A New Relation between the Absolute Magnitudes of bulges and Spiral Arm Pitch Angles (p)

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Abstract

In this study, we have found a new relation between the absolute magnitudes of bulges and "pitch angles" (P) (M_{bulge}-P). Pitch angles (P) were estimated for 40 images of galaxies from "Spitzer/IRAC" at 3.6-µm, by applying a "2D Fast Fourier Transform decomposition" method "(2DFFT)". A sample of nearly face-on spiral galaxies were selected and applied IRAF ellipse to estimate the ellipticity and major-axis position angle, and applying a 2DFFT method, the pitch angles were determined. The measurement of the absolute magnitudes of bulges is depend on a "2D (bulge - bar - disk) decomposition" program. The absolute magnitudes of bulges were estimated using the 2D multi component decomposition method.

Key Words: Spiral Galaxies, Pitch Angle, Absolute Magnitudes of Bulges, Classical Bulges.

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Introduction

"Black Hole" is a zone of "space-time" which have so high gravity, and nothing can escape from it [1].
Super massive black holes (SMBHs) are existing at galactic centers [2][3]. In addition, the masses of SMBH have billions of solar masses [4][5][6].
Over the last twenty years, researchers of SMBH have driven to the detection that there are number tight relations for the "SMBHs" masses and characteristics of their hosts. This indicates an interesting relate between the forming and evolution of SMBH [7]. Astronomers think that the power released via the growth of SMBHs play significant role in "shaping" the characteristics of the build of the "host galaxies"[8][9].
Astronomers found a growing directory that point out the correlations for SMBH masses and all the host galaxies. Most of bulges galaxies consist of SBH in the it center have mass relates s with dispersion velocity (σ*) into the effective radius (re) (M_{BH}-σ*)[3][10][11]; with luminosity of the bulge (L_{bulge}) (M-L_{Bulge})[2][4][11][12], with mass of the bulge (M_{bulge}) [2][13], and rotation velocity [14], with the light concentration of galaxy[15], the "halo dark matter"[14], with the "effective radius" [11], the "Sersc index"[15][16].
All scaling relations have pointed advanced researchers to the result that development of SMBHs, and the forming of bulges organize each other [17][18]. That means that "SMBH" masses is somehow related to the parameters "structural of the galaxy".
In this work, using more sophisticated methods of estimating the absolute magnitudes of bulges such as two-dimensional image decompositions[13] [17][19] [20][21], produces a new tighter correlation for pitch angles and magnitudes of the bulges of their host.

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The structure this work is divided into: part 2, I briefly explain the sample. part 3 is a discussion of the measurements. The conclusions are in part 4.

Sample

A sample of 40 Spitzer/IRAS (3.6μm) spiral galaxies were selected (see Table (1). The absolute magnitudes of bulges estimates in this search are according to "2D (bulge - bar - disk) decomposition program" which more accurately model "Spitzer/IRAC" of 3.6 μm images [22]. The absolute magnitudes of bulges was determined at 3.6 μm for 40 spiral galaxies using a two-dimensional multi component decomposition technique [21][22].
In addition, we used pitch angles for number of the spiral galaxies taken from the literature, such as B and K band galaxy's images, which were used to measure P [23][24]. Pitch angles (P) have been evidenced to be independent of the wavelength at which it are determine [25]; so, a different band of images were applied to measure P. The remaining of "pitch angles" were determine by "Spitzer/IRAC" 3.6μm of 22 "galaxies" applying a 2D fast Fourier transformation, assuming logarithmic spirals [26].
In this work, a sample of 40 galaxies are considered, that consisted of 14 "non-barred galaxies", 17 "AGN-galaxies", 23 "non-AGN galaxies", 20 "classical bulges", and 20"pseudobulges".

Absolute Magnitudes of Bulges

In this section we have offered a mid-infrared research of the "scaling relations" for pitch angles and the structural parameters of the host spheroids in the galaxies that are represented by the absolute magnitudes of bulges(M_{Bulge}), based on "2D-dimensional disk -bulge-bar decompositions of Spitzer/IRAC 3.6 μm" using images of 40 "galaxies". Although, there are problems in determining the absolute magnitudes of bulges of spiral galaxies, as a result of the hardness in getting the values accurate for bulge–disk decomposition, we used 2D bulge-disk decomposition, where there is a minimum in the bright foreground from interplanetary dust. In addition, we used Sex tractor to mask out the pixels from foreground stars or bright neighbors, galaxy's background. In this work, we preferred to avoid compilations of M_{bulge} values from various authors using a different method, as these involve a range of morphology various of spiral galaxies in the M_{bulge} -P relation.

The interesting about this study is that the bulges absolute magnitudes is based on a large number of pseudobulges exceeding the number of pseudobulges used in most of the previous research [17][21], (i.e. the poor statistics of pseudobulges in each paper prevent reaching a firm conclusion about the nature of their relation with each part of the galaxy). That means that our sample in this work is one of the bigger samples applied so far to study M_{bulge}- P compared with previous works.
In this work, "a mid-infrared (MIR)" view is presented for the M_{bulge} -P scaling relations using a 2D photometric decomposition.
Here we studied the relations between the absolute magnitudes of bulges(M_{bul}), and (P) shown in Table (1).
To the best of our knowledge, this paper is the first study to show the,

Measurement of the" absolute magnitudes of bulges"(M_{bulge})

The determination of "bulge" absolute magnitude is according to a 2D (bulge - bar - disk) decomposition progrom[22]. The bulge absolute magnitude of was measured for 40 spiral galaxies using the 2D multi component decomposition technique. In this technique, the bulges are characterized by a Seresic function:

$$I_b(r_b) = I_{0b}\exp\left[-(r_b/h_b)^{\beta}\right], \quad (1)$$

Where I_{ob} is the "bulge central surface density", h_b is the "bulge scale parameter", β=1/n where n=sere sic index. The "half-light radius (effective radius)', r_e, of the "bulge" was getting by using h_b,

$$r_e = (b_n)^n h_b$$

where the value of "b_n is a constant" defined "such that Γ(2n) = 2γ(2n,b_n)". Γ is the complete and γ is incomplete gama function,. We use the approach "$b_n \approx 2.18n_b - 0.365$" [27], where nb is Sersic index of the bulge
The "foreground stars" were extracted and all point sources from the images were masked out by applying "SExtractor" [28]. Second, the profiles of surface brightness were measured applying the ELIPSE routine in IRAF [22][29]. To change "surface brightness" units to "mag arcsec^{-2}", the following formula was used:

$$\mu_{3.6\mu m} = -2.5 \times \log_{10}\left[\frac{S_{3.6\mu m} \times 2.35 \times 10^{-5}}{ZP_{3.6\mu m}}\right] \quad (2)$$

Where S3.6μm is the "flux value" of the "3.6 μm

band" in units of "MJy sr−1, ZP" at 3.6µm is the "IRAC zero magnitude flux density" in Jyand is "280.9" [9][18].
"Apparent magnitude" was converted to "absolute magnitude" was convert using "luminosity distance" and "absorption" in the galaxies according to the "NEDdatabase".
To measure the bulges absolute magnitudes, we used luminosity distance for a sample of 40"spiral galaxies" galaxy using the NED database. The absolute magnitude at 3.6 µm was calculated using the standard relation:

$$M_{3.6\mu m} = m_{3.6\mu m} + 5 - 5 \log D, \quad (3)$$

Where (D): the luminosity distance in parsecs.

Results and Discussion

By using the sample of 40 images of galaxies and drawing M_{bulge} − P correlation, we conclude that there is a new correlation between M_{bulge} and "pitch angles".
Table (2) illustrates "the parameters of the best-fitting lines for this diagram".
Figures (1) shows the correlation for M_{bulge}-P (we specified a special marker to these galaxies based on their type of "morphological bulge": i.e. "classical bulge and pseudobulge". In Fig. (1) we note that both "classical bulges and pseudobulges" are existing between the "fitting line". The best-"fitting line" are display in figure (1):

$$M_{\text{bulge}} = (25.13 \pm 0.81) - (0.123 \pm 0.015)P \quad (4)$$

We found that "Pearson's linear correlation coefficient" for aM_{bulge} and p relation is 0.83 for both pseudobulges and classical bulges. This means a good relation between the absolute magnitudes of bulges and "pitch angle".
Figure (1) explains the correlation of the absolute magnitudes of bulges with pitch angle for 40 galaxies showed as “bulge” in Table (2), where the "scatter" looks somewhat large in the M_{bulge}-P correlation. Based on the result of number of astronomers [14][30][31], the M_{bulge}-P correlation backing the notion of regulated forming mechanisms and "co-evolution" for the galaxy’s absolute magnitudes of bulges(the smallest structures in a "galaxy") and the "pitch angle of a galaxy's" (the largest structures in a galaxy).
During the decomposition process, the absolute magnitudes of bulges were measured. For this figure, we have recomputed these values, particularly for pseoudobulges with n ≤ 2.5, to get more exactly values.

