



Investigation of the gravitational interaction between the components of the galaxy pairs Arp 242, CPG 165, and CPG 410



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Abstract In this paper the effect of interaction between the components of the galaxy pairs Arp 242, CPG 165, and CPG 410 on the symmetry of their morphologies and structures is studied by applying the technique of surface photometry. For each component of each pair we present the isophotal contours, profiles of surface brightness (SB), major-axis position angle (PA), and isophotal center-shift. The present analysis is done using the r- and i-band images from the Sloan Digital Sky Survey (SDSS) observation.

It is found that the position angle and the isophotal center shift are strongly affected by the state of interaction between the components of the pairs.

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1. Introduction

Interactions between galaxies are thought to be a common phenomenon (Donzelli and Pastoriza, 1997). Since many galaxies are relatively found close together in groups and clusters, the percentage of collision between galaxies is very high. Even if galaxies did not actually collide, they can affect each

other by the mutual gravitational force which can cause both components to slightly change in shape.

Binary galaxies constitute about 10% of the noncluster population (Xu and Sulentic, 1991), and disturbed morphologies are a common property of a large fraction of such pairs (e.g., Arp, 1966; Karachentsev, 1972). Many catalogs e.g. “The Catalog of Pairs of Galaxies” (CPG, Karachentsev, 1972) and “The Atlas of Peculiar Galaxies” (Arp, 1966) are an ideal sample for binary galaxy studies (see, e.g., Sulentic, 1989). De Propriis et al. (2007) found that galaxies in close pairs are generally more asymmetric than isolated galaxies and the degree of asymmetry increases for closer pairs.

In this paper, the photometric analysis of the three galaxy pairs (GP) Arp 242, CPG 165, and CPG 410 was presented to study the effect of interaction between the components of

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Table 1 The SDSS retrieved FITS files of the components of the three GP Arp 242, CPG 165, and CPG 410.

Galaxy pair	Galaxy ID	SDSS name	Observation date	FITS file name
Arp 242	ARP 242a	SDSS J124610.10 + 304354.8	23-05-2004	fpC-004649-r6-0063.fit
	ARP 242b	SDSS J124611.24 + 304321.8		fpC-004649-i6-0063.fit
CPG 165	KPG 165a	SDSS J083431.70 + 013957.9	30-11-2000	fpC-001907-r4-0040.fit
	KPG 165b	SDSS J083433.78 + 014015.7		fpC-001907-i4-0040.fit
CPG 410	KPG 410a	SDSS J140323.14 + 092653.1	28-04-2003	fpC-003909-r5-0103.fit
	KPG 410b	SDSS J140327.10 + 092802.2		fpC-003909-i5-0103.fit

the pair on the symmetry of their morphology and structure. Section 2 explored the observation and the basic parameters of the three mentioned pairs. In Section 3, we discussed the technique applied in the present work. Sections 4–6 are a brief discussion on the parameters obtained from surface photometry analysis with respect to the three GP Arp 242, CPG 165, and CPG 410 respectively. Finally, in Section 7, the conclusions are outlined. Throughout the paper we used $H_0 = 100 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

2. The observation and data of the three GP Arp 242, CPG 165, and CPG 410

The data for this study are based on the SDSS Data Release 7 (Abazajian et al., 2009). The SDSS has imaged the sky in the u, g, r, i, and z photometric bands (Fukugita et al., 1995; Smith et al., 2002). The reduced images of the three mentioned pairs in r- and i-bands were retrieved from the SDSS archive (see Table 1).

Basic reductions, including the bias and dark corrections, and flat fielding, had already been carried out at the SDSS archive. A necessary reduction step that had not yet been carried out on the frames was the sky subtraction. The sky background, expressed in ADU/pix², for each band is extracted from the image header. There is also 1000 ADU added to each pixel as a soft-bias value which must be subtracted from each pixel. After subtracting the sky background value and the soft-bias, it is necessary to convert SDSS raw count rate (counts/exposure time) to actual magnitudes via the equation:

$$\text{mag} = -2.5 \log [(\text{counts/exptime}) \times 10^{0.4(aa+kk*\text{airmass})}], \quad (1)$$

where aa represents the photometric zero point, and kk is the extinction coefficient. The values of these parameters are obtained from the “tsField” files accompanying each field and are presented in Table 2 for each band for each galaxy. A more detailed description of this process is laid out in Lupton et al., 2001; Lupton et al., 2003.

For a more simple way we can calculate the magnitude by getting the “Flux20” of each GP from its image header instead of using the zeropoint, and airmass corrections. Hence, the f-factor in this case will given by the following:

$$f/f_0 = \text{counts}/(10^8 * \text{flux20}), \quad (2)$$

Then the magnitude will be calculated as follows:

$$m = -2.5 \log \left(\frac{f}{f_0} \right), \quad (3)$$

In the present GPs we use the first method to get the magnitude of CPG 165 only because its image header doesn't

Table 2 The calibration constant of the r- and i-bands in the SDSS photometric system for the CPG 165.

Galaxy pair	aa	kk	airmass
CPG 165 (r-band)	−24.0838	0.07954	1.2331
CPG 165 (i-band)	−23.7496	0.03687	1.231

Table 3 The calibration of flux20 of ARP 242 and CPG 410 in the r- and i-bands.

Galaxy pair	Flux20 in r-band	Flux20 in i-band
ARP 242	$1.81 * 10^3$	$1.35 * 10^3$
CPG 410	$1.95 * 10^3$	$1.42 * 10^3$

contain the value of flux20. For ARP 242 and CPG 410 we use the second simple method to get their magnitudes. Values of aa , kk , airmass of CPG 165, and flux20 of ARP 242, and CPG 410 are given in Tables 2 and 3 respectively.

3. Surface photometry and analysis

Surface photometry is an important and powerful tool to study the photometric properties of galaxies. In this technique, the isophotes of the galaxy are fitted to ellipses to derive the radial profiles e.g. surface brightness, ellipticity, position angle, and the x and y centers. These profiles provide basic information such as twisting, ellipticity, off-centering, and shape of the isophotes.

The technique of surface photometry is applied to the images of each component of the GPs Arp 242, CPG 165, and CPG 410 using the task *ellipse* from IRAF¹.

Using surface photometry we get, for each component of each GP, the contour maps, the surface brightness profile, the position angle profile, and the x and y isophotal center-shifts.

The contours in both r- and i-bands for each component of each GP are drawn by using IRAF CONTOUR task and then used to describe the pair.

Surface brightness profile is traced out along the line joining the centers of both components. This profile helps us to

¹ IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

explore the effect of gravitational interaction on the symmetry of the galaxy by comparing both sides of each component (far-side: the side of the galaxy that is far away from the other component and near-side: the side of the galaxy that is near to the other component). In general, for normal (non-interacting) galaxies the two sides will be nearly symmetric without remarkable deviation. On the other hand, for interacting galaxies (IGs), the behavior of the two sides of each component is expected to be asymmetric.

The position angle profile for each component may help us to study the effect of interaction between galaxies on the outer parts of each component.

The x and y isophotal center-shifts of each component are drawn. Generally, for isolated galaxies the isophotes are expected to be nearly centered about a common center. On the other hand, for interacting galaxies, the isophotes of the outer parts show some shift toward the other components due to the mutual attraction.

