EDUSJ, Vol, 33, No: 2, 2024 (108-114)

Journal of Education and Science (ISSN 1812-125X)

www.edusj.mosuljournals.com

Investigation of the Fundamental Plane Relationship For the Evolution of the Elliptical and Lenticular Galaxies

K. K. Mohammed

Department of Physics, College of Science, University of Sulaimani, Iraq

Article information

Article history:
Received: March 18, 2024
Accepted: May 28, 2024
Available online: June 01, 2024

Keywords:
Elliptical Galaxies
Faber-Jackson relation
Fundamental plane
Kormendy relation
Lenticular galaxies

Correspondence:
Khalid K. Mohammed
Khalid.mohammad@univsul.edu.iq

Abstract

The Fundamental Plane relates the effective radius and surface brightness of an early-type galaxy to its velocity dispersion. It is important in understanding galaxy formation and evolution processes. The present work aims to investigate this relation as well as Faber-Jackson and Kormendy relations for both elliptical and lenticular galaxies separately in order to compare them. For this purpose, we take a sample of 140 early-type galaxies (70 elliptical galaxies and 70 lenticular ones), extracted from the extensive catalogue of early-type galaxies, and investigate them by using data analysis and visualization software. This work confirms that elliptical and lenticular galaxies are located almost in the same fundamental plane, with an rms scatter of 0.140 for ellipticals and 0.172 for lenticulars. Yet, elliptical galaxies show a tighter relationship than lenticular galaxies. This implies that elliptical galaxies obey the Fundamental Plane relation better than lenticular galaxies. Also, the two morphological types of galaxies obey Faber-Jackson relation, with an rms scatter of 0.101 for ellipticals and 0.873 for lenticulars. They, also, obey Kormendy relation, with an rms scatter of 0.600 for elliptical and 0.685 for lenticulars. These results indicate that the two relations are, also, more obvious in the case of elliptical galaxies.

DOI: 10.33899/edusj.2024.147953.1433,

1. Introduction

Early-type galaxies (ETGs), which include both elliptical (E) and lenticular (S0) galaxies, are found to follow a tight correlation in the three-dimensional parameter space defined by their effective or half-light radii (R_e), central velocity dispersion (σ_0) and mean effective surface brightness (μ_e) within R_e. These parameters are confined to a plane called the Fundamental Plane (FP) defined by $R_e \propto \sigma^{\alpha} \langle \mu_e \rangle^{\beta}$, where α and β are constants [1,2]. This relation can be derived from the virial theorem, according to which, the mass-to-light (M/L) ratio may be given in terms of the effective radius, the central velocity dispersion, and the mean effective surface brightness. The deviation of the observed FP from the virial theorem causes a "tilt" whose origin may be variations in M/L ratio with mass or structural variations with mass [3]. The small scatter in the edge-on projection of the FP reflects the high degree of regularity in the formation process of these early-type galaxies [4]. The reason for this scatter may be variations in the M/L ratio as a result of metallicity or age effects in stellar populations [5]. A number of studies showed that E galaxies and bulges of S0 galaxies are located in the same FP (see, e.g. [6]). However, a slight difference between them has been revealed in a separate study [4].

One of the projections of the FP is the Faber-Jackson relation (FJR) [7], in which the luminosity (L) of elliptical galaxies varies directly with σ_0^n, where n is the Sérsic index, being 4 for bright Es and nearly 2 for faint Es [8]. It is found that bulges of S0s follow a very similar relation to bright Es [9].

Another projection of the FP is the Kormendy relation (KR) [10] which relates the mean effective surface brightness of early-type galaxies to their effective radii. A number of studies [11,12] showed that E galaxies and bulges of S0 galaxies obey the same KR. Yet, according to another study, this is true only for bright S0 galaxies [13].

