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Explaining the photometric and spectroscopic properties of The Sip-39 galaxy pair

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Abstract

The Sip-39 pair's galaxies have been investigated using photometric and spectroscopic methods; the observation data was collected from the SDSS's Data Release (DR17) and fitted to ellipses through utilizing the Image Reduction and Analysis Facility (IRAF) with STSDAS Library using ELLIPS task. The surface brightness of the two galaxies in the pair, as well as total flux, ellipticities, major axis position angles, both vertical and horizontal shifts, isophotal shape factors (B4), magnitudes, and the star-forming rates (SFR), in addition to the astrometric parameters of the pair, were evaluated. It appeared through data analysis that the Sip-39 pair is a closely interacting pair with clear interaction signs, and it is deemed to be a physical system with enhanced SFR.

Keywords: Galaxies, Interacting galaxies, Sip-39 galaxy pair, spectroscopy, and surface photometry.

Introduction

The distribution of galaxies throughout the universe is not exactly uniform. Approximately half of the galaxies in the local Universe appear to have been consolidated into groups and clusters at redshifts equal to or less than 0.1. An additional 20% of galaxies are in collapsing areas near these groups and clusters[1]. Current three-dimensional redshift surveys for galaxies in large-scale visible universe structures, such as the Sloan Digital Sky Survey (SDSS)[2], have revealed a hierarchical organisational structure of galaxies' distribution in which there is a region with a very high population density known as filaments that are surrounded by vast areas with almost no galaxies defined as Voids[3]. This random distribution of galaxies increased the possibility of galaxy pairs forming and interacting[4].

The study of pairs of galaxies and their interactions was critical in order to investigate these impacts on the morphological features of galaxies, creation of galaxies, the star-forming rate, and gravity interaction among galaxies [5].

Surface photometry is an effective method in astronomy for measuring the brightness of galaxies' surfaces. These measurements are coupled with spectroscopic analysis of galaxies to obtain important details about the galaxies' morphology, formation, evolution, and rate of star formation [6-8]. The studied pair was an isolated pair, which consists of two galaxies as shown in Deep Space 9 software (DS 9) Fig 1.

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Baghdad Science Journal

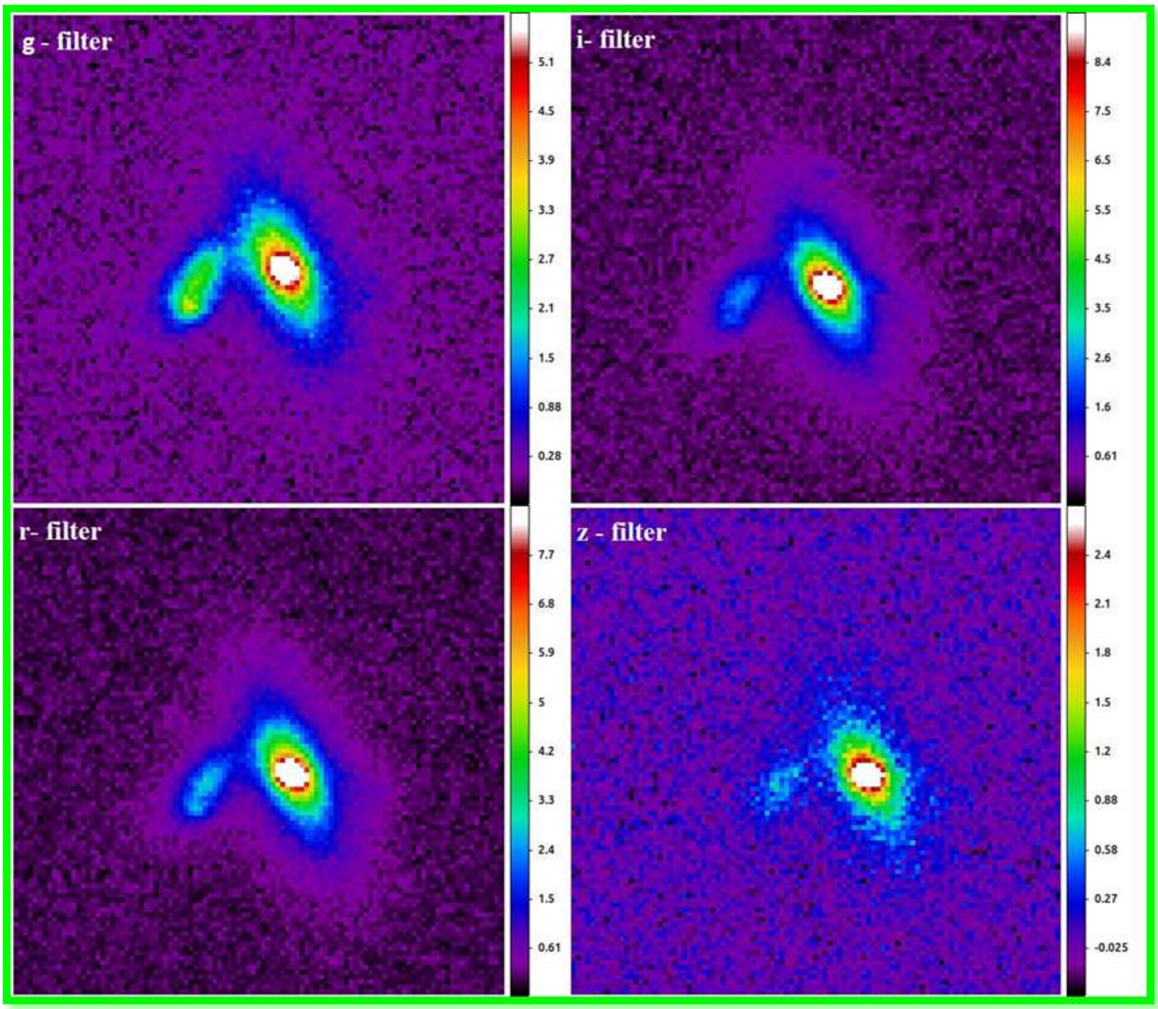

Figure 1. Griz-filtered color images of the Sip-39 pair galaxy, the north was indeed up, and the east was to the left.

