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The morphological study of spiral/lenticular galaxies in some pairs

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ABSTRACT

This work presents the optical observations for three galaxy pairs. We have presented the isophotal contours and geometrical analysis (*x*-center shift (*xc*), y-center shift (*yc*), ellipticity (*Ellip* $= 1 - b/a$) *and position angle* (*P.A.*)) for each component of the pair. The projected linear separations r_p and the relative velocity Δv of each pair have been determined.

This sample of galaxy pairs has been reported by Karachentsev Catalog without interaction signs. Our analysis shows that the galaxies had signs of interaction (tidal tail and tidal bridge or only tidal tail). The length and thickness of the tidal tails and tidal bridges have obtained and presented in this study.

Our results show that two of the galaxy pairs are close pairs, i.e. contact systems ($r_p < 30\ h_{70}^{-1}$ kpc and $\Delta v < 200$ km/s) with the tidal interaction of tails and bridges. While the other pair is an intermediate pair ($30 < r_p < 55\ h_{70}^{-1}$ kpc and$\Delta v < 5$ km/s) with the tidal tail in the western side.

1. Introduction

Karachentsev's catalog is one of the earlier contributions and one of the biggest catalogs of Isolated Pairs of Galaxies (*KPG*: Karachentsev, 1972). This catalog contains 603 galaxies pairs up to 15.5 magnitude and covering the northern hemisphere. Karachentsev (1987) built a scheme to describe the interaction type between components: the tidal linear structure of tails and bridges (L), the atmosphere around both components (A) and the distortion (D) in the structure of one or both components. This classification is simple to be compared with the description of interaction in the Atlas of Peculiar Galaxies (Arp, 1966) and the Morphological Catalog of Galaxies MCG (Vorontsov-Velyaminov et al., 1962–1974).

To know that the galaxies in pairs are interacting galaxies or non-interacting galaxies, we have investigated each galaxy in pairs using the four different parameters (x-center shift (*xc*), y-center shift (*yc*), ellipticity (*Ellip* $= 1 - b/a$) and position angle (*P.A.*)). Table 1, lists of the basic data for the selected sample of the galaxy pairs in the present study.

We have used the cosmological model with $H_o = 70\,h_{70}\,\mathrm{km\ s^{-1} Mpc^{-1}}$, $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$ for obtaining the numerical values in this work. The paper is organized as follows: The observations and data analysis are presented in Section 2, the results and discussions are described in Section 3. Finally, the conclusions are presented in Section 4.

2. Observations and data analysis

We observed a sample of galaxy pairs using CCD camera EEV 42-40 (2048×2048 pixels) mounted at the Newtonian focus of the 1.88-m telescope, KAO, of National Research Institute of Astronomy and Geophysics (NRIAG), Egypt. The pixel scale and field of view of the imaging system are 0.304″/pixel and 10 square arcminutes respectively. The filter, exposure time, seeing, airmass and the date of observations are presented in Table 2.

We corrected the images for overscan, bias and flat-fielded and then we combined the individual images in each band by using the IRAF package. The cosmic rays events were subtracted using the Pych's algorithm (Pych, 2004).

We used the contour maps and geometrical profiles of surface photometry technique to obtain the x-center shift (*xc*), y-center shift (*yc*), ellipticity (*Ellip* $= 1 - b/a$) and position angle (*P.A.*). We applied the tasks of CONTOURS and ELLIPSE from the IRAF program to obtain the contour maps and geometrical profiles for each galaxy respectively.

The contour maps in the R-band for each component are used to describe the galaxies in pairs. Using geometrical profiles for each galaxy, we investigated the galaxies for interaction signs.

3. Results and discussions

We used both the visual inspection of the images and the contour

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Table 1
Basic data for the galaxies in each pair.

Pair ID	Name	z[a]	Type[b]	PA[b] (deg)	B_T[b] (mag)	d25[b] (arcmin)
KPG422a	*NGC 5544*	0.010140	S0/a	–	13.77 ± 0.57	1.02
KPG422b	*NGC 5545*	0.010270	Sbc	58.7	12.38 ± 0.50	0.98
KPG455a	*NGC 5857*	0.015901	SBab	136.9	13.24 ± 0.04	1.15
KPG455b	*NGC 5859*	0.015891	SBbc	133.7	12.15 ± 0.04	2.57
KPG458a	*PGC 54194*	0.030491	Sbc	5.1	14.33 ± 0.30	0.83
KPG458b	*PGC 54195*	0.030101	Sc	19.1	14.31 ± 0.25	1.07

[a] NED.
[b] HyperLeda.

Table 2
Journal of the observational data of the sample.

Pair ID	Filter	Exposure time (s)	Seeing (arcsec)	Airmass	Date
KPG 422	B	7 × 300	1.41	1.025	2014-06-25
	V	1 × 300	1.20	1.030	
	R	1 × 300	1.30	1.051	
KPG 455	B	8 × 300	1.63	1.031	2014-06-24
	V	6 × 300	1.60	1.043	
	R	2 × 300	1.64	1.038	
KPG 458	B	6 × 300	1.53	1.125	2014-06-25
	V	5 × 300	1.69	1.183	
	R	3 × 300	1.56	1.240	

Table 3
The surface brightness of the outer isophote and the interval between successive isophotes in R-band.