2. Sample and Data

Our sample consists of 140 early-type bright galaxies (70 elliptical galaxies plus 70 lenticular galaxies), with absolute magnitudes $M_B < -18$, selected from the extensive catalogue of early-type galaxies [14]. The effective radii of these galaxies and their central velocity dispersions are taken from this catalogue. The mean effective surface brightnesses and the B-band absolute magnitudes (corrected for galactic extinction, internal extinction, and K-correction) are extracted from Hyperleda database [15]. Table 1 displays some of these sample galaxies.

Table 1. Some sample galaxies with their required data

No.	Galaxy	Morph. type	MB [mag]	σ_0 [km/s]	Re [pc]	<μe> [mag/arcsecond^2]
1	NGC0315	E	-22.48	351.6	17023.6	22.01
2	NGC1600	E	-22.42	320.6	12709.0	22.53
3	NGC0410	E	-22.27	305.1	9986.2	22.11
4	NGC3842	E	-22.21	147.0	3968.3	21.74
5	NGC7728	E	-22.18	362.2	13379.6	22.12
6	NGC0777	E	-22.11	348.3	8526.2	22.17
7	NGC7619	E	-21.96	337.3	8375.7	21.44
8	NGC5322	E	-21.48	246.0	5811.1	21.07
9	NGC7626	E	-21.44	233.9	9117.9	21.64
10	NGC7562	E	-21.41	256.3	6353.7	21.51
11	NGC0420	S0	-21.34	179.5	5514.2	21.10
12	NGC3816	S0	-21.33	204.6	3518.0	21.57
13	NGC0379	S0	-21.16	239.7	10291.3	21.68
14	NGC0687	S0	-21.15	244.2	4949.0	21.59
15	NGC2563	S0	-20.99	287.3	7330.8	21.89
16	NGC0431	S0	-20.97	162.2	6207.6	21.55
17	NGC0528	S0	-20.95	287.3	9471.9	22.83
18	NGC5353	S0	-20.90	267.3	3105.0	20.49
19	NGC0712	S0	-20.86	266.2	16518.6	22.87
20	NGC3665	S0	-20.84	147.6	3358.3	21.74

3. Results and discussion

3.1. The fundamental plane (FP) in $\log(R_e)$, $\langle\mu_e\rangle$, $\log(\sigma_0)$ space

The FP can be written as [16]

$$\log(R_e) = a\log(\sigma_0) + b\langle\mu_e\rangle + c \quad \dots\dots\dots\dots\dots (1)$$

where *a*, *b* represent slopes and vary with the passband used. The constant *c* represents the intercept of the fundamental plane. The physical basis of this relationship was mentioned in Section 1. Figures 1 and 2 show the edge-on view of the FP for our E and S0 samples, respectively. Our results for both samples are outlined in Table 2. The values of *a* and *b*, shown in the table, are obtained by multiplying the slope in each graph by the value on *x*-axis ($1.203\log\sigma_0 + 0.352\langle\mu_e\rangle$). The value of *c* represents the *y*-intercept in each graph. As we see, from the root-mean-square (rms) values given in the table, elliptical galaxies show more tight relationship than lenticular galaxies. This tightness implies mutual relationships between galaxy properties and star formation activity [17]. In general, the results show a close similarity between the corresponding coefficients for both Es and S0s, in agreement with Ref. [18]. Therefore, we can say that E and S0 galaxies are located nearly in the same FP, with a somewhat smaller rms deviation for Es. These differences in rms deviations indicate differences in stellar ages and, hence, star formation activity in both types of galaxies.

