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Inspecting PGC 165324 and PGC 977941 Galaxies Using a Combination of Photometric and Spectroscopic Methods

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Abstract.

Photometric and spectroscopic approaches were utilized to examine the two galaxies, PGC 165324 and PGC 977941. Data releases (DR7 and DR17) from "The Sloan Digital Sky Survey (SDSS)" were employed to acquire the observed data. Then, ellipsoids were fitted via employing the Image Reduction and Analysis Facility (IRAF) with utilising STSDAS Library, the ELLIPS task. Along with the astrometric characteristics, the surfaces' brightness of the galaxies PGC 165324 and PGC 977941, as well as their magnitudes, cumulative flux, central axis position angles, ellipticities, vertical and horizontal shifts, isophotal shape variables (B4), and also the star-forming rates (SFRs), were analysed and evaluated. It was indicated that the two galaxies, are members of a close pair galaxy system; in addition, they are considered a physical system; the PGC 165324 galaxy was a merging galaxy with a higher SFR. It was likely that the PGC 977941 had separated itself from the galaxy collision and drifted away.

Keywords: Interacting galaxies, merging galaxies, PGC 165324, PGC 977941, spectroscopy, and surface photometry.

فحص المجرتين PGC 165324 و PGC 977941 باستخدام مزيج من الطرق الضوئية والطيفية

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الخلاصة

تم استخدام طرق التحليل الضوئي والطيفي لفحص المجرتين PGC 165324 و PGC 977941 ; اصادرين البيانات السابع والسابع عشر (DR7 and DR17) من "The Sloan Digital Sky Survey (SDSS)" وظفت لجمع البيانات الرصدية ، ثم عمل ال fitted للقطع الناقص باستخدام برنامج "The Image Reduction and Analysis Facility (IRAF)" مع استخدام مكتبة STSDAS , ELLIPS task . إلى جانب الخصائص الفلكية ، لمعانية اسطح المجرات PGC 165324 و PGC 977941 و الاقدار و الانبعاث التراكمي و زوايا انحراف المحور المركزي و شكل القطع الناقص و الانحرافات العمودية والأفقية و ومتغير كيرشوف الرابع للشكل (B4) و ايضا معدلات تشكل النجوم(SFR) تم تحليلها وتقيمها . تبين ان المجرتين عضوتان في نظام مجري زوجي قريب ؛ بالإضافة إلى ذلك ، اعتبرا نظامًا فيزيائيًا ؛ المجرة PGC 165324 مجرة مندمجة مع معدل تشكل نجوم عالي . من المحتمل ان تكون المجرة PGC 977941 قد انفصلت من الاصطدام المجري وانحرفت بعيدا عنه.

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1. Introduction

The visible universe constitutes of nearly 2×10^{12} galaxies[1], which are the primary structural components of the universe [2]. Galaxies are not precisely evenly spread all through the universe [3].The cosmic web has been composed of voids and also filaments throughout the universe. Galaxy groups and clusters have been found at the grid's knots, where filaments intersect[4]. Due to this irregular spread of galaxies, galaxy pairs were more likely to form and interact [5]. It was essential to examine pairs of galaxies and also their interactions to understand these influences on the morphological characteristics, star-forming rate, formation, and gravity effects of galaxies[6, 7]. In astronomy, surface photometry is a useful method to determine the brightness of galaxies' surfaces. These indicators are integrated with spectral analysis of galaxies to yield crucial data about the morphology, evolution, formation, and rate of star - forming of galaxies [8, 9]. The analysed pair was an isolated pair composed of two galaxies [10], as displayed in Figure1.

The primary galaxy of the pair is SDSS J014448.46 - 102726.3, also referred to as PGC 165324, and 2MASX J01444841-1027260 per (SDSS), "The Principal Galaxy Catalog (PGC)", and"2 Micron All Sky Survey Extended (2MASX)" ,respectively according to HyperLEDA. It had an unknown morphology type, but with an interaction sign according to Lintott [11], several catalogers found that the galaxy had a probability to be a late type galaxy, a spiral [12, 13] with a bar signature, a disky system, and a merger [11].
The pair's secondary galaxy is SDSS J014448.02-102737.4, also termed as PGC 977941. It was noticed that perhaps the galaxy was a merger with an uncertain shape, according to Lintott [11], However, Kuminski also identified that the galaxy was likely to have a spiral morphology [13]. The basic information for the pair's two galaxies is presented in Table 1.

Table 1: The basic information for the pair of galaxies

Galaxy Name	PGC 165324	PGC 977941
RA(deg)	26.202 [a]	26.200 [a]
Dec(deg)	-10.457 [a]	-10.460 [a]
Redshift	0.0433 [b]	0.0433 [b]
Type	S ? [d]	? [d]
Sub type	Starburst [c]	Starforming [c]
Semi major axis (kpc)	19.43 [a]	4.61 [a]
Inclination (deg)	59.4 [d]	51.4 [d]
Position Angle (deg)	169.5 [d]	43.7 [d]
Apparent magnitude in B-band (mag)	15.02 [d]	16.54 [d]