The brighter galaxy is SDSS J143010.90-010227.6, also known as SIP 0039-1, 2MASS J14301090-0102274, PGC 1128276, and GAMA 544891, and it had an uncertain spiral morphology type, it was categorized as Sb with interaction sign[9],and also with an elliptical structure according to (Dobrycheva) [10]. The pair's fainter galaxy is SDSS J143011.40-010229.4, also known as SIP 0039-2 ,and GAMA 544892 ,and it also has an uncertain spiral morphology, according to both the "NASA/IPACK Extragalactic Database (NED)" as well as “Hypercat Lyon Meudon Extragalactic database) HyperLEDA)” ,Table 1 presents the basic information for the pair's two galaxies based on data of SDSS, NED, HyperLEDA and VizieR (which is a database of astronomical catalogues collected by the “Centre de Donn´ees de Strasbourg” (CDS) and partner institutes) . The goal of this study is to investigate the photometric and spectroscopic properties of a galaxy pair Sip-39 in order to determine the interaction status of the two members of the galaxy pair, as well as their effect on the gravitational attraction between these galaxies and the star-forming rate of two galaxies.

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Table 1. The fundamentals data of the Sip-39 pair galaxy

Galaxy Name	SIP 39-1	SIP 39-2
RA(deg)	217.5454 [a]	217.5475 [a]
Dec(deg)	-1.04101 [a]	-1.04151 [a]
Redshift	0.030241 [b]	0.02985 [b]
Type	S ? [a]	S ? [a]
Sub type	Starforming [c]	Starburst [c]
Semi major axis (kpc)	20.23 [a]	2.604 [c]
Inclination (deg)	38.9 [d]	68.8 [d]
Position Angle (deg)	33.0 [d]	138.1 [d]
Apparent magnitude in B-band (mag)	16.15 [d]	17.16 [d]

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

Materials and Methods

Method and Data Reduction:

The observation data comes from the SDSS's Data Release (DR17) [11], The SDSS pipeline adjusted the flat and biased field frame for each image. The Sip-39 galaxy pair isophotes in griz filters were fitted to ellipses by utilizing the Image Reduction and Analysis Facility (IRAF) with STSDAS Library using the ELLIPS task. The surface brightness of two galaxies in the pair, as well as total flux, ellipticities, major axis position angles, both vertical and horizontal shifts, and isophotal shape factors (B4) as functions of the semi-major axis of these galaxies, can be estimated by using the ELLIPS task[12, 13].

These photometric measurements enabled us to examine the Sip-39 galaxy pair's interacting status by observing distortions and centres shifting of galaxies' isophotes' outer parts[14]. Prior to fitting, the following data reduction steps have been accomplished:

- Sky background intensities are deducted from each frame of the galaxy pair's images.
- The pixel units of each frame of images of the galaxy pair are transformed into arcsec^2 units.
- The exposure time for all frames of the galaxy pair is united to be one second, by dividing each frame by the frame's initial exposure time.
- Convert the intensities flux value (*b*) of each filter of the pair galaxy's image frames to magnitude units (*m*), each frame of the galaxy pair images is adjusted for atmospheric as well as galactic extinction, and those are also converted towards the standard system through multiplying the flux measurements by the correcting factors through using Eq 1 [15].

$$m = -2.5 \times \log\left(b * 10^{(m_z + k_a + \mathrm{airmass})}\right) \quad 1$$

Where m_z: the zeropoint magnitude, k_a the atmospheric extinction, airmass photometric system airmass of SDSS observations. Table 2 lists these parameters for the griz filters of the Sip-39 galaxy pair.

Table2. The zeropoint magnitude, an atmospheric extinction, and an airmass for the griz filters of the Sip-39 galaxy pair from SDSS.

filters	air mass	m_z	K_a
g	1.196018	-24.5856	0.283262
r	1.196024	-24.1401	0.156347
i	1.195973	-23.5441	0.097350
z	1.195970	-21.9747	0.066598

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Results and Discussion

Morphologies with galaxy pair Sip-39 contour Maps

The griz contour maps of the Sip-39 galaxy pair generated by DS9 analysis are illustrated in Fig 2. The galaxy pair's Sip-39-1 member seems to have a central bright bulge surrounded by a symmetry disc system till the outer layers, and then it started losing this symmetry with a major axis diameter of around 7.13 kpc in the g band at surface brightness level 23.7 mag /arcsec^2.

While Sip-39-2 has a non-concentric and unsymmetrical structure, it also appears to be interfering with the other member of the pair, Sip-39-1, at the outer edges, with a major axis diameter of about 3.2 kpc in the g band at a surface brightness level of 23.7 mag/arcsec ^{2}. The griz outer isophotes' surface brightness levels of Sip-39 pair galaxy contour maps, and the steps among these levels are shown in Table 3

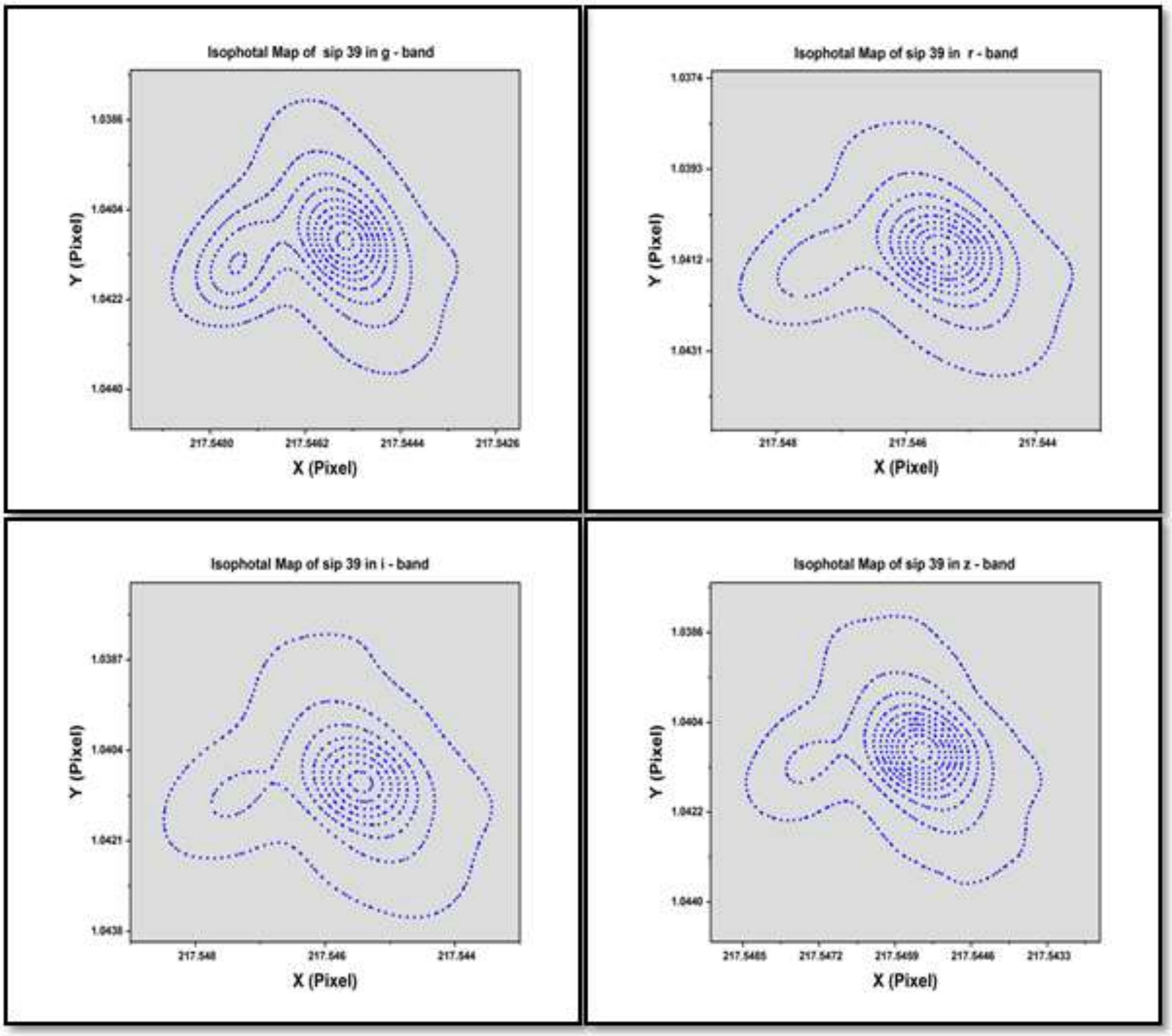

Figure 2.The griz contour maps of the Sip-39 galaxy the north was indeed up, and the east was to the left

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Table 3. The outer isophotes' surface brightness levels of Sip-39 pair galaxy

galaxy	filter	Step	Surface brightness (mag/arcsec ^{2})	Magnitude (mag)
SIP 39	g	0.55	23.72	25.73
	r	0.84	22.94	24.95
	i	1.01	22.57	24.58
	z	0.23	22.41	24.42

The sip-39 pair galaxy center shifts

The parameters that describe the shift of the centres of galaxy pair Sip-39 1 and 2 (x_c, y_c) in the griz band are depicted in Figs 3 and 4. Fig. 3 demonstrates the x_c of both members of the pair, with the x_c of the Sip-39-1 galaxy appearing to have a slight shift toward the Sip-39-2 galaxy in the gr and i bands from around 3.8 kpc to the galaxy's outer edges, whereas the x_c of the Sip-39-2 galaxy would seem to have a noticeable shift, especially in the g band, toward the Sip-39-1 galaxy beginning at 0.64 kpc.

The y_c values of the Sip-39-1 galaxy are obviously shifted in the direction of the Sip-39-2 galaxy, beginning at about 3.7 kpc and extending to the galaxy's outer layers in the griz band, while the Sip-39-2 galaxy y_c results indicated simple shifting values, particularly in the g band, toward another galaxy in the pair starting at 0.64 kpc, as seen in Fig 4.

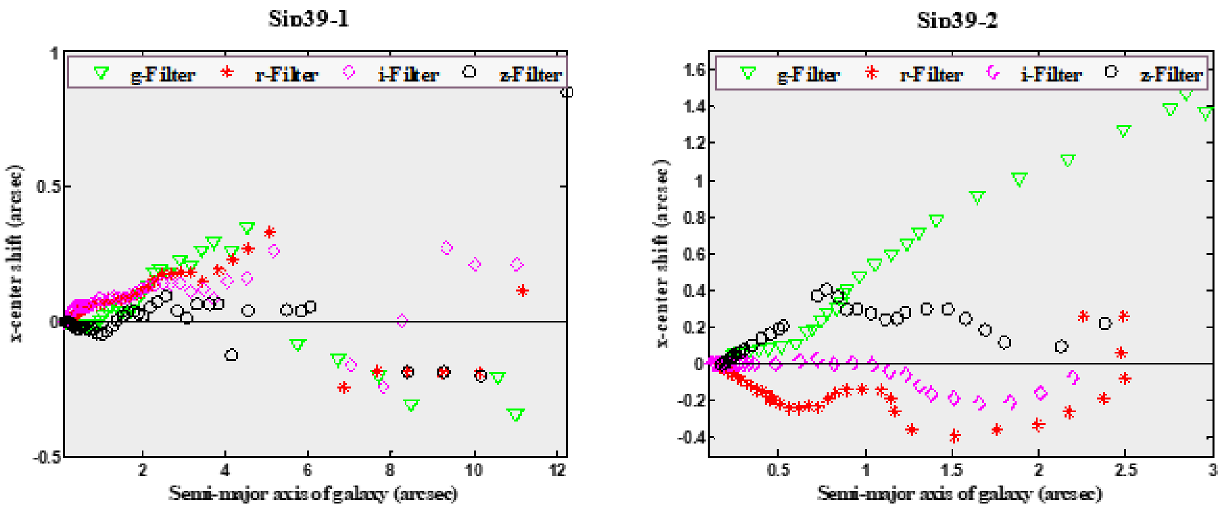

Figure 3. The x center shift (x_c) as function of semi major axis of the galaxies Sip-39-1 (left) and 2 (right).

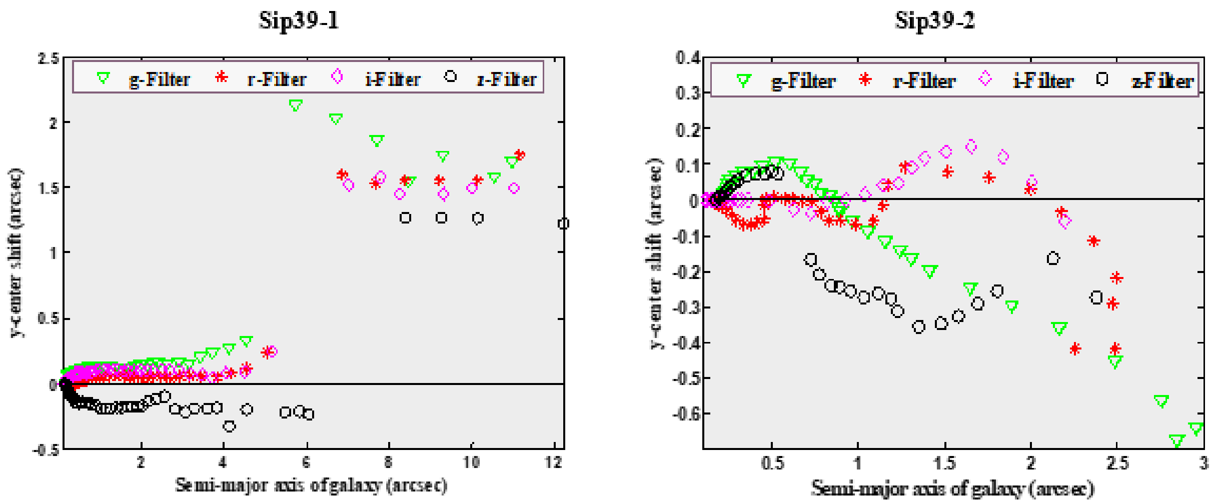

Figure 4. The y center shift (y_c) as function of semi major axis of the galaxies Sip-39-1 (left) and 2 (right).

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Baghdad Science Journal

The Sip-39 galaxy pair's position angles

The galaxy Sip-39-1 and the galaxy Sip-39-2's position angles (PA) in the griz band are represented in Fig 5. The PA of the Sip-39-1 galaxy tends to decrease in all bands at around 5, 4.5, and 5.5 kpc from the center by roughly 50, 40, and 20 degrees in the g, r, and i and z bands, respectively, indicating that the galaxy convolutes to the north apart from the other member of the pair, thereafter gradually returning to being flat throughout all bands.

In contrast, the Sip-39-2 galaxy's PA rises in the outer part of the galaxy in the g, r, and z bands by more than 50 degrees; in other words, the galaxy convolutes to the south apart from the Sip-39-1 galaxy, See Fig 5.

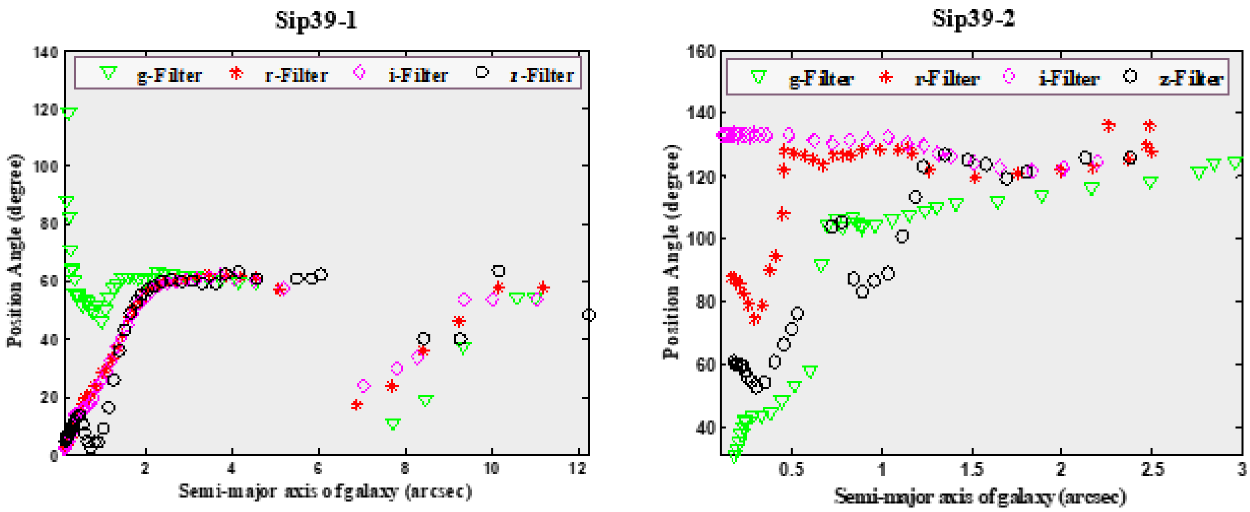

Figure 5. The Position Angle (PA) of the galaxies Sip-39-1 (left) and 2 (right) as a function of their semi-major axes.