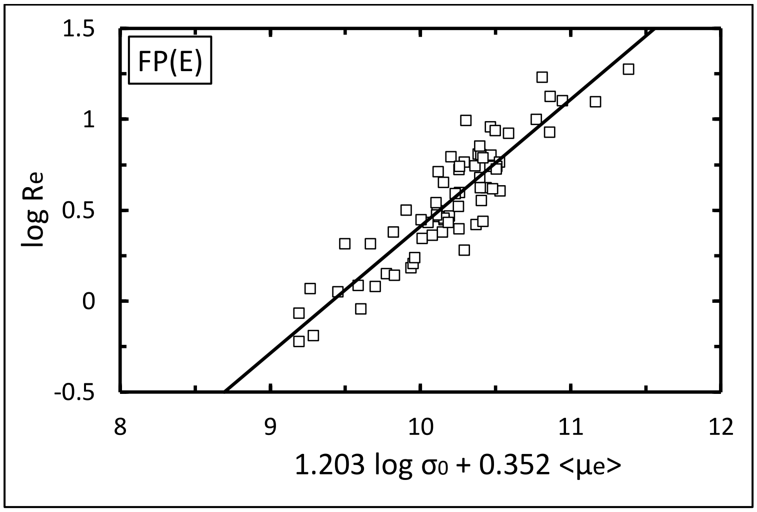

Figure 1. The FP for E galaxies

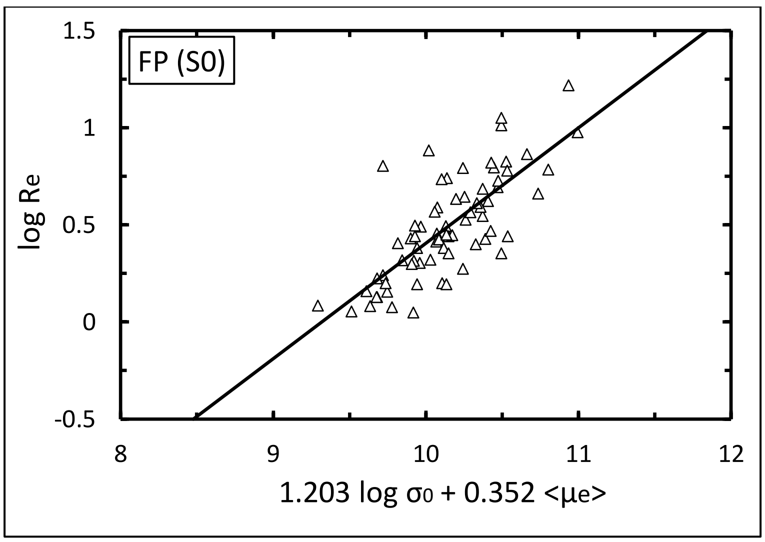

Figure 2. The FP for S0 galaxies

Table 2. The FP coefficients of E and S0 galaxies

Type	*a*	*b*	*c*	rms
E	0.840 ± 0.040	0.246 ± 0.040	-6.566 ± 0.406	0.140
S0s	0.715 ± 0.062	0.209 ± 0.062	-5.537 ± 0.630	0.172

3.2 The fundamental plane (FP) in κ-space

Another expression of the FP is given in κ-space, suggested by Bender et al. [19], using a simple orthogonal coordinate transformation. This coordinate system is found to be very significant and easy to recall. The axes of this space are related to galaxy photometric and kinematic parameters. They are given by

$$\kappa_1 = \frac{\log \sigma_0^2 + \log R_e}{\sqrt{2}} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

$$\kappa_2 = \frac{\log \sigma_0^2 + 2\log I_e - \log R_e}{\sqrt{6}} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

$$\kappa_3 = \frac{\log \sigma_0^2 - \log I_e - \log R_e}{\sqrt{3}} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

where ($\log I_e = -0.4(\langle\mu_e\rangle - 27)$. In this parameter space, $\kappa_1 \propto \log M$, $\kappa_2 \propto \log(M/L)\, I_e^3$, and $\kappa_3 \propto \log(M/L)$. The edge-on view of the FP in this space is represented by κ_1 and κ_3. This is illustrated in Figure 3 for our E and S0 samples. It is obvious from this figure that the two types lie nearly on the same FP, with Es being less scattered (rms = 0.119) than S0s (rms = 0.148). According to Bender et al. [19], these deviations from the average are caused by differences in *M/L* ratios of galaxies, which indicate differences in their stellar ages.