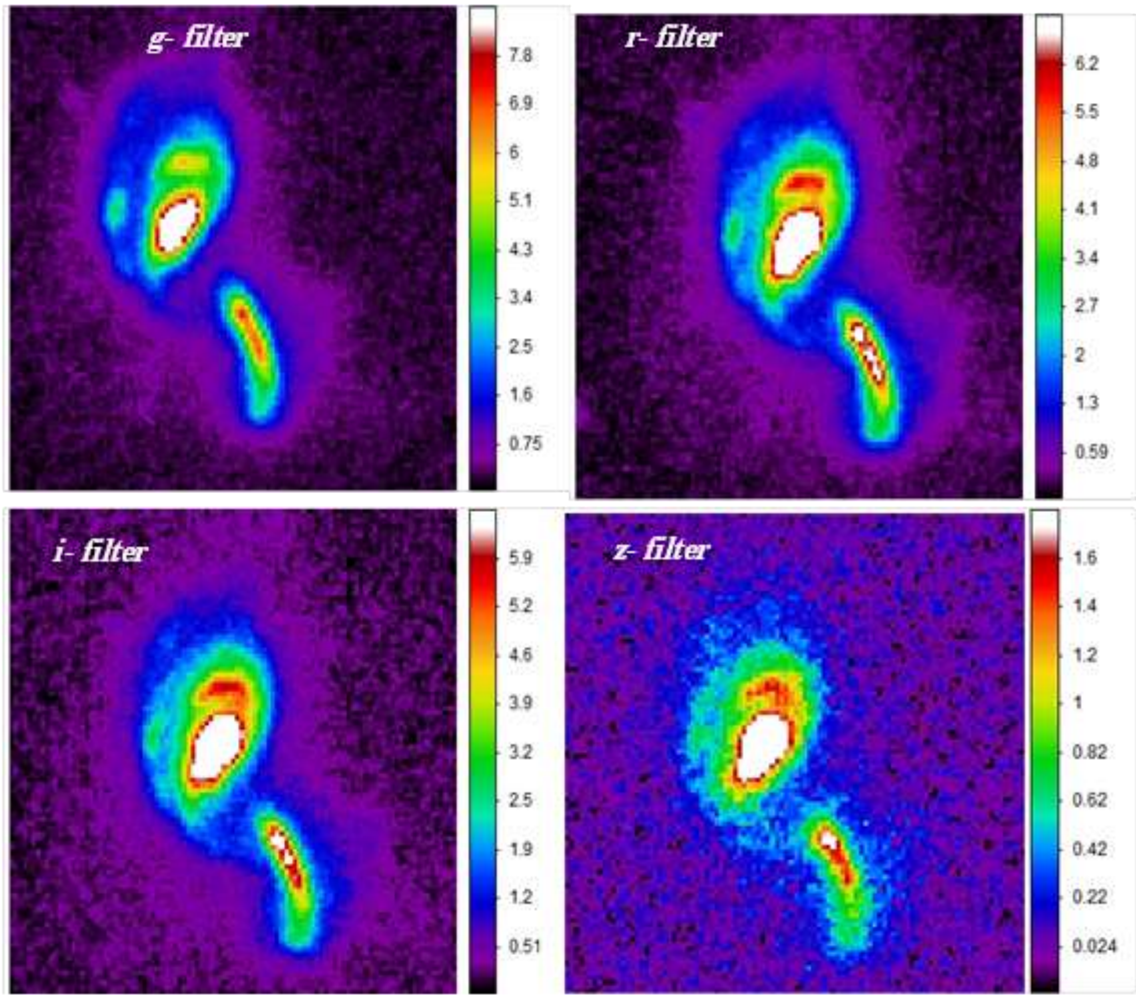

Figure 1: Griz-filtered color images of the Sip-39 pair galaxy, the north was indeed up, and the east was to the left.

[a] NED , [b] SDSS , [c] VizieR , [d] HyperLEDA

2. Observations and Reduction of Data

The SDSS's data releases (DR7 and DR17) provide the observational data of the galaxies in the pair [14, 15]. For each image of these galaxies, the flat and bias field frames were modified via the SDSS pipeline. Image Reduction and Analysis Facility (IRAF) with STSDAS Library's ELLIPS task were employed to fit the galaxy pair's isophotes in griz filters to ellipses. The ELLIPS task can then be used to determine two galaxies in the pair PGC 165324 and PGC 977941 intensities (I) , total fluxes (f), ellipticities (e), position angles (PA), vertical and horizontal variations (x_c, y_c -shift), and isophotal shape parameters (B4) as functions of these galaxies' semi-major axes[16]. Due to the distortions and centre shifts of the isophotes of galaxies, those photometric results allowed us to investigate the interaction and merger situations of the galaxy pair[7].

The reductions of observation data have been done for all frames of images of the two galaxies in the pair PGC 165324 and PGC 977941 by deducting intensities of the sky background, transforming frame units from pixels to arcsec^2, and uniting the exposure time to 1 second. Utilizing Eq. 1[17], the magnitude (m) of each frame of a galaxy image is computed from the intensities (I) and compensated for galactic and also atmospheric extinction.

$$m = 2.5 \log\left(I * 10^{(m_z + k_a + airmass)}\right) \tag{1}$$

Where m_z: the magnitude of zeropoint, k_a the extinction of atmosphere, airmass the SDSS observations airmass. Those griz filter values are presented in Table 2 for both galaxies.

Table 2: The zeropoint magnitude (m_z), an atmospheric extinction (k_a), and an airmass for the two galaxies in the pair PGC 165324 and PGC 977941 from SDSS

Filters	Air mass	m_z	K_a
g	1.389	-24.563	0.175
r	1.384	-24.083	0.105
i	1.385	-23.661	0.062
z	1.388	-21.956	0.034

3. Results and Discussions:

3.1 PGC 165324 and PGC 977941 Morphologies and Contour Maps

The contour maps of both galaxies in the pair in g, r, i, and z filters, created as a result of DS9 analysis, were plotted in Figure 2.

