A Comparison between Different Methods to Study the Supermassive Black Hole Mass - Pitch Angle Relation

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Abstract. In this study, we compared the different Methods of determination of SMBH masses to study a correlation between mass of supermassive black hole and spiral arm pitch angle for 41 images of spiral galaxies using Spitzer/IRAS 3.6-μm. We selected four methods to find a determination mass of SMBH. Velocity dispersions (σ) measurements and pitch angle of spiral arm took from the literature. In addition, SMBH masses estimates using a several methods (reverberation mapping RM, stellar dynamics SD, gas dynamics GD) from the literature from. In addition, the determinations of SMBH masses were found using the (MBH-) relation. Finally, we compared the (MBH-P) relation for these galaxies using each method with the Seigar's equation, and found the results to agree for these methods.

Key words: supermassive black holes, spiral galaxies, pitch angle, dispersion velocity.

1. Introduction

SMBH masses at the center of all galaxies play important role in the evolution of host galaxies. Over the past 30 years, one of the most significant advances and the most amazing inventions was that all or most galaxies contain a black hole at the centers of galaxies [1].

It is now recognized that SMBHs regulate the formation and evolution of all galaxies. The development of methods for measuring masses of SMBH has led to the discovery of the tight relations between the SMBHs mass and several parameters of host of galaxies properties [2,3,4,5]. These correlations imply that the processes, which drive SMBH growth are intimately linked galaxy growth [6].

The relationships between the mass of SMBHs and properties of their host galaxies support to study the mechanism of the formation of SMBHs [7], with their hosts which impacts current models of cosmological structure formation [8,9].

The measurement of SMBH mass can be divided into direct and indirect methods. Direct methods measure the effect a SMBH has on the stars of the bulge, using the observation instrumentation of the
motion the parameters of their host galaxies [5,10]. Indirect methods of SMBH measurements of mass rely on calibrations, i.e., these methods use measurements which have been found to scale with SMBH mass from the direct methods.

One of the strong correlation that used to find the SMBH mass is: the SMBH correlated with the bulge velocity dispersion [11]. This is a strong relation between MBH and the bulge velocity dispersion $\sigma$, which has a lower intrinsic scatter for late-type.

The previous studies have discovered that SMBH mass is related with pitch angle of spiral arm. Seigar et al. (2008) found out a significant relationship between pitch angle and the mass of SMBH in the center of disk galaxies. This correlation provides comparatively easy method to calculate SMBH mass by estimating pitch angle of spiral galaxies [12, 13,14].

In this paper, first, we compared the different Methods of determination of SMBH masses to study a relation between SMBH mass and pitch angle ($M_{\text{BH}}-P$), which discover by Seigar et al. [12]. Second, we selected four techniques to provide a measurement of mass SMBHs. Third, we took velocity dispersions ($\sigma$), pitch angle, and the determination of BH mass using several methods (reverberation mapping RM, stellar dynamics SD, gas dynamics GD) from the literature from the literature. In addition, the determinations of SMBH masses were found using the ($M_{\text{BH}}-\sigma$) relation. Finally, we compared ($M_{\text{BH}}-P$) Seigar's relation for these galaxies using each method.

This paper is as follows: in Section 2, we briefly describe 41 images of spiral galaxies. Section 3 presents the ($M_{\text{BH}}-\sigma$) and ($M_{\text{BH}}-P$) relations to calculated the SMBH masses, Section 4 is a discussion and analysis these results. The conclusions in Sect. 5.

2. Sample

In this paper, we select a numbers of spiral galaxies with reliable SMBH mass estimates. Our main sample is based on that used by group of researchers [12], Treuthardt et al. (2012) [15] and Berrier et al. (2013) [14]. We chose supermassive black hole masses measured using a different technique (reverberation mapping, maser modeling, stellar dynamics and gas dynamics). Pitch angles, and the stellar velocity dispersion of these galaxies are taken from the literature.

Our sample consists of 41 galaxies whose relevant properties are given in Tables 3, 4, and 5. According to HYPERLEDA and de Vaucouleurs et al. (1991, hereafter RC3), the basic morphological Hubble type has been taken from HYPERLEDA\(^1\) and NED\(^2\).

