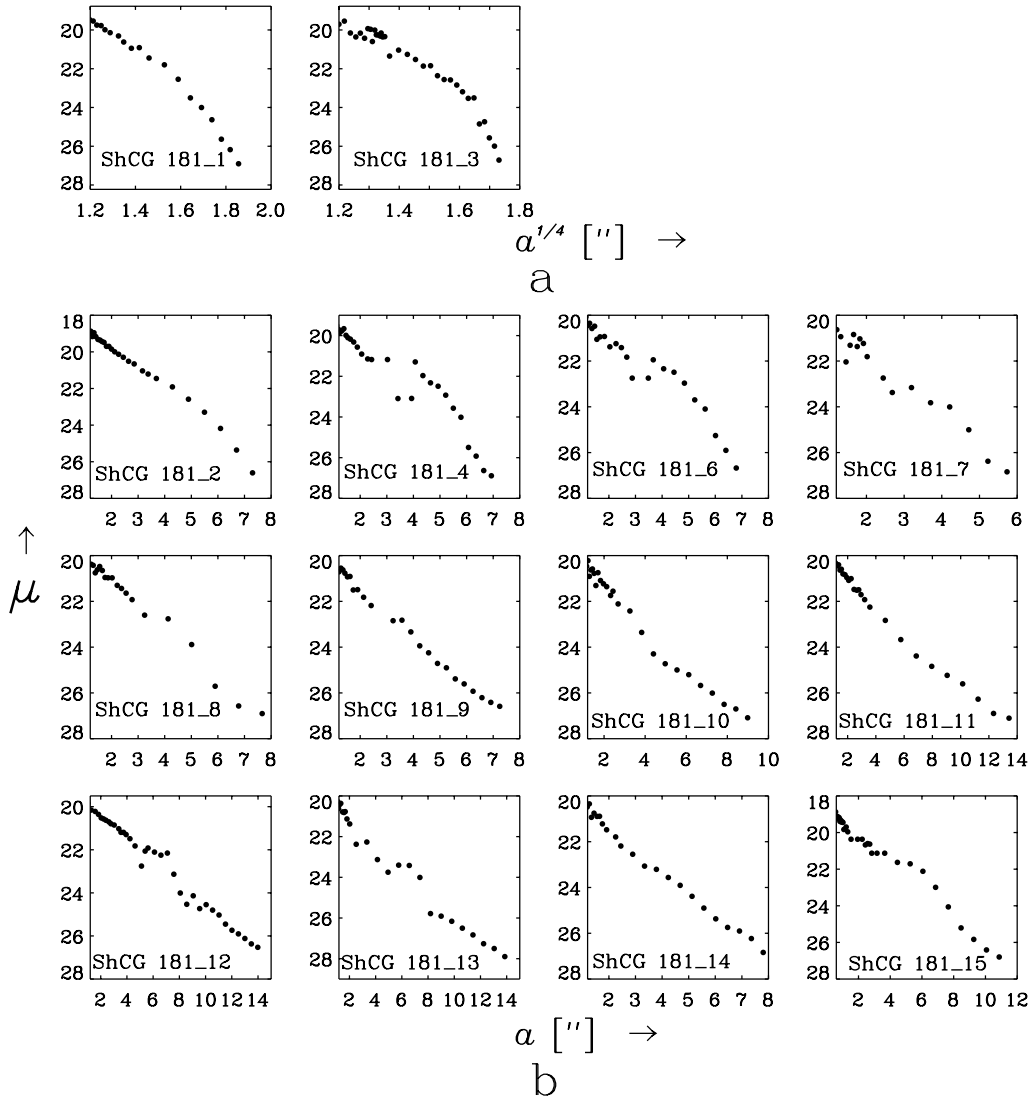


Fig. 2. Isophotal surface brightness, μ , of galaxies in ShCG 181 (in R) versus semi-major axis, a .

