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The photometric and geometric analysis of galaxy pair KPG 578

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ABSTRACT

We have presented BVR surface photometry and geometric analyses for galaxy pair KPG 578 a, b (NGC 7537, NGC 7541). The contour maps, BVR surface brightness profiles (*SB*) and geometric profiles (x_c, y_c, *PA* and *Ellip* $= 1 - b/a$) have been used for each galaxy in the pair. The galaxy pair KPG 578 is an intermediate pair with projected separation $r_p = 35.4\ h_{70}^{-1}$ kpcand relative velocity$\Delta v = 15$ km/s. The total orbital mass of KPG 578 is determined to be $M_t = 6.03\ x\ 10^9\ M_\odot$. While the total luminosity and the total orbital mass to the total luminosity of KPG 578 are found to be $L_t = 4.49\ x\ 10^{10}\ L_\odot$ and $M_t/L_t = 0.13 M_\odot/L_\odot$ respectively.

While it has been believed that the galaxy pair KPG 578 is non-interacting system, in this work we have found that the galaxy pair KPG 578 has signs of interaction. The KPG 578a contains one short curved tidal tail in northeast. The KPG 578b has two curved tidal tails: the first is long in west and the second is short in east. The geometrical parameters of tidal tails (length (l_t), thickness (h_t) and area (A_t)) have been presented in this study.

1. Introduction

The galaxy pairs are considered as natural resources to study the gravitational interaction between galaxies. They play a strong role for increasing star formation (Bell et al., 2006, Lin et al., 2004, Bundy et al., 2004, Patton et al., 2002, Carlberg et al., 2000, Patton et al., 2000; Le F'evre et al., 2000).

The KPG 578 is a pair of the two spiral galaxies from Karachentsev catalog (1972). The galaxy KPG 578a (NGC 7537) is classified as normal spiral Sbc. The galaxy KPG 578b (NGC 7541) is classified as barred spiral SBc. The major diameter in the B-band at the isophotal level 25 mag/arcsec^2 equals to 1.82 and 3.02 arcmin of KPG 578a and KPG 578b respectively. The total magnitude in the B-band at the same isophotal level equals to 12.68 ± 0.06 and 11.39 ± 0.09 of KPG 578a and KPG 578b respectively, see Table 1.

Karachentsev (1987) gives the radial velocity as 2834 km/s and 2793 km/s of KPG 578a and KPG 578b respectively. The angular separation between the pair is equals to 3.05 arcmin. The projected linear separation equals to 33.3 kpc for Hubble constant$H_0 = 75\ h_{75}$ km s^{-1}Mpc^{-1}. Karachentsev (1987) classified this pair as an isolated pair without details about whether this pair represents interacting galaxies or non-interacting galaxies. de Vaucouleurs and de Vaucouleurs (1964) found that the KPG 578 is a non-interacting pair with angular separation between galaxies 2.7 arcmin.

Heraudeau et al. (1996) found that KPG 578a has very faint bulge, while the galaxy KPG 578b is the brighter member of a physical pair with KPG 578a. The projected linear separation equals to 44 kpc at the distance of 56 Mpc with the Hubble constant $H_0 = 50\ h_{50}$ km s^{-1}Mpc^{-1} (Sandage and Bedke, 1994). The KPG 578b is a peculiar galaxy in pair with KPG 578a (Elfhag et al., 1996). It is nearly edge-on, with strong asymmetry along semi-major axis (Heraudeau et al., 1996). The KPG 578b has no nucleus and a straight line of matter proceeds to west from the center along the major axis (Curtis, 1918).

Our aim in this study is to investigate and determine the photometric parameters for galaxy pairs KPG 578 a,b. The geometric parameters of interacting galaxies were determined in a previous study (Mohamed and Reshetnikov, 2011, Mohamed et al., 2011, and Reshetnikov and Mohamed, 2011).

We have adopted a numerical values in this study using $H_0 = 70\ h_{70}$ km s^{-1}Mpc^{-1}, $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$. The paper is organized as follows: observations, data reduction and photometric calibration have been presented in Section 2. The results and discussions have been described in Section 3. Finally, conclusions have been shown in Section 4.

2. Observations, data reductions and photometric calibration

We observed the galaxy pair KPG 578a,b in 2014 June 24 - 26 in three BVR bands. Using CCD camera EEV 42–40 (2 k × 2 k pixels) at Newtonian Focus of the Kottamia telescope 188 cm, Egypt, see Table 2.