4. The interacting system Arp 242

The interacting system Arp 242 is a pair of two spiral galaxies located in the second order of “Toomer sequence” for spiral merger galaxies. They are called the Mice and are a member in the Coma Cluster. Both galaxies are faint compact objects of about $0.5' \times 0.3'$ in size with large bright nuclei (Hill, 2000). The basic parameters of this pair are listed in Table 4.

The component Arp 242a shows a long, narrow, nearly straight tail feature with high surface brightness. This tail measures about $241''.36$ (77.24 kpc) in the r-band and $229''.6$ (52.81 kpc) in the i-band. The other component Arp 242b also has a tail of faint, broad, and curved feature. These long tails indicate the difference in gravitational pull between the two

galaxies (tidal action). Both galaxies show large amount of dust indicating the existing of triggered star formation (Stockton, 1974). A bridge of stars and gas is observed connecting the two galaxies together.

Morphology image of Arp 242 (Fig. 1) shows the close interaction between the two components. The component Arp 242b shows a tightly arm in the inner region and an open one in the external region. By carefully inspecting the contour maps of Arp 242 (Fig. 1) we notice that, the outer contours are deformed in shape. This deformation appears clearly in the r-band more than the i-band. The extended tail of the component Arp 242a and the curved one of the component Arp 242b are clearly observed in the contour map in both bands.

4.1. The SB profile of the GP Arp 242

Comparison between the two sides of the SB profile of the component Arp 242a is shown in Fig. 2a in the r-band, and b in the i-band. Some features appear in this profile making it unsmoothed. These features are probably representing the spiral arms of this spiral galaxy. These arms appear in the form of humps in the SB profile of both bands. In the r-band (Fig. 2a), two humps or spiral arms appear in both sides of the galaxy. The first hump appears at $SB = 20.67 \text{ mag/arcsec}^2$ in the far side, and at $SB = 20.45 \text{ mag/arcsec}^2$ in the near side. The second arm appears at $SB = 20.22 \text{ mag/arcsec}^2$ in the far side, and at $SB = 20.25 \text{ mag/arcsec}^2$ in the near one. In the i-band (Fig. 2b), two humps are also noticed but in this band they look more smooth. The first arm appears at $SB = 20.34 \text{ mag/arcsec}^2$ in the far side, and at $SB \sim 19.52 \text{ mag/arcsec}^2$ in the near side.

Regarding the outer regions of the far and the near sides in both bands we notice that for $d > 12''$, the near side is pulled away from the center of this component till reaching the outer

Table 4 The basic parameters of the GP Arp 242 (NED^a).

Arp 242	R.A (2000) ^a	Dec (2000) ^a	cz (km/s) ^a	B_{TC} ^b	Type ^b
Arp 242a	12h46m10.18s	30d43m53.7s	6582	14.57	Sa, barred, peculiar
Arp 242b	12h46m11.30s	30d43m20.7s	6453	14.24	Sa, barred, peculiar

^a NASA Extragalactic Data Base.

^b LEDA.

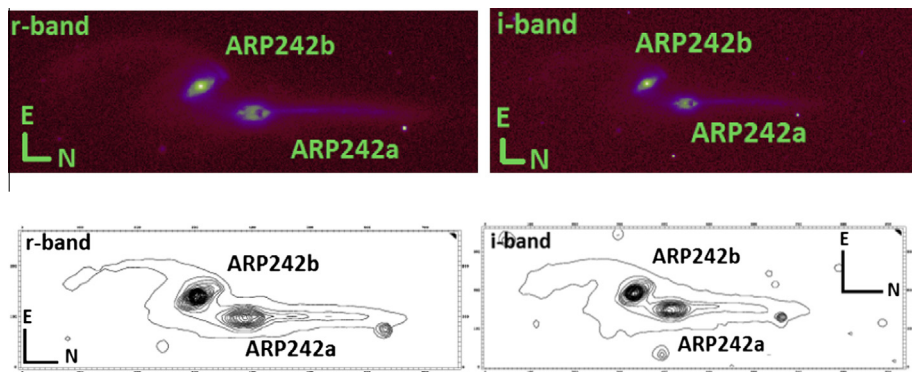


Figure 1 Images and contour maps of Arp 242 in the r-band (left panel) and the i-band (right panel). Each image has a size of about $299'' \times 105''$ in the r-band, and $368'' \times 141''$ in the i-band. The isophotes start from 24.4 to $18.9 \text{ mag/arcsec}^2$ in r-band, and from 24.8 to $18.6 \text{ mag/arcsec}^2$ in i-band.

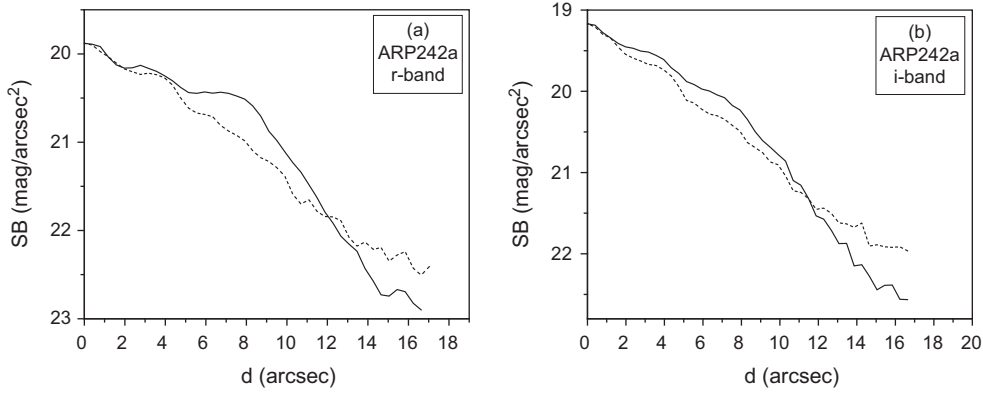


Figure 2 Comparison between the SB of the near side (dotted line) and far side (solid line) of the component Arp 242a in both bands.

most regions. In the r-band, and at $SB = 22.51 \text{ mag/arcsec}^2$, $d = 16''.6$ in the near side, and $d = 14''.02$ in the far side. In the i-band, at $SB = 21.98 \text{ mag/arcsec}^2$, $d = 16''.7$ in the near side and $d = 13''.64$ in the far side. This means that the side near to the interacting region deviated away from the center of component Arp 242a by $\Delta d = 2''.58$ (0.827 kpc) in the r-band, and by $\Delta d = 3''.06$ (0.981 kpc) in the i-band.

On the other hand, the component Arp 242b (Fig. 3a and b) shows a nearly symmetric behavior in the inner region ($0'' < d < 8''$, $0'' < d < 4''$ for the r- and the i-bands respectively) of the two sides of its SB profile. After that ($d > 8''$, $d > 4''$ for the r- and the i-bands respectively) the near side starts to deviate outward from the far one. In the r-band, and at $SB = 25.1995 \text{ mag/arcsec}^2$ $d = 13''.21$ in the near side, and $d = 10''.63$ in the far side. In the i-band, at $SB = 22.24 \text{ mag/arcsec}^2$ $d = 14''.99$ in the near side, and $d = 12''.63$ in the far side. This means that the side near to the interacting region deviated away from the center of this component by $\Delta d = 2''.58$ (0.827 kpc) in the r-band, and by $\Delta d = 2''.36$ (0.757 kpc) in i-band.