Pair ID	SB (mag/arcsec^2)	Interval (mag/arcsec^2)
KPG422	22.95	0.21
KPG455	23.00	0.18
KPG458	23.05	0.16

Table 4
The projected linear separation and relative velocities of the galaxies in the pair.

Pair ID	r_p (kpc)	Δv (km/s)
KPG 422a	7.2	39
KPG 455a	39.2	3
KPG 458a	26.8	117

maps to investigate the galaxies in the galaxy pair for the presence of interaction signs. The surface brightness of the outer isophote and the interval between two successive isophotes are listed in Table 3.

The linear projected separation between the galaxies has been determined using the formula of Karachentsev (1987) as $r_p = x_{12}\, c\, (z_1 + z_2) / 2H_0$. The x_{12} is the angular separation between galaxies, $c\, z_1$ and $c\, z_2$ is the radial velocity of first and second galaxy in the pair. The difference between the radial velocities of the galaxies in the pair in km/s is obtained from $\Delta v = \sqrt{(c\, z_1 - c\, z_2)^2}$. The results of linear projected separation and relative velocities have presented in Table 4. Patton et al. (2011) found that $r_p < 30\, h_{70}^{-1}$ kpc for the close galaxy pairs, and $30 < r_p < 55\, h_{70}^{-1}$ kpc for the intermediate pairs. Based on this classification the galaxy pairs *KPG 422* and *KPG 458* are close pairs, while *KPG 455* is an intermediate galaxy pair.

The length and the thickness of a tidal tails and a tidal bridge are calculated using the method of Mohamed et al. (2011). The results of the geometric properties of the interaction signs for each pair have been described in Table 5.

3.1. The galaxy pair KPG 422

The component *KPG 422a* (NGC 5544) is classified as S0/a (i.e. a transition stage between lenticulars and spirals), while the component *KPG 422b* (NGC 5545) is normal spiral as Sbc. The images and contours of the system *KPG 422* are shown in Fig. 1. We found that KPG 422 has the tidal bridge of a straight line shape; it has a length of 4.7 kpc and a thickness of 1.8 kpc. We notice that the eastern part of the component *KPG 422b* contains the tidal tail of a curved line shape with a length of 9.40 kpc and thickness of 0.92 kpc (see Fig. 1 and Table 5).

de Vaucouleurs et al. (1976) has described the component *KPG 422b* as a colliding or strongly interacting with the component *KPG 422a* at the angular separation of 0.6 arcmin. These results are in agreement with our results of the tidal tail and the tidal bridge. Also, we have calculated the angular separation between the two components equals 0.57 arcmin, in agreement with de Vaucouleurs et al. (1976). Curtis (1918) found that component *KPG 422*b did not appear to be physically connected with another component *KPG 422*a, but our results show that component *KPG 422a* and *KPG 422b* are a connected system with interaction signs (one tidal tail and tidal bridge). HI observations of van Driel et al. (2001) show that the galaxy pair *KPG 422* is a very close interacting pair, and these are in agreement with the our investigation.

3.1.1. The x-center and y-center shifts profiles of the KPG 422

The *x*-center and *y*-center shifts profiles of the component *KPG 422a* in BVR bands have been illustrated in Fig. 2(a). The *x*-center of the outer isophotes starts to shift from a = 8″ to a = 15″ towards KPG 422b by $\Delta x_c = 1.08$ kpc in B-band and $\Delta x_c = 1.25$ kpc in VR-bands, while *y*-center decreases rapidly towards KPG 422b by 0.26, 0.35 and 0.30 kpc in B, V and R band respectively. This means that the component *KPG 422a* has moved towards the component *KPG 422b* (i.e. towards the tidal bridge). The *x*-center and *y*-center shifts profiles of component *KPG 422b* in BVR bands have been illustrated in Fig. 2(b). The *x*-center

Table 5
The geometric properties of the interaction signs for each pair.

Pair ID	Tidal tail			Tidal bridge		
	Length (kpc)	Thickness (kpc)	Interaction type	Length (kpc)	Thickness (kpc)	Interaction type
KPG 422b	9.40	0.92	CL[a] (E[c])	4.7	1.8	SL[b]
KPG 455b	31.9	1.4	CL[a] (W[d])	–	–	–
KPG 458b	31.7	3.7	CL[a] (W[d])	55.4	2.3	CL[a]

[a] Curved line.
[b] Straight line.
[c] East.
[d] West.