In all the bands, the primary galaxy in the pair PGC 165324 appears to have a major axis diameter of roughly 9 kpc with surface brightness levels of 22.19, 21.61, 21.25, and 21.20 (mag/arcsec^2), respectively. It would seem to have a bright bulge encircled by a symmetrical disc system until 2.7 kpc, where contour layers appear to have expanded to the north due to an influence corresponding to another mass located close to the galactic center. In other words, there is a second bulge fainter than the main one that causes this behavior, and it increases the possibility of the galaxy being a merger.

Whereas the PGC 977941 galaxy would appear to have a vertically stretched bright bulge surrounded by an asymmetric structure, it would appear to have a major axis diameter of approximately 5.5 kpc at the surface brightness levels of 22.19, 21.61, 21.25, and 21.20 (mag/arcsec2). Table 3 presents the surface brightness levels of the griz outer isophotes of the two galaxies

Table 3: The outer isophotes' surface brightness levels of two galaxies

Galaxy	Filter	Step	Surface brightness (mag/arcsec ^{2})	Magnitude (mag)
PGC 165324 PGC 977941	g	1.1	22.19	24.20
	r	1.3	21.61	23.62
	i	1.3	21.25	23.26
	z	0.3	21.20	23.21

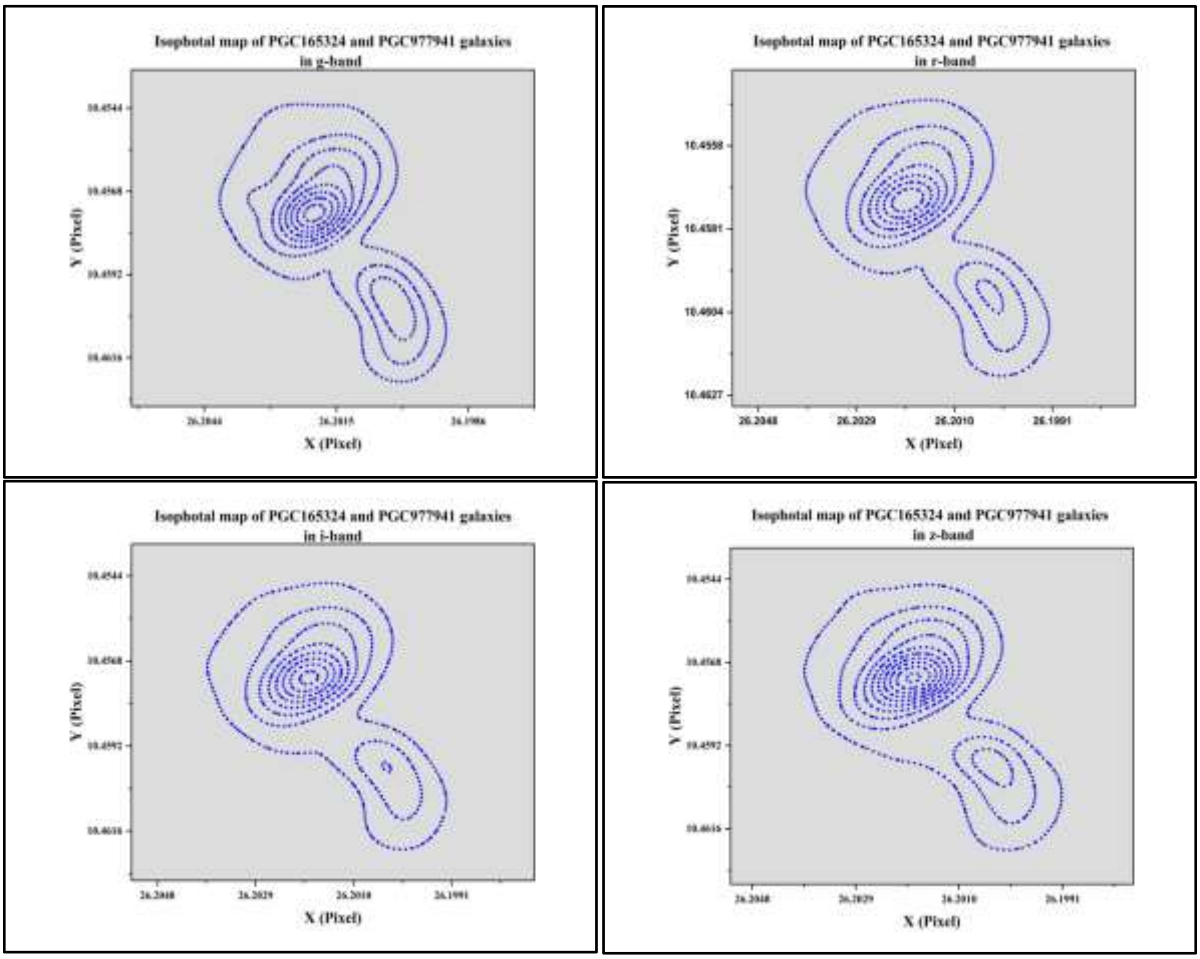

Figure -2 The griz contour maps of the PGC 165324 and PGC 977941 galaxies. The north was indeed up, and the east was to the left

The PGC 165324 and PGC 977941 Galaxies' Center Shifts The factors (x_c, y_c) that clarify the shift of the centres of the two galaxies in the pair PGC 165324 and PGC 977941 in the g, r, i, and z filters are shown in Figs. 3 and 4. Figure 3 shows the x_c of the two components of the galaxy pair. The PGC 165324 galaxy's x_c values appear to demonstrate a considerable shift apart from the other pair's member in the g, r and i bands, beginning at about 2.7 kpc from the centre and extending to the galaxy's edges. These deviations reach around 2.6, 1.7, and 0.9 kpc in the g, r and i bands, respectively. Additionally, the x_c values exhibit a significant variation at the galaxy's outer edge, especially in the g band, and to a lesser extent in the r and i bands.