4.2. The PA profile of the GP Arp 242

Starting with the PA profile of component Arp 242a (Fig. 4a) we notice that, a part from the inner region at $a > 5''$, no pronounced twist is observed in the PA till reaching the outer most shell at $a = 33''.95$ in both bands. This stability in the

PA of the outer region is due to the tail structure of this component which is aligned with the N direction (see Fig. 1).

On the other hand, the PA profile of component Arp 242b (Fig. 4b) shows a slowly increase for $a > 2''.14$ in both bands. This means that the PA of outer isophotes of this component is twisted toward the E direction i.e. away from component Arp 242a by $39''.87$ in the r-band and $48''.01$ in the i-band. This may reflect that the isophotes of component Arp 242b are twisted away from component Arp 242a due to the very close interaction between the components of this pair, where the two components are probably passing the stage of attraction and are going to the encounter and merger stage.

4.3. The x and y isophotal center-shifts of the GP Arp 242

The x and y isophotal center-shifts in the r- and the i-bands of the component Arp 242a are illustrated in Fig. 5a and b respectively. From this illustration we notice that, apart from the inner region ($a > 6''.11$) of the component Arp 242a, the x isophotal center-shift decreases monotonically from $x_c = 1''.32$ to $-0''.61$ in the r-band, and from $x_c = 0''.69$ to $-1''.27$ in the i-band (Fig. 5a). This means that the outer isophotes of the component Arp 242a are shifted in the W direction away from component Arp 242b by about $1''.93$ (0.619 kpc) and $1''.96$ (0.628 kpc) in the r- and i-bands respectively. On the other hand, the y isophotal center-shift of the outer parts ($a > 2''.4$) of the component Arp 242a is slowly

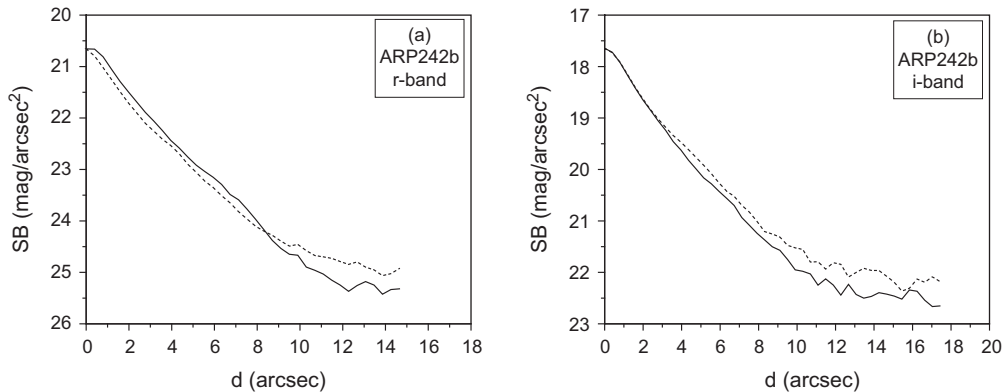


Figure 3 The same as Fig. 2 but for the component Arp 242b.

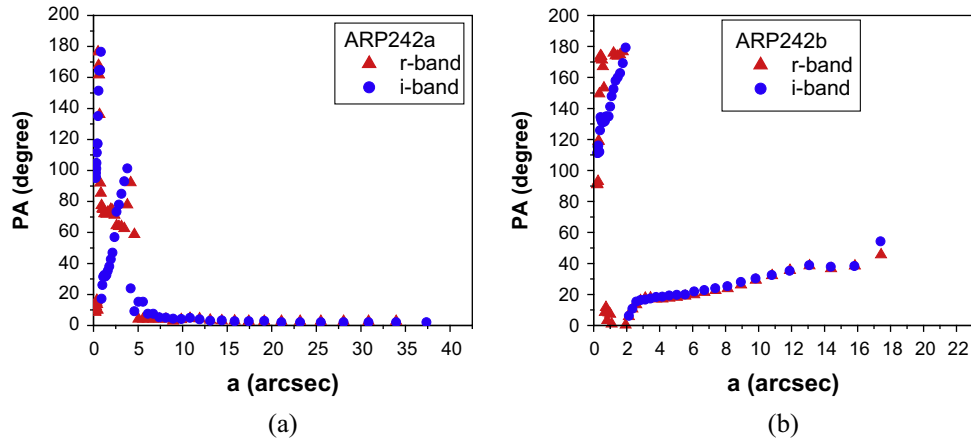


Figure 4 The PA profile of Arp 242a (left) and Arp 242b (right).

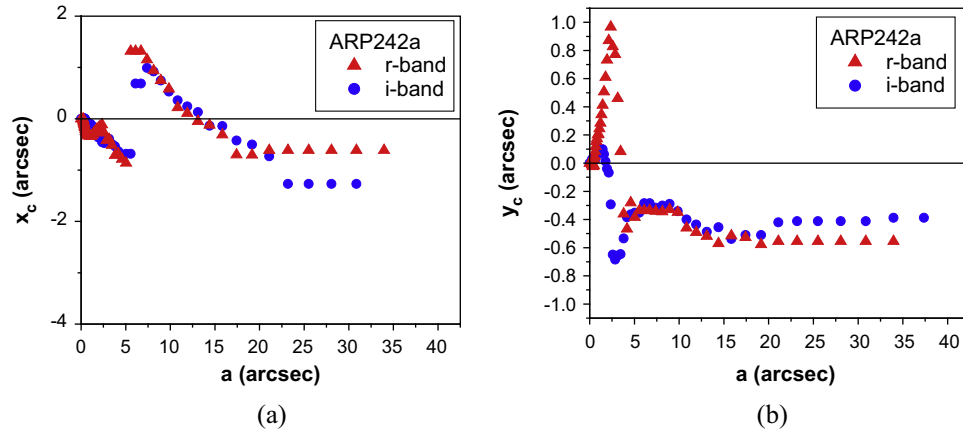


Figure 5 The x and y isophotal center-shifts of Arp 242a.

decreasing in the W direction away from component Arp 242b by about $1''.516$ (0.628 kpc) and $0''.49$ (0.157 kpc) in the r- and i-bands respectively.

The x and y isophotal center-shifts in the r- and i-bands of the component Arp 242b are illustrated in Fig. 6a and b respectively. In the inner part ($a < 14''.4$) of the component Arp 242b, the x isophotal center is slightly fluctuating (Fig. 6a), while in the outer isophotes ($a > 14''.4$), x_c increases rapidly toward the E direction by about $3''.84$ (1.231 kpc) in the i-band. On the other hand, the y isophotal center-shift is also slightly fluctuating in the inner part ($a < 13''.07$), while in the outer part ($a > 13''.07$) the isophotes are monotonically shifted in the N direction toward the component Arp 242a by about $1''.61$ (0.516 kpc) and $2''.6$ (0.834 kpc) in the r- and i-bands respectively. This means that the isophotes in the outer part of y_c of this component are shifted in the N direction where the component Arp 242a is located.

5. The interacting system CPG 165

CPG 165 (KPG 165a/165b) is a pair of two spiral galaxies and is thought to be in a true interacting stage. The component KPG 165a is a barred spiral galaxy (SBb) with heavy disrupted arms, while the component KPG 165b is classified as a spiral

galaxy (Sab). The basic data of the GP CPG 165 are presented in Table 5.

The images of the system as well as their isophotes in the r- and i-bands are shown in Fig. 7. By carefully inspecting Fig. 7 we notice that, outer contours are unsmoothed and irregular in shape especially in i-band. They are non-co-planarity except in the most inner region of the two components (at the core).