The overscan, bias and flat-field corrections of raw images are

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Table 1
Basic data for galaxies in the studied sample.

Pair ID	z[a]	Type[b]	PA[b] (degree)	B_T[b] (mag)	d25[b] (arcmin)
KPG 578a	0.008920	Sbc	73.8	12.68 ± 0.06	1.82
KPG 578b	0.008969	SBc	101.6	11.39 ± 0.09	3.02

[a] NED.
[b] HyperLeda.

Table 2
Journal of the observational data of the studied sample on 2014 June 24–26.

Pair ID	Filter	Exposure time (s)	Seeing (arcsec)	Airmass
KPG 578	B	6 × 300	2.41	1.172
	V	2 × 300	1.82	1.034
	R	2 × 300	1.90	1.222

calibrated using a code of IRAF package that has been developed by us. We have used the algorithm of Pych (2004) to clean the Cosmic Rays from all images.

The standard stars of Landolt (2009) have been used to calibrate the instrumental magnitude. We have used the transformation equations to convert the instrumental magnitudes (bvr) to standard magnitudes (BVR).

$$B = b - K_b X_b + CT_b (b-v) + ZP_b \quad (1)$$

$$V = v - K_v X_v + CT_v (b-v) + ZP_v \quad (2)$$

$$R = r - K_r X_r + CT_r (v-r) + ZP_r \quad (3)$$

The zero-points magnitudes areZP_b, ZP_v and ZP_r in BVR bands. The color terms are CT_b, CT_v and CT_r in BVR bands. The extinction coefficients for the atmosphere are K_b, K_v and K_r in BVR bands. The air masses are X_b, X_v and X_r in BVR bands.

We have measured the instrumental magnitudes of the standard stars using the aperture photometry package of IRAF. We have determined the best aperture to obtain the magnitude in BVR bands by using curve-of-growth technique (Stetson, 1990).

Using Eqs. (1)–(3) we have determined the transformation coefficients. The zero-points magnitudes in BVR bands ZP_b, ZP_v and ZP_r equal to 19.934 ± 0.224, 21.726 ± 0.081 and 22.063 ± 0.039 respectively. The color terms are CT_b, CT_v and CT_r equal to 0.331 ± 0.027, −0.027 ± 0.013 and −0.097 ± 0.012 respectively. The extinction coefficients are K_b, K_v and K_r equal to 0.528 ± 0.153, 0.272 ± 0.053 and 0.130 ± 0.027 respectively.

3. Results and discussions

3.1. Surface photometry and analysis

We have used the surface photometry technique of IRAF to measure the photometric properties of each galaxy in the studied sample of galaxy pair. The ELLIPSE task used the isophotes around the galaxies from inner regions to outer regions. The ELLIPSE fitted the isophotes to obtain ellipses. The outputs of photometric parameters of each ellipse are the intensity, the total flux, the x and y center-shift, the ellipticity and position angle. Using these outputs, we have obtained the luminosity profiles, the x and y center-shift profiles, the ellipticity profiles and position angle profiles. These profiles helped us to investigate the galaxy pair KPG 578, i.e. this galaxy pair is interacting galaxy pair or non-interacting galaxy pair. The interacting galaxy pairs appear distorted and off-centering of the isophote in the outer regions (Ali, 1993; Ali et al., 2015).

The photometric parameters have been measured within isophote at semi-major axis (a) of 0.30 arcmin and 1.50 arcmin of galaxy KPG 578a and galaxy KPG578b respectively, see Table 3. We have corrected the magnitudes for internal-extinction (Schlafly and Finkbeiner, 2011). We applied the k-correction using Chilingarian et al. (2010) and the cosmological dimming by subtracting 10 log (1 + z).

Table 3
Measured photometric parameters for the studied sample.

Parameters	KPG 578a	KPG 578b
SMA (arcmin)	0.30	1.50
Ellipticity	0.690 ± 0.008	0.656 ± 0.006
PA (deg)	77.285 ± 0.574	99.717 ± 0.357
B	14.564 ± 0.006	12.489 ± 0.012
V	13.187 ± 0.006	11.608 ± 0.005
R	12.708 ± 0.004	11.085 ± 0.003
M(R)	−20.31	−21.95

3.2. Morphologies and contour maps of galaxy pair KPG 578

The galaxy pair KPG 578 has been investigated using the visual inspection in R-band of both the image and contour maps. This investigation was for KPG 578 in R-band using Kottamia observatory (Fig. 1). Then we compared it with r-band of SDSS survey (Fig. 2) to confirm the interaction signs. This galaxy pair contains two galaxies KPG578a (NGC 5737) and KPG578b (NGC 7541). We have presented the surface brightness of the outer isophotes and the interval between them in Table 4. The major diameter of the main body of KPG 578a is equals to d ~ 7.5 kpc (0.64 arcmin) at level 21 mag/arcsec^2, while diameter of KPG 578b is equals to d ~ 7.3 kpc (0.62 arcmin) at level 19.8 mag/arcsec^2. The contour maps in Fig. 1 show the existence of asymmetric and non-concentric isophotes of galaxy KPG 578 indicating new interaction signs.

3.3. geometrical parameters of tidal tails of galaxy pair KPG 578

Using visual inspection of the studied sample in Figs. 1 and 2, the galaxy KPG 578a has one tidal tail in north-east from the center. The geometrical parameters of tidal tail of this galaxy are the length l_t = 6.9 kpc (0.59 arcmin), the thickness h_t = 1.5 kpc (0.12 arcmin) and area $A_t = h_t \times l_t$ = 10.4 kpc^{2}of the tidal tail, see Table 5. This tidal tail is curved line not straight line at north-east.

The KPG 578b has two tidal tails with curved lines. The first tail is at east and the second at west from the center. The length of the first tidal tail is l_t = 6.6 kpc (0.56 arcmin), its thickness is h_t = 1.0 kpc(0.09 arcmin) and its area is A_t = 6.6 kpc^2, while the second tidal tail has length l_t = 11.2 kpc (0.96 arcmin), thickness h_t = 1.2 kpc (0.1 arcmin) and area A_t = 13.4 kpc^2. Bridge et al. (2010) classified tidal tails into long tidal tails ($l_t > d$), medium tidal tails ($l_t \simeq d$) and short tidal tail ($l_t < d$). According to this classification, KPG 578a has short tidal tail in east from its center, while the first tidal tail of KPG578b is long tidal tail in west and the second one is short tidal tail in east.

3.4. The projected separation, total orbital mass and total luminosity of galaxy pair KPG 578

The projected separation between galaxies of the pair r_p is calculated using formula of Karachentsev (1987).

$$r_p = x_{12} \frac{c\ (z_1 + z_2)}{2\ H_0} \quad (4)$$

Where x_{12} represents the angular separation between the first and the second galaxy in the pair, $c\ z_1$ and $c\ z_2$ are the radial velocity of the first and second galaxy in the pair and H_0 is Hubble constantH_0 = 70 h_{70} km s^{-1}Mpc^{-1}. The relative velocity Δv in km/s of the galaxies is calculated using this formula:

