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# Shakhbazian compact galaxy groups

## II. Photometric and spectroscopic study of ShCG 376

H. M. Tovmassian[1], H. Tiersch[2], V. H. Chavushyan[1], and G. H. Tovmassian[3]

[1] Instituto Nacional de Astrofísica Óptica y Electrónica, AP 51 y 216, 72000 Puebla, Pue, México
e-mail: vahram@inaoep.mx
[2] Sternwarte Königsleiten, 81477 München, Leimbachstr. 1a, Germany
e-mail: htiersch@uni.de
[3] Observatorio Astronomico Nacional, Instituto de Astronomia, UNAM, 22860 Ensenada, BC, México
e-mail: gag@astrosen.unam.mx

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**Abstract.** The results of the redshift measurements and of the detailed surface photometry in *BVR* of the compact group ShCG 376 are presented. The radial velocity dispersion, the virial mass, the total luminosity, the $\mathcal{M}/L$ ratio, and the crossing time of the group are estimated. The group consists of eight accordant redshift spiral galaxies. Four (or possibly five) of the group members have emission-line spectra. Such morphological content and the number of emission-line galaxies are very atypical for compact galaxy groups. There are signs of interaction between some members of the group. It is suggested that the irregular shape of the brightest galaxy No. 4 is probably due to interaction with other members of the group, particularly, the emission line galaxy No. 6 with a discordant redshift ($\Delta v$ = 2600 km s$^{-1}$). It is speculated that the latter galaxy may be a infalling intruder to the group.

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

## 1. Introduction

Shakhbazian compact groups (ShCG) are richer and generally more dense groups of galaxies than HCGs (Hickson 1982). They were selected on the Palomar Observatory Sky Survey (POSS) prints by *visual* search (Shakhbazian 1973; Baier & Tiersch 1979, and references therein). In the first list of ShCGs the groups were described as "compact groups of *compact* galaxies", since on the POSS E prints the images of member galaxies usually lack diffuse borders and seem to have high surface brightness. Later observations showed, however, that most members of these groups are ordinary E or S0 galaxies. ShCGs consist generally of 5–15 members; the distances between member galaxies are typically 3–5 times the diameter of galaxies; the apparent magnitudes in R of individual galaxies measured on E plates of the Palomar Observatory Sky Survey images are between $\approx 14^{\rm m}$ and $\approx 19^{\rm m}$; almost all member galaxies are compact and extremely red; there are at most 1–2 blue galaxies in a group. In many ShCGs the space density reaches the values of about $10^4$–$10^5$ galaxies per Mpc$^3$. However, since these groups are, on average, at least three times farther than HCGs (Tiersch et al. 1996; Tovmassian et al. 1998), and member galaxies are sufficiently faint, only a few of them have been investigated in detail until recently. About two dozen ShCGs have been observed spectroscopically (Robinson & Wampler 1973; Arp et al. 1973; Mirzoyan et al. 1975; Kirshner & Malamuth 1980; Amirkhanian 1989; Kodaira et al. 1988, 1990; Kodaira & Sekiguchi 1991; Lynds et al. 1990; del Olmo & Moles 1991). A few years ago we commenced a spectroscopic and photometric study of a large number of ShCGs (Tiersch et al. 1995a, 1995b, 1996a, 1996b, 1999a, 1999b). The number of the spectroscopically observed groups reaches at present about 100. The results of the study of the groups ShCG 154, 166, 328 and 360 have been published by Tiersch et al. (2002, hereafter Paper I). The reduction of observations of about 80 groups is in progress.

During spectral and photometric study of ShCGs we encountered a unique group ShCG 376. In this paper we present the results of spectral and detailed photometric study of this group. While ShCGs consist mainly of E and S0 galaxies,