3. Techniques

3.1 Measurement of SMBHs:

There are varieties of methods for estimating masses of SMBH. In this study, we selected galaxies which have BH mass measurements by applying four methods: the relation between ($M_{\text{BH}}$) and velocity dispersion of bulge ($\sigma$) ($M_{\text{BH}}-\sigma$) [3,11,16], the relation between BH mass and pitch angle of spiral arm ($P$) ($M_{\text{BH}}-P$) [12,14], reverberation mapping RM, stellar dynamics SD, and gas dynamics GD.

3-2 Measurement SMBHs using ($M_{\text{BH}}-\sigma$) relation:

Although there are many different methods, the $M_{\text{BH}}-\sigma$-method is the most prominent in determining the mass of supermassive black holes (SMBHs) [17]. Because SMBH masses found in late-type spirals have

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\(^1\)http://leda.univ-lyon1.fr/
\(^2\)http://nedwww.ipac.caltech.edu/
lower mass, we used M_{BH-} relation. This technique is based on the measurements that SMBH masses correlate with the dispersion velocity of the bulge of galaxies [3,11].

SMBHs masses at the center of spiral galaxies with classical bulges determined using velocity dispersion (*), and converting to SMBH masses using the relation:

\[ M_{BH}/M = 10^{8.13 \pm 0.06} (\sigma/200 \text{ km s}^{-1})^{4.02\pm0.32} \]  

(1)

3.3 Measurement of SMBHs using pitch angle of spiral arm:

One of the more amazing methods to estimate SMBHs masses in spiral galaxies uses the relation between the central mass in the nuclei of disk galaxies and pitch angle (P) (Seigar et al. 2008; Berrier et al. 2013). Seigar et al. (2008) found that SMBH masses are strongly linked with pitch angle. Additionally, a relation between pitch angle and rotation curve shear (S) was also found [12, 14, 18, 19, 20].

We applied the relationship between SMBHs and (P) discovered by Seigar et al. (2008) [12]. The M_{BH-P} relation is fit by Seigar et al. (2008) using a double-power-law model given as:

\[ M_{BH}/M = 2^{(B-P)_{B}} M_{BHb} (P/P_b)^{P} [1 + (P/P_b)^{P}]^{-(0.76 - 0.05) P} \]  

(2)

where \( B \) is the slope of the power law for large pitch angles, \( P_b \) is the slope of the power law for small pitch angles, \( P_b \) is the transition from small to large pitch angles, \( \beta \) governs the sharpness of the transition, and \( M_{BHb} \) is the black hole mass for a pitch angle \( P_b \). The SMBH mass was estimated with values of parameters provided by this best fit model = 126.1, \( B = 2.92 \), \( P_b = 40.8^\circ \), \( P = 23.5 \), and \( M_{BHb} = 1.72 \times 10^4 \) \( M_\odot \) (Seigar et al. 2008) [12], i.e., the equation of the relation between SMBHs mass and pitch angle (Seigar's equation) is:

\[ \log_{10} M_{BH} = (8.44 - 0.0) - (0.76 - 0.05) P \]  

(3)

4. Results and discussions

In Tables 3, 4 and 5, we presented our results. We used equations (1) to estimate the masses of SMBHs, which is listed in Col. (6) in Tables 3, 4 and 5. By the M_{BH-} * relation, we used equations (1) to estimate the SMBHs masses from the bulge velocity dispersion ( * ) and pitch angle of spiral arm (P), which is listed in Col. (6) in Table 3, 4, and 4. In addition, SMBH masses listed in col. (3) are taken from the literature, which are measured using direct methods: reverberation mapping (RM), maser modeling (MM), stellar dynamics (SD), gas dynamics GD.

In figure 1, the SMBH mass estimates by using direct method (RM) and indirect method (M_{BH-} *) relation to find (M_{BH-P}) relations. These relation are moderately consistent, within 1 of each other; because Pearson's linear correlation coefficient for them are 0.96 and 0.82, whereas the slope of the M_{BH(RM)} - P and M_{BH(M-\sigma)} - P relation are 8.508 and 8.525 respectively. From this figure, we note the (M_{BH(RM)} - P) and (M_{BH(M-\sigma)} - P) relations seem to follow the Seigar's equation[3], though with a larger scatter. From the direct M_{BH} measurements (RM), the Pearson’s linear correlation coefficient is 0.96 and the significance level at which the null hypothesis of zero correlation is disproved is 3\sigma. This means, we can determined the supermassive black hole using the spiral arm pitch angle. Our results in both methods are similar to some extent with Seigar's relation (equ. (3)).