$$\Delta v = \sqrt{(c\ z_1 - c\ z_2)^2}. \quad (5)$$

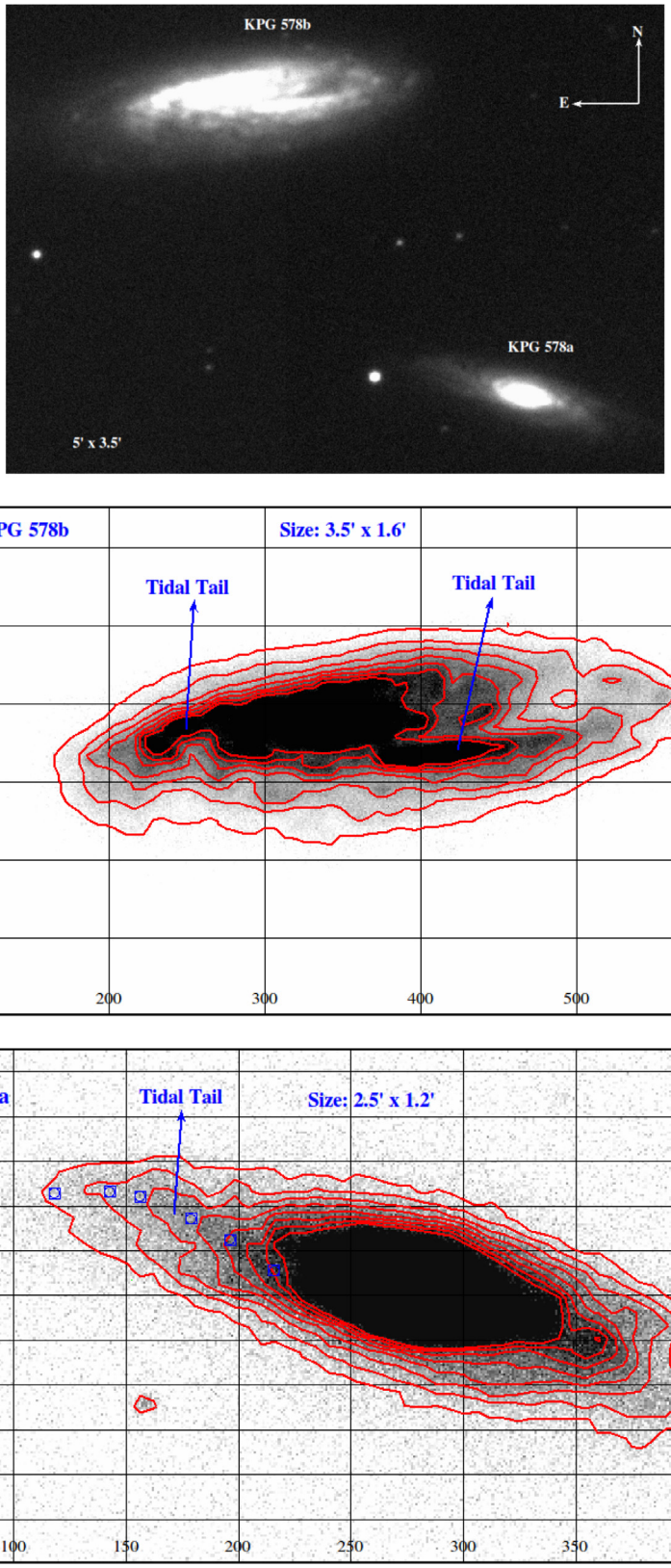

Fig. 1. The first panel: grey image in R-band of the system KPG 578. The second panel: contour maps overlaid on R-image of the KPG 578b. The third panel: contour maps overlaid on R-image of the KPG 578a.

The mean distance D in Mpc of the galaxies in the pair is calculated using this formula:

$$D = \frac{c\ (z_1 + z_2)}{2\ H_0}. \tag{6}$$

The total orbital mass of the pair M_t is calculated using formula of

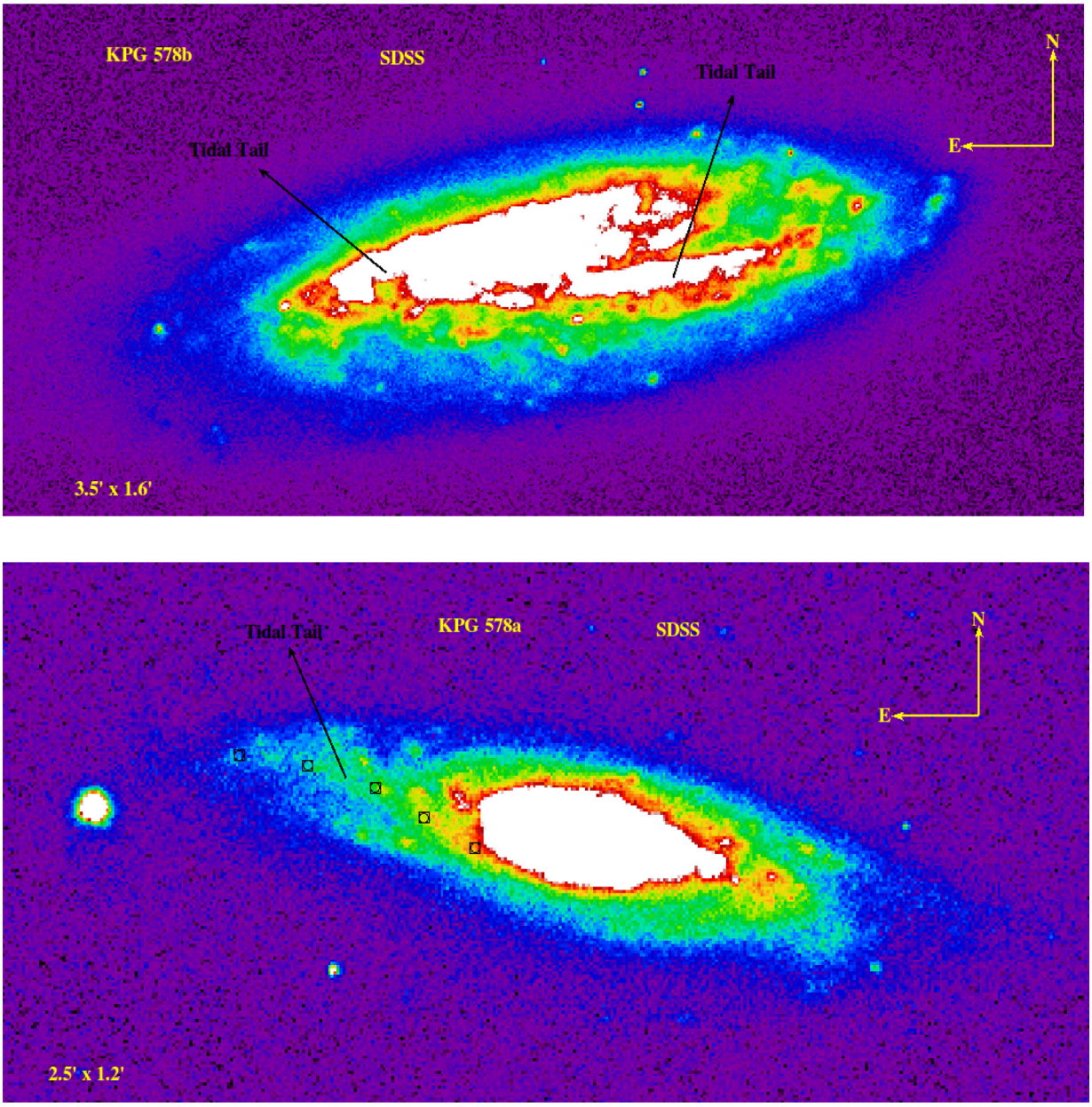

Fig. 2. The first panel: color image in *r*-band of the KPG 578b and the second panel: color image in *r*-band of the KPG 578a of SDSS survey respectively.

Table 4
The surface brightness of the outer isophotes and the interval between successive isophotal contours.

Pair ID	SB (mag/arcsec^2)	Interval (mag/arcsec^2)
KPG 578a	23.11	0.25
KPG 578b	21.53	0.23

Karachentsev (1987):

$$M_t = \frac{32}{3\pi}\frac{r_p\,\Delta v^2}{G}. \quad (7)$$

Where total orbital mass M_t of the pair is in units of solar mass $M_\odot$, G is the universal constant of gravity and the coefficient $(32/3\pi)$ represents projection factors depending on the assumption of a random distribution of the orientation of the pairs and circular motion of the galaxies in the pairs.

The total orbital luminosity of the pair L_t is in units of solar luminously $L_\odot$.

$$L_t = \sum L = L_1 + L_2 \quad (8)$$

Where L_1 and L_2 are the total luminosity of first and second galaxy in the pair with units of solar luminously $L_\odot$.

Table 5
The geometric properties of the interaction signs for the galaxy pair KPG 578.

Pair ID	Tidal Tail		
	Length (kpc)	Thickness (kpc)	Interaction type
KPG 578a	6.9	1.5	CL[a] (NE[b])
KPG 578b	6.6	1.0	CL[a] (E[c])
	11.2	1.2	CL[a] (W[d])

[a] Curved line.
[b] North-East.
[c] East.
[d] West.

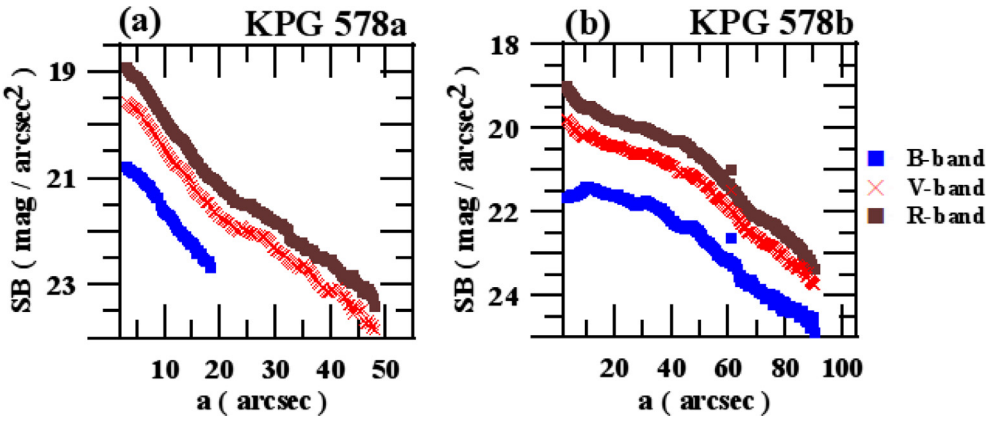

Fig. 3. The surface brightness (*SB*) profiles of the galaxy pair KPG 578.

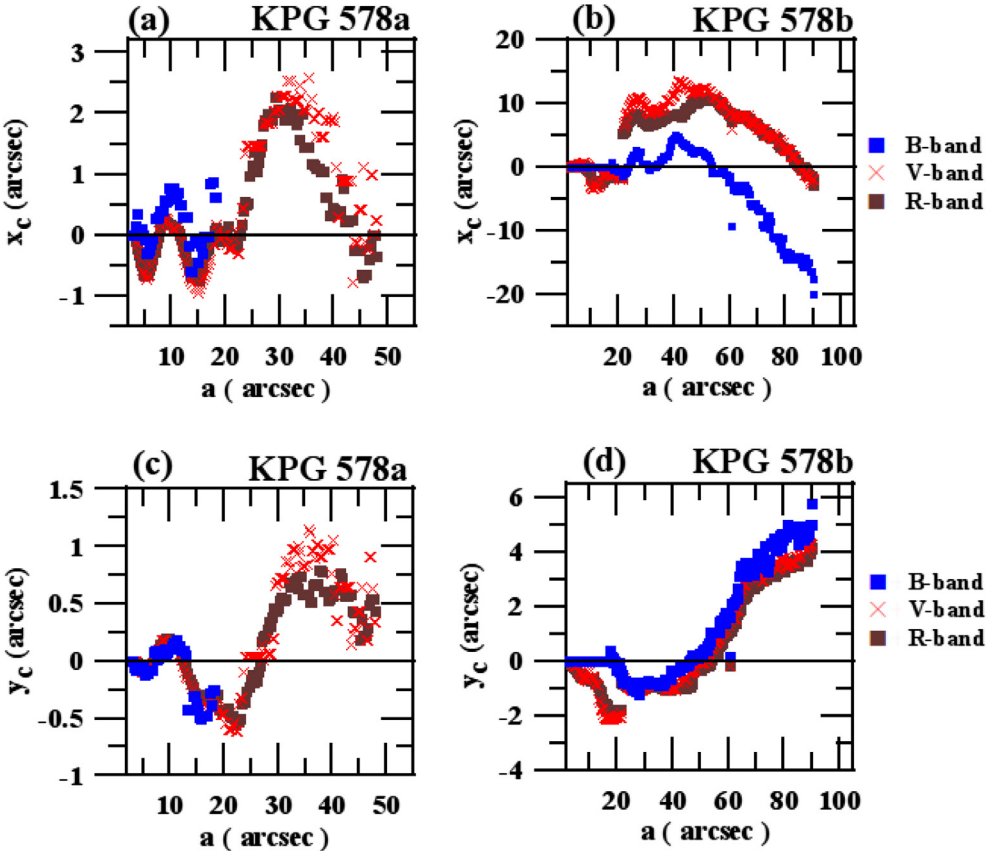

Fig. 4. The first panel presents *x* center-shift profiles, while second panel presents the *y* center-shift profiles of the galaxy pair KPG 578.

Using Eqs. (4) and (5) we have obtained the projected separation of the galaxy pair KPG 578 to be $r_p = 35.4\ h_{70}^{-1}$ kpc and relative velocity$\Delta v = 15$ km/s. Patton et al. (2011) classified galaxy pairs into close pairs ($r_p < 30\ h_{70}^{-1}$ kpc), intermediate pairs ($30 < r_p < 55\ h_{70}^{-1}$ kpc) and wide pairs ($55 < r_p < 80\ h_{70}^{-1}$ kpc) with its relative velocity$300 < \Delta v < 1200$ km/s. According to this classification KPG 578 pair is intermediate pairs.

The calculated mean distance of the galaxy pair KPG 578 is D = 38.3 Mpc (see Eq. (6)). Using Eq. (7) we have determined the total orbital mass of the galaxy pair KPG 578 to be $M_t = 6.03\ x\ 10^9\ M_\odot$. Using the absolute magnitude in R-band of the Sun M(R) = 4.43 mag in the *Vega-mag* system (Willmer, 2018), we have estimated the total luminosity of the pair as $L_t = 4.49\ x\ 10^{10}\ L_\odot$ (see Eq. (8)). The ratio of total orbital mass to total luminosity of the galaxy pair was estimated to be $M_t/L_t = 0.13\ M_\odot/L_\odot$.