*Send offprint requests to*: H. M. Tovmassian,
e-mail: hrant@inaoep.mx

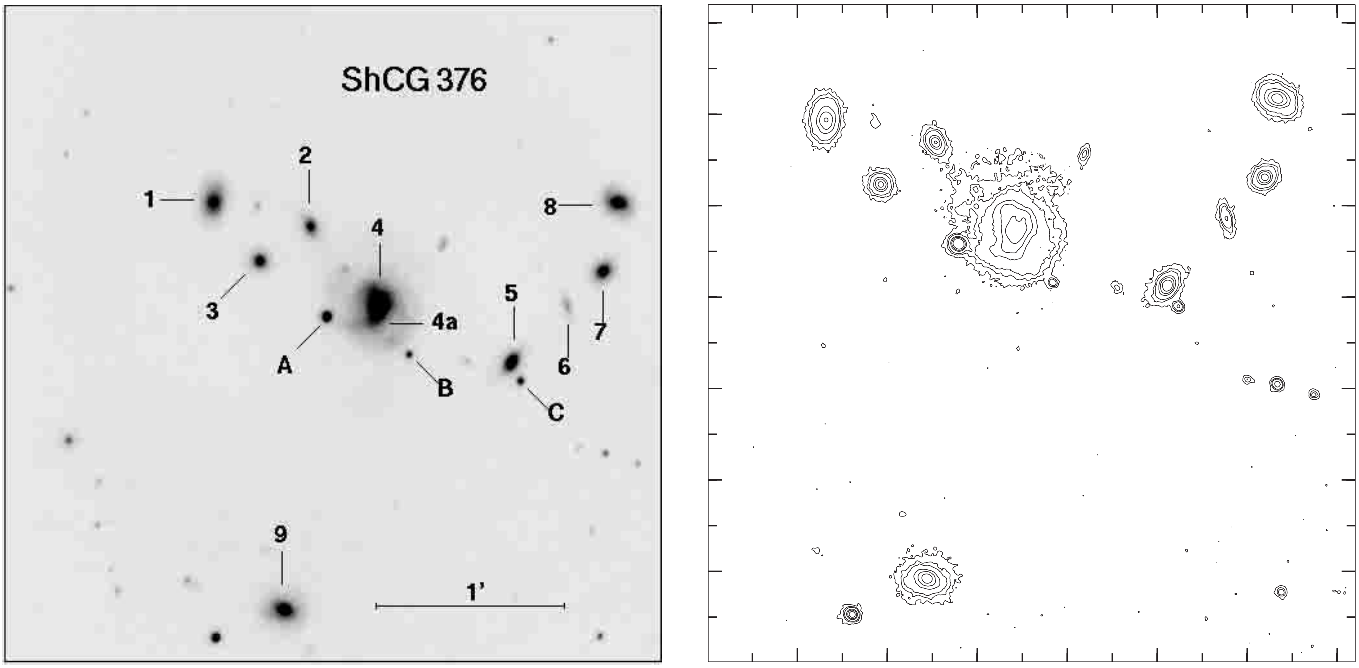


**Fig. 1.** The image of ShCG 376 in *B* (left panel) and contourplots of galaxies (right panel). North is up, east is left. Designations of galaxies are given according to Stoll et al. (1997).

all galaxies in ShCG 376 are spirals. This group differs from other observed ShCGs also by its high content of emission-line galaxies.

## 2. Observations and results

### 2.1. Direct imaging and photometry

We obtained high-resolution images of the group ShCG 376 in *BVR*. The image of ShCG 376 in *B* is presented in the left panel of Fig. 1, in the right panel of which the isophotes of galaxies in arbitrary units are presented. They are drawn down to the background level. The image of the group in *R* is presented in Fig. 2. Observations were made with the 1.5 m telescope of the Observatorio Astronómico Nacional, UNAM, at San Pedro Mártir, México. Observations in *R* were carried out in March 1998, and in *B* and *V* in May 2001. The seeing during observations was better than 2″. The TEK2 CCD detector used had 1024 × 1024 pixels of 24 $\mu$m squared with an image scale of 10.54″/mm = 0.25″/pxl. It covers a sky area of about 4.3 arcmin squared. The TEK2 detector with similar parameters was used in *B* and *V* observations.

The reduction procedure was performed in the usual way. After subtracting the bias (the dark emission from the CCD itself was negligible) and the sky background, the image frames were divided by the evening and morning twilight flat fields of blank sky areas (Christian et al. 1985) to normalize the variations from pixel to pixel caused by different optical transmission and quantum efficiency. For the *R* colour a night sky flat field was used to avoid fringes. The diameters of the galaxies in ShCG 376 are quite small with respect to the CCD field, therefore sampling of the sky on the astronomical frame and its interpolation with a polynomial was possible.

The star cluster NGC 4147 was used as a standard. It is suitable for photometry of galaxies because $B-V$ colours of its stars are in the range 0.163−1.055. The instrumental magnitudes were transformed to a standard *BVR* magnitudes using relations:

$$B = b - 0.31M(z) + (0.202 \pm 0.11)(B - B) + (22.040 \pm 0.038),$$
$$V = v - 0.16M(z) - (0.040 \pm 0.10)(B - V) + (23.158 \pm 0.057),$$
$$R = r - 0.11M(z) - (0.098 \pm 0.08)(B - V) + (21.914 \pm 0.048),$$

where $M(z)$ is the airmass. The magnitudes are calibrated in the Kron/Cousins photometric system.

The galaxy characteristics were deduced using the SURPHOT application package of the MIDAS program. In general we reach the surface brightness limit $\mu = 26\overset{\rm m}{.}5$/arcsec$^2$ in all three bands. The magnitudes were corrected for galactic extinction which in the direction of ShCG 376 (RA = $13^{\rm h}56^{\rm m}36^{\rm s}$, Dec = $23°21'37''$) is $0\overset{\rm m}{.}094$ in *B* (Schlegel et al. 1998). The measured magnitudes in *B* are corrected also for the extinction within galaxies according to $A_B$ = 0.72 $\log(1/\cos i)$). The corrections in *V* and *R* are calculated using the color excesses $E_{B-V} = 0.238A_B$ and $E_{V-R} = 0.590A_V$ respectively. The K correction is neglected because the group is relatively nearby. The estimated accuracy of magnitudes is about $0.06^{\rm m}$. The diameters, the axial ratios, $b/a$, the position angles of major axis, $\alpha$, and the inclinations, $i$, of galaxies are measured from the $\mu = 26\overset{\rm m}{.}5$/arcsec$^2$ contour.