\[ \log_{10} = (8.508 \pm 0.02) - (0.080 \pm 0.04) P \]  

using (RM) method
\log_{10} = (8.525 \pm 0.03) - (0.085 \pm 0.06) P \quad \text{using (MBH-\sigma*) relation}

The direct $M_{\text{BH}}$ measurements (RM) for spiral galaxies would be desirable or reliable to study the important and analyse the behaviour of ($M_{\text{BH}}$ - P) for late-type galaxies. For comparison, note that the slope is not significantly different for RM method and $M_{\text{BH}}$ - * relation. Thus, RM method and $M_{\text{BH}}$- * relation follow the same $M_{\text{BH}}$ – P relation within the errors, although a small offset between these methods. Thus, the reverberation mapping methods a very useful and reliable technique to study and measure SMBH mass.

Figure 1. Shows ($M_{\text{BH}}$-P) relations, using SMBH masses from direct measurements (reverberation mapping RM) and indirect measurements ($M_{\text{BH}}$-\sigma*).

In Figures 2 is presented plot of ($M_{\text{BH}}$-P) using SMBHs masses from direct method (maser modeling MM) and SMBHs masses from the $M_{\text{BH}}$ - * relation versus spiral arm pitch angle (P). We found Pearson’s linear correlation coefficient for a correlation between SMBH by (MM) and SMBH by ($M_{\text{BH}}$-\sigma*) versus pitch angle of spiral arm (P) are 0.51, and 0.49 respectively, whereas the slope of the $M_{\text{BH}}$(MM) – P and $M_{\text{BH}}$(\sigma*) – P relation are 7.785, 7.354 respectively. From figure (2), we found a large percentage of non-correspondences between values from both relations ($M_{\text{BH}}$-P), due to the reason using two different techniques produce SMBH masses which are $M_{\text{BH}}$ - * [4] and a direct method (MM), where SMBH using masses maser modeling do not follow the same MBH– *. Averagely, we found the SMBHs masses from the maser modeling method are little larger than that found by using $M_{\text{BH}}$-\sigma* relation.

Our results in both methods are:

$\log_{10}=(7.785\pm 0.2)-(0.024\pm 0.07)P \quad \text{using (MM) method}$

$\log_{10}=(7.354\pm 0.1)-(0.022\pm 0.05)P \quad \text{using (MBH-\sigma*) relation}$
Figure 2. Shows (MBH-P) relations, using SMBH masses from direct measurements (maser modeling MM) and indirect measurements (MBH-\*).

In Figure 3 is presented plot of supermassive black hole masses from the $M_d$ direct method (SD and GD) and $M_{BH-}$ relation versus arm pitch angle. We found Pearson's linear correlation coefficient for a correlation between SMBH and (P) by ($M_d$) and SMBH and (P) by ($M_{BH-}\*$) are 0.63, and 0.43 respectively, whereas the slope of the $M_{BH(SD,GD)}$ – P and $M_{BH-}$ – P relation are 8.31, 8.18 respectively.

Our results in both methods are:

$$\log_{10} = (8.312 \pm 0.3) - (0.063 \pm 0.05) P$$ using (SD and GD) method

$$\log_{10} = (8.183 \pm 0.2) - (0.051 \pm 0.06) P$$ using ($M_{BH-}\*$) relation

Our results in both methods are similar to some extent with Seigar's relation (equ. (3)).

This study found that methods for determining SMBH masses RM, SD and GD galaxies follow $M_{BH-}$ – P relation. On the contrary, the method for determining SMBH masses MM may be offset from the $M_{BH-}$ – P relation.

Figure 3. Shows ($M_{BH-P}$) relations, using SMBH masses from direct measurements (stellar dynamics (SD) and gas dynamics (GD)) and indirect measurements ($M_{BH-}\*$).
Figure 4 shows a plot of supermassive black hole masses from the $M_d$ direct method (RM, MM, SD and GD) and $M_{BH-}$ relation versus spiral arm pitch angle. We found Pearson's linear correlation coefficient for a relation between SMBH and (P) by $(M_d)$ and SMBH and (P) by $(M_{BH-}\sigma_\ast)$ are 0.83, and 0.81 respectively, whereas the slope of the $M_{BH(RM, MM, SD, & GD)}$ - P and $M_{BH-}$ - P relation are 8.241, 8.084 respectively. As expected, we find a strong correlation between the mass of SMBHs and pitch angle. Our results in both methods are:

\[
\log_{10} = (8.241 \pm 0.2) - (0.091 \pm 0.04) P \quad \text{using (RM, MM, SD and GD) methods}
\]

\[
\log_{10} = (8.084 \pm 0.3) - (0.054 \pm 0.05) P \quad \text{using (M_{BH-}\sigma_\ast) relation}
\]

Our results in both methods are similar to some extent with Seigar's relation (equ. (3)).