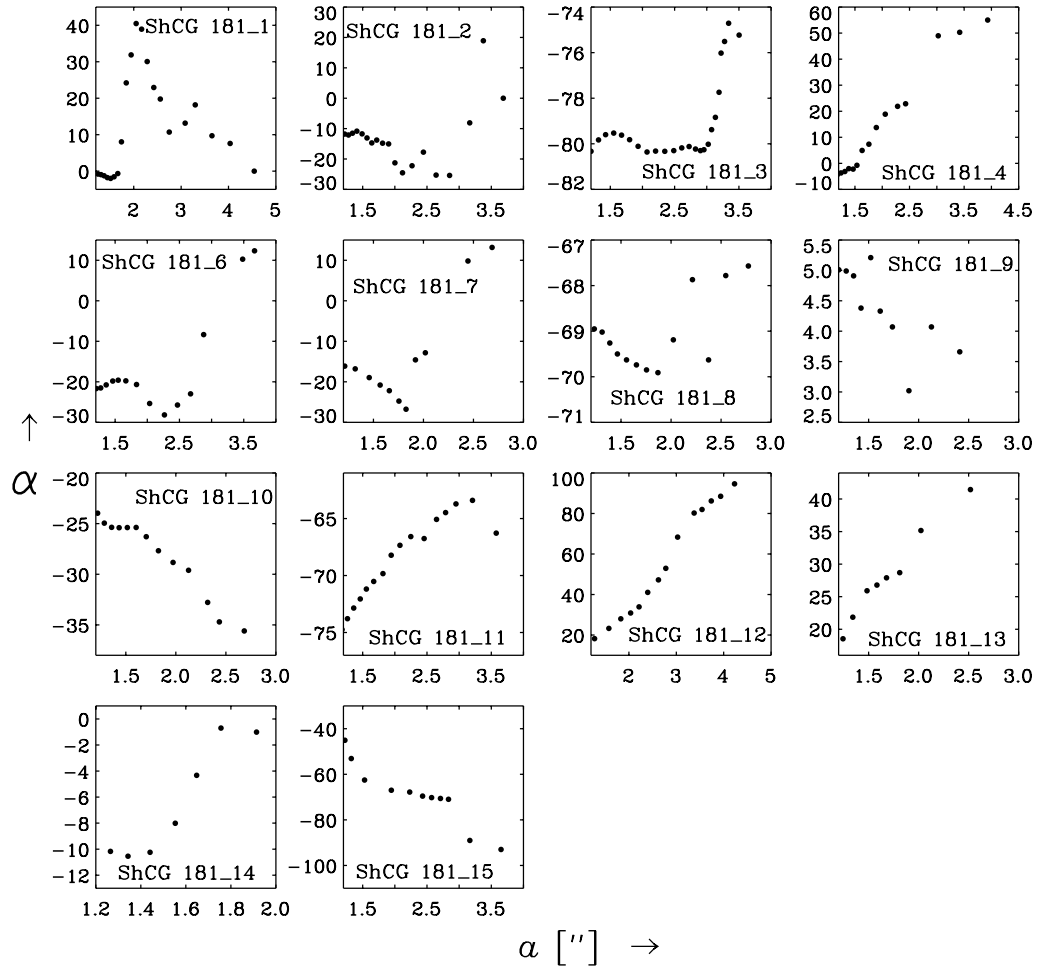


Fig. 3. Position angle α , versus semi-major axis a , for galaxies in ShCG 181.