The two components are embedded in a common envelope at levels $23.16 \text{ mag/arcsec}^2$ in the r-band, and $21.22 \text{ mag/arcsec}^2$ in the i-band. Spiral arms structures of the two galaxies, especially the component KPG 165b are clearly observed in both bands (Fig. 7).

5.1. The SB profile of the system CPG 165

Starting with SB profile of KPG 165a (Fig. 8a and b in the r- and i-bands respectively) we compare between the SB of the two sides of component KPG 165a to show whether they are symmetric or not. The SB of the near-side (dotted line) and the SB of the far-side (solid line) look symmetric. It seems that both sides are nearly symmetric in both r- and i-bands.

On the other hand, the comparison between the two sides of SB profile of the component KPG 165b is illustrated in

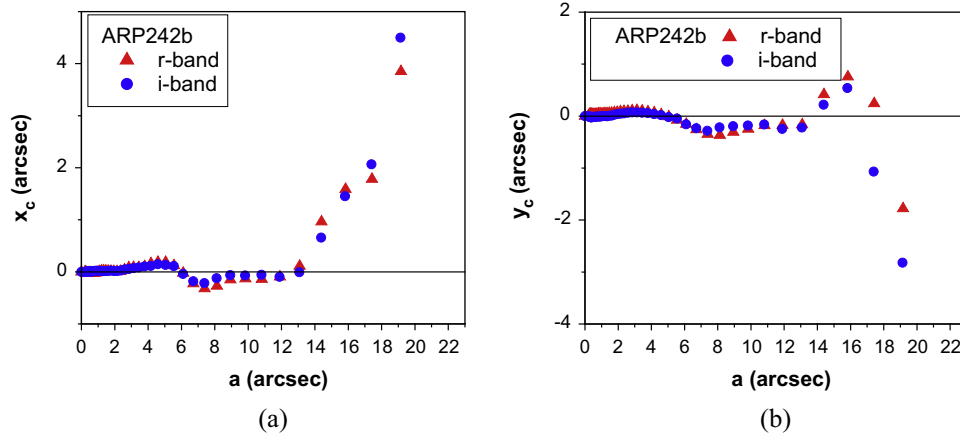


Figure 6 The same as Fig. 5 but for Arp 242b.

Table 5 The basic data of CPG 165 (NED^a).

CPG 165	R.A (2000) ^a	Dec (2000) ^a	cz (km/s) ^a	B_{TC} ^b	Type ^b
KPG 165a	08h34m31.703s	+01d39m57.91s	4131 ± 2	14.19	SBb
KPG 165b	08h34m33.73s	+01d40m16.2s	4126 ± 10	14.70	Sab

^a NASA Extragalactic Data Base.

^b SIMBAD.

Fig. 9a and b in r- and i-bands respectively. For this component both sides show a large deviation. The SB of the near-side is decreasing faster than that of the far-side. This means that there is a deviation between the near side and the far one by $\Delta d = 0''.4$ (0.08 kpc) in the r-band, and $\Delta d = 0''.43$ (0.086 kpc) in the i-band. This deviation occurs due to the gravitational force between the two components of the pair.

The deviation between the two sides occurs only in the component KPG 165b in this system, due to the highly different masses of the two components which makes the gravitational attraction affects the less massive component only.

5.2. The PA profiles of the system CPG 165

The PA profiles in the r- and i-bands for both components of CPG 165 are given in Fig. 10a and b respectively. The PA profiles of the component KPG 165a are nearly consistent in the r- and i-bands (Fig. 10a). Within $a = 17''.4$, the PA fluctuates between $81^\circ.99$, and $92^\circ.52$. For the outer part ($a > 17''.4$), the PA of the isophotes decreases steeply from about $86^\circ.78$ to about $82^\circ.78$, which means that the isophotes in the outer part of this component are twisted toward the N-direction where the component KPG 165b is located. This may reflect the real state of attraction between the two components.

For the component KPG 165b, the PA profile looks similar in the r- and i-bands (for $a > 2''.4$) (Fig. 10b). Beyond $a = 2''.4$ the PA slowly increases till about $a = 13''.1$ and then rapidly increases outward. This means that the isophotes of the outer part of this component are twisted in the E-direction i.e. toward the other component. This also reflects the fact that the outer part of the component KPG 165b is attracted toward the other component. In general, the behavior of the PA profile of the outer parts of both components may confirm the state of attraction between them.

5.3. The x and y isophotal center-shifts of the system CPG 165

The x and y isophotal center-shifts of the component KPG 165a are illustrated in Fig. 11a and b respectively. In the inner part ($a < 11''.9$ and $a < 14''.1$ in the r- and i-bands respectively) of the component KPG 165a, the centers of the isophotes are slightly fluctuating (Fig. 11a and b), while in the outer part, the centers of the isophotes are monotonically shifted in both the N- and E-directions toward the other component. This means that the isophotes in the outer part of the component KPG 165a are shifted in NE direction where the component KPG 165b is located. The amount of the shift in the r-band is estimated to be about $1''.59$ (0.318 kpc) and $7''.83$ (1.568 kpc) in the N and E directions respectively where the component KPG 165b is located.

For the component KPG 165b, the x and y isophotal center-shifts are illustrated in Fig. 12a and b respectively. Within the inner part ($a < 14''.5$) the x isophotal center-shift increases gradually, then it rapidly increases till about $18''.5$ (Fig. 12a), while in the outer part ($a > 18''.5$) the isophotes are monotonically decreasing in the W direction toward the component KPG 165a (see Figs. 7 and 12a). On the other hand, the y isophotal center-shift decreases rapidly for $1''.0 < a < 8''.7$, and then slightly fluctuates in the outer part (see Fig. 12b). The amount of the x-shift in the r-band is estimated to be about $1''.21$ (0.242 kpc) in the S-direction i.e., toward the component KPG 165a.

6. The interacting system CPG 410

CPG 410 or KPG 410a/KPG 410b is an interacting system of two spiral galaxies. The two companions are nearly equal in