PGC165324 **PGC977941**

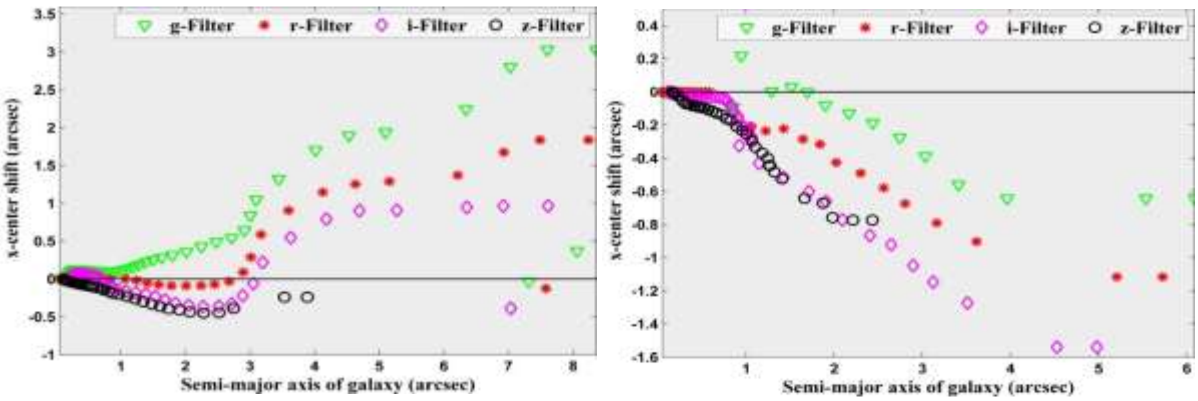

Figure - 3 The x centre shift (x_c) of the galaxies PGC 165324 (left) and PGC 977941 (right) as a function of their semi-major axes

However, from the other side, the x_c values of the PGC 977941 galaxy seem to exhibit a distinct change as opposed to the PGC 165324 galaxy in all bands, starting nearly one kpc from the galaxy's centre and going to the galaxy's edges. These variations in the g, r, i and z bands are roughly 0.6, 1, 1.4, and 0.7 kpc, respectively.

The y_c results of the PGC 165324 galaxy are first starting to reduce from around 2.75 to 4.5 kpc from the galaxy's centre with shift values roughly 0.5 and 0.15 in the g, r, and i bands, but then rising from about 4.5 kpc to the outer parts of the galaxy away from the PGC 977941 galaxy with shift values that are around 0.8, 0.7, and 0.85 in the g, r, and i bands. Besides that, the y_c values showcase a slight change at the galaxy's outer layers, particularly in the g band and, to a lesser extent, in the r and i bands.

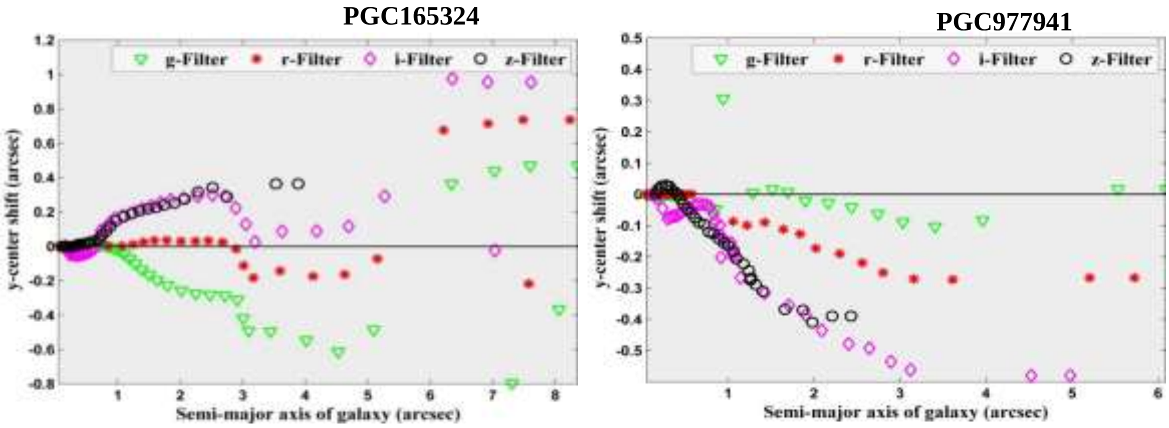

Figure - 4 The y centre shift (y_c) of the galaxies PGC 165324 (left) and PGC 977941 (right) as a function of their semi-major axes

While the PGC 977941 galaxy yc measurements begin to fall from the inner to the outer parts of the galaxy with shift values, they reach 0.24, 0.53, and 0.35 kpc in the r, i, and z bands in the reverse direction to another galaxy in the pair, as shown in Figure 4. This is evidence that the two galaxies are moving apart from one another.