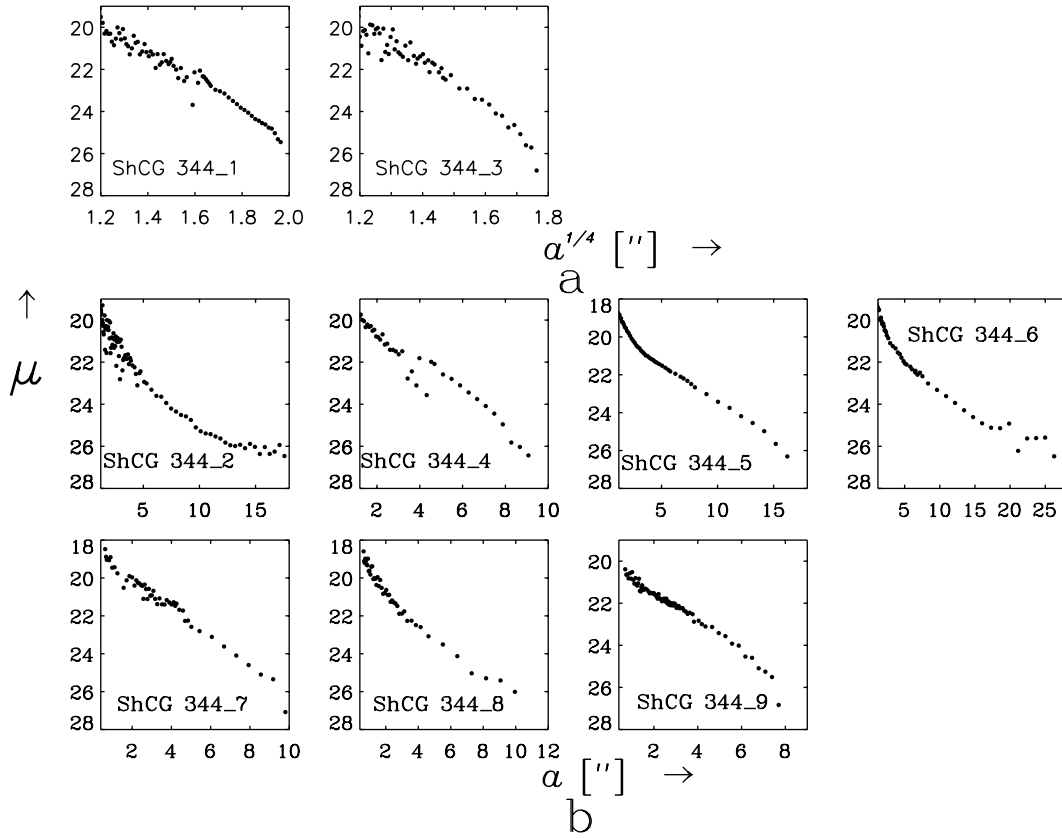


Fig. 5. Isophotal surface brightness, μ , of galaxies in ShCG 344 (in R) versus semi-major axis, a .