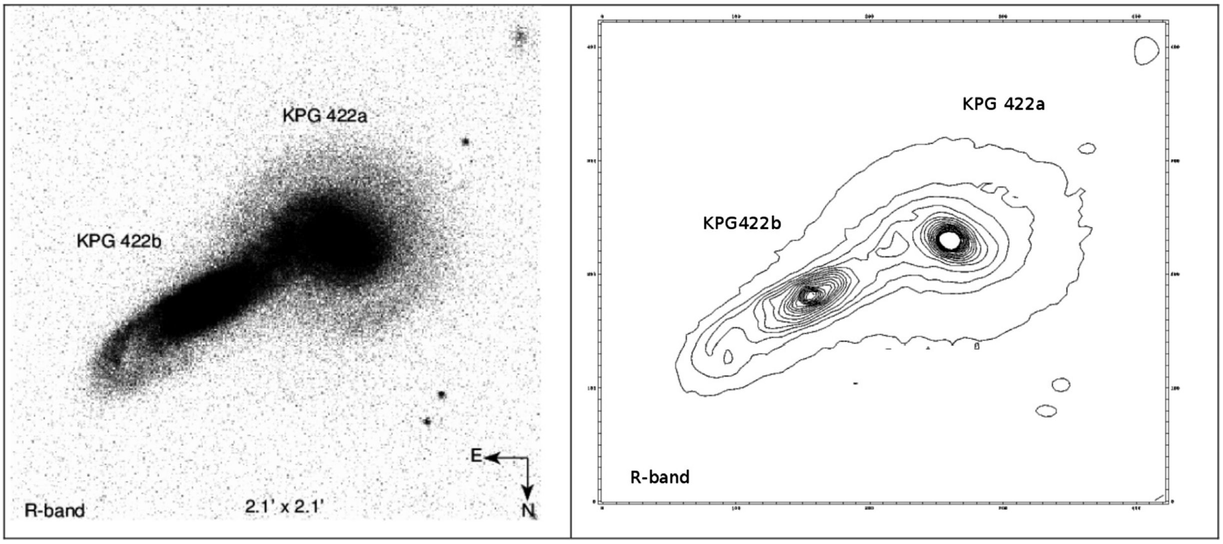

Fig. 1. The R images (Left) and the contour maps (Right) of the system *KPG 422*.

and *y*-center shifts of outer isophotes of component *KPG 422b* in BVR bands start to increase steeply from a = 8″ to a = 12″, i.e. toward the component *KPG 422a*. The amount of shift of x-center is 0.85, 1.05 and 0.59 kpc in B, V and R respectively, while in y-center is 0.53, 0.55 and 0.24 kpc in B, V and R respectively. This means that the *KPG 422* is an interacting system, the component *KPG 422a* attracted the component *KPG 422b* toward it and the component *KPG 422b* attracted the component *KPG 422a* toward it.

3.1.2. The ellipticity profiles of the KPG 422

The ellipticity profiles of the component *KPG 422a* is presented in Fig. 2(a). The ellipticity in the outer parts is nearly stable in B-band, while in V and R band increases by 0.15 and 0.11 respectively. For the component *KPG 422b* (Fig. 2b), the ellipticity fluctuates within a = 0″–5″, while in outer parts the ellipticity increases rapidly by 0.27, 0.24 and 0.17 in B, V and R respectively. This means that both components are more flat, due to interaction signs between them.

3.1.3. The position angle profiles of the KPG 422

The position angle of the component *KPG 422a* in BVR bands increases from 120° to 140° in the inner parts within a = 0″–5″ then decreases from 140° to 100° within a = 5″–8″. The outer parts in position angle of component *KPG 422a* at a > 8″ position angle are twisted towards the north by 87°, 77° and 20° in B, V and R respectively, which may be attributed to the close collision with the component *KPG 422b* (Fig. 2a). In the position angle profiles of the component *KPG 422b* (Fig. 2b) at a > 8″, position angle is twisted to the east due to the attraction of the component *KPG 422a* for the component *KPG 422b* toward it.

3.2. The galaxy pair KPG 455

The system *KPG 455* consists of two barred spiral galaxies with the component *KPG 455*a (NGC 5857) classified as SBab, and the component *KPG 455b* (NGC 5859) classified as SBbc. The images and contours of the system *KPG 455* are shown in Fig. 3. We found that the KPG 455b has the tidal tail of curved line shape in the west with length equals to 31.9 kpc and thickness equals to 1.4 kpc (see in Fig. 3 and Table 5).

de Vaucouleurs and de Vaucouleurs (1964) has described the system *KPG 455* as an interacting pair with separation equals 2.0 arcmin. These results are in agreement with our results of the tidal tail of KPG 455b, due to the interaction between the galaxies. We have found the angular separation between the two components equals 1.98 arcmin, in agreement with de Vaucouleurs and de Vaucouleurs (1964).

3.2.1. The x and y isophotal center-shift of the KPG 455

The *x*-center and *y*-center shifts profiles of the component *KPG 455a* in the BVR bands were illustrated in Fig. 4(a). The *x*-center in V and R band of the outer isophotes of component *KPG 455a* starts to decrease gradually at a > 20″ toward KPG 455b by 0.67 and 1.01 kpc, while the *y*-center profiles of the outer isophotes of the component *KPG 455a* start to increase gradually toward KPG 455b by 0.70 kpc and 0.87 kpc in V and R respectively. This means that the component *KPG 455a* has been moved toward the component *KPG 455b*.