3.2 The PGC 165324 and PGC 977941 Galaxies' Position Angles

The galaxy PGC 165324, as well as the galaxy PGC 977941, position angles (PA) within the griz bands are displayed in Figure 5. The PA of the PGC 165324 galaxy tends to drop along the semi-major axis until 3.2 kpc by approximately 60, 30, and 45 degrees in the g, r, and i bands, respectively, and then modestly increase from 3.2 to 5.8 kpc by nearly 5-10 degrees in the g, r, and i bands, whereas at the galaxy's outer layers, from 5.8 kpc forward, the PA dips to the east by around 20 and 10 degrees in the g , r, and i bands, respectively. Furthermore, the PA shows a significant variation at the galaxy's outer layers, with values reaching 30, 25, and 15 degrees to the north in the g, r, and i bands, they show that the galaxy PGC 165324 convolutes apart from the galaxy PGC 977941.

However, unlike the PGC 165324 galaxy, the PA of the PGC 977941galaxy increases gradually by around 10–30 degrees in the outer region of the galaxy in the g, r, and i bands; this means that the PGC 977941 galaxy convolves to the east away from the PGC 165324galaxy; see Figure 5.

3.3 The PGC 165324 and PGC 977941 Galaxies' Ellipticities

The ellipticity (E) values of the PGC 165324 galaxy show significant fluctuations in the inner part until approximately one kpc; after that, there is an explicit behaviour in which the E values drop along the semi-major axis unless a hump arises that is prolonged from 2.5 to 5 kpc; moreover, the E values demonstrate a noticeable upward shift at the outer borders, in the g, r, and i bands. That seems to be the flattening of the outer part of the galaxy declined slightly.
Nevertheless, the PGC 977941 galaxy's ellipticity estimates also exhibit considerable fluctuations in the i and z bands in the inner part till around one kpc; afterwards, the E values drop slightly along the semi-major axis in the g, r, i, and z bands, suggesting that the outer parts of the PGC 977941galaxy tend to be less flattened (see Figure 6).

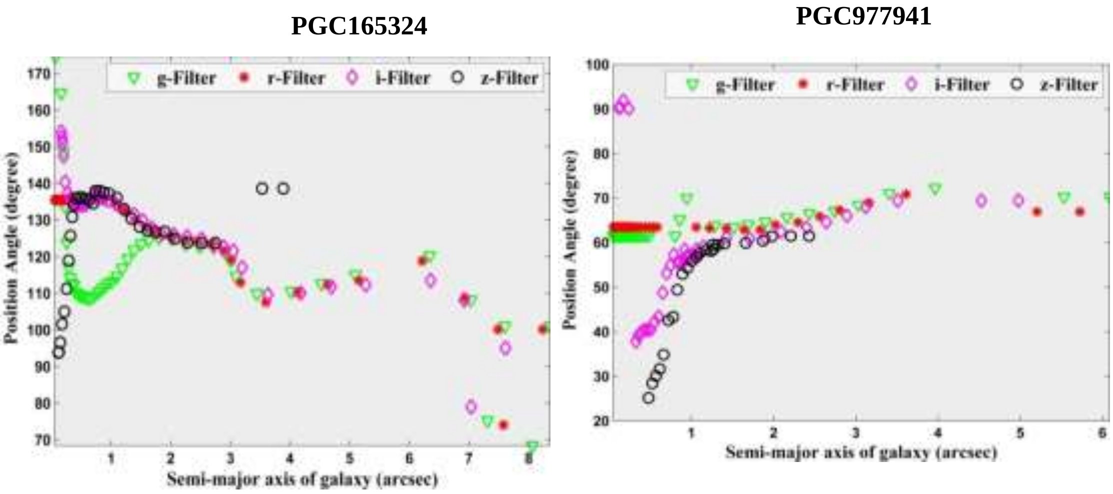

Figure 5: The Position Angle (PA) of the galaxies PGC 165324 (left) and PGC 977941 (right) as a function of their semi-major axes

3.4 The Fourth Harmonic Deviation from an Ellipse (B4) of the Two Galaxies

The measurements of the 4th harmonic variance from that of an ellipse (B4) of the galaxy PGC 165324, in addition to the galaxy PGC 977941, are shown in Figure 7. In the g, r, i and z bands, firstly, the B4 values for the PGC 165324 galaxy oscillate around zero until 1.8 kpc. Secondly, at roughly 2.8 kpc, a distinct hump appears. Thirdly, the behaviour of B4 after that remains somewhat stable along the semimajor axis until the outer layers once the B4 levels are sifted downward; the above indicates a distortion in shape in both the interior and exterior regions of the PGC 165324 galaxy.
Whereas the B4 values of the galaxy PGC 977941 begins to fall along the galaxy's semimajor axis, which appears obviously in the g and r bands, however, the i and z bands demonstrate some fluctuations of the B4 in the inner part of the galaxy, implying that the PGC 977941 galaxy is becoming more distorted. See Figure 7.