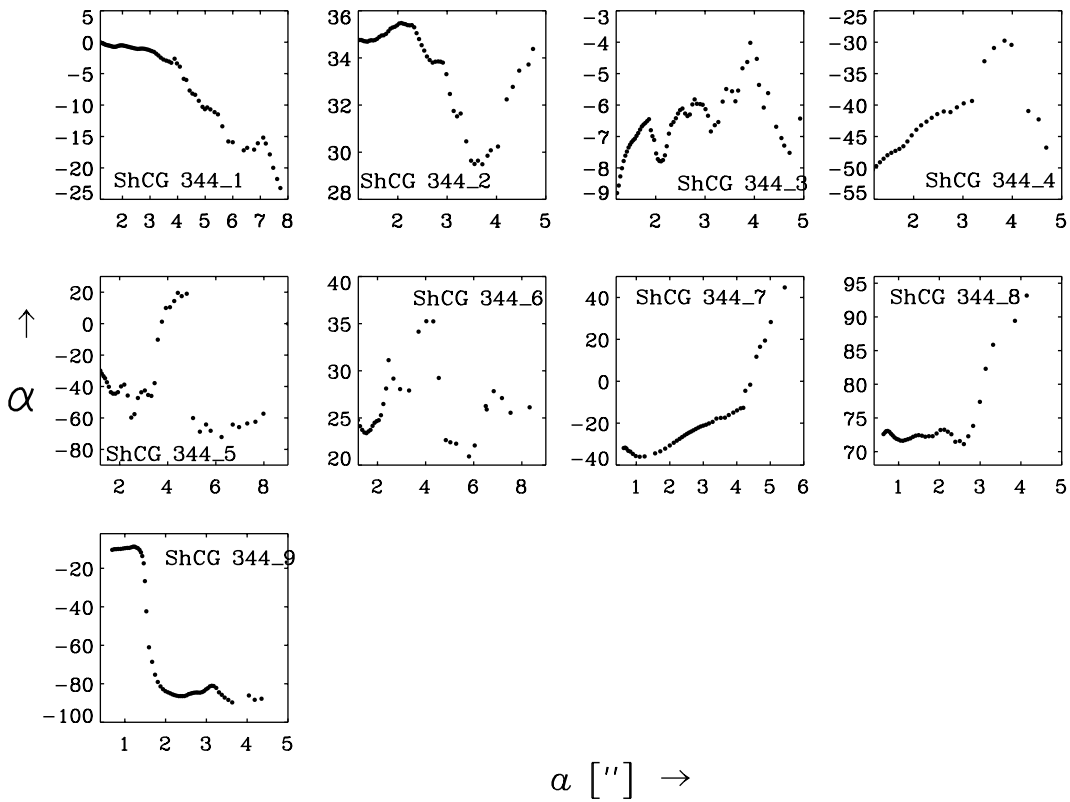


Fig. 6. Position angle α versus semi-major axis a for galaxies in ShCG 344.

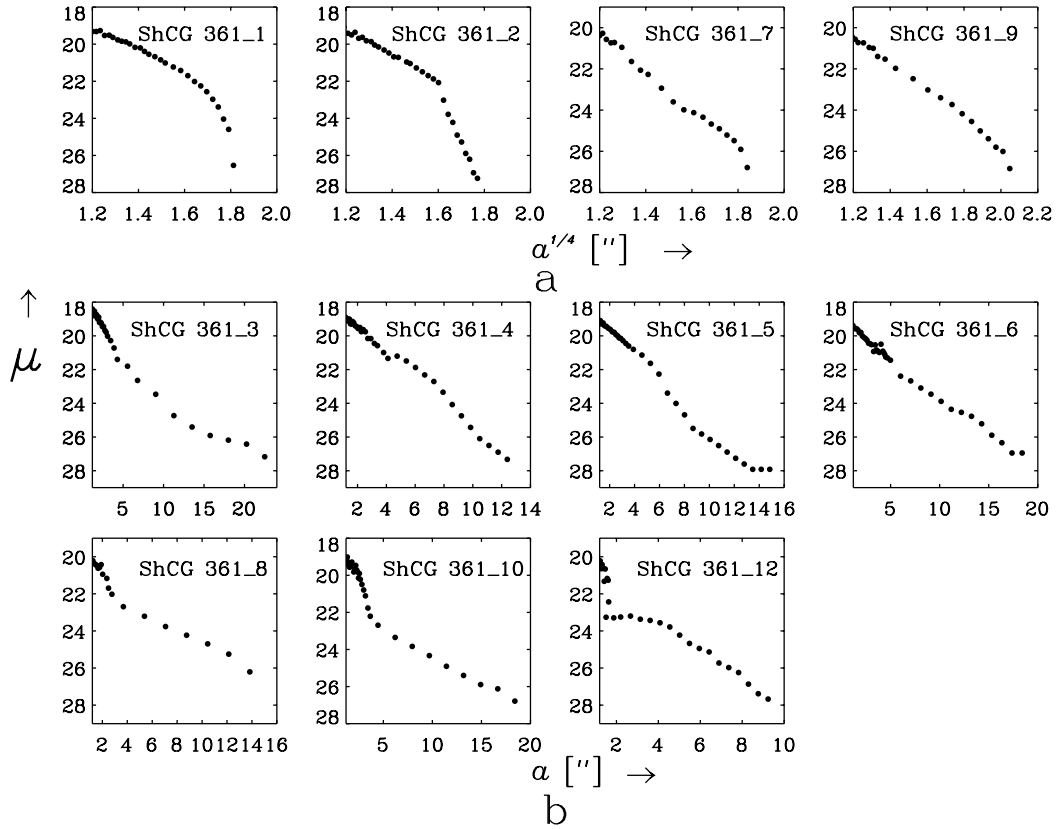


Fig. 8. Isophotal surface brightness, μ , of galaxies in ShCG 361 (in R) versus semi-major axis, a .

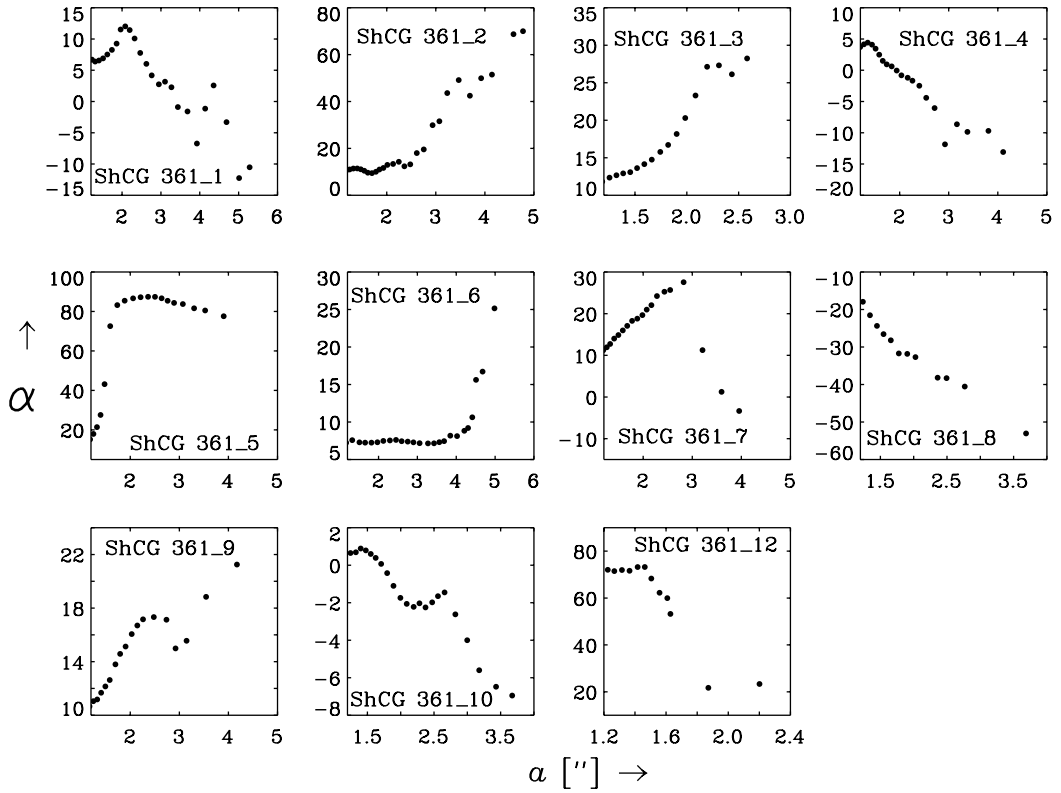


Fig. 9. Position angle α versus semi-major axis a for galaxies in ShCG 361.