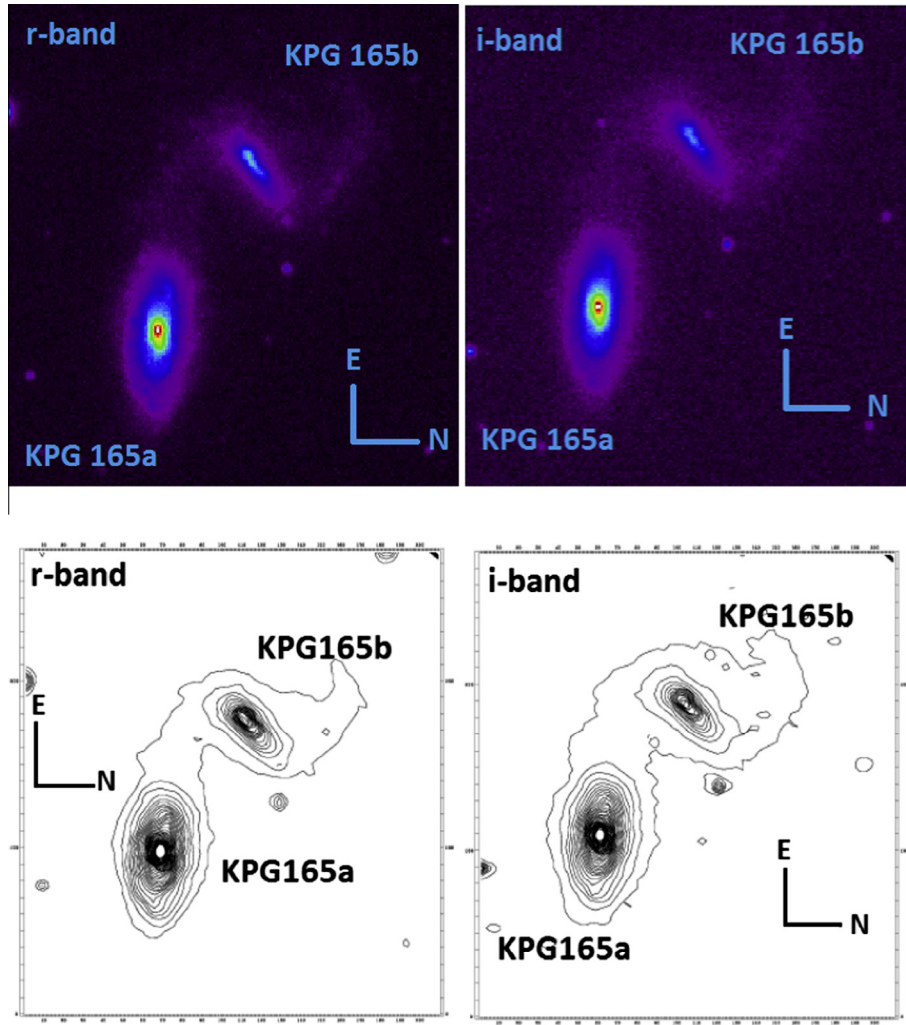


Figure 7 Images and contour maps of CPG 165 in the r-band (left panel) and the i-band (right panel). Each image has a size of about $83'' \times 110''$. The isophotes start from 23.16 to 19.05 mag/arcsec² in r-band, and from 21.22 to 18.9 mag/arcsec² in i-band.

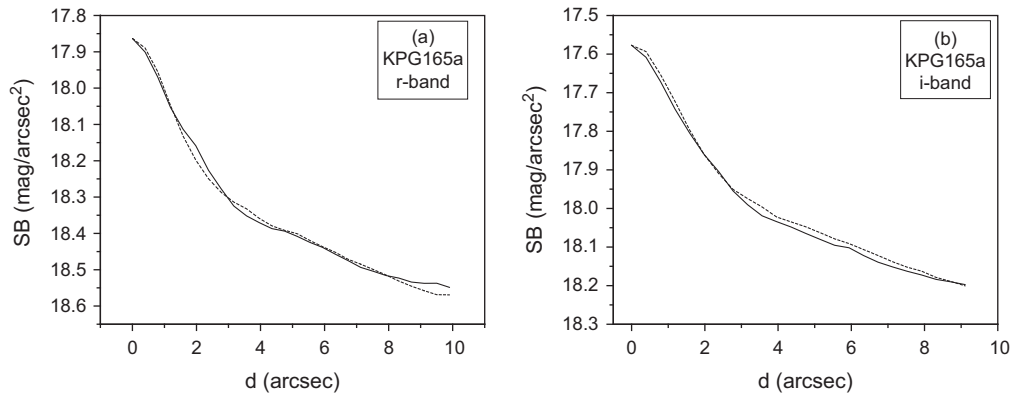


Figure 8 Comparison between the SB of the near- and far-sides of the component KPG 165a in both bands.

mass and with similar nearby velocity (Pohlen et al., 2002). The nucleus of each component is observed clearly at the center of each galaxy. Spiral arms of both galaxies are also observed clearly especially those of KPG 410a. The basic parameters of this system are listed in Table 6.

Morphology image of KPG 410 (Fig. 13) shows that the component KPG 410a has a set of tightly wrapped and prominent arms forming a ring. These arms are clearly observed in the r-band. This image also shows the presence of dust lanes in the component KPG 410b. A prominent bulge is observed

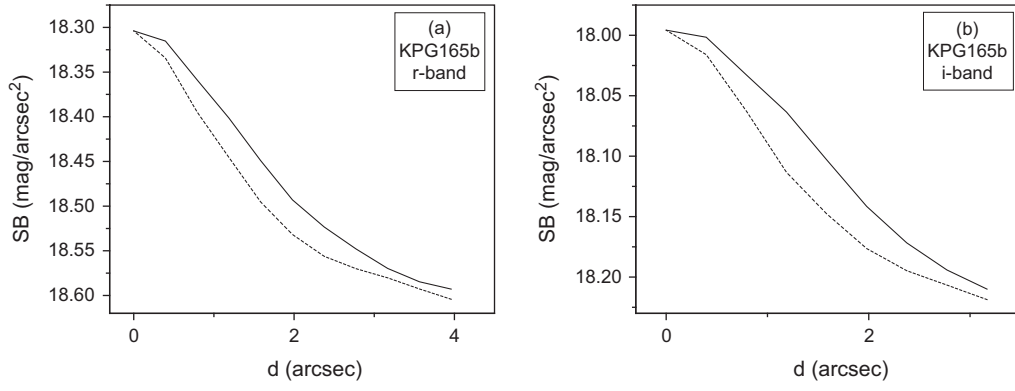


Figure 9 The same as Fig. 8 but for the component b.

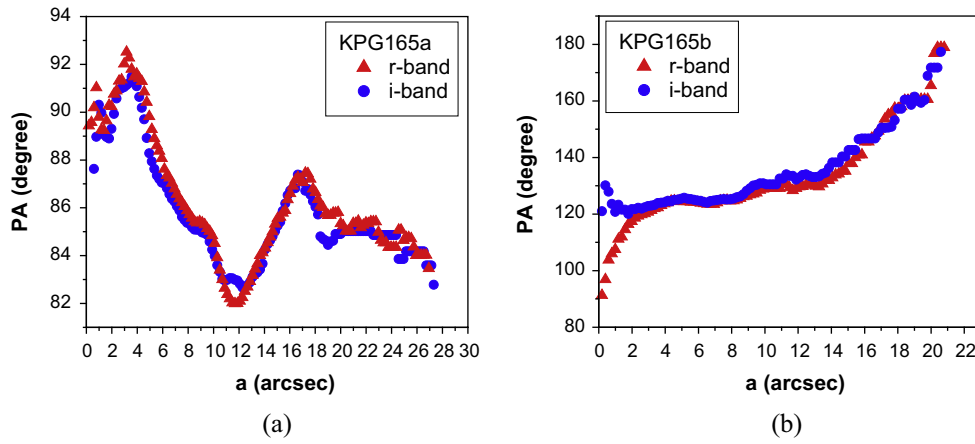


Figure 10 PA profile of KPG 165a (left) and KPG 165b (right).

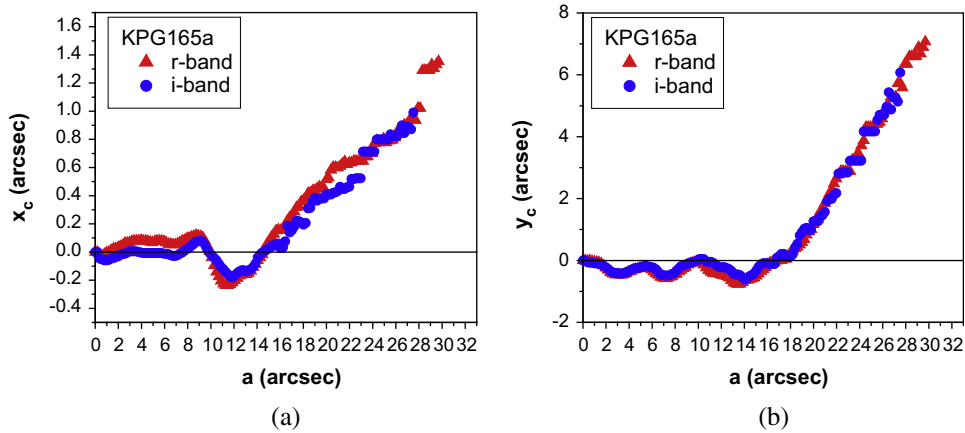


Figure 11 The isophotal center-shift of KPG 165a.

in each component. By inspecting the contour maps of KPG 410a/KPG 410b (Fig. 13) we notice that, outer contours are unsmoothed and irregular in shape in both bands. Spiral arms structures are observed clearly in both bands of the component KPG 410a more than the other component (KPG 410b).

6.1. The SB profile of the GP CPG 410

Starting with KPG 410a we notice that this component has a face on view with many spiral arms (see Fig. 13). Hence, asymmetric behaviors are difficult to be observed in this case. So,

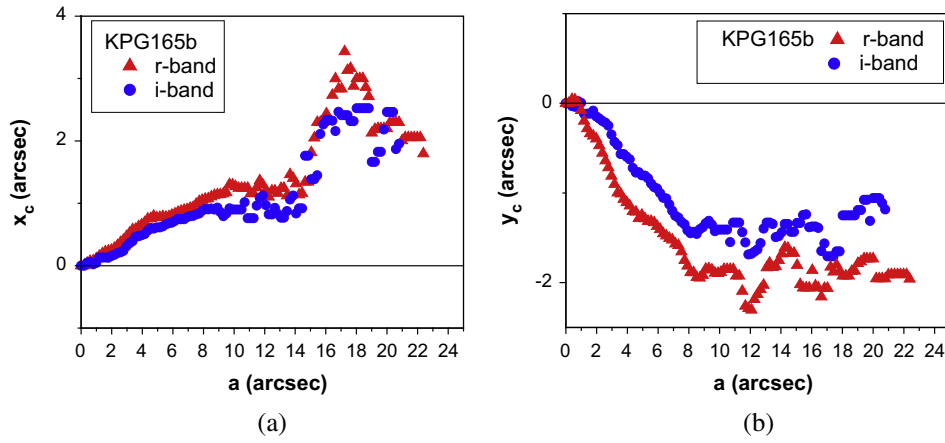


Figure 12 The isophotal center-shift of KPG 165b.

Table 6 The basic parameters of CPG 410 (NED^a).

CPG 410	R.A (2000) ^a	Dec (2000) ^a	cz (km/s) ^a	Type ^a
KPG 410a	14h03m25.1s	09d27m27s	5638 ± 5	SAC
KPG 410b	14h03m27.110s	09d28m02.20s	5637 ± 6	Sbc

^a NASA Extragalactic Data Base.

comparison between the two sides of the SB profile of KPG 410a (Fig. 14a and b in the r-, and the i-bands respectively) will show many unsmoothed features (due to spiral arms) making

the deviation between the two sides to be hardly detected and calculated.

While comparison between the two sides of KPG 410b (Fig. 15a and b in the r- and the i-bands respectively) shows that, the two halves are nearly symmetric till $d \sim 2''$ in both bands. After this point, the near side begins to shift from the far side toward the center of the galaxy till reaching the outer region. In the r-band at $SB = 21.75 \text{ mag/arcsec}^2$, $d = 9''.02$ in the near side, and $d = 11''.53$ in the far side. In the i-band at $SB = 18.02 \text{ mag/arcsec}^2$, $d = 3''.64$ in the near side, and $d = 4''.73$ in the far side. This means that the side near to the interacting region deviated toward the center of the galaxy

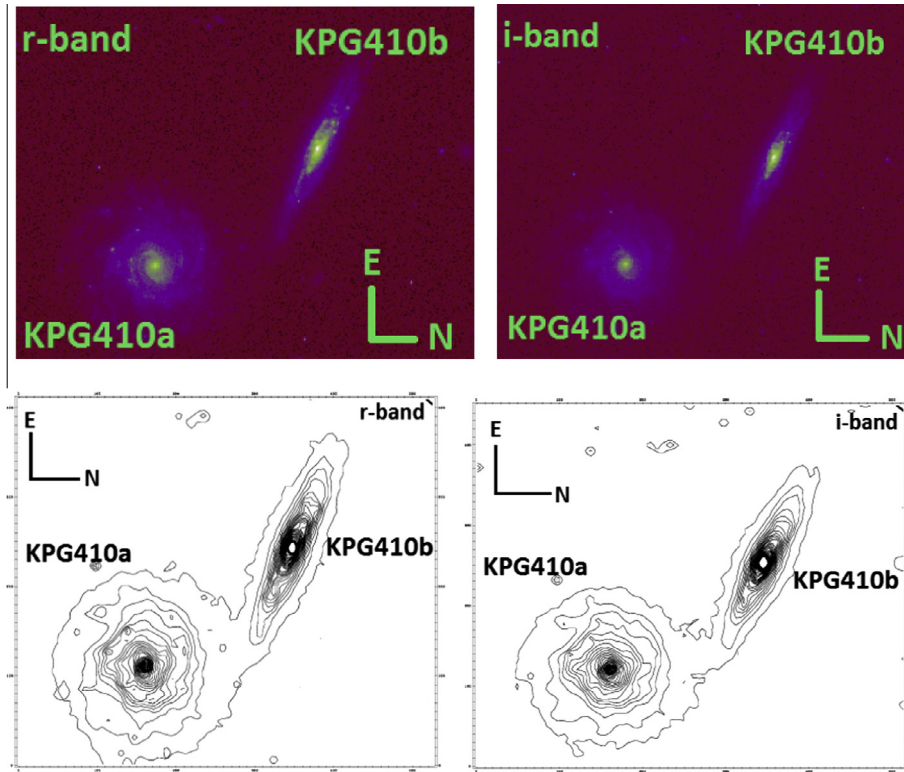


Figure 13 Images and contour maps of CPG 410 in the r-band (left panel) and the i-band (right panel). Each image has a size of about $208'' \times 162''$ in the r-band, and $203'' \times 178''$ in the i-band. The isophotes start from 24.7 to 19 mag/arcsec^2 in r-band, and from 24.1 to $18.6 \text{ mag/arcsec}^2$ in i-band.

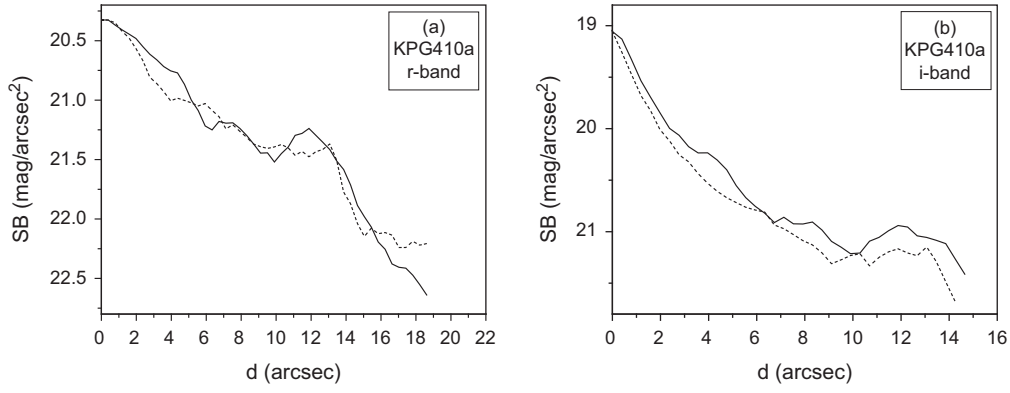


Figure 14 A comparison between the SB of the near side (dotted line) and far side (solid line) of the component KPG 410a in both bands.

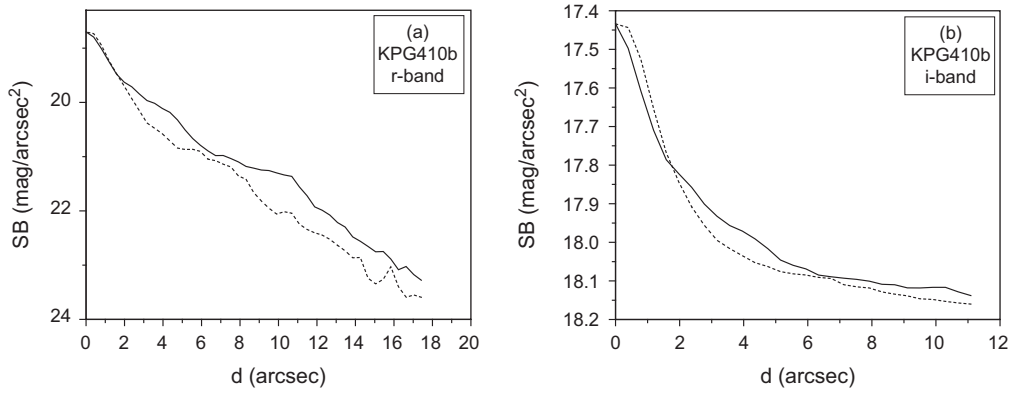


Figure 15 The same as Fig. 14 but for the component KPG 410b.

by $\Delta d = 2''.51$ (0.626 kpc) in the r-band, and $\Delta d = 1''.09$ (0.272 kpc) in the i-band. This observed deviation may be interpreted as a result of the interaction between the two components.

6.2. The PA profile of the GP CPG 410

The PA profile of CPG 410 is shown in Fig. 16. The behavior of the PA of KPG 410a (Fig. 16a) shows many peculiar structures in the inner region. The behavior of the PA of this galaxy shows many peculiar structures make the twist in the PA be difficult to calculate. These peculiar features appear due to the face-on view of this galaxy.

Now going to Fig. 16b which shows the PA of KPG 410b in both the r- and the i-bands respectively we note that within $a = 27''.5$, the PA fluctuates between $64^\circ.13$ and $66^\circ.17$. Then the PA in outer isophotes ($a > 27''.5$) decreases steeply till reaching $PA = 62^\circ.8$. This means that the outer isophotes of this component are twisted in the N direction toward the component KPG 410a by $3^\circ.39$ in r-band.

6.3. The x and y isophotal center-shifts of the GP CPG 410

The x and y isophotal center-shifts of (KPG 410a/410b) are shown in Fig. 17a and b for KPG 410a and Fig. 18a and b for KPG 410b in both bands. Starting with the x and y

isophotal center-shifts of the component KPG 410a (Fig. 17a) we notice that, within about $a = 35''$, many fluctuations occur in the x isophotal center-shift. After that the x isophotal center-shift in the outer isophotes ($a > 35''$) increases rapidly in the E direction toward the component KPG 410b (see Figs. 13 and 17a). On the other hand, the y isophotal center-shift is also fluctuating in the inner part ($a < 32''.87$), while in the outer part ($a > 32''.87$) the isophotes are monotonically shifted in the E direction toward the component KPG 410b. This means that the isophotes in the outer part of this component are shifted in the E direction where the component KPG 410b is located. The amount of the shift in the r-band is about $8''$ (2 kpc) and $2''.71$ (0.675 kpc) in the E direction.

Now going to the x and y isophotal center-shifts of the component KPG 410b (Fig. 18a and b), we notice that, in the inner part ($a < 34''.5$) of the component KPG 410b, the x isophotal center-shift shows many fluctuations in both bands. After that, the x isophotal center-shift decreases monotonically in the outer region ($a > 35''$) in the N direction toward the component KPG 410a (see Figs. 13 and 18a). On the other hand, the y isophotal center-shift is also fluctuating in the inner part ($a < 34''.5$), while in the outer part ($a > 34''.5$) the isophotes are monotonically shifted in the W direction toward the component KPG 410a. This means that the isophotes in the outer part of this component are shifted in the NW direction where the component KPG 410a is located. The amount

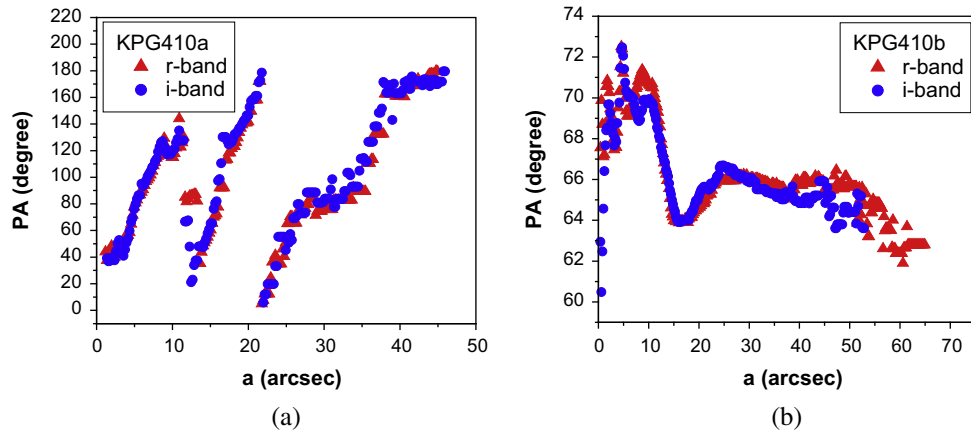


Figure 16 The PA profile of KPG 410a (left) and KPG 410b (right).

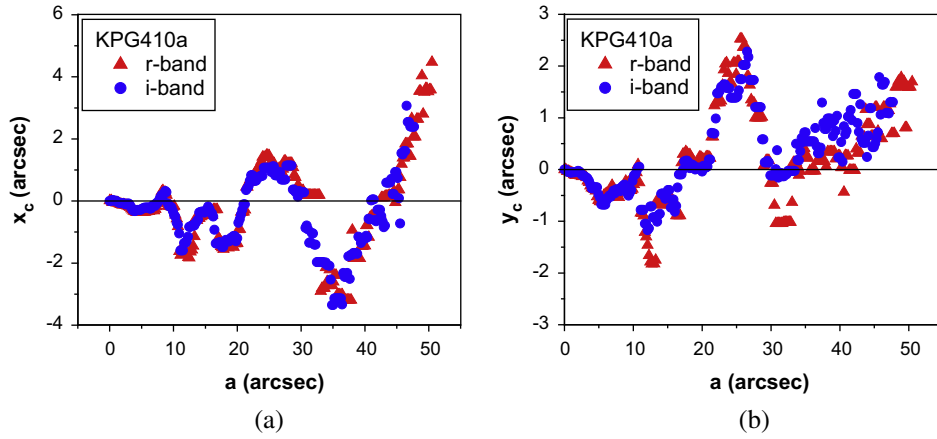


Figure 17 The x and y isophotal center-shifts of KPG 410a.

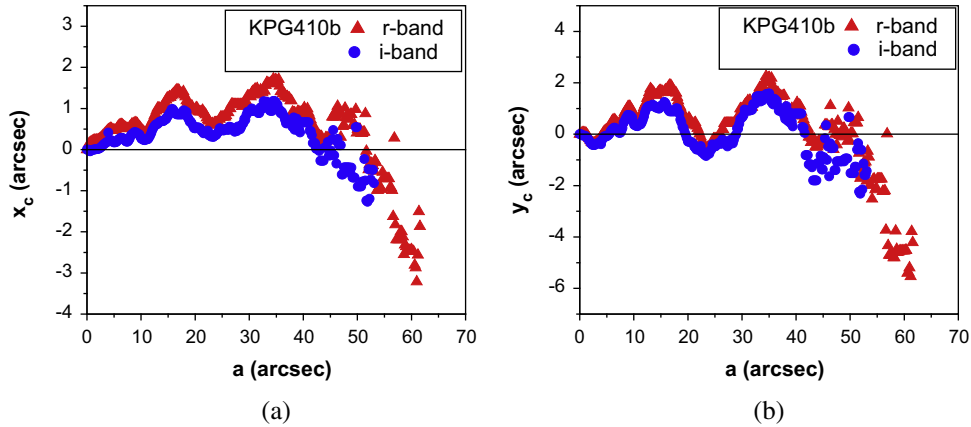


Figure 18 The same as Fig. 17 but for KPG 410b.

of the shift in the r-band is about $4''.9$ (1.22 kpc) and $7''.65$ (1.907 kpc) in the N and W directions respectively.

7. Conclusions

In this paper, we present a study for a sample of 3 GPs using the SDSS r- and i-band images. The main aim is to investigate

the effect of gravitational interaction between the components of IGs on their morphology, profiles of SB, PA, and isophotal center shift.

From observations and simulations it follows that interaction between galaxies is an important process during their lifetime and evolution. It was shown that, the symmetry of the morphology and structure of the components of a GP are affected by the interaction between them.

Table 7 Estimated values of the twist and center shift of the outer isophotes for the components of the three GP Arp 242, CPG 165, and CPG 410.

GP	Scale (kpc/'')	Δd (arcsec)	Δd (kpc)	Δx_c (arcsec)	Δx_c (kpc)	Δy_c (arcsec)	Δy_c (kpc)	Twist (°)
Arp 242a	0.32	2.58	0.827	1.93	0.619	1.52	0.487	–
		3.06	0.981	1.96	0.628	0.49	0.157	–
Arp 242b		2.58	0.827	3.74	1.199	1.61	0.516	39.9
		2.36	0.757	3.84	1.231	2.6	0.834	48.0
KPG 165a	0.20	–	–	1.59	0.318	7.83	1.568	4
				1.17	0.234	6.70	1.342	4
KPG 165b		0.4	0.080	1.21	0.242	–	–	49.3
		0.43	0.086	0.55	0.110			44.3
KPG 410a	0.25	–	–	8	2	2.71	0.675	–
				3.66	0.912	1.46	0.364	–
KPG 410b		2.51	0.626	4.9	1.221	7.65	1.907	3.39
		1.09	0.272	2.42	0.603	3.79	0.945	3.08

Estimated values of the twist and center shift of the outer isophotes for the studied systems for all the studied systems are listed in Table 7.

The first column represents the components of each GP. The second one represents the scale (kpc/'') calculated for each pair.

This scale is calculated by considering the average distance of the two components ($D = 0.5 (v_1 + v_2)/H_0$).

The third and fourth columns represent the shifted values between the two halves of the SB for each component in arcsec and kpc respectively. The fifth, sixth, seventh, and eighth columns represent the shifted values of the x and y isophotal center shifts respectively. The last column represents the amount of twist in the PA of each component. For each component, the first line is the values in the r-band while the second line is for the i-band.

By carefully inspecting Table 7 we can conclude that:

1. For the system Arp 242 (Arp 242a/Arp 242b), remarkable deviation between the SB of both sides is clearly noticed on both components and is estimated in the r-band to be 2''.58 (0.827 kpc) for both the components Arp 242a and Arp 242b. The PA profile of the component Arp 242a shows no pronounced twist in the outer isophotes due to the tail structure found in the outer part of this component which is very alignment with the N direction. On the other hand, the PA of the outer isophotes of the component Arp 242b is twisted away from the component Arp 242a. This is expected to be due to the very closed interaction between the two components of the pair, where the two components are probably passing the stage of attraction and are going to the encounter and merger stage. In this case all the expected results can be opposite so, the PA of each component will twist away from each other instead of twisting toward each other.

The x and y isophotal center-shifts show a shifted value in the outer isophotes of both components. For the component Arp 242a the amount of the shift in the r-band is estimated to be 1''.93 (0.619 kpc), and 1''.52 (0.487 kpc) in the W direction away from the component Arp 242b. This opposite result is probably due to the encounter stage between the two components. On the other hand the component Arp 242b shows a shifted value toward the component Arp 242a. The amount of the shift in the r-band, is

estimated to be 3''.74 (1.199 kpc) and 1''.61 (0.516 kpc) in the E and N directions respectively.

2. For the system CPG 165 (KPG 165a/KPG 165b), component KPG 165a shows that both the near- and far-sides are nearly symmetric and there is no remarkable deviation between them as is clear in both bands. On the other hand the component KPG 165b shows a remarkable deviation between the SB of both sides.

Twist in the outer isophotes of the PA profile, and shifted values in the x and y isophotal center-shifts are noticed in both components. These behaviors are expected to be due to the fact that the outer isophotes are affected by the gravitational attraction between the two components.

3. For the system CPG 410 (KPG 410a/KPG 410b), component KPG 410a shows a difficulty in detecting the deviation between the two sides and the twist in PA profile due to the face-on view of this component. This makes the component KPG 410a to appear as a circle i.e. the semi-major axis (a) is equal to the semi-minor axes (b) and no elliptical isophotes can be obtained to work on them. While in the component KPG 410b a remarkable deviation between the SB of both sides and twist in the outer isophotes of its PA profile are clearly noticed. On the other hand, the x and y isophotal center-shifts show a shifted value in the outer isophotes of both components toward each other. This shifting reflects the real state of attraction between the two components.

To summarize, the concluded remarks are as follows:

- For some components of the studied sample of GPs, we found that both the near- and far-sides are nearly symmetric and there is no remarkable deviation between them as is clear in both bands. For other components a remarkable deviation between the SB of both sides is clearly noticed.
- The PA profile shows that the outer isophotes of the two components of the studied sample of GPs are twisted toward each other. This behavior is expected to be due to the fact that the outer isophotes are affected by the gravitational attraction between the two components.
- The x and y isophotal center-shifts show a considerable shift in the outer isophotes of both components of the studied sample of GPs toward each other.

Last but not least, we can confirm from all the above results and conclusions that gravitational interaction between galaxies has a great effect on their morphology and structure.

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