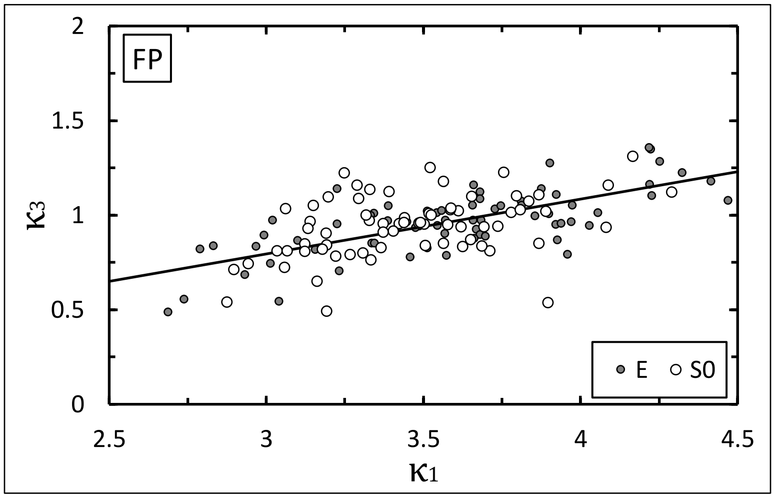

Figure 3. The FP in κ space

3.2. The Faber-Jackson relation (FJR)

This relation can be written as

$$\log \sigma_0 = -0.1 M_B + \text{const.} \ldots\ldots\ldots\ldots\ldots (5)$$

where M_B is the B-band absolute magnitude. Figures 4 and 5 show the FJR for our E and S0 samples, respectively. These results are outlined in Table 3. The results show a similar FJR for both Es and S0s, although Es are clearly less deviated (rms = 0.101) from the relation than S0s (rms = 0.873). As we mentioned earlier, this similarity is found only for bright Es [9].

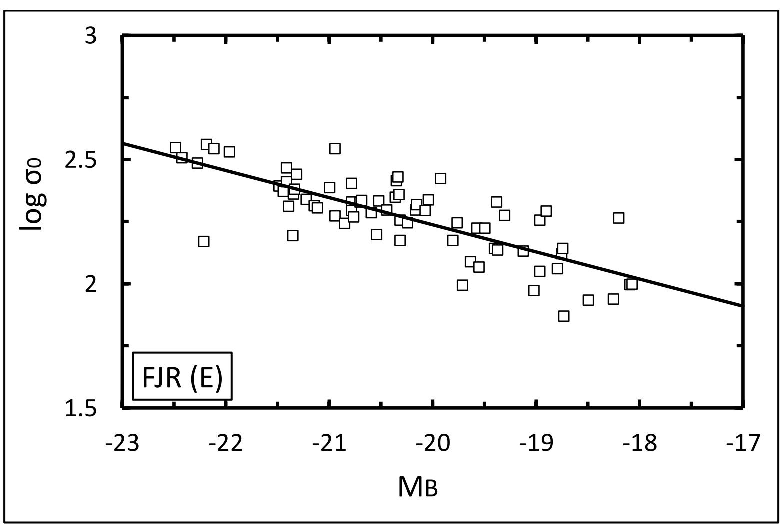

Figure 4. The FJR of E galaxies

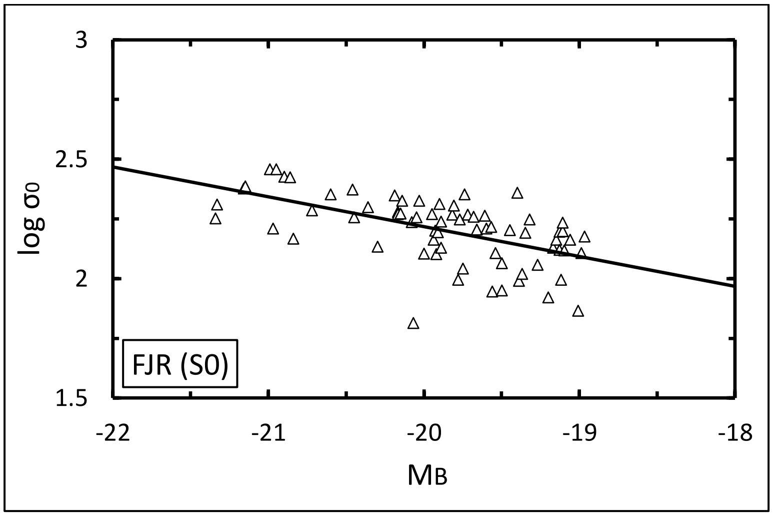

Figure 5. The FJR of S0 galaxies

Table 3. FJR slope and y-intercept for E and S0 galaxies

Type	slope	y-intercept	rms
E	-0.109 ± 0.011	0.053 ± 0.220	0.101
S0	-0.125 ± 0.022	-0.283 ± 0.433	0.873

3.3. The Kormendy relation (KR)

This relation can be written as [20]

$$\langle \mu_e \rangle = a \log(R_e) + b \quad \ldots\ldots\ldots\ldots\ldots (6)$$

where a is the slope and b is the zero point. Figures 6 and 7 show the KR for our elliptical and lenticular samples, respectively. These results are outlined in Table 4. We see that Es and S0s follow nearly the same KR. This is obvious from the comparable values of the slope, y-intercept, and rms for both Es and S0s in the table. Yet, according to Barway et al. [21], this is only true for bright S0s.

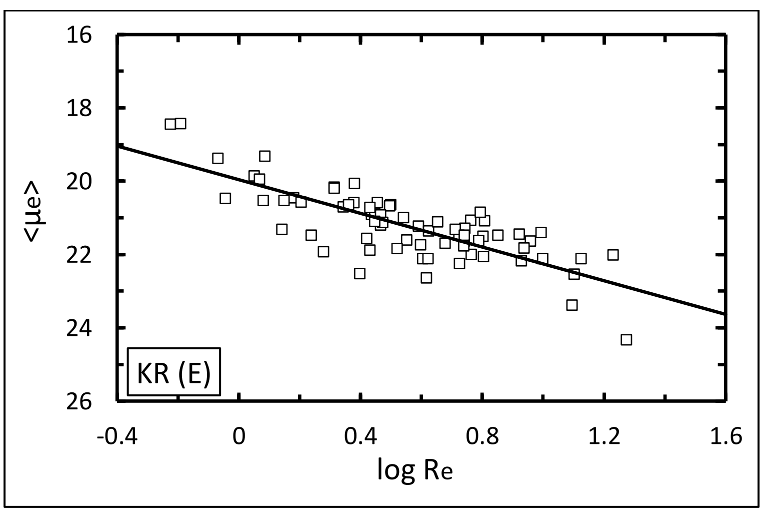

Figure 6. The KR of E galaxies

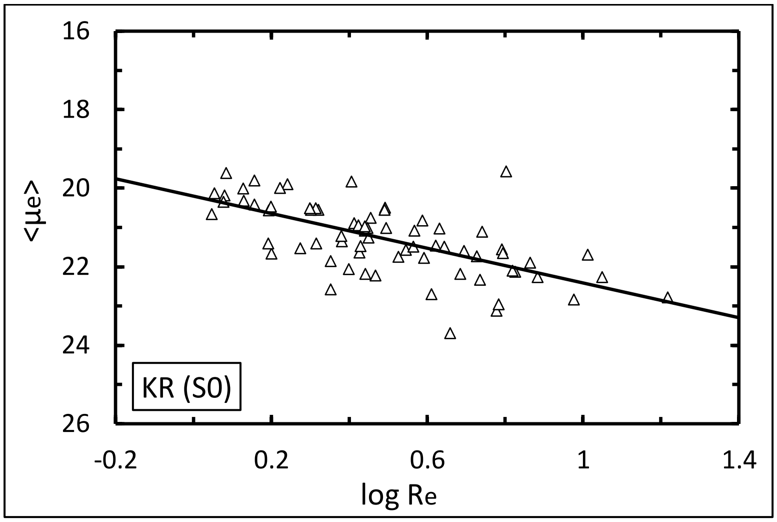

Figure 7. The KR of S0 galaxies

Table 4. KR slope and y-intercept for E and S0 galaxies

Type	slope	y-intercept	rms
E	2.297 ± 0.220	19.960 ± 0.142	0.600
S0	2.211 ± 0.315	20.202 ± 0.175	0.685