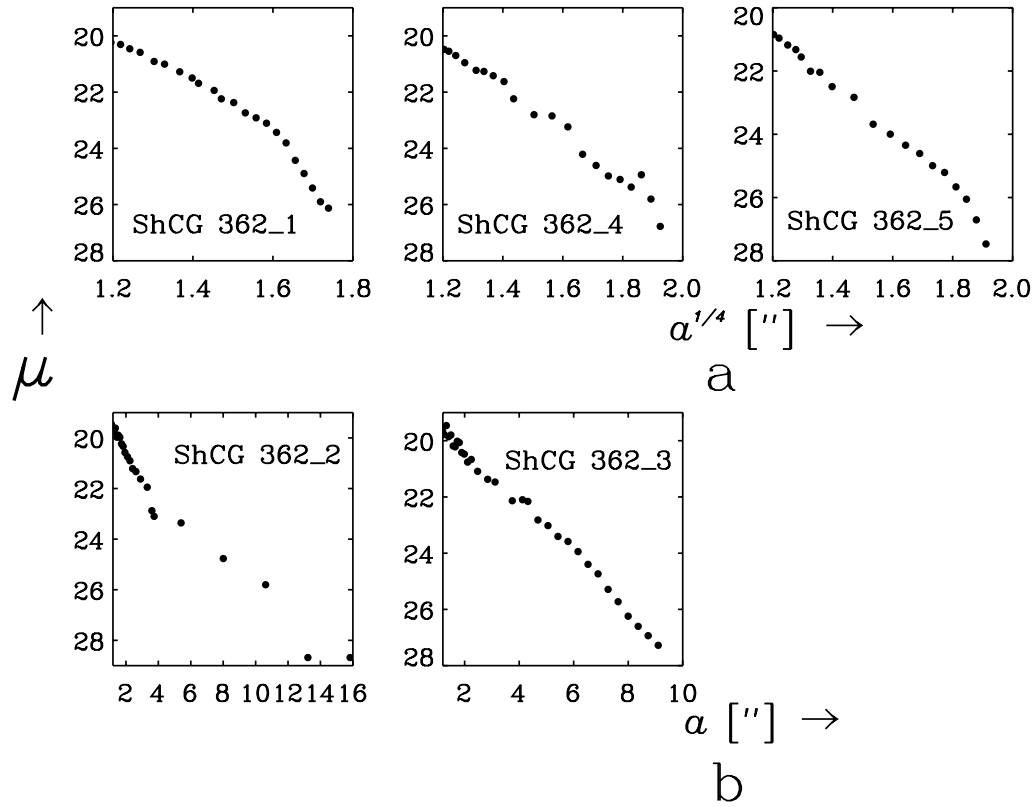


Fig. 11. Isophotal surface brightness, μ , of galaxies in ShCG 362 (in R) versus semi-major axis, a .

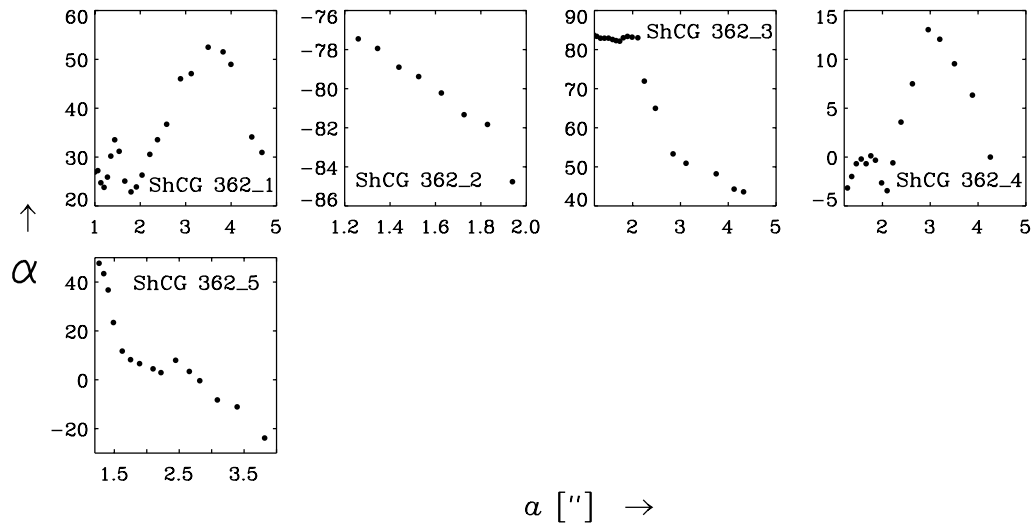


Fig. 12. Position angle α versus semi-major axis a for galaxies in ShCG 362.