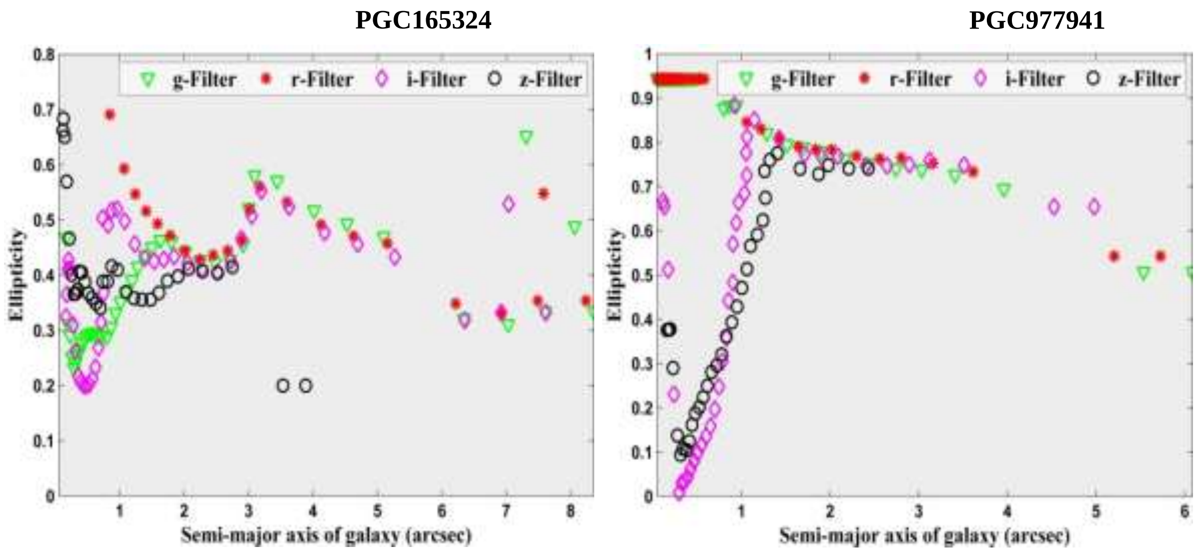

Figure 6: The Ellipticity (E) of the galaxies PGC 165324 (left) and PGC 977941 (right) as a function of their semi-major axes

3.5 The Magnitude of the PGC 165324 and PGC 977941 Galaxies

The magnitudes of the PGC 165324 galaxy display acceptable behaviour in all bands, starting to drop from the galaxy's centre towards its periphery unless a hump arises at about 2.8, as well as some variability at the galaxy's periphery in the g, r, and i bands. While the magnitude of the PGC 977941 galaxy similarly shows normal behaviour, decreasing along the semimajor axis from the galaxy centre toward the galaxy edges in all bands, as seen in Figure 8
Using equation 1, cumulative flux measurements could be utilized to determine the two galaxies' total apparent magnitudes. Table 4 presents both computed adjusted apparent magnitudes (m) and SDSS apparent magnitude values (for contrast) in griz bands.

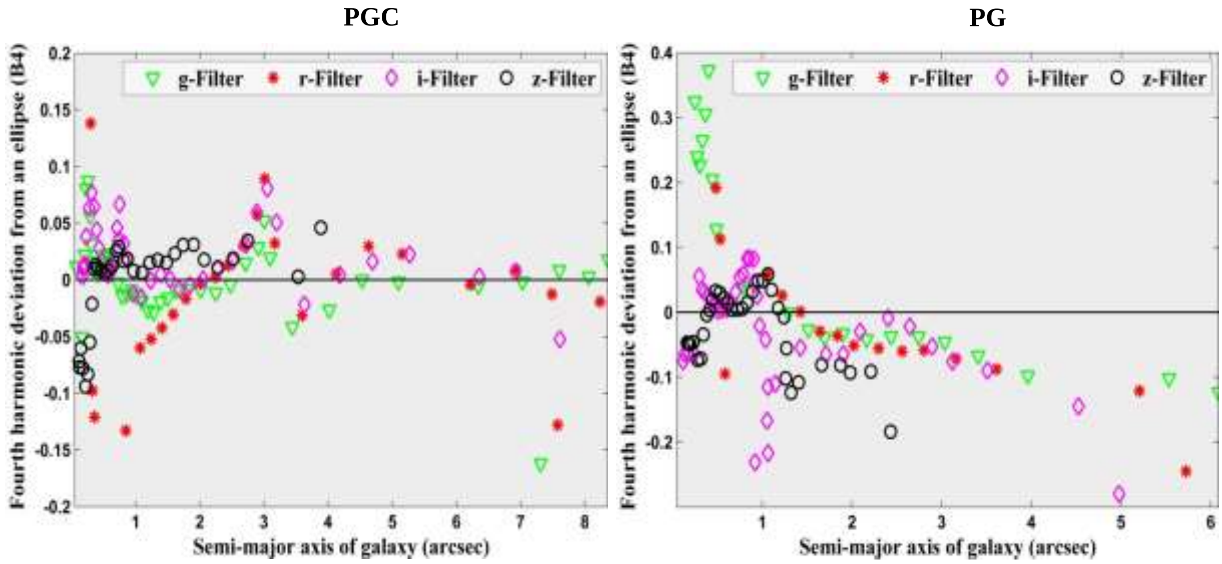

Figure -7 The fourth harmonic deviation from an ellipse (B4) of the galaxies PGC 165324 (left) and PGC 977941 (right) as a function of their semi-major axes