The *x*-center and *y*-center shifts profiles of the component *KPG 455b* in the BVR bands have been illustrated in Fig. 4(b). The x and y centers of outer isophotes of the component *KPG 455b* in VR bands at a > 40″, is steeply shifting toward KPG 455a. The shifted values in V and R band of x-center is 3.01 and 2.00 kpc respectively, while y-center is shifted by 1.70 and 1.67 kpc in V and R respectively, i.e. component KPG *455b* moves toward component *KPG 455a*.

This means that the KPG 455 is an interacting galaxy pair, the component KPG 455a attracted the component KPG 455b towards it and the component KPG 455b attracted the component KPG 455a towards it.

3.2.2. The ellipticity profile of the KPG 455

The ellipticity profiles of component *KPG* 455a and component *KPG 455b* are presented in Fig. 4(a) and (b) respectively. The ellipticity in the BVR bands fluctuates in the inner parts for both components, while in the outer parts the ellipticity is nearly stable for both components.

3.2.3. The position angle profiles of the KPG 455

The position angle profiles in the BVR bands of the component *KPG 455a* have been given in Fig. 4(a). The position angle of outer isophotes of the component *KPG 455a* shows a slow increase by 3° and 1° in V and R band respectively. This means that the outer isophotes are twisted toward the south due to the attraction of the component *KPG 455b* for the component *KPG 455*a towards it.

The position angle profiles of the component *KPG 455b* in the BVR bands have been given in Fig. 4(b). The position angle of the outer isophotes of the component *KPG 455b* is rapidly decreasing by 8° in both VR bands. This means that the position angle is twisted to the east due to the attraction of the component *KPG 455a* for the component *KPG 455b* towards it.

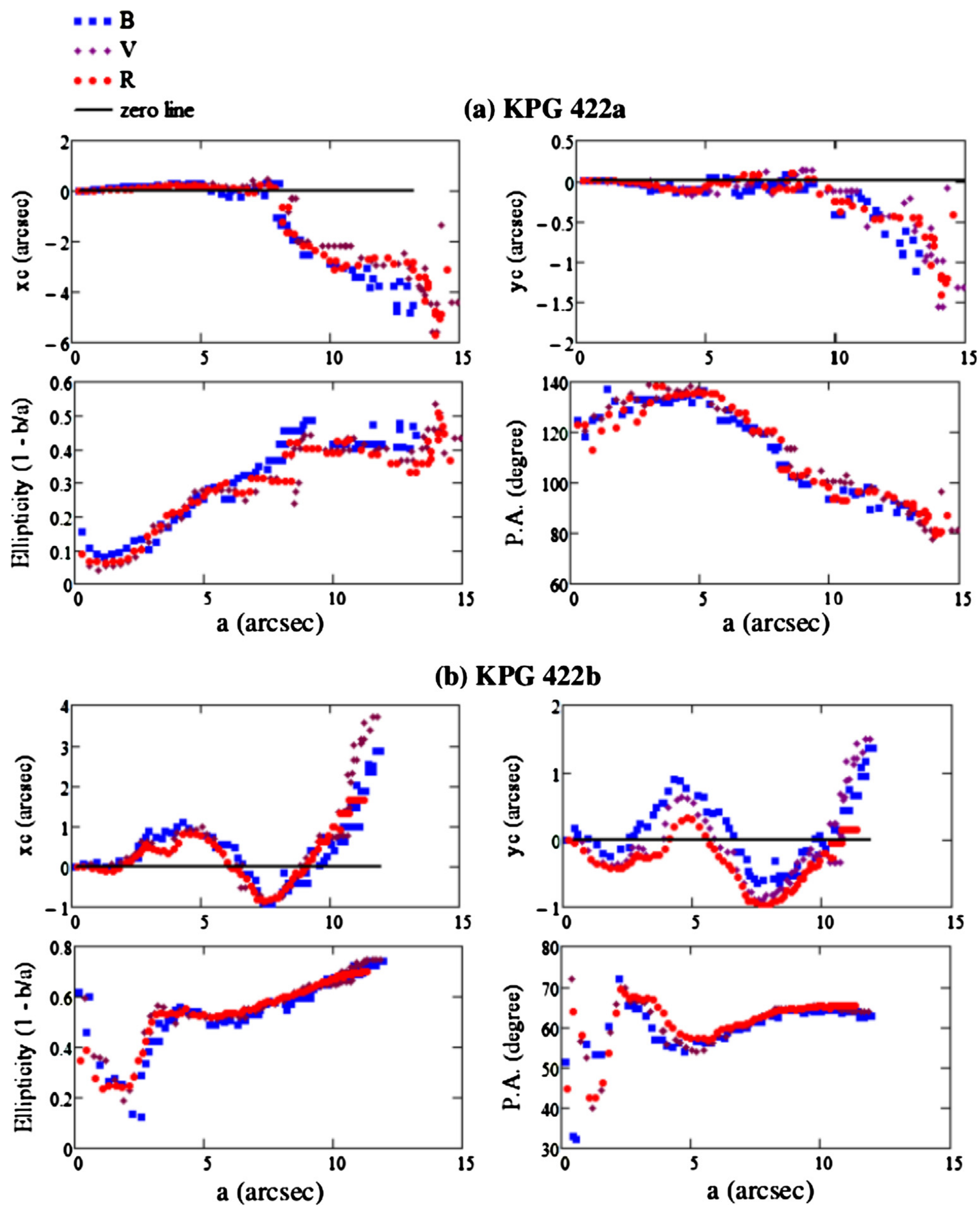

Fig. 2. The first panel (a): *xc*, *yc*, ellipticity and position angle (*P.A.*) profile of *KPG 422a*. The second panel (b): the same as panel (a), but for *KPG 422b*.