4. Conclusions

The fundamental plane (FP) and its projections, Faber-Jackson relation (FJR), and Kormendy relation (KR) were studied for 70 elliptical (E) galaxies and 70 lenticular (S0) ones. The results showed a close similarity between the corresponding FP coefficients of Es and S0s, indicating they lie nearly on the same FP, with an rms scatter of (0.140) for Es and (0.172) for S0s. This means that the correlation is more tight for elliptical galaxies. The results, also, showed that both elliptical and lenticular galaxies follow FJR almost similarly, with their corresponding coefficients being close to each other. Yet, the rms scatters of (0.101) for Es and (0.873) for S0s indicate the strongest correlation for Es. The results also showed that Es and S0s obey KR, with their corresponding coefficients and rms scatters (0.600 for Es and 0.685 for S0s) being close to each other.

ACKNOWLEDGEMENT

We acknowledge the usage of the HyperLeda database (http://leda.univ-lyon1.fr).

References:

[1] Dressler A, Lynden-Bell D, Burstein D, "Spectroscopy and photometry of elliptical galaxies. I- a new distance estimator", ApJ, vol. 313, pp. 42-58, 1987, doi: 10.1086/164947

[2] Djorgovski S, Davis M, "Fundamental properties of elliptical galaxies", ApJ, vol. 313, pp. 59-68, 1987, doi: 10.1086/164948

[3] Mould J, "Understanding the fundamental plane and the Tully Fisher relation", Front. Astron. Space Sci., vol. 7, article 21, 2020, doi: 10.3389/fspas.2020.00021

[4] Jorgensen I, Frank M, Kjaergaard P, "Sources of scatter in the fundamental plane and the D_n-σ relation", ApJ, vol. 411, p. 34-42, 1993, doi: 10.1086/172805

[5] Faber SM. In: Nearly Normal Galaxies: From Planck time to the present; Proc. Eighth Santa Cruz Summer Workshop in Astronomy and Astrophysics, Springer, 1987.

[6] Gerhard O et al., "Dynamical family properties and dark halo scaling relations of giant elliptical galaxies", AJ, vol. 121, pp. 1936-1951, 2001, doi: 10.1086/319940

[7] Faber SM, Jackson RE, "Velocity dispersions and mass-to-light ratios for elliptical galaxies", ApJ, vol. 204, pp. 668-683, 1976, doi: 10.1086/154215