Kormendy& Fisher (2008) pointed out that bulges have steep brightness profiles for bulge light in galaxies which often dilute the contrast with the spiral structure, and that bulge light especially affects discernibility of the spiral structure very strongly at smaller galaxy radii. Note, the structure of spiral depends little on radius that is essentially a property of the pseudobulge galaxy.

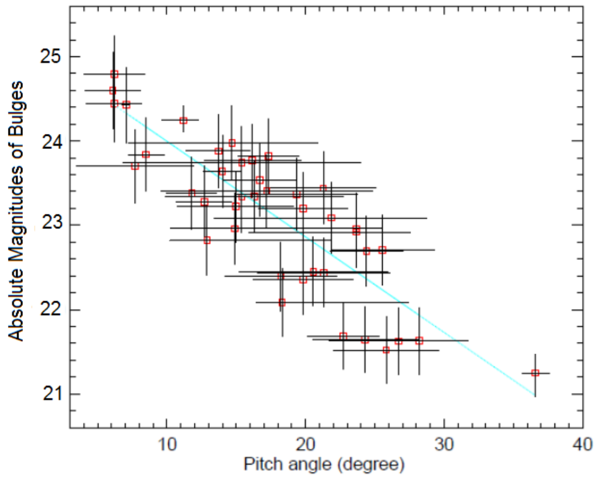

Figure 1. The absolute magnitudes of bulges (M_{bulge}) as a function of pitch angle

The essential M_{bulge} − P relation of galaxies was examined while taking into account the nature of the "classical bulge or pseudobulge". Figure (2) explains the relations in M_{bulge}-P, where the pseudobulges and classical bulges have distinguished relations. The "best-fitting lines" are: 10

$$M_{\text{bulge}} = (23.8 \pm 0.4) - (0.46 \pm 0.01)P \quad (5)$$

pseudobulges

$$M_{\text{bulge}} = (24.4 \pm 0.25) - (0.37 \pm 0.013)P \quad (6)$$

classical bulges

Pearson's linear relation coefficient for M_{bulge} and pitch angle are 0.78, and 0.86 for pseudobulges and classical bulgses. The values of Pearson's linear relation coefficient for classical bulgess and pseudobulgess of "galaxies" are clarified to have a good relation. These values have a "significance" of 99.7%, a 3σ.
Fig. (2) Explains that there are statistically significant relation for the absolute magnitudes of bulges and the "pitch angle": "galaxies" with high absolute magnitudes of bulges have smaller "pitch angles". The correlation looks somewhat better for "pseudobulges" with n ≤ 2.5. Also, "pseudobulges" with small pitch angles follow the same scaling correlations as "classical bulges", while those with large "pitch angles" deviate from the "scaling relations" of "classical bulges".

The absolute magnitudes of bulges–pitch angle relation ('non-barred, AGN and non-AGN galaxies") (Fig.(3)) shows the same behavior. There is a important relation for the pitch angle and the absolute magnitudes of bulges of the bulge for all of them.

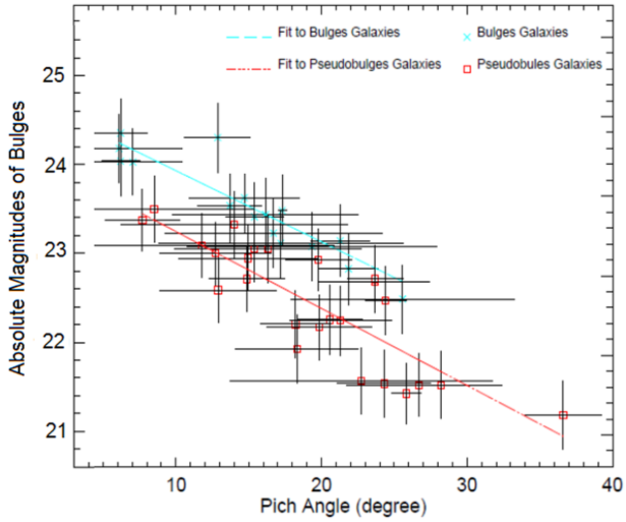

Figure 2. The absolute magnitudes of bulges (M_{bulge}) as a function of pitch angle. The linear regression are shown as long red color and blue color, respectively, for pseudobulges, and bulges galaxies.

Figure (3) explains the (M_{bulge}-P) relation, for "non-barred, non-AGN, and AGN galaxies". "Pearson's linear correlation coefficient" for a relation for M_{bulge} and P was found to be 0.78, 0.83, and 0.79 for "non-barred, non-AGN, and AGN galaxies".

Most of the AGNs are host to low-mass black holes (BHs) [17][20][31], so the slope of the M_{bugel}–P correlation in the "AGNs" is somewhat low when compared to "non-barred, non-AGN galaxies". "Pearson's linear correlation coefficient" results for all types of "galaxies" are noted to have the significance level at which the "null hypothesis of zero correlation" is disproved, is 3σ.

The "best-fitting lines" are explained for this figure:

$$M_{\text{bulge}} = (24.57 \pm 0.7) - (0.56 \pm 0.01)P\ Non - Barred \quad (7)$$

$$M_{\text{bulge}} = (24.87 \pm 0.5) - (0.61 \pm 0.009)P \text{ Non} - \text{AGN} \quad (8)$$

$$M_{\text{bulge}} = (24.49 \pm 0.4) - (0.55 \pm 0.008)P \text{ AGN} \quad (9)$$

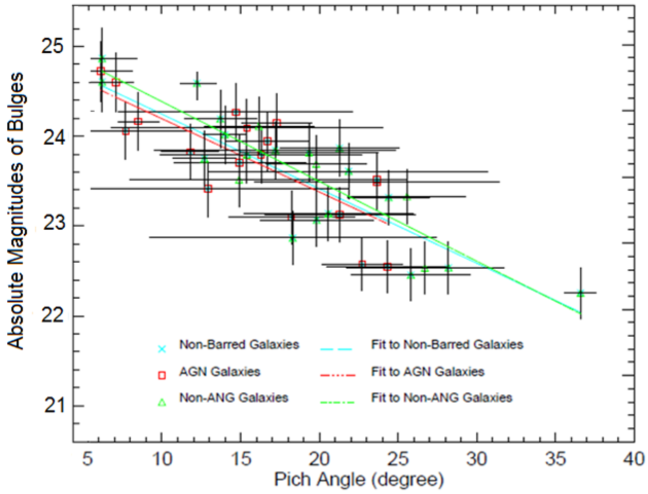

Figure 3. The absolute magnitudes of bulges (M_{bulge}) as a function of "pitch angle". The linear regression are shown as long blue color, green color, red color respectively, for," non-barred, Non-AGN, and AGN galaxies".

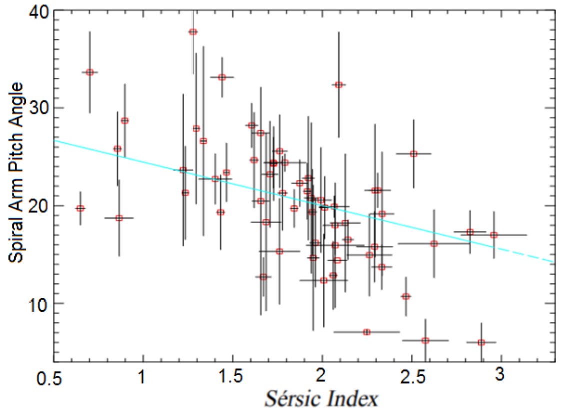

Figure 4. Plot of pitch angle as a function of Sérsic index.

When using P of the 40spiral galaxies (Figure4), 18 classical bulge galaxies and22pseudobulges (Figure 5); and the Sérsic index, the linear regressions of (n) on P give the respective relations:

$$P = (-0.0394 \pm 0.007)n + (28.286 \pm 1.54) \quad (10)$$

$$P = (-0.0944 \pm 0.007)n + (35.653 \pm 1.49) \text{ Classical Bulges} \quad (11)$$

$$P = (-0.0278 \pm 0.008)n + (27.045 \pm 1.51) \text{ Pseudobulges} \quad (12)$$

Weak correlations were found between them, using Pearson's linear correlation coefficients for 40 spiral galaxies, classical bulges, and pseudobulge galaxies; these were 0.36, 0.56, and 0.25, respectively.