3.5. The surface brightness profiles of galaxy pair KPG 578

The surface brightness (*SB*) profile of the galaxy KPG 578a shows a normal profile in BVR bands (Fig. 3a). In B-band, SB started to decreases from a = 3″ to a = 18″, while in VR bands SB started to decrease from a = 3″ to a = 48″, the inner regions are found at semi-major a ≤ 30″, while the outer regions are found within semi-major a > 30″. The SB of the galaxy KPG 578b shows a peculiar structure and peculiar feature profile (Fig. 3b). In B-band, SB started to increase a = 3″–10″ then decreases from a > 10″ to a = 90.3″. In VR bands, SB started to decrease a = 3″–10″. Then again decreases from a > 10″ to a = 90.3″. The inner regions are found within a ≤ 40″, while the outer regions are found within a > 40″. One hump is found on the profile of the galaxy KPG 578a in BVR bands at semi-major from a = 3″ to semi-major a = 8″, some humps in VR bands stared from a = 25″ outward.

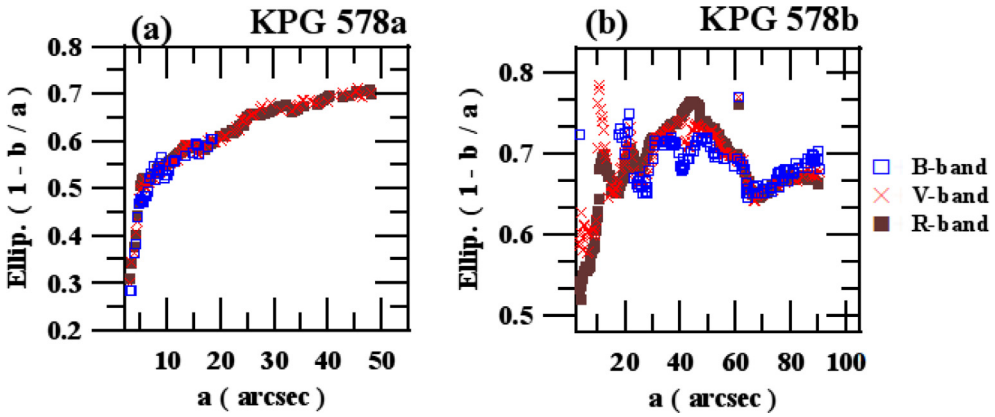

Fig. 5. The ellipticity (*Ellip*) profile of the galaxy pair KPG 578.

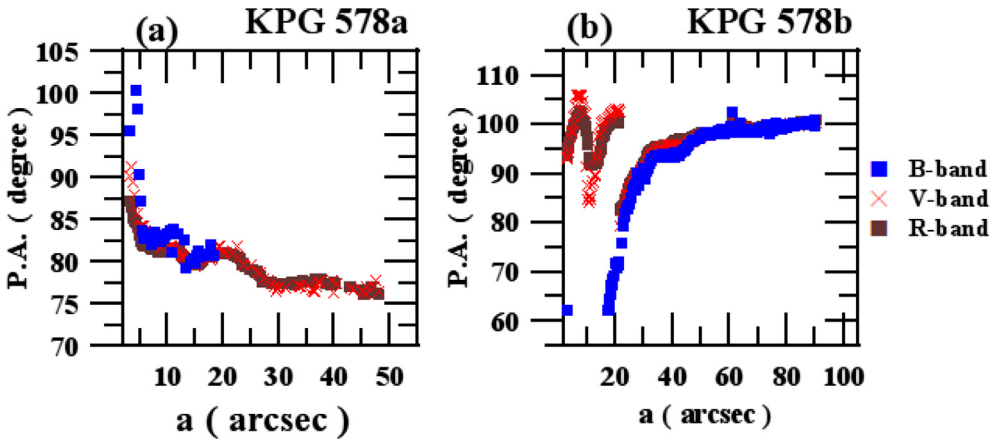

Fig. 6. The position angle (*PA*) profiles of the galaxy pair KPG 578.

Some humps are found on the profile of the galaxy KPG 578b in BVR bands from a = 10″ to 60″.