3.3. The galaxy pair KPG 458

The component *KPG 458a* (PGC 54194) is classified as normal spiral (Sbc) and the component *KPG 458b* (PGC 54195) is classified as normal spiral (Sc). The images and contours of the system *KPG 458* are shown in Fig. 5. We found that this pair contains the curved line of the tidal bridge with length equals to 55.4 kpc and thickness equals to 2.3 kpc (Fig. 5 and Table 5). The component *KPG 458*b contains the curved line of the tidal tail in the west with length equals to 31.7 kpc and thickness equals to 3.7 kpc (Fig. 5 and Table 5). Using 2MASS data, Geller et al. (2006) selected 800 galaxies (i.e. *KPG 458a* is one of them) in close pairs with small projected separation as $r_p < 50\,h^{-1}$kpcand $\Delta v < 1000$ km/s. These results are in agreement with ours and with that of Patton et al. (2011), i.e. close pairs are found at $r_p < 30\,h^{-1}$kpc and$\Delta v < 1200$ km/s. We have measured the angular separation between the two component equals 0.71 arcmin.

3.3.1. The x and y isophotal center-shift of the KPG 458

The x-center and y-center profiles of the component KPG 458a in the BVR bands illustrated in Fig. 6(a). We noticed that the BV bands of the x-center and y-center of outer isophotes at a > 8″ of the component *KPG 458a* have some scatter, while in R-band the x-center increases gradually by 0.24 kpc towards the tidal tail of KPG 458b. On the other hand, the y-center of outer isophotes of the component *KPG 458a* is shifted towards the tidal bridge of the component *KPG 458b* by 1.59, 1.53 and 2.04 kpc in B, V, and R respectively.

The x-center and y-center profiles of the component *KPG 458b* in BVR bands have been illustrated in Fig. 6(b). The x-center of outer isophotes at a > 17″ of the component *KPG 458b* in increases rapidly by $\Delta x_c = 2.07$ kpc and $\Delta x_c = 1.51$ kpc in V and R band respectively, while y-center of the outer isophotes decreases rapidly towards the component *KPG 458a*. This means that the *KPG 458* is an interacting galaxy pair, the component *KPG 458a* attracted the component *KPG*

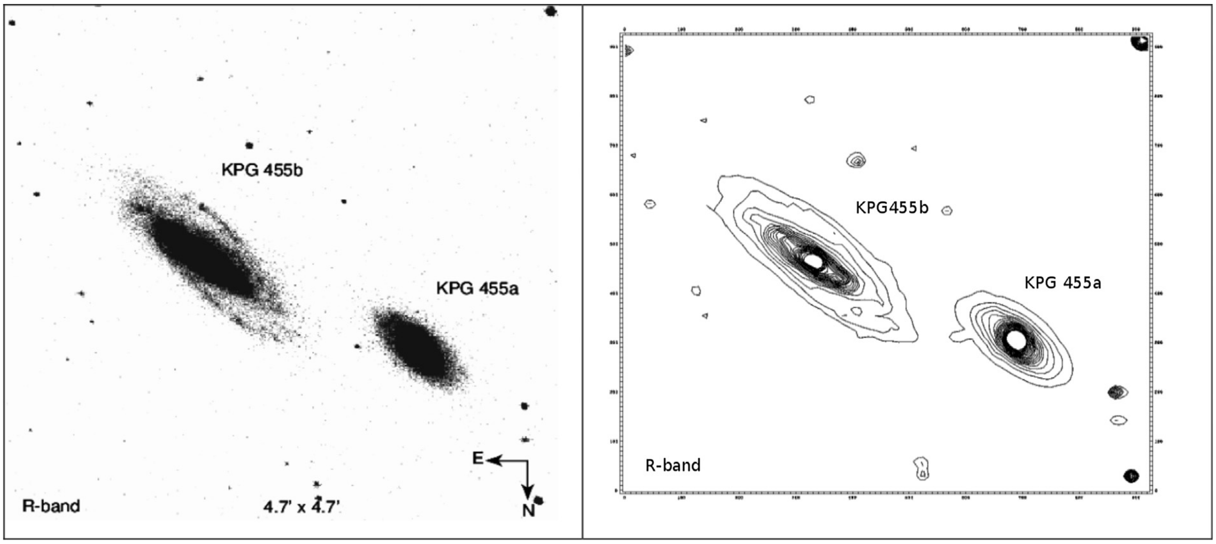

Fig. 3. The same as Fig. 1 but for *KPG 455*.