The Sip-39 galaxy pair's ellipticities

The Sip-39-1 galaxy's ellipticity values vary from its interior to its exterior in the gri and z bands; in the first, they tend to rise between about 1 and 2.7 kpc, while in the latter, they begin to decline at 2.9 kpc and keep falling until the galaxy's outer edges. That is, the flatness of the Sip-39-1 galaxy's external part decreases significantly.

But on the other side, the ellipticity values of the Sip-39-2 galaxy also vary from its interior to its exterior in the gr and z bands, at which they change dramatically at the bulge but then start to rise at 0.5 kpc and keep rising till the galaxy's exterior, implying that the outer parts of the Sip-39-2 galaxy get to be flatter due to pressure caused by the impactful gravity of another member of the pair, see Fig 6.

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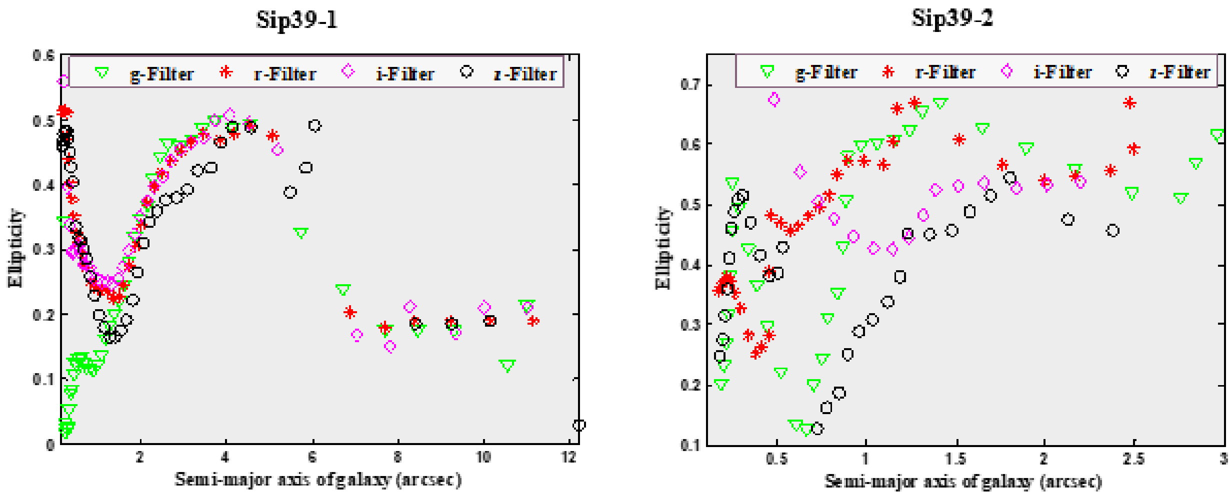

Figure 6. The Ellipticity (E) as function of semi major axis of the galaxies Sip-39-1 (left) and 2 (right)

The Fourth harmonic deviation from an ellipse (B4) of Sip-39 galaxy pair

The values of the fourth harmonic deviation from an ellipse (B4) of the Sip-39 galaxy pair are presented in Fig 7. The Sip-39-1 galaxy's B4 values in the gri and z bands fluctuating in the interior regions around zero, with an average value of (0.0049) in the g band below 3.9 kpc. In contrast, at the exterior regions, the values of B4 above 3.9 kpc begin obviously declining until 6.6 kpc but then rise at the outer edges. According to these average results, the Sip-39-1 galaxy has a disk-shaped system inside and a distorted shaped outside.

In the interior regions of the galaxy Sip-39-2 under 0.65 kpc, the B4 values in the gri and z bands fluctuate considerably, with an average value in the g band of (-0.01931). In comparison, at the outer regions, the values of B4 above 0.65 kpc begin to decline in the gri and z bands, inferring that the Sip-39-2 galaxy becomes more distorted. See Fig 7.