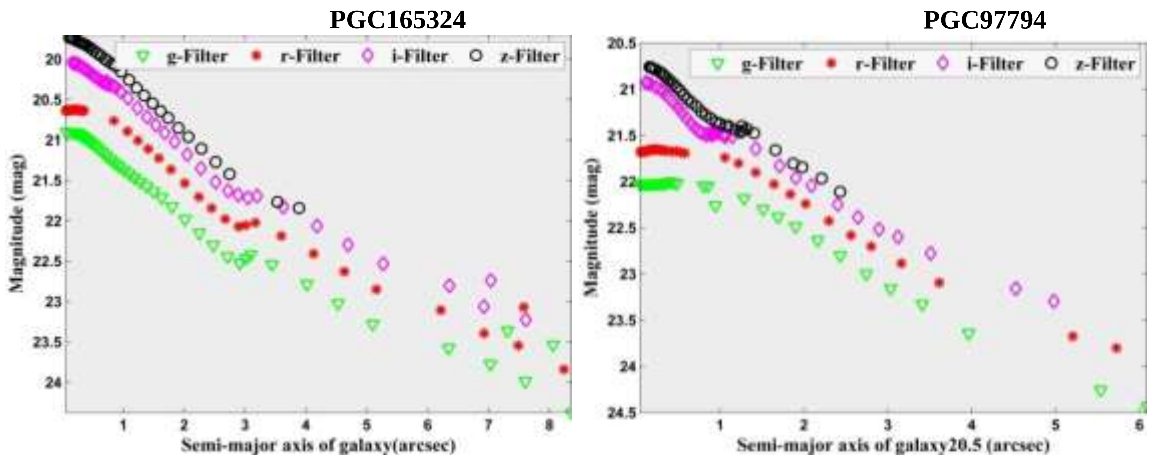

Figure 8: The magnitude of the galaxies PGC 165324 (left) and PGC 977941 (right) as a function of their semi-major axes

Table 4 -The computed adjusted apparent magnitudes (m) and the apparent magnitudes from SDSS in the g, r, i, and z bands

Galaxy	Our work				SDSS			
	(m_g)	**(m_r)**	**(m_i)**	**(m_z)**	**(m_g)**	**(m_r)**	**(m_i)**	**(m_z)**
PGC 165324	15.29	14.80	14.50	14.90	15.07	14.54	14.1	13.82
PGC 977941	16.16	15.83	15.70	16. 40	16.54	16.17	15.91	15.79

3.6 The Astrometric Results of the PGC 165324 and PGC 977941 Galaxies

After implementing Hubble's law, Eq. (2) is used to determine the average distance (D_a) of the two galaxies as a pair in megaparsecs (Mpc)[18]:

$$D_a = \frac{c\, z_a}{H_o} \tag{2}$$

Where H_o represents the Hubble constant (70 km/s .Mpc), za the average redshift ($z_a = z_1+z_2$ / 2), and c the speed of light[19].

The separation distance (d_{sep}) between the two galaxies has been calculated using Karachentsev's equation[20]:

$$d_{sep} = \theta_{12} D_a \tag{3}$$

Wherein the two galaxies are isolated by an angle called θ_{12}. The following equation is also employed to obtain the relative velocity (v_r) of the two galaxies [20]:

$$v_r = \sqrt{(cz_1 - cz_2)^2} \tag{4}$$

Whereas the following equation can actually be used to derive the combined orbital mass of the two galaxies as a pair (Mp) in terms of the sun's mass ($M_\odot$) [20]:

$$M_p = 3.4\, \frac{d_{sep}\, v_r^2}{G} \tag{5}$$

(G: the gravity's constant), the results of the calculations mentioned above are shown in Table 5.

Table 5: The Astrometric results of the PGC 165324 and PGC 977941 galaxies

D_a(Mpc)	d_{sep} (kps)	v_r ($km.s^{-1}$)	M_p ($M_\odot$)
185.68	11.60	7.29	4.84×10^{8}

Cumulative flux data from the two galaxies PGC 165324 and PGC 977941 can be used to calculate their apparent magnitude (m_G), absolute magnitude (M_G), and luminosity (L_G) as a pair relative to the luminosity of the sun ($L_\odot$) for g, r, i, and z bands by applying Eqs. (1, 6, and 7), Consequently, the mass-to-light ratio (M_p/L_G) is also predicted for the same bands, as seen in Table 6 [17, 21, 22].

$$m_G - M_G = 5 \times \log g \left(\frac{D_a(\text{Mpc})}{10}\right) \qquad (6)$$

$$M_G - M_{(g,r,i,z)\odot} = 2.5 \times \log g \left(\frac{L_\odot}{L_G}\right) \qquad (7)$$

Where $M_{(g,r,i,z)\odot}$ denoted the absolute magnitude of the sun per the Vega system[23], and $L_\odot$ luminosity of the sun .

Table 6: Apparent magnitude (m_G), absolute magnitude (M_G), luminosity (L_G),the mass-to-light ratio of the galaxies PGC 165324 and PGC 977941

Bands	m_G(mag)	M_G(mag)	L_G ($L_\odot$)	M_p/L_G ($M_\odot/L_\odot$)
g	14.89	-21.46	4.74×10^{10}	0.0102
r	14.44	-21.90	3.74×10^{10}	0.0123
i	14.20	-22.15	3.43×10^{10}	0.0141
z	14.65	-21.60	1.91×10^{10}	0.0252

3.7 The PGC 165324 and PGC 977941 Galaxies' Spectrum and Star Formation Rates

The spectra of the PGC 165324 galaxy reveal significant emission lines of OII, Hβ, Hα, NII, and SII. On the other hand, the spectra of the PGC 977941 galaxy likewise demonstrate significant emission lines of OII, OIII, Hα, NII, and SII, as seen in Figs. 9 and 10. Because the OII emission lines' luminosity depends on ionisation photons, it is possible to use them to estimate the star-forming rates (SFR) of the PGC 165324 and PGC 977941 galaxies.