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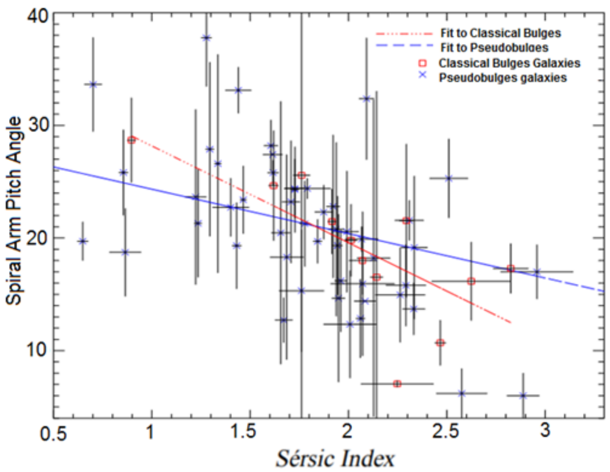

Figure 5. "Pitch angle" as a function of Sérsic index. The "linear regression" are shown as dash dot and dashed, respectively, for "classical bulges and pseudobulges galaxies".

In addition, the sample galaxies are classified into those which harbor classical bulges and those which harbor pseudobulges according to Sérsic indices (n_b) and the ratio of bulge-to-total (B/T) luminosities. Two ways were adopted for this classification: first, "pseudobulges" have $n_b \leq$ 2.5while"classical bulges" have $n_b >$ 2.5 [32]. Second, the average B/T of pseudobulges is (0.16) whereas, the average "B/T" of "classical bulges" is (0.4) [4][6][32].The basic "morphological Hubble type" has been taken from "HYPERLEDA" and "NED".

Using the decomposition, we indicate that the distribution of Sérsic indices in the host galaxy bulges is bimodal, suggesting that pseudobulges are foundn<2.5 while "classical bulges" are foundn>2.5.

Table 1. Columns: (1) nameof "galaxies". (2) "Hubble type" taken from the "Hyper-Leda" catalogue. (3) "Pitch angle" (P). Most of (P) taken from [24][33][34]. (4) Absolute magnitudes of bulges. (5) C – classical bulge; P - pseudobulge.

Name (1)	Leda Type (2)	P (deg.) (3)	M_{bulge} (4)	(n) (4)	C or P (5)
Circinus	Sb	26.7	-21.285 ± 3	1.6 ± 0.2	P
IC 2560	SBb	16.3	-23.51 ± 4	1.8 ± 0.3	P
NGC 224	Sb	8.5±1.3	-24.01 ± 3	3.19 ± 0.5	C
NGC 613	Sbc	23.68±1.77	-23.01 ± 2	1.2 ± 0.2	P
NGC 1022	SBa	19.83±3.6	-22.26 ± 2	1.7 ± 0.4	P
NGC 1068	Sb	17.3±2.2	-24.09 ± 3	1.7 ± 0.3	P
NGC 1097	SBb	16.7±2.62	-23.76 ± 3	1.7 ± 0.4	P
NGC 1300	Sbc	12.7±1.8	-23.26 ± 2	3.6 ± 0.2	C
NGC 1350	Sab	20.57±5.38	-22.26 ± 2	1.6 ± 0.3	P
NGC 1353	Sb	36.6±5.4	-20.81 ± 3	1.7 ± 0.2	P
NGC 1357	Sab	16.16±3.48	-24.01 ± 4	1.5 ± 0.3	P
NGC 1365	Sb	15.4±2.4	-23.51 ± 2	1.4 ± 0.5	P
NGC 1398	SBab	6.2±2	-24.76 ± 4	4.3 ± 0.2	C
NGC 1433	SBab	25.82±3.79	-21.16 ± 3	2.6 ± 0.3	C
NGC 1566	SABb	21.31±4.78	-22.26 ± 4	1.7 ± 0.3	P
NGC 1672	Sb	18.22±14.07	-22.26 ± 3	2.7 ± 0.2	C
NGC 1808	Sa	23.65±7.77	-23.01 ± 3	0.8 ± 0.1	P
NGC 2442	Sbc	14.95±4.2	-23.26 ± 4	1.3 ± 0.1	P
NGC 3031	Sab	15.4±8.6	-24.01 ± 2	3.23 ± 0.5	C
NGC 3227	SABa	12.9±9	-22.76 ± 2	2.6 ± 0.4	C
NGC 3368	SABa	14±1.4	-23.76 ± 3	2.4 ± 0.1	C
NGC 3511	SABc	28.21±2.27	-21.285 ± 3	1.6 ± 0.2	P
NGC 3521	SABb	21.86±6.34	-23.01 ± 2	2.6 ± 0.2	C
NGC 3673	Sb	19.34±4.38	-23.51 ± 3	3.4 ± 0.3	C
NGC 3783	SBab	22.73±2.58	-21.36 ± 3	2.9 ± 0.2	C
NGC 3887	Sbc	24.4±2.6	-22.51 ± 2	1.5 ± 0.1	P
NGC 4030	Sbc	19.8±3.2	-23.26 ± 2	1.7 ± 0.2	P
NGC 4151	SABa	11.8±1.8	-23.51 ± 4	3.6 ± 0.4	C
NGC 4258	SABb	7.7±4.2	-24.01 ± 3	5.4 ± 0.2	C
NGC 4462	SBab	17.2±5.42	-23.51 ± 3	1.6 ± 0.2	C
NGC 4594	Sa	6.1	-25.01 ± 2	1.5 ± 0.1	P
NGC 4699	SABb	6.2±2.2	-25.26 ± 2	3.1 ± 0.2	C
NGC 5054	Sbc	25.57±3.73	-22.76 ± 4	3.3 ± 0.3	C
NGC 5055	Sbc	14.9±6.9	-23.01 ± 3	1.3 ± 0.2	P
NGC 6300	SBb	24.3±3.8	-21.31 ± 4	0.6 ± 0.1	P
NGC 6902	SBab	13.71±2.3	-24.01 ± 3	2.7 ± 0.2	C
NGC 7213	Sa	7.05±0.28	-24.76 ± 3	3.4 ± 0.4	C
NGC 7531	SABb	18.31±9.09	-21.76 ± 2	1.8 ± 0.2	P
NGC 7582	SBab	14.7±7.44	-24.26 ± 3	3.7 ± 0.3	C
NGC 7727	SABa	15.94±6.39	-25.51 ± 3	3.1 ± 0.4	C

Table 2. "Linear correlation coefficient" and "linear regression coefficients" of theabsolute magnitudes of bulgesas a function of the "pitch angle", [(M_{bulge}) = α − βP]:

Types of galaxies	A	β	No. of galaxies	correlation coefficient
All galaxies	25.13 ± 0.81	0.123 ± 0.015	40	0.87
Pseudobulges galaxies	23.8 ± 0.4	0.046 ± 0.01	20	0.78
Bulges galaxies	24.4 ± 0.25	0.37 ± 0.013	20	0.78
Non-Barred galaxies	24.57 ± 0.7	0.56 ± 0.01	14	0.83
AGN galaxies	24.87 ± 0.5	0.61 ± 0.008	18	0.79
Non-AGN galaxies	24.49 ± 0.4	0.55 ± 0.008	23	0.83

Conclusions

Based on this search, the conclusions can be made:

1. The scaling relations were found new correlation for the absolute magnitudes of bulges (M_{bulge}), and the pitch angles. The bulge Sérsic index (n) was determined based on a "2D decomposition" of "3.6 μm""Spitzer/IRAC" images of 40 spiral galaxies, and luminosity distance values obtained from Hyperleda which were used to estimate the absolute magnitudes of bulges.
2. The relations between the absolute magnitudes of bulges (M_{bulge}), and spiral arm pitch angle (P) were investigated using "2D decomposition" of "Spitzer/IRAC" images at "3.6 μm", and the best-fitting linear regressions are:

$$M_{\text{bulge}} = (25.13 \pm 0.81) - (0.123 \pm 0.015)P$$

$$M_{\text{bulge}} = (23.8 \pm 0.4) - (0.46 \pm 0.01)P \text{ Pseudobulges}$$

$$M_{\text{bulge}} = (24.4 \pm 0.25) - (0.34 \pm 0.013)P \; \textit{Classical bulges}$$

$$M_{\text{bulge}} = (24.57 \pm 0.7) - (0.56 \pm 0.01)P \text{ Non} - \text{Barred}$$

$$M_{\text{bulge}} = (24.87 \pm 0.5) - (0.61 \pm 0.009)P \text{ Non} - \text{AGN}$$

$$M_{\text{bulge}} = (24.49 \pm 0.49) - (0.55 \pm 0.008)P \text{ AGN}$$

3. The results of this study indicated that secular evaluation for the pseudobulges and minor mergers for the classical bulges played an significant role in growing masses of "supermassive black hole" in center of "galaxies".
4. The absolute magnitudes of bulges and that of the bulge structure parameters was determined using "2D decompositions" of "Spitzer/IRAC""3.6 μm" images, with high accuracy. A new relation was found to exist for the pitch angles and the absolute magnitudes of bulges of disk galaxies.

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