3.6. The x and y center-shift profiles of galaxy pair KPG 578

The x and y center-shift (x_c, y_c) profiles of the galaxy KPG 578a in BVR bands are shown in Fig. 4(a) and (c). The x and y center of the outer isophotes of the galaxy KPG 578a are shifted toward the galaxy KPG 578b, started from 30″ and 35″ respectively to 47″. The x and y center-shift of the galaxy KPG 578b in BVR bands are shown in Fig. 4(b) and (d). The x center of the outer isophotes of the galaxy KPG578b is shifted away from galaxy KPG 578a, started from 40″ in B and 50″ in VR bands respectively outward. The y center of outer isophotes of galaxy KPG 578b is shifted toward galaxy KPG 578a in BVR bands, started from 50″ outward. This confirms that both galaxies KPG 578a and KPG 578b have signs of interaction.

3.7. The ellipticity profiles of galaxy pair KPG 578

The ellipticity (*Ellip*) profile of the galaxy KPG 578a has been presented in Fig. 5(a). The ellipticity increases in both inner and outer regions in BVR bands. The ellipticity profile of the galaxy KPG 578b has been presented in Fig. 5(b). The ellipticity in the inner regions in BVR bands increases. In the outer regions, the ellipticity decreases within a = 40″–64″, then increases from a > 64″ outward. The outer isophotes of galaxy KPG 578a and galaxy KPG 578b are more flat (i.e. ellipticity values increase). This is due to the gravitational interaction between the galaxies.

3.8. The position angle profiles of galaxy pair KPG 578

The position angle (*PA*) profiles of the galaxy KPG 578a in the BVR bands have been shown in Fig. 6(a). The outer isophotes of the galaxy KPG 578a in BVR bands (a > 30″) are fluctuated from a = 30″ outward. The position angle profiles of the galaxy KPG 578b in the BVR bands are shown in Fig. 6(b). The outer isophotes of the galaxy KPG 578b in BVR bands (a > 40″) are twisted to south toward the tidal tail of galaxy KPG 578a at north-east. This means that the KPG 578a attracted the galaxy KPG 578b from side of its tidal tail at the east. The twisted outer isophotes of KPG 578b confirm that the galaxy pair KPG 578 is an interacting system.

4. Conclusions

The gravitational interactions between the galaxies of galaxy pair KPG 578 have been investigated using our method: contour maps, surface brightness (*SB*) profiles, x and y center shift (x_c, y_c) profiles, ellipticity (*Ellip*) profiles and position angle (*PA*) profiles. We have confirmed that the galaxy pair KPG 578 is an interacting system. We have found that galaxy KPG 578a has one tidal tail in the north-east from the center with its length is l_t = 6.9 kpc, its thickness h_t = 1.5 kpcand its areaA_t = 10.4 kpc^2. The KPG 578b has two tidal tails, one of them in east from the center with its length is l_t = 6.6 kpc, its thickness is h_t = 1.0 kpcand its area is A_t = 6.6 kpc^2, while second tidal tail is in the west with its length is l_t = 11.2 kpc, its thickness is h_t = 1.2 kpcand area isA_t = 13.4 kpc^2. Only one author noticed that KPG 578b has a straight line of matter proceeds to west from the center along the major axis (Curtis, 1918). This straight line of matter proceeds to west is tidal tail with curved line not a straight line. We

confirmed that the galaxy pair is an interacting system which is opposite to what found by Karachentsev (1987) and de Vaucouleurs and de Vaucouleurs (1964).

Using surface brightness profile, we have confirmed that the KPG 578b is a peculiar galaxy with peculiar features in a good agreement with Elfhag et al. (1996). Also our results of contour maps show that KPG 578b has asymmetry along the semi-major which agrees with Heraudeau et al. (1996). Using *PA* profiles, we noticed that the KPG 578b is twisted to south toward KPG 578a.

Using classification of Patton et al. (2011) for galaxy pairs, the KPG 578 is classified intermediate pair with projected separation $r_p = 35.4\ h_{70}^{-1}$ kpcand relative velocity$\Delta v = 15$ km/s. By assuming that galaxies in galaxy pairs are in a circular orbit relative to each other, the total orbital mass of KPG 578 is $M_t = 6.03 \times 10^9\ M_\odot$, while the total orbital mass to the total luminosity is $M_t/L_t = 0.13\ M_\odot/L_\odot$. Karachentsev (1987) found that galaxy pairs are physical systems if $M_t/L_t < 100 M_\odot/L_\odot$. So the KPG 578 is considered as physical systems.

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