The results of the photometry of the observed galaxies in ShCG 376 are presented in Table 1 in the consecutive columns of which the following information is given: 1 - the galaxy identification number; 2 - the magnitude in $B_{26.5}$; 3 - the axial ratio, $b/a$, in *B*; 4 - the diameter, $D$, of the galaxy out to the surface brightness of $26\overset{\rm m}{.}5$/arcsec$^2$ in *B*; 5–7 - the latter

**Table 1.** Photometric parameters of galaxies in ShCG 376.

| g-xy | B | | | V | | | R | | | | | type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $m$ | $b/a$ | $D$ $''$ | $m$ | $b/a$ | $D$ $''$ | $m$ | $b/a$ | $D$ $''$ | $\alpha$ $^\circ$ | $i$ $^\circ$ | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 1 | 17.00 | 0.7 | 11 | 16.78 | 0.7 | 13 | 16.62 | 0.8 | 19 | 10 | 46 | S |
| 2 | 18.85 | 0.6 | 10 | 17.83 | 0.7 | 9 | 17.45 | 0.8 | 14 | −25 | 41 | S |
| 3 | 18.54 | 0.9 | 8 | 17.56 | 0.9 | 12 | 17.57 | 0.9 | 11 | 12 | 8 | S |
| 4 | 15.20 | 0.9 | 50 | 15.23 | 0.9 | 23 | 15.00 | 1.0 | 37 | 32 | 19 | S/Ir |
| 5 | 18.02 | 0.6 | 11 | 17.03 | 0.6 | 13 | 16.63 | 0.7 | 17 | 25 | 45 | S |
| 6 | 19.47 | 0.5 | 9 | 19.10 | 0.6 | 9 | 19.12 | 0.6 | 9 | −12 | 48 | S |
| 7 | 18.38 | 0.8 | 9 | 17.38 | 0.7 | 12 | 17.00 | 0.8 | 15 | 44 | 38 | S |
| 8 | 17.60 | 0.8 | 11 | 16.84 | 0.8 | 11 | 16.60 | 0.8 | 14 | −63 | 40 | S |
| 9 | 17.63 | 0.8 | 11 | 16.66 | 0.8 | 15 | 16.65 | 0.8 | 18 | −68 | 37 | S |

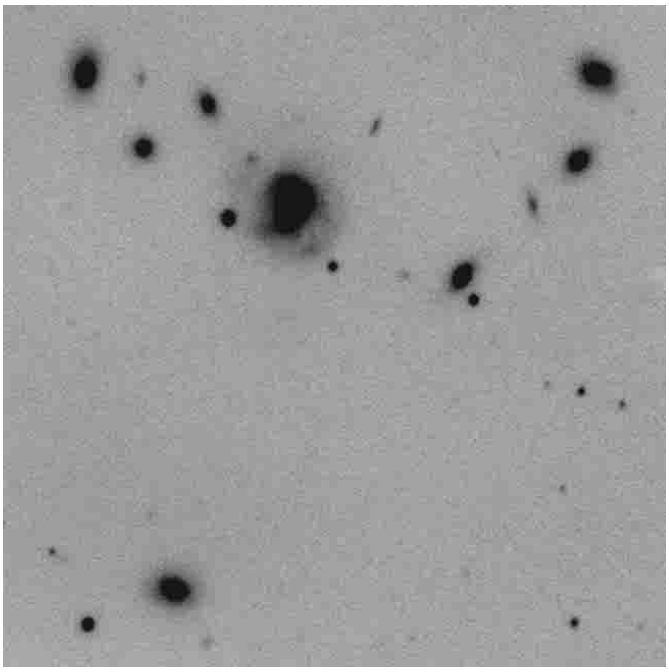

**Fig. 2.** The image of ShCG 376 in $R$ filter.

three parameters in $V$; 8–10 - the same three parameters in $R$; 11 - the position angle of the major axis, $\alpha$, in $R$ at $26\overset{\text{m}}{.}5$/arcsec$^2$; 12 - the inclination, $i$, in $R$; 13 - the galaxy type.

We plotted curves of the isophotal surface brightness, $\mu$, versus effective radius, $r_{\text{eff}}^n$ for galaxies in ShCG 376 in colours $B$ and $R$. De Vaucouleurs showed that ellipticals are represented by a straight line on the graph $\mu$ versus $r_{\text{eff}}^{1/4}$, while spirals are represented by a straight line on the graph $\mu$ versus $1/r_{\text{eff}}$ (Schombert 1987). Since ellipticals consist mainly of population II stars, we plotted the isophotal luminosity profiles $\mu - r_{\text{eff}}^{1/4}$ in $R$ (Fig. 3). The spirals are dominated by blue population. Therefore, the isophotal surface brightness curves $\mu - 1/r_{\text{eff}}$ were drawn in $B$ (Fig. 4). The twisting profiles, position angle $\alpha$ versus $r_{\text{eff}}^{1/4}$ are presented in Fig. 5.

## 2.2. Spectroscopy

Spectral observations of ShCG 376 were carried out with the 2.1 m telescope of the Guillermo Haro Observatory in Cananea operated by the Instituto Nacional de Astrofísica Óptica y Electrónica, México. The LFOSC spectrophotometer (Zickgraf et al. 1997) is fitted with a $600 \times 400$ pixel CCD with 1 arcsec/pxl. The read-out noise of the detector is 8 $e^-$. A set-up covering the spectral range of 4000–7100 Å with a dispersion of 5.3 Å/pixel was adopted. The slit width was $2''$ and the effective instrumental spectral resolution was about 11 Å. Nine galaxies of the group were observed in May 1998. The galaxy 4 and concentration 4a (Fig. 1) were re-observed in March 1999. In the last run we obtained spectra also for objects A, B, and C, images of which are somewhat elongated on the POSS prints, and therefore could be faint galaxies. In addition to the emission lines, discussed below, absorption features of H$\beta$, MgIb and NaD were generally seen in the spectra. For determination of redshifts the MIDAS package (*standard reduction – long* and *standard reduction – spec*) with programs therein was used. The radial velocities (RV) of galaxies are measured with an accuracy of about 40–60 km s$^{-1}$. The RVs of the observed galaxies are presented in Table 2. They are corrected for solar motion ($\Delta v = 300 \ \sin l^{\text{II}} \cdot \cos b^{\text{II}}$ km s$^{-1}$). Objects A, B and C turned out to be stars.

**Table 2.** Radial velocities and equivalent widths of emission lines in the spectra of galaxies in ShCG 376.

| gal. | $v$ km s$^{-1}$ | $EW$ | gal. | $v$ km s$^{-1}$ | $EW$ |
|---|---|---|---|---|---|
| 1 | 19 680 | 10 | 5 | 19 890 | - |
| 2 | 18 430 | - | 6 | 17 160 | 26 |
| 3 | 20 160 | 5? | 7 | 20 070 | - |
| 4 | 20 220 | 100 | 8 | 19 860 | 19 |
| 4a | 20 220 | | 9 | 20 130 | 10 |

The spectra of the observed galaxies are presented in Fig. 6. Three galaxies (No. 1, 4 and 6) show emission line features of H$_\alpha$. In galaxy 8 the blend of H$_\alpha$ with [SII](6717/31) is registered. In galaxy 9 the blend with [NII] is measured. The presence of the emission line H$_\alpha$ is suspected also in the spectrum

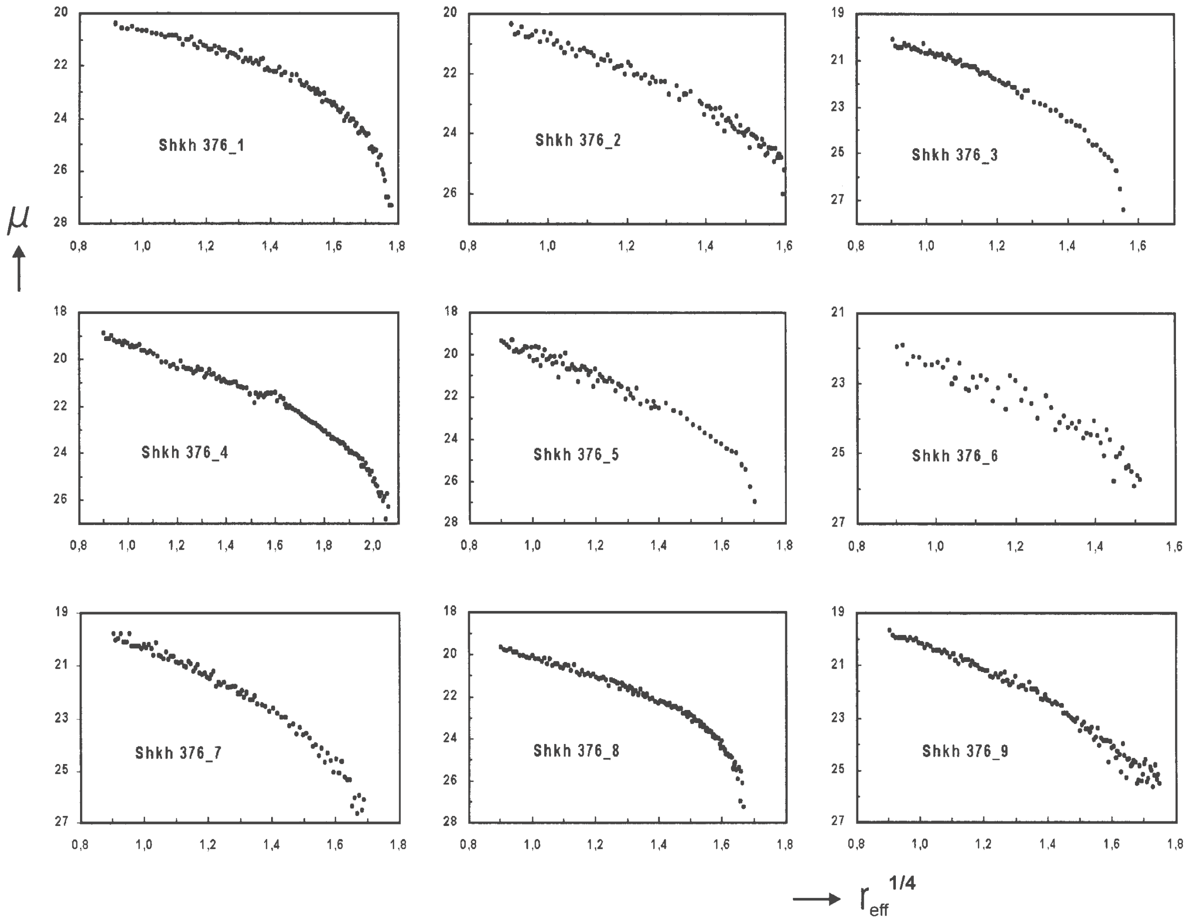


**Fig. 3.** Isophotal surface brightness, $\mu$, in $R$ of galaxies in ShCG 376 versus $r_{\rm eff}^{1/4}$.

of galaxy 3. The equivalent widths of emission lines $H_\alpha$ or the blends are given in Table 1. Emission lines are absent in the spectra of three galaxies: 2, 5 and 7.

## 3. Discussion

It is assumed that a galaxy is a member of a compact group if its RV does not differ from the mean RV of the group by more than $\Delta v \approx 1000$ km s$^{-1}$ (Hickson et al. 1992). The RVs of galaxies 2 and 6 differ from the mean RV of other seven galaxies by ≈1550 and ≈2800 km s$^{-1}$ respectively. Therefore, these galaxies generally should be treated as foreground galaxies projected by chance over the group. However, in spite of rather high difference in RV, we suggest that the galaxy 2 is a member of the group ShCG 376. Consideration of Fig. 1 shows that outer isophotes of the central brightest galaxy 4 are extended towards galaxy 2. This extension is hardly a result of photographic summation of images of halos of both galaxies, since the basement of the extension in galaxy 4 is very wide. Such a form of the extension may obviously be due to a tidal interaction between both galaxies.

Tovmassian & Tiersch (2001) showed that ShCGs are generally embedded in loose groups, members of which are distributed along the elongation determined by the proper members of corresponding groups. Therefore, a member of a group may have a RV exceeding the limit assumed for compact groups with smaller masses. Thus, galaxy 2 may be considered as a member of ShCG 376. The mean RV of eight galaxies (including galaxy 2) is 19 800 ± 585 km s$^{-1}$. Then, the RV of galaxy 2 differs from the mean RV of the group by 1380 km s$^{-1}$.

Morphological types of galaxies in ShCG 376 are determined by inspection of the isophotal surface profiles (Figs. 3 and 4), as well as by inspection of the prime images of galaxies (Figs. 1 and 2). None of the profiles in Fig. 3 ($\mu$ - $r_{\rm eff}^{1/4}$) is straight, which is typical for ellipticals. Meanwhile all profiles in Fig. 4 ($\mu - 1/r$) are straight up to the faint outskirts of galaxies. This means that all galaxies of the group are *spirals*. Direct images (Figs. 1 and 2) show that galaxy 4 is an irregular or highly distorted spiral. The isophotes of this galaxy show a very complicated structure with a few irregular concentrations and clumps. The spiral arms, if any, are apparently distorted. This galaxy has also FIR (Tovmassian et al. 1998) and radio emission (Tovmassian et al. 1999). Its luminosity at 1.4 GHz is $1.1 \times 10^{43}$ erg s$^{-1}$. The FIR luminosity in the interval 60–100 $\mu$ is $2.6 \times 10^{44}$ erg s$^{-1}$. The position of this galaxy on the log $F_{60}$ − log $F_{1.4}$ graph (Fig. 4 in Tovmassian et al. 1999) shows that it obeys the correlation between the thermal emission from dust and the synchrotron radio emission from relativistic electrons found for star-burst galaxies.

As well as the above mentioned possible interaction of galaxy 4 with galaxy 2, the group demonstrates other signs of interaction between member galaxies. One may notice some

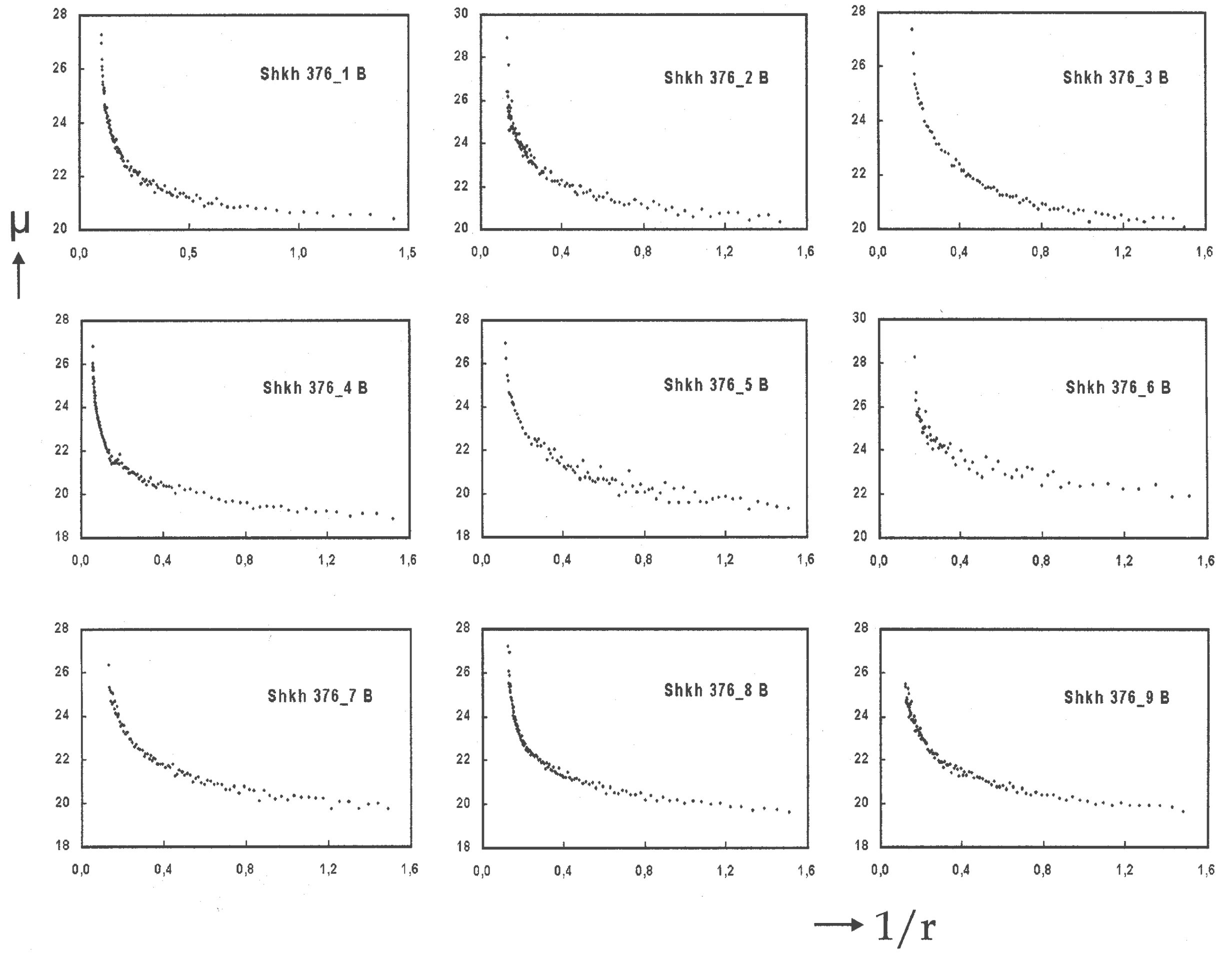


**Fig. 4.** Isophotal surface brightness, $\mu$, in $B$ of galaxies in ShCG 376 versus $1/r_{\rm eff}$.

asymmetry in the distribution of the brightness over galaxy 1: its bulge is somewhat shifted toward the central galaxy 4 (Figs. 1 and 2). Such asymmetry may be a result of interaction with the central galaxy. The twisting profiles (Fig. 5) show that the position angle of twisting in galaxies 1, 4, 7 and 8 varies with $r$. This may be considered as evidence of interaction between galaxies (di Tullio 1979; Kormendy 1982).

The physical parameters of ShCG 376, deduced as in Paper I, are presented in Table 3. They are within the limits of corresponding parameters deduced for other Shakhbazian groups (Paper I; Tiersch et al., in preparation). The masses of galaxies have been estimated using the $V$ magnitudes and adopting a mass-to-luminosity ratio equal to 4 for spirals (Karachentsev 1987). In the consecutive lines of Table 3 the following information is given: line 1 - the redshift, $z$, weighted by masses of member galaxies; line 2 - the distance, $d$, of the group ($H$ = 55 km s$^{-1}$ Mpc$^{-1}$); line 3 - the projected linear diameter of the group, $D$; line 4 - the radial velocity dispersion, $\sigma_{\rm v}$, (weighted by masses of galaxies); line 5 - the virial radius, $R_{\rm vir}$, of the group (weighted by masses of galaxies); line 6 - the virial mass; line 7 - the luminosity of the group, $L$, in solar units; line 8 - the mass-to-luminosity ratio in solar units, $\mathcal{M}_\odot/L_\odot$; and line 9 - the crossing time, $\tau_{\rm c}$.

The situation is intriguing in the case of galaxy 6. Its RV is smaller than the mean RV of eight other galaxies by 2600 km s$^{-1}$. Hence, it apparently should be closer to us than the group itself. However, some arguments allow us to suggest that this discordant redshift galaxy may be physically associated with the group ShCG 376. The point is that galaxy 6 is an emission line galaxy (ELG). The equivalent width of the H$\alpha$+[NII] blend in its spectrum is ≈25 Å. We estimated the probability of a chance projection of such a galaxy over the group ShCG 376 using the results of the survey of ELGs carried out by Alonso et al. (1999) who found that the overall density of ELGs with apparent $B$ magnitudes reaching 20$^{\rm m}$ (which is by about 0$^{\rm m}_{.}$5 fainter than that of galaxy 6) and limiting distance ≈250 Mpc ($H$ = 55 km s$^{-1}$ Mpc$^{-1}$) is 0.59 per deg$^2$. If galaxy 6 is located at the distance of ShCG 376 (360 Mpc),

**Table 3.** Physical parameters of ShCG 376.

| | |
|---|---|
| $z$ | 0.0667 |
| $d$ [Mpc] | 364 |
| $D$ [kpc] | 290 |
| $\sigma_{\rm v}$ [km s$^{-1}$] | 132 |
| $R_{\rm vir}$ [kpc] | 111.2 |
| $\mathcal{M}_{\rm vir}$ [$10^{11}\mathcal{M}_\odot$] | 21.0 |
| $L$ [$10^{11}L_\odot$] | 3.7 |
| $\mathcal{M}/L$ [$\mathcal{M}_\odot/L_\odot$] | 5.7 |
| $\tau_{\rm c}$ [$10^6$ years] | 348 |

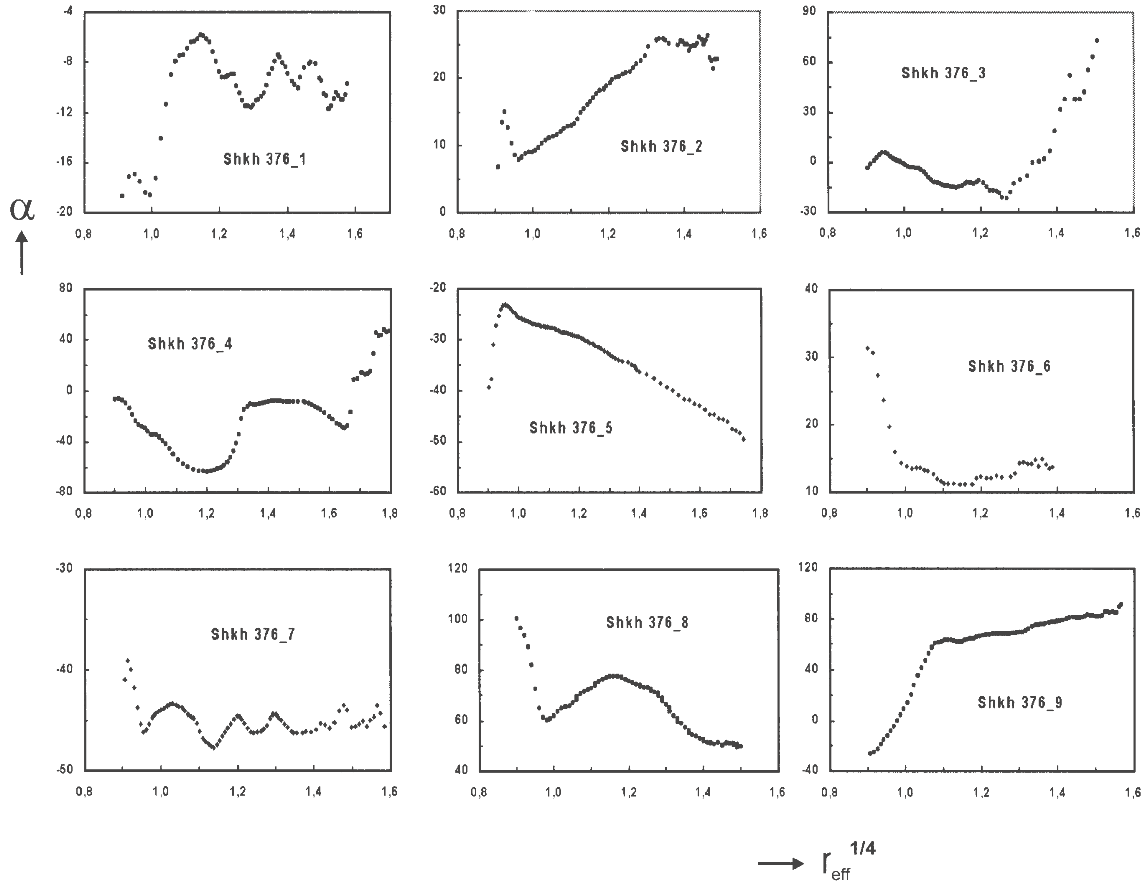


**Fig. 5.** Position angle $\alpha$, versus $r_{\rm eff}^{1/4}$, for galaxies in ShCG 376.

then its absolute magnitude would be $M_B = -18.9$ and would be equal to the mean absolute magnitude of the sample considered by Alonso et al. (1999). Assuming that galaxies (including ELGs) are distributed in space uniformly (at least up to 360 Mpc), we deduce by extrapolation that the surface density of ELGs until the distance of ShCG 376 would be $\approx 2/{\rm deg}^2$. The group ShCG 376 occupies an area of $\approx 2.5$ arcmin$^2$ on the sky (a triangle determined by galaxies 1, 8 and 9, see Fig. 1). The probability that we observe one ELG with $B = 19\overset{m}{.}5$ projected by chance over the area of $\approx 2.5$/arcmin$^2$ is equal to $P = 0.0013$.

On average, only about 20% of member galaxies in ShCGs are spirals (Tiersch et al. 1996a, 1996b; Paper I). Such a small number of spirals in ShCGs is apparently due to the selection criteria, since groups of only *compact* galaxies were sampled (Shakhbazian 1973). Therefore, ELGs among ShCG members are generally very rare. Contrary to the typical ShCGs, the group ShCG 376 consists of *only* spirals, and the relative number of ELGs is high here. Hence, independent of the reasons, the group ShCG 376, because of large number of spirals, is unique among ShCGs. A few HCGs (e.g. HCG 16, 80, 88, 89) also consist of only spirals and irregular galaxies (Hickson 1994). However, each of the latter groups contains only four accordant redshift spirals, while ShCG 376 has the twice number of spirals. If one takes into account that an ELG is "projected" over this unique group (one in about 100), the probability of a chance projection deduced above would be even smaller. Therefore, though the probability is estimated for a single observed case, one may suppose that galaxy 6 is, probably, physically associated with ShCG 376. It may be an infalling intruder to the group.

If galaxy 6 passed recently at a distance of about 10–40 kpc from the gravitational center of the group, and its residual velocity happened to be oriented in the direction close to the line of sight, it could have about the observed value, 2000–3000 km s$^{-1}$. A disturbed forms of the central galaxy 4 may be a result of such passage. Moreover, as it is seen in Fig. 2, the outer envelope of galaxy 5 is directed exactly toward galaxy 6, while the orientation of the bulge is different. This may be considered as a hint that the accordant redshift galaxy 5 is in interaction with discordant redshift galaxy 6. Thus, galaxy 6 may indeed be dynamically associated with ShCG 376. If so, then we see the second intruder in a compact group, the first one being NGC 7318B in Stephan's Quintet (SQ) found by Burbidge & Burbidge (1961) more than forty years ago. Although the suggestion of the infall of galaxy 6 into the group is very speculative, we think that it is worth obtaining deep images of the group ShCG 376 and some other data to see whether there are direct signs of encounter of galaxy 6 with other members of the group, as in the case of SQ (Moles et al. 1997). If the collision of galaxy 6 with ShCG 376 would be proved, then the fact mentioned by Sulentic (1987, 1997) that the number of discordant redshift galaxies in HCGs is too large to be explained by a chance projection, may be due to the galaxies infalling to the corresponding groups with relatively

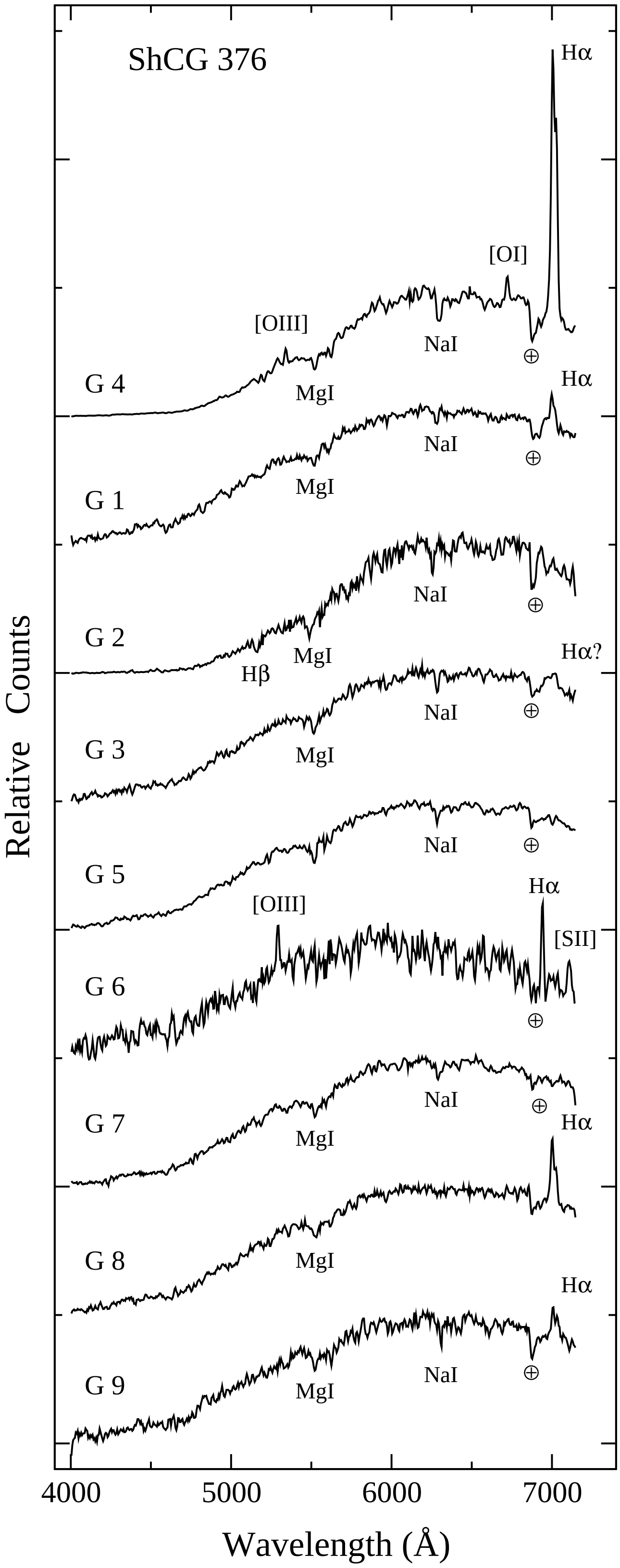


**Fig. 6.** The spectra of galaxies in ShCG 376.

high velocities, and therefore considered as field galaxies, not related dynamically to these groups.

## 4. Conclusions

Spectral and photometric study showed that the group ShCG 376 is very peculiar among about 100 ShCGs. Its all eight accordant redshift members are spirals, four (or possibly five) of which have emission lines in spectra. Such a morphological content is very unusual for ShCGs even taking into account the selection effects. By its physical parameters (the radial velocity dispersion, the virial radius, the virial mass, the mass-to-luminosity ratio, and the crossing time) ShCG 376 does not differ from the other studied ShCGs.

It is shown that a few galaxies in the group are probably interacting with each other. The brightest galaxy of the group, No. 4, is the most disturbed one.

We speculate that the discordant redshift galaxy 6 ($\Delta v$ = 2600 km s$^{-1}$) is probably colliding with the group. The apparently disturbed forms of galaxy 4, its radio and FIR emission may be the result of the passage of galaxy 6 through the group.

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