[8] Matkovic A, Guzman R, "Kinematic properties and stellar populations of faint early-type galaxies – I. Velocity dispersion measurements of central coma galaxies", MNRAS, vol. 362, pp. 289-300, 2005, doi: 10.1111/j.1365-2966.2005.09298.x
[9] Méndez-Abreu et al., "Structural properties of disk galaxies – I. The intrinsic equatorial ellipticity of bulges", A&A, vol. 478, pp. 353-369, 2008, doi: 10.1051/0004-6361:20078089
[10] Alfonso J, Aguerri L, "Properties of the photometric components of lenticular galaxies", Advances in Astronomy, vol. 2012, article ID 382674, doi: 10.1155/2012/382674
[11] Falcón-Barroso J, Peletier RF, Balcells M, "Bulges on the fundamental plane of early-type galaxies", MNRAS, vol. 335, pp. 741-752, 2002, doi: 10.1046/j.1365-8711.2002.05656.x
[12] Kormendy J, "Brightness distributions in compact and normal galaxies. III- decomposition of observed profiles into spheroid and disk components", ApJ, vol. 217, pp. 406-419, 1977, doi: 10.1086/155589
[13] Burnstein D, "Structure and origin of S0 galaxies. II- disk-to-bulge ratios", ApJ, vol. 234, pp. 435-447, 1979, doi: 10.1086/157512
[14] Dabringhausen J, Fellhauer M, "An extensive catalogue of early-type galaxies in the nearby Universe", MNRAS, vol. 460, pp. 4492-4512, 2016, doi: 10.1093/mnras/stw1248
[15] Makarov D et al., "HyperLEDA. III. The catalogue of extragalactic distances", A&A, vol. 570, A13, 2014, doi: 10.1051/0004-6361/201423496
[16] Samir R et al., "The fundamental plane of early-type galaxies in different environments", NRIAG Journal of Astronomy and Geophysics, vol. 5, pp. 277-288, 2016, doi: 10.1016/j.nrjag.2016.06.004
[17] Lu Sh et al., "Redshift evolution of the fundamental plane relation in the IllustrisTNG simulation", MNRAS, vol. 492, pp. 5930-5939, 2020, doi: 10.1093/mnras/staa173
[18] Jorgensen I, Frank M, Kjaergaard P, "The fundamental plane for cluster E and S0 galaxies", MNRAS, vol. 280, pp. 167-185, 1996, doi: 10.1093/mnras/280.1.167
[19] Bender R, Burstein D, Faber S, "Dynamically hot systems. I- Structural properties", ApJ, vol. 399, pp. 462-477, 1992, doi: 10.1086/171940
[20] Nigoche-Netro A, Ruelas-Mayorga A, Franco-Balders A, "The Kormendy relation for early-type galaxies. Depensence on the magnitude range", A&A, vol. 491, pp. 731-738, 2008, doi: 10.1051/0004-6361:200810211
[21] Barway S et al., "Near-infrared bulge-disc correlations of lenticular galaxies", MNRAS, vol. 394, pp. 1991-2000, 2009, doi: 10.1111/j.1365-2966.2009.14440.x

التحقق من علاقة المستوي الأساسي في تطور المجرات البيضوية والعدسية

خالد كامل محمد
قسم الفيزياء، كلية العلوم، جامعة السليمانية، العراق

الخلاصة

تربط علاقة المستوي الأساسي نصف القطر الفعال والسطوع السطحي لأية مجرة قديمة بمقدار تشتت سرعتها. وهي مهمة لفهم عمليات نشوء وتطور المجرات. والهدف من البحث الحالي هو دراسة هذه العلاقة بالاضافة الى علاقتي فيبر-جاكسون و كورمندي لكل من المجرات البيضوية والعدسية بصورة مستقلة لأجل المقارنة بينهما. ولهذا الغرض أخذنا عينة مؤلفة من 140 مجرة قديمة (70 مجرة بيضوية مع 70 مجرة عدسية) مستخرجة من (الفهرس الشامل للمجرات القديمة) وتمت دراستها باستخدام برنامج لتحليل و رسم البيانات. يؤكد بحثنا على أن المجرات البيضوية والعدسية تقعان تقريبا في نفس المستوي الأساسي، مع كون مقدار التشتت بالنسبة للمجرات البيضوية هو 0.140 وللمجرات العدسية 0.172. ولكن المجرات البيضوية تبدي علاقة أوثق من المجرات العدسية. وهذا يتضمن كون المجرات البيضوية تخضع لعلاقة المستوي الأساسي أكثر من المجرات العدسية. وكذلك يخضع كلا الصنفين من المجرات لعلاقة فيبر-جاكسون ، مع كون مقدار التشتت 0.101 للمجرات البيضوية و 0.873 للمجرات العدسية. ويخضع الصنفان أيضا لعلاقة كورمندي , مع كون مقدار التشتت 0.600 للمجرات البيضوية و 0.685 للمجرات العدسية. وتشير هذه النتائج الى أن هاتين العلاقتين هما أيضا أكثر وضوحا في حالة المجرات البيضوية.