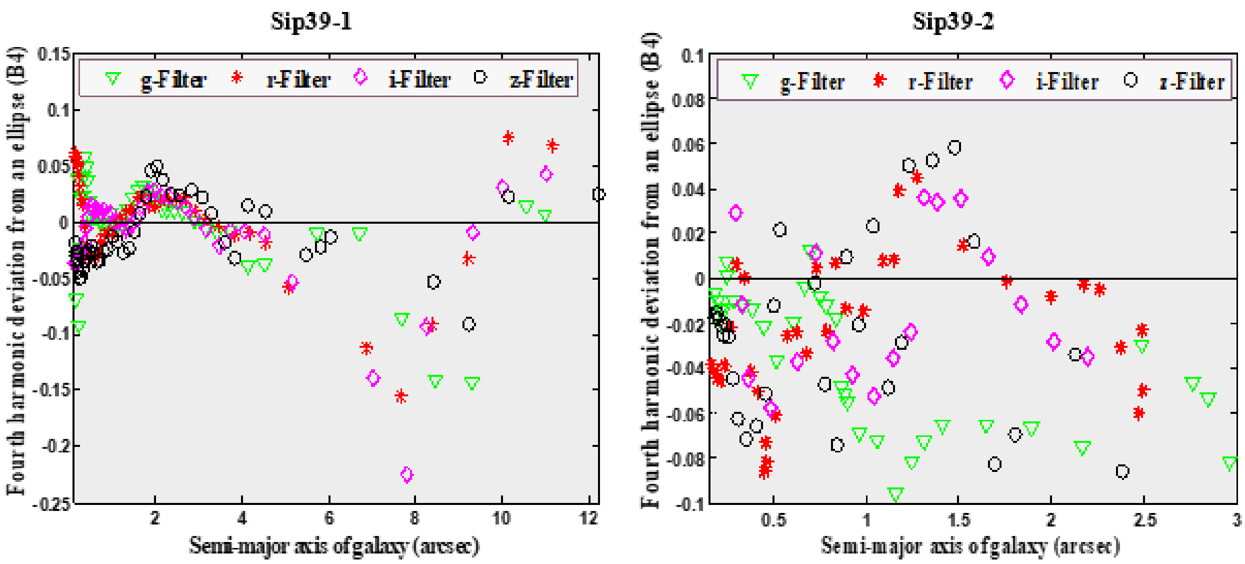

Figure 7. The Fourth harmonic deviation from an ellipse (B4) as function of semi major axis of the galaxies Sip-39-1 (left) and 2 (right).

2024, 21(4): 1403-1415
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P-ISSN: 2078-8665 - E-ISSN: 2411-7986
Baghdad Science Journal

The Magnitude of Sip-39 galaxy pair

The Sip-39-1 galaxy's magnitude exhibits atypical behaviour in all bands, beginning to fall off from the galaxy's centre before relatively stabilising in a region between 3.2 (4.5") and 5 (7.8") kpc. The Sip-39-2 galaxy's magnitude also expressed unusual behaviour with multiple humps in the griz bands, particularly in the r band at 0.74 (1.2"), 1.45 (2.3"), as well as 1.6 (2.5") kpc and in the g band at 1.8 kpc (2.8"), as visualized in Fig 8.

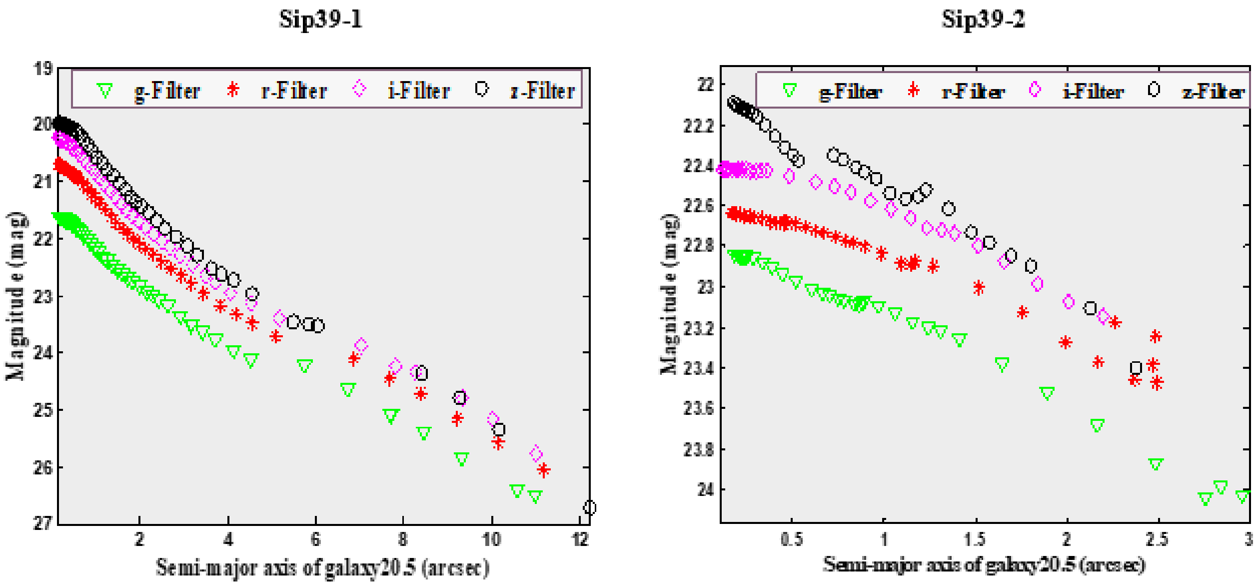

Figure 8. The magnitude (m) of the galaxies Sip-39-1 (left) and 2 (right) as a function of their semi-major axis.

Total flux measurements can be used to estimate the total apparent magnitude of each galaxy in the pair by applied equations 1, the calculated corrected apparent magnitudes (m) and the apparent magnitudes data from SDSS (for comparison) in the griz bands are listed in Table 4.

Table 4. The calculated corrected apparent magnitudes (m) and the apparent magnitudes data from SDSS in the griz bands

galaxy	Our work				SDSS			
	(m_g)	(m_r)	(m_i)	(m_z)	(m_g)	(m_r)	(m_i)	(m_z)
Sip-39-1	16.12	15.46	15.09	14.82	16.34	15.50	15.07	14.74
Sip-39-2	17.78	16.88	16.45	16.40	17.84	17.54	17.39	17.30

The Astrometric Results of Sip-39 Galaxy Pair

Following the application of Hubble's law, the average distance (D_p) of the Sip-39 galaxy pair was estimated in megaparsecs (Mpc) using Eq 2 [16]:

$$D_p = \frac{C\, z_m}{Ho} \qquad 2$$

where c denotes for the light speed, z_m denotes for the average redshift ($z_m = z_1 + z_2 / 2$), and Ho denotes for the Hubble constant (70 km / s.Mpc).

The Karachentsev equation can be employed to determine the Sip-39 galaxy pair's two galaxies' separation distance (d_s)[17]:

$$d_s = a_{12} D_p \qquad 3$$

which the Sip-39 galaxy pair's two galaxies are separated by an angle termed a_{12} . The two galaxies' relative velocity in the pair (v_{re}) can also be determined by the equation below [17]:

$$v_{re} = \sqrt{(cz_1 - cz_2)^2} \qquad 4$$

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Baghdad Science Journal

while the Sip-39 galaxy pair's orbital mass (M_p) can really be obtained in terms of the mass of the sun ($M_\odot$) through the following equation [17]:

$$M_p = 3.4 \frac{d_s v_{re}^2}{G} \quad 5$$

(G: the gravity constant), the results of above calculations are listed in Table 5.

Table 5. The Astrometric results of Sip-39 galaxy pair

D_p(Mpc)	d_s (kps)	v_{re} (km/s)	M_p ($M_\odot$)
128.77	4.846	115.56	5.08×10^{10}

The Sip-39 galaxy pair's total apparent magnitude (m_G), total absolute magnitude (M_G), and total luminosity (L_G) in terms of the luminosity of the sun ($L_\odot$) for griz bands can be measured using Eqs 1, 6, and 7 [15, 18 19],from measurements of the total flux of the two galaxies in the pair, and eventually the mass to the light ratio (M_p/ L_G) can also be estimated for griz bands, as shown in Table 6.

$$m_G - M_G = 5\log\left(\frac{D_p(\mathrm{Mpc})}{10}\right) \quad 6$$

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

where $M_{(g,r,i,z)\odot}$ represented the absolute magnitude of sun according to Vega system [20], 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 Sip-39 galaxy pair in griz bands

bands	m_G(mag)	M_G(mag)	L_G ($L_\odot$)	M_p/ L_G ($M_\odot$/$L_\odot$)
g	15.91	-19.64	8.9×10^9	5.73
r	15.2	-20.35	9×10^9	5.66
i	14.83	-20.72	9.2×10^9	5.52
z	14.5	-20.96	9.7×10^9	5.23

Spectrum and Star formation rate of the Sip-39 pair galaxies

The Sip-39-1 galaxy's spectra exhibit strong emission lines of OII,Hα, NII, NIII, and SII, whereas the Sip-39-2 galaxy's spectra also show strong emission lines of OII,Hβ,OIII, Hα, and SII as shown in Figs 9 and 10. The OII emission lines can be employed to determine the star-forming rates (SFR) of galaxies in the Sip-39 pair since their luminosity is based on ionization photons.

The SFR based on the OII emission lines of the Sip-39 pair's galaxies are calculated by using Eqs 8 and 9 [21, 22], the results listed in Table 7:

$$\mathrm{SFR}\ (M_\odot/\mathrm{yr}) = \frac{L}{2.97\times10^{33}\,W} \quad 8$$

$$L = 4\pi \times D_L \times f_{OII} \quad 9$$

Where L is Luminosity of OII emission line, D_L is the galaxy luminosity distance, fOII is Flux of OII emission line.

2024, 21(4): 1403-1415
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Baghdad Science Journal

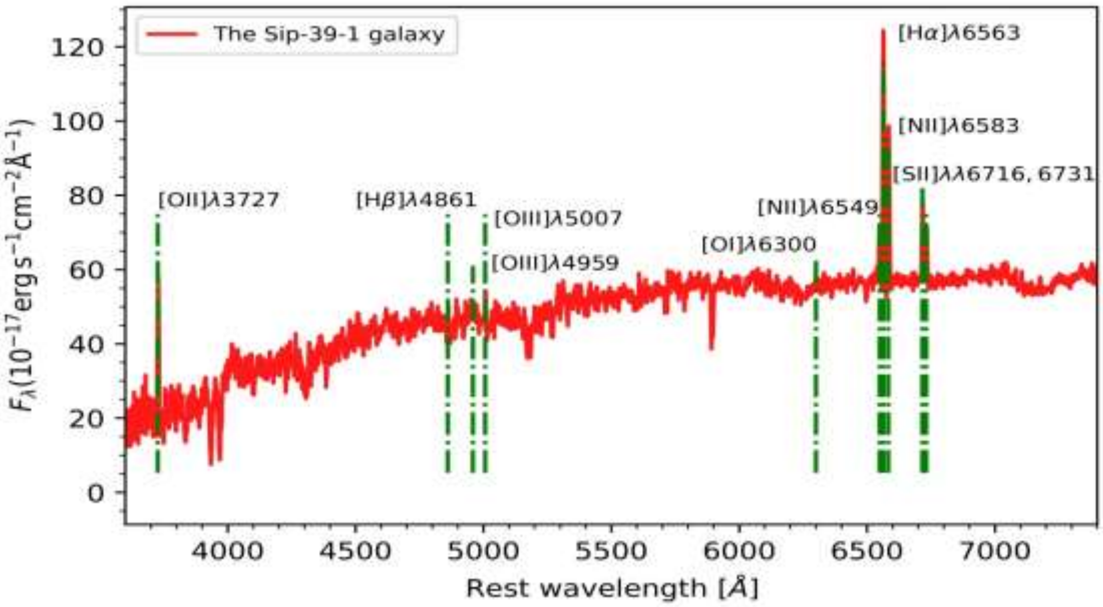

Figure 9. The Sip-39-1 galaxy's spectra

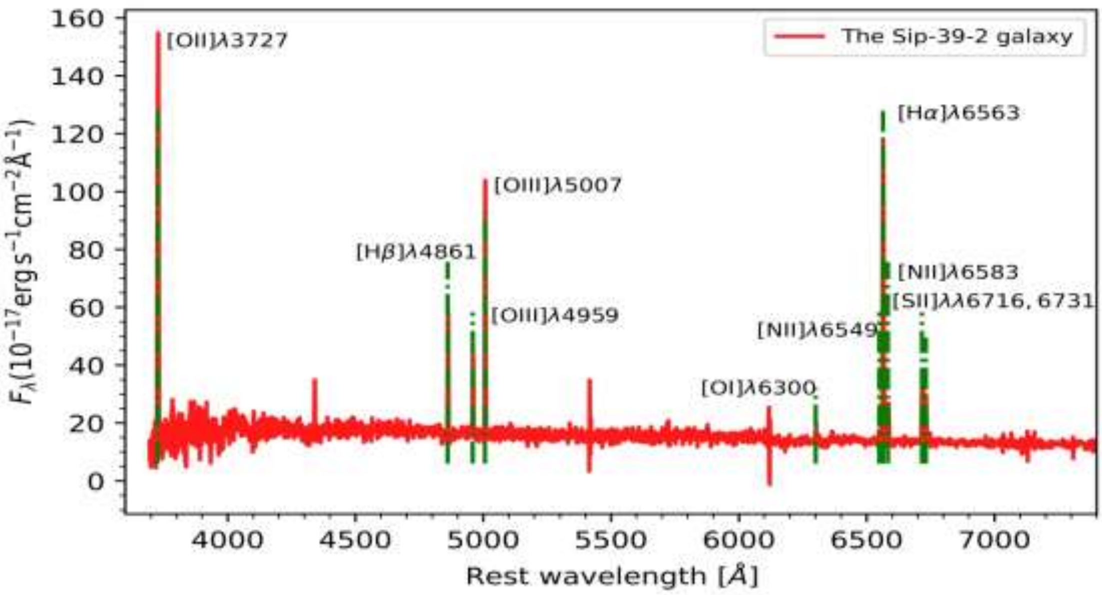

Figure 10. The Sip-39-2 galaxy's spectra

Table 7. The calculated SFR, flux, redshift and distance of Sip-39-1 and Sip-39-2 galaxies

Galaxy	f_{OII} (10^{-17} erg.s^{-1}.cm^{-2})	Redshift	D_L (Mpc)	SFR ($M_\odot$/Yr)
Sip-39-1	149.4	0.03	131.4	0.104
Sip-39-2	476.3	0.029	127.0	0.31

Conclusion

- The photometric results indicate that the Sip-39 pair is an interacting galaxy pair with obvious interaction signs; the contour maps of the Sip-39 galaxy pair show non - symmetric structure;

there are recognizable shifts of the centres of galaxies in pair Sip-39 1 and 2, one toward the other galaxy in the pair; the Sip-39 1 galaxy convolutes to the north, apart from the other member of the pair by roughly 40 degrees, while the Sip-39-2 galaxy convolutes to the south, apart from the Sip-39-1 galaxy by more than 50 degrees; The Sip-39-1 galaxy's flatness declines while the Sip-39-2 galaxy's flatness rises; the Sip-39-1 galaxy seems to have a disk-shaped system inside and a distorted shaped outside, whereas the Sip-39-2 galaxy appears more distorted; The magnitudes of the Sip-39-1 and 2 galaxies display abnormal behavior, with several humps. These signs appear due to the gravitational attraction and overlapping of galactic matter between the two galaxies at the site of interaction.

- The astrometric results imply that the Sip-39 pair is categorised as a close pair according to Patton's classification[23], were the separation distance and relative velocity of the Sip-39 galaxy pair's two galaxies are 4.846 kpc and 115.56 km/s, respectively.
- The Sip-39 pair's mass-to-light ratio is estimated to be around 5.5 $M_{\odot}/L_{\odot}$, that The Sip-39 pair deems physical system, following the Karachentsev definition.
- The SFR of the Sip-39 pair's galaxies are determined to be 0.104 and 0.31 $M_{\odot}$/Yr for Sip-39-1 and Sip-39-2, respectively. The minor galaxy Sip-39-2 has a higher SFR than the major galaxy Sip-39-1, which is because the minor galaxy is strongly affected by the gravity of the major galaxy, leading to deformations of the galaxy and an increase in the SFR.

These study results are important in trying to understand the main structural components of the universe, which are galaxies, and thus to comprehend the universe's structure, history, and evolution.

Acknowledgment

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Authors' Declaration

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images, that are not ours, have been included with the necessary permission for re-publication, which is attached to the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University of Baghdad.

Authors' Contribution Statement

The proposed concept was created by A.K.A. A.K.A. and H.R.A. participated in the analysis method. The manuscript was written by H.R.A. under the supervision of A.K.A. The two authors discussed their findings and made contributions to the final manuscript.

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شرح الخواص الضوئية والطيفية للزوج المجريSip-39

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الخلاصة

تمت دراسة الزوج المجري Sip-39 باستخدام طرق القياس الضوئي والطيفي. البيانات الرصدية اخذت من اصدار البيانات السابع عشر (DR17) من "Sloan Digital Sky Survey (SDSS)" وتمت عمل ال fitting لصور المجرتين باستخدام برنامج (IRAF) من خلال المكتبةSTSDAS باستخدام task ELLIPS.تم دراسة وحساب كل من اللمعان السطحي للمجرتين في الزوج ، بالإضافة إلى الانبعاث الكلي ، وشكل القطع الناقص ، وزوايا انحراف المحور الكبير، الانحرافات العمودية والأفقية ، ومعاملات كيرشوف للشكل (B4)، والاقدار ، ومعدلات تشكل النجوم (SFR) ، بالإضافة إلى خواص القياسات الفلكية للزوج ، حيث ظهر من خلال تحليل البيانات أن زوج Sip-39 هو قريب مع علامات تفاعل واضحة ، ويعتبر نظامًا فيزيائيا مع معدلات محسنة ل SFR.

الكلمات المفتاحية: المجرات, المجرات المتفاعلة, الزوج المجري Sip-39, التحليل الطيفي, اللمعان السطحي.