The SFR has been derived utilizing Eqs. (8 and 9) [24], relying on just the OII emission lines of the PGC 165324 and PGC 977941 galaxies, the results are presented in Table 7:

$$\text{SFR } (M_\odot/\text{year}) = \frac{F}{3\times10^{33}} \qquad (8)$$

$$F = 4\times\pi\times D_F \times S_{OII} \qquad (9)$$

Where F is Luminosity of OII emission line, D_F is the galaxy luminosity distance, S_{OII} is Flux of OII emission line.

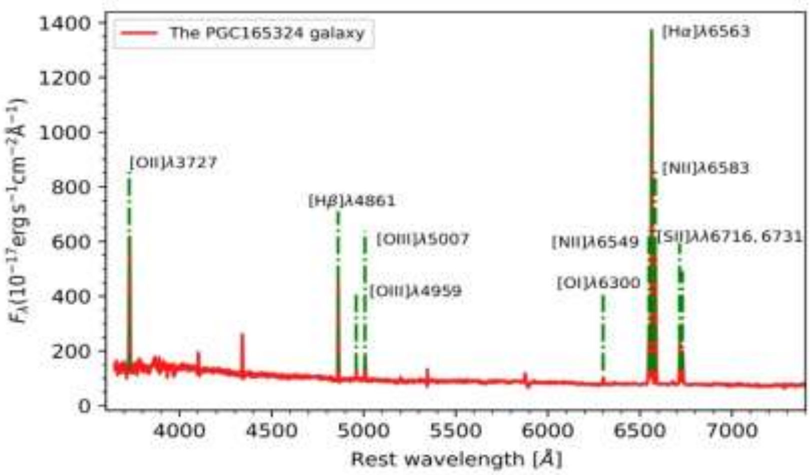

Figure - 9 The PGC 165324 galaxy's spectra

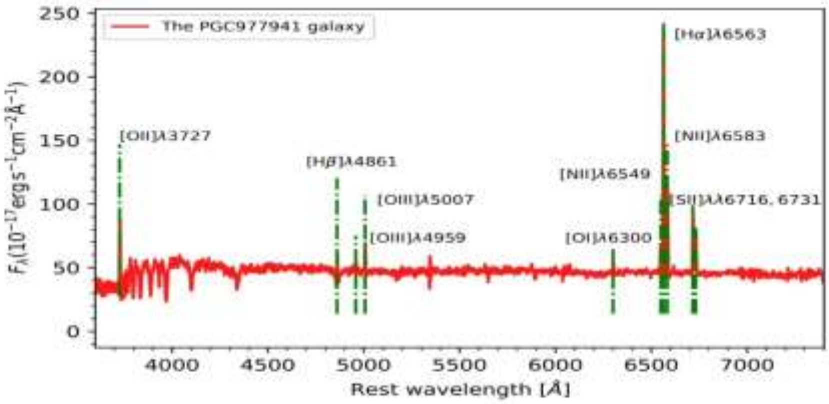

Figure 10: The PGC 977941 galaxy's spectra

Table 7: The PGC 165324 and PGC 977941 galaxies' estimated SFR, distance, redshift, and flux

Galaxy	S_{OII} (10^{-17} erg.s^{1}.cm^{-2})	z	D_F (Mpc)	SFR ($M_\odot$/Yr)
PGC 165324	2078.9	0.043	190.2	3.03
PGC 977941	160.6	0.043	190.2	0.234

4. Conclusions

All of the preceding estimates and discussions lead to the following conclusion:

1. The PGC 165324 galaxy's contour maps and photometric results revealed two distinct, peculiar effects occurring in two different regions of the galaxy; the first, in the inner region, belonged to the gravitational influence of the secondary mass located close to the galactic centre, indicating that the galaxy was a merging galaxy. In the outer region, the latter belonged to the gravity effect of the PGC 977941 galaxy, implying that the PGC 165324 galaxy was paired with it. At the same time, the results of the galaxy PGC 977941 also imply that the galaxy was affected by the other one and paired with it as well.
2. Following Patton's description [25], the two galaxies PGC 165324 and PGC 977941 have been considered a close galaxy pair, with a separation distance of 11.6 kpc and a relative velocity of 7.29 km/s.
3. The mass-to-light ratio of the two galaxies PGC 165324 and PGC 977941 as a pair was determined to be approximately 0.01 $M_\odot/L_\odot$, confirming that they are a physical system per Karachentsev's Conception [20].
4. The SFRs of the two galaxies, PGC 165324 and PGC 977941, have been derived to being 3.03 and 0.234 $M_\odot$/Year, in both. However, the PGC 165324 galaxy has a greater SFR than the PGC 977941 galaxy PGC 977941; due to its being a merged galaxy that led to an increase in the SFR.

From all the above, we indicate that the two galaxies PGC 165324 and PGC 977941 are a close pair galaxy system; the PGC 165324 is a merged galaxy. The PGC 977941 may be separated from galaxy collision and moving away; these partially agree with those of Lintott et al. [11] and Kuminski et al. [13].

5. Acknowledgments

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