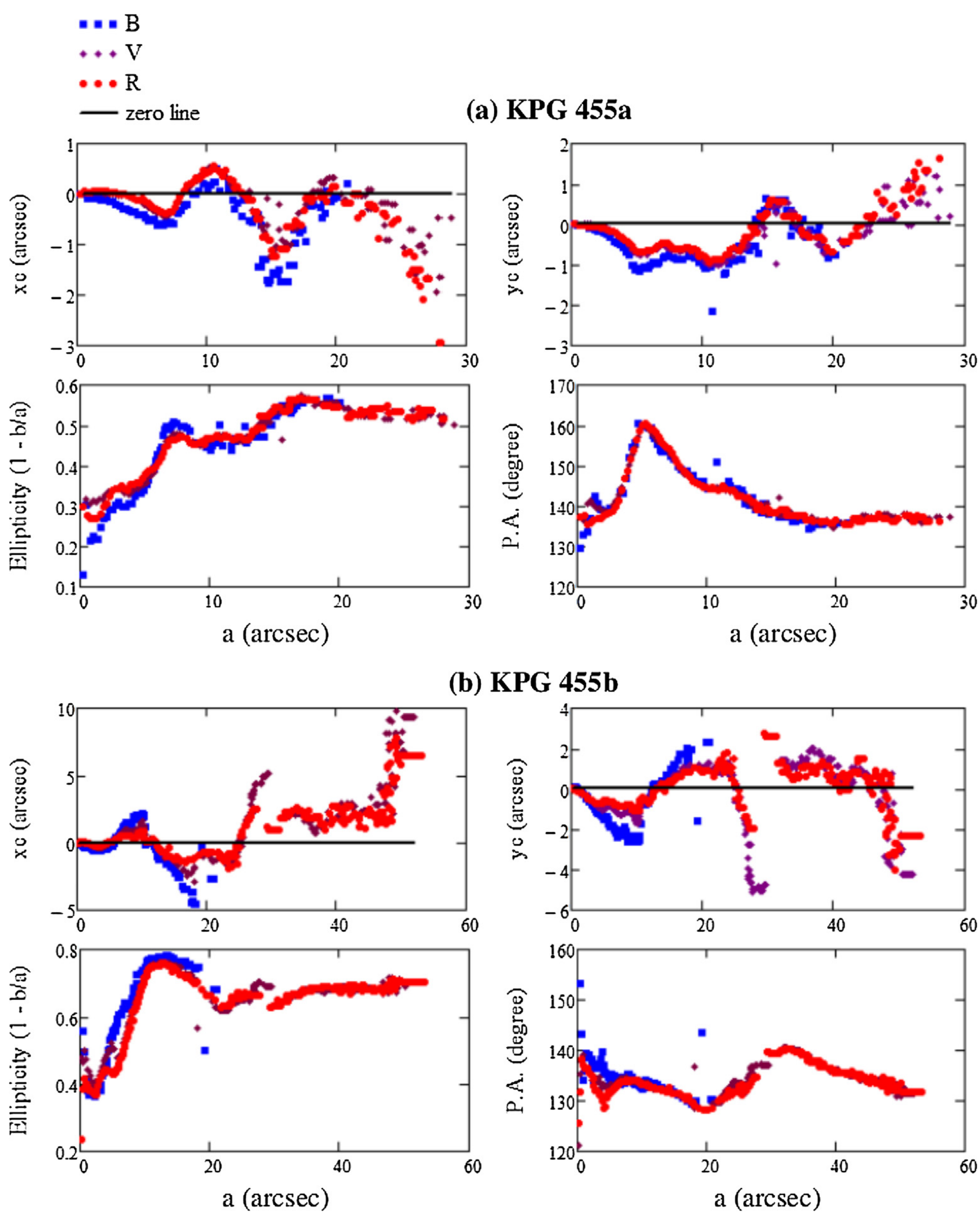

Fig. 4. The same as Fig. 2 but for *KPG 455*.