Figure 4 shows $(M_{BH-}P)$ relations, using SMBH masses from direct measurements $(RM, MM, SD$ and GD$)$ and indirect measurements $(M_{BH-}\ast)$ versus spiral arm pitch angle.

Figure 5 illustrates a comparison using combining these four techniques produce BH masses which are $M_{BH-} \ast$ relation, stellar dynamics, gas dynamics, and reverberation mapping versus pitch angle. The averages masses of SMBH (using four methods) seem to lie close some extent with the $M_{BH-}$ - P relation. Our results (RM and S/G methods) are consistent to some extent with the previous result of Seigar's equation [17]. This is consistent to some extent with the agreement between SMBH masses (using RM and S/G methods) and $M_{BH-}^\ast$ pitch angle (Seigar et al. 2008) [12]. This Figure shows that MBH-P relation used to determine SMBH mass of spiral galaxies with pitch angles $P < 34$. The fitting results of $M_{BH-}^\ast$ relations are presented in Table (1).
Figure 5. Shows that different techniques produce BH masses which are RM, MM, SD, & GD, and \( M_{\text{BH}}-\sigma \) relation and the relation between SMBH mass and pitch angle (Seigar's equation).

Table 1. Linear correlation coefficient and linear regression coefficients of masses of SMBH as a function of the pitch angle \([\log(M_{\text{BH}})= \alpha + \beta (P)]\):

| Relations                  | \( \alpha \)        | \( \beta \)        | No. of galaxies | correlation coefficient |
|-----------------------------|----------------------|---------------------|-----------------|------------------------|
| \( M_{\text{BH(MR)}} - P \) | 8.508 ± 0.02         | 0.080 ± 0.04        | 10              | 0.96                   |
| \( M_{\text{BH(MM)}} - P \) | 8.525 ± 0.03         | 0.085 ± 0.06        | 10              | 0.82                   |
| \( M_{\text{BH(MS/G)}} - P \) | 7.785 ± 0.2          | 0.024 ± 0.07        | 14              | 0.51                   |
| \( M_{\text{BH(MM)}} - P \) | 7.354 ± 0.1          | 0.022 ± 0.05        | 14              | 0.49                   |
| \( M_{\text{BH(MS/G)}} - P \) | 8.312 ± 0.3          | 0.063 ± 0.05        | 17              | 0.63                   |
| \( M_{\text{BH(MM, MS/G)}} - P \) | 8.183 ± 0.2          | 0.051 ± 0.06        | 17              | 0.43                   |
| \( M_{\text{BH(MS/G)}} - P \) | 8.241 ± 0.2          | 0.063 ± 0.04        | 41              | 0.63                   |
| \( M_{\text{BH(MM, MS/G)}} - P \) | 8.084 ± 0.3          | 0.051 ± 0.05        | 41              | 0.43                   |

4.1 Comparison with previous studies

The previous studies by Seigar et al. (2008) [12], Berrier et al. 2013[14], and Davis et al. 2018[13], found new correlations \( M_{\text{BH}}-P \) using new techniques of measuring the pitch angle of the host galaxy and SMBH masses.

In Table (2), the results were compared with three other results: Seigar et al. (2008) [12], Berrier et al. (2013) [14], Davis et al. (2018) [13], and our work. In all cases, the previous studies found different values of the slope of the galaxies in the \( M_{\text{BH}}-P \) correlation.
Table 2. Comparison with previous results [log (MBH) = \(\alpha\) \(P\) + \(\beta\)]:

| \(\alpha\) | \(\beta\) | \(N\) | Ref.                  |
|-----------|-----------|-------|-----------------------|
| 8.44±0.10 | 0.076±0.005 | 27    | Seigar et al. 2008    |
| 8.36±0.15 | 0.076±0.008 | 67    | Berrier et al. 2013   |
| 8.12±0.16 | 0.062±0.009 | 34    | Berrier et al. 2013 (Direct method) |
| 8.47±0.24 | 0.089±0.013 | