Difference between Dynamical Masses and Stellar Masses of the Bulge in Spiral Galaxies

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Abstract

This work aims to study the difference between bulge dynamical masses and bulge stellar masses for Spitzer/IRAC 3.6 μm images of 41 spiral galaxies. The ratio between the stellar and dynamical masses for the spiral galaxies were studied using the virial relation and mass to light ratio (M*/Lbulge) to find M* and Mdyn masses respectively. We found the dynamical mass was found applying the virial relation with the virial coefficient (K = 5). We obtained a stellar velocity dispersion from the literature. We obtained the bulge effective radius (re) using 2D decomposition of Spitzer/IRAC at 3.6 µm images. The stellar mass M* of each galaxy measured using the bulge luminosity and (M*/Lbulge) ratio.

Key Words: Dynamical Mass, Stellar Mass, Bulge Luminosity, Mass to Light Ratio.

Introduction

Several previous studies have found the unphysical result that the stellar masses (M*) of many galaxy bulges are bigger than their dynamical masses (Mdyn). Many of authors have reported the surprising fact that they find stellar masses greater than dynamical masses for some massive compact galaxies both at low and high z [1, 2].

To measure the bulge mass, astronomers applied the virial theorem, which show to be quite accurate [2], and this method needs accurate of spectroscopical measurement of the velocity dispersion. Also, some researchers used different method for M* by merging Lbulge with a M/L according to calibrated correlations [2, 3, 4].

Stellar masses measurements are depend on the ratio of real data with synthetic spectra that use the current information of spectra of the stars, history of forming of stars and attenuation of the dust. It thought that the uncertainty on host galaxies could produce an error in the measurement of the masses up to factors of 2–4 [3, 4].

The differentiation with stellar population synthesis methods can be done applying a band of wide range photometric spectral energy distribution (SED) [5]. This method has the advantage that can be applied easily at high-redshift [6].

Several methods used to find dynamical masses. In general, the correct techniques are depend on the result of the equations of Poisson and Jeans [7], or the characterization of the system applying an orbit-superposition technique [8]. The techniques are expensive in terms of observing time. A cheaper alternative is to use a simple mass estimation or according on the virial theorem [2, 9].

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Our study distinguished the ratio $M_*/M_{\text{dyn}}$ at the several of the dynamical parameters of the host galaxies (e.g. classical, pseudo bulge, barred, AGN, non-AGN). To the best of our knowledge, this paper is the first study to show the discrepancy between stellar masses and dynamical masses for a sample of 41 spiral galaxies from Spitzer/IRAC at 3.6 µm band by applying two methods.

### Methods

In this work, we have studied the discrepancy between stellar masses and dynamical masses in 41 IRAS (3.6µm) spiral galaxies by applying two methods:

#### 1- Measurement of the bulge luminosity ($L_{\text{bulge}}$)

In this method, the mass of SMBH measurement depend on the bulge luminosity. The value of bulge luminosity measured by apply a 2D (bar - bulge - disk) decomposition program to model of images from Spitzer/IRAC at 3.6 µm band [10]. The luminosity of bulge measured of 41 galaxies images using the 2D multicomponent decomposition method.

The description of bulge is by a Sersic function:

$$I_b(r_b) = I_{eb} \exp\left(-\left(\frac{r_b}{h_b}\right)^n\right)$$

Where $I_{eb}$ is the density of central surface, $h_b$ is the value of parameter, $\beta=1/n_b$ with $n=$sérsic index. $r_c$ is the effective radius), and was obtained using:

$$r_c = (b_n)^{1/n_b}$$

Using the $b_n \approx 2.171 n_b - 0.356$; [33], where $n_b$s is Sersic index of the bulge.

The orientation parameter was found using 3.6 µm images of spiral galaxy with $M_{\text{bul}}$ measurement [32]. In this work, the imagewere masked out by using the program of S Extractor [11], Second, the profile of surface brightness using the ELLIPSE routine in IRAF1 [10, 12, 13, 14]. By applying the following formulato change unit of surface brightness to (mag arcsec$^{-2}$):

$$I_{3.6,\mu m} = -2.5 \times \log_{10}\left[\frac{L_{3.6,\mu m}}{2.5 \times 10^{30} \text{Jy sr}^{-1}}\right]$$

Where:

- $S_{3.6,\mu m}$: the rate of flux at 3.6 µm (units of MJy sr$^{-1}$),
- $ZP_{3.6,\mu m}$: the zero magnitude of flux density, its value is 280.90 in Jy [15].

To measure the bulge luminosity, First; we used luminosity distance for M31 galaxy using the NED database. Second; the absolute magnitude at 3.6 µm was calculated using the standard relation:

$$M_{3.6,\mu m} = m_{3.6,\mu m} + 5 \log D + 5$$

Where (D) is the luminosity distance in parsecs. Third; the bulge luminosity of spiral galaxy was found using the relation [14]:

$$\log (L_{3.6,\mu m}/L_\odot) = 0.4(-M_{3.6,\mu m} + 3.24)$$

The resultant of the bulge luminosity of 41 spiral galaxy at 3.6 µm is listed in the column 5in Table (1).

#### 2- Stellar mass Measurement ($M^*$) using $M/L$ Ratio

Astronomers [2, 16] found in this work a relation between optical colors of the disk of the galaxy (e.g., B−V, B−R) and the ratio of stellar mass / light ($M^*/L_{\text{bulge}}$ or $\gamma$).

Previous researches did not find the ($M/L$) measurement sat 3.6um band. In this study, we used a new correlation to measure ($\gamma$).

This correlation is related ($\gamma^*$) and ($\gamma^{3.6 \mu m}$) which found by group of astronomers 2008 [17]:

$$\gamma^{3.6} = B^{3.6} \times A^{3.6} \times a^{3.6}$$

Where $A^{3.6} = -0.05$ and $B^{3.6} = 0.921$, and a relation related ($\gamma^*$), and optical colors:

$$\log(\gamma^*) = b^* \times \text{Optical Color} \times a^*$$

Where $a^*$ and $b^*$ are coefficients that related ($\gamma^*$) and optical colors are shown in [2, 16].

By adding Equations (6) with (7), and taking on 20% solar metallicity [18], with the data of optical colors [2, 16], and using a scaled Salpeter IMF cutting off the stars less massive than $\sim 0.36M_\odot$, we measured $M/L$.

The resultant of the bulge stellar masses of 41 spiral galaxy at 3.6 µm is listed in the column 7in Table (1).

#### 3- Dynamical mass measurement

We described the method to measure the bulge mass. The bulges dynamical masses ($M_{\text{dyn}}$) are measured by applying the virial theoremis[19, 20, 21]:

$$M_{\text{dyn}} = K \sigma^2 \ r_e/G$$

Where $k$ is the function of Sérsic index [21, 22], we follow (Cappellari, 2006) [23] to use $k=5$ that shows that the value of ($k$) is a constant average value which can measure the accurate value of $M_{\text{dyn}}$.

$\sigma$ and $r_e$ are the dispersion velocity and the effective radius respectively, and $G$ is the constant.
of gravitation.
The resultant of the bulge dynamical masses of 41 spiral galaxy at 3.6 µm is listed in the column 6in Table (1).

Result and Discussion

The dynamical mass and the stellar mass of the bulge estimated by using the model of isothermal [21], and applying a new calibration for 3.6 µm [17] are consistent within 1σ of two types of methods; no systematic offset is discovered. In addition, the dispersion velocity of the galaxies taken from the literature.

Figures (1, 2, 3) show two techniques producing bulge dynamical and stellar masses which used to measure and compares dynamical and stellar masses based on the these techniques.

There are several explanations which can be used to explain these figures: (1) We measured and compared the stellar and dynamical masses for 41 spiral galaxies by using equations 1,2,3. (2) Measured the masses of dynamical and stellar for AGN, non-AGN, barred galaxies. (3) Measured and compared the masses of dynamical and stellar for classical bulges and pseudo-bulges galaxies.

Fig. (1) Shows a comparison between the bulge dynamical masses and accurate determinations of the bulge stellar masses for the 41 spiral galaxies. We fit the residual systematic difference accounting for errors in both the stellar and dynamical masses applying fitexy.pro in the IDL program. We found that the systematic difference can be as high as 1.2 times. The ratio of stellar to dynamical masses is $(M_*/M_{\text{dyn}} > 1)$. This ratio is linked to the compactness of the most spiral galaxies. The discrepancy of mass is small to be caused by the accuracy of the stellar mass determination using two techniques producing bulge dynamical and stellar masses.

Figure 2 illustrates a comparison of different types of bulge mass estimates for classical bulges and pseudo-bulges galaxies. We noted different $M_*/M_{\text{dyn}}$ relations obeyed by the two type of bulges (classical bulges and pseudobulges). Pseudobulges are located below the classical bulges are emphasized in Figure 2.

In Fig 3, we shown the distributions of inferred $M_{\text{dyn}}$ and $M_*$masses for AGN (red), non-AGN (green), and the barred galaxy (blue). These histograms obviously highlight the various distributions of $M_{\text{dyn}}$ and $M_*$ masses. We found: AGN and non-AGN galaxies have lower $M_{\text{dyn}}$ and $M_*$ masses than barred galaxies.

The median measurements of the $M_{\text{dyn}}$ and $M_*$ masses for AGN and non-AGN galaxies are similar to each other. We found that the systematic difference can be as high as 0.68 and 0.25 times. $M_*/M_{\text{dyn}}$ is masses ratio dependent, higher or lower for massive bulges or small bulges. In this the cases, pseudo-bulges follow a different relation, slope and the intercept comparing with the relation for classical bulges. However the average $M_*/M_{\text{dy}n}$ ratio is small, this difference related to the mass contribution from the small bulges and massive bulges.
The difference ($M_*/M_d$ ratio) can be as high as 0.62, 0.26 and 0.23 times for barred, AGN and non-AGN galaxies. In all cases, the average $M_*/M_d$ ratio is small, this difference linked to the contribution of bulge masses from the dark matter, the baryonic matter, stars, stellar remnants and gas.

In general, $M_*$ can be affected by dust extinction, depending on wavebands, and by the assumption of a constant $M/L$ over the entire galaxy.

In this work, it is found that $M_*$ is easily measured than $M_{\text{dyn}}$ especially at 3.6um.

![Figure 3: Bulge Dynamical masses as a function of Bulge Stellar Mases. The Linear Regression are shown as Long Dash, Dash Dot Dot Dot, Dash Dot and Dashed, Respectively, for Barred, Nonbarred, and AGN Galaxies.](image)

In this part, the correlations between dynamical and stellar masses for bulges with spiral arm pitch angle are re-examined. These were initially determined by Al-Baidhany et al. 2017 for 41 spiral galaxies.

The $M_{\text{bulge}} - P$ correlations are shown in Figures (4), and (5). In Figure (4), we found that Pearson's linear correlation coefficient for this correlation was 0.817, and the fit is a linear relation:

$$\log_{10} \frac{M_{\text{bulge}}}{M_*} = (8.42 \pm 0.14) - (0.058 \pm 0.01)P$$

From Figure (4) and Pearson's linear correlation coefficient, this work confirmed the conclusion by Al-Baidhany et al. (2017) that a significant correlation exists between bulge dynamical masses and the spiral arm pitch angles.

![Figure 4: Bulge Dynamical Masses as a Function of Spiral Arm Pitch Angles. The Linear Regression is the Fit to all Spiral Galaxies.](image)

The $M_*/P$ correlations is shown in Figure (5). In Figure (5), we found that the Pearson's linear correlation coefficient for this correlation was 0.825. From Pearson's linear correlation coefficient which is 0.825, it can be concluded that most spiral galaxies, which have pseudobulges and classical bulges, have a correlation between $M_*$ and $P$. To the best of our knowledge, this is a new correlation between bulge stellar masses and spiral arm pitch angles.

The linear fit of the relation is:

$$\log_{10} \frac{M_*}{M_0} = (12.59 \pm 0.4) - (0.051 \pm 0.006)P$$

![Figure 5: Bulge Stellar Masses as a Function of Spiral Arm Pitch Angles. The Linear Regression is the Fit to all Spiral Galaxies.](image)
We studied the difference between dynamical masses and stellar masses for bulges of Spitzer/IRAC 3.6 μm images of 41 spiral galaxies. In this work, we concluded that the ratio of stellar to dynamical masses ($M_*/M_{dyn}$) is linked to the compactness of the bulges of spiral galaxies, the mass discrepancy for most spiral galaxies is small to be caused by the accuracy of the stellar mass determination, where the stellar mass determination can be both mass estimators, and the
discrepancy ratio of stellar to dynamical masses can be explained by a variation in the compactness of the bulges of spiral galaxies. In general, ratio of dark matter for spiral galaxies is small, and the variation in the dark matter fraction is a different with the type of galaxy or its morphology. In addition, we found the ratio of dark matter depend on the M$_{\ast}$/L, where the low M$_{\ast}$/L shows that dark matter is mostly, the baryonic matter, stars, stellar remnants and gas, and, the systematic difference (M$_{\ast}$/M$_{\star}$ ratio) can be as high as 0.62, 0.26 and 0.23 times for barred, AGN and non-AGN galaxies. Finally, we found that the systematic difference (M$_{\ast}$/M$_{\star}$ ratio) can be as high as 0.68 and 0.25 times for classical bulges and Pseudobulges.

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