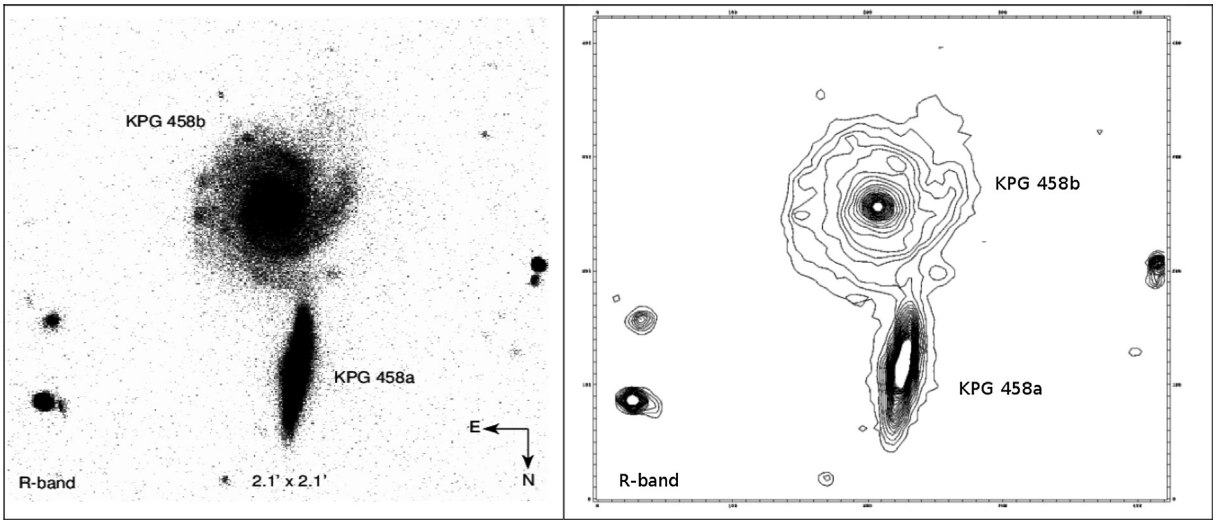

Fig. 5. The same as Fig. 1 but for *KPG 458*.

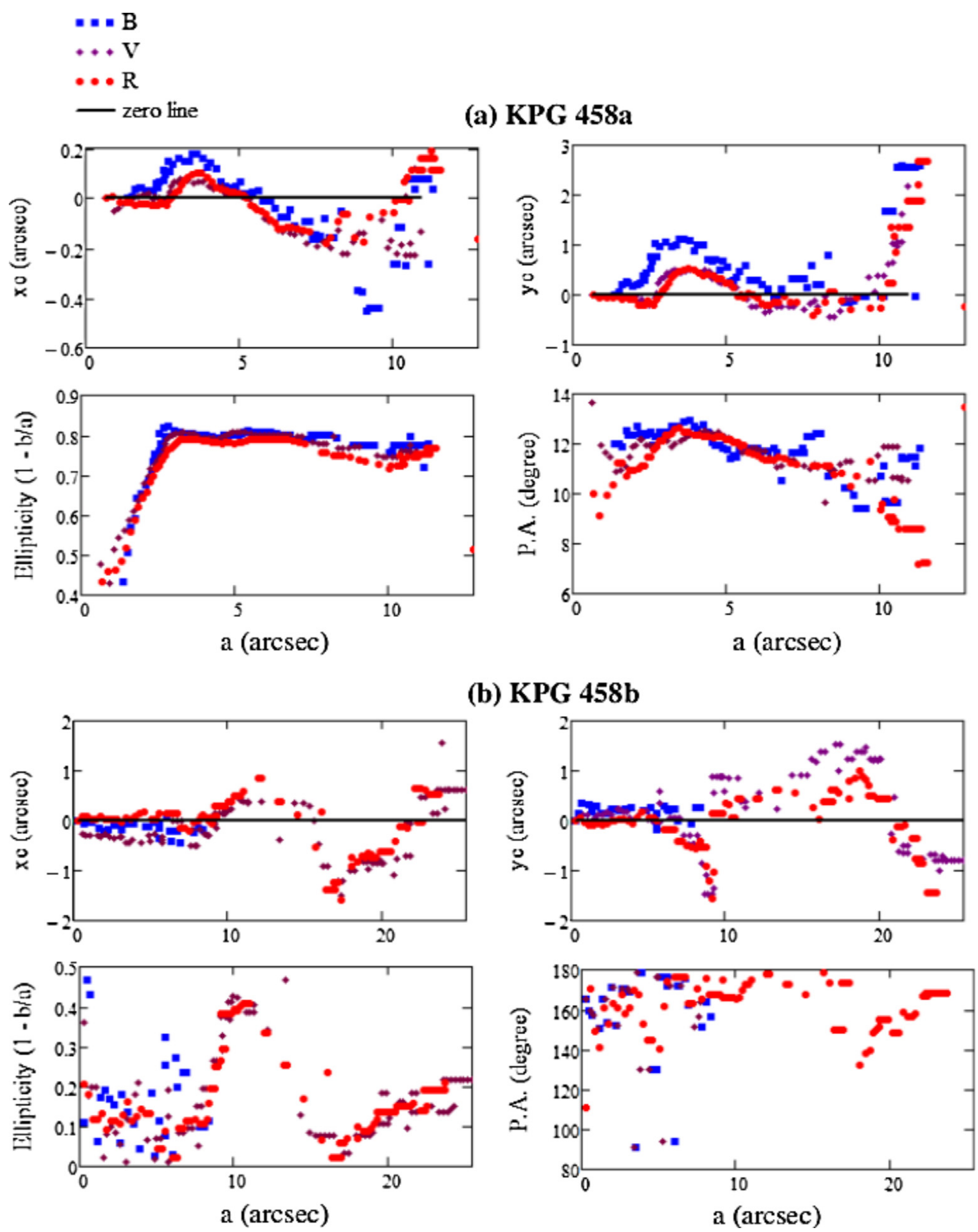

Fig. 6. The same as Fig. 2 but for KPG 458.

Table 6
The amount of shift in outer isophotes of *xc*, *yc*, *E* and twist in the position angle.

Pair ID	Filter	Δx_c		Δy_c		ΔE	Twist (deg)
		(arcsec)	(kpc)	(arcsec)	(kpc)		
KPG 422a	B	5.00	1.08	1.20	0.26	–	87
	V	5.80	1.25	1.60	0.35	0.15	77
	R	5.90	1.25	1.40	0.30	0.11	20
KPG 422b	B	3.90	0.85	2.40	0.53	0.27	3
	V	4.80	1.05	2.50	0.55	0.24	4
	R	2.70	0.59	1.10	0.24	0.17	6
KPG 455a	B	–	–	–	–	–	–
	V	2.00	0.67	2.10	0.70	–	3
	R	3.00	1.01	2.60	0.87	–	1
KPG 455b	B	–	–	–	–	–	–
	V	9.00	3.01	5.1	1.70	–	8
	R	6.00	2.00	5.0	1.67	–	8
KPG 458a	B	–	–	2.50	1.59	–	–
	V	–	–	2.40	1.53	–	–
	R	0.38	0.24	3.20	2.04	–	4
KPG 458b	B	–	–	–	–	–	–
	V	3.30	2.07	2.50	1.57	0.19	–
	R	2.40	1.51	2.50	1.57	0.19	40

458b towards it and the component *KPG 458b* attracted the component *KPG 458a* towards it.

3.3.2. The ellipticity profile of the KPG 458

The ellipticity profiles of the component *KPG 458a* are presented in Fig. 6(a). The ellipticity in BVR bands fluctuates in the inner parts. On the other hand, the ellipticity of outer parts in B band is nearly stable, while in VR-bands the ellipticity starts to decrease from a = 7″ then increase from a = 10″ outward. This means that the component *KPG 458a* becomes less flat and then more flat, due to the interaction between galaxies. The ellipticity profiles of the component *KPG 458b* is presented in Fig. 6(b). The ellipticity in BVR bands fluctuates in the inner parts within a = 0″–17″, while the ellipticity of the outer parts in VR bands increases from a > 17″ by $\Delta E = 0.19$ outward. This means that the component *KPG 458b* is more flat, due to the tidal interaction between galaxies (i.e. due to tidal tail and tidal bridge).

3.3.3. The position angle profiles of the KPG 458

The position angle profiles in the BVR bands of the component *KPG 458a* have been given in Fig. 6(a). The outer isophotes in BV bands of the component *KPG 458a* are nearly flat with some scatter. But in R-band, the outer isophotes are twisted to the north by 4°, i.e. away from component *KPG 458b* due to the attraction of the component KPG 458b for component KPG 458a from the southern side of KPG 458a through the tidal bridge between galaxies. The position angle profiles in the BVR bands of the component KPG 458b have been given in Fig. 6(b). The outer isophotes in R band of the component KPG 458b are twisted to the south by 40°, i.e. away from component *KPG 458a*. This is due to the attraction of the component KPG 458a for component KPG 458b from the northern side of KPG 458b.

4. Conclusions

We have presented the morphological analysis of some galaxy pairs in Karachentsev catalog in three optical bands (BVR) using the 74″ Kottamia telescope in Egypt.

The contour maps in R-band show that KPG 422 and KPG 458 contain the tidal bridge and tidal tail, while the KPG 455 contains one tidal tail. The results of geometrical tidal structures (i.e., tidal tails and tidal bridges) have been shown in Table 5. The KPG 458 contains the largest tidal bridges (55.4 kpc) and thickness tidal bridges (2.3 kpc). The component KPG 455b contains the largest tidal tail (31.9 kpc).

Our analysis indicates that, KPG 422 and KPG 458 are close pairs, while KPG 455 is an intermediate pair. The projected separation (r_p) and relative velocity (Δv) are 7.2 h_{70}^{-1} kpc, 39 km/s for KPG 422, 26.8 h_{70}^{-1} kpc, 117 km/s for KPG 458, 39.2 h_{70}^{-1} kpc, 3 km/s for KPG 455.

The shifted values of the four parameters (x-center shift (xc), y-center shift (yc), ellipticity (Ellip = 1 − b/a) and position angle (P.A.)) are presented in Table 6.

The effect of the gravitational interaction between the components has been investigated. The four geometrical parameters confirm that the three galaxy pairs are interacting systems. This interaction is due to that each component attracts another one towards it. The two systems (KPG 422, KPG 458) may be in a state of merging interaction, while KPG 455 is in a process of interaction. For KPG 422, our results are in a good agreement with the results of de Vaucouleurs et al. (1976) and of van Driel et al. (2001). For KPG 455 our results agree with de Vaucouleurs and de Vaucouleurs (1964). For KPG 458, no signs of interaction, however (Geller et al. 2006) selected it to be closed pair with $r_p < 50\,h^{-1}$ kpc and $\Delta v < 1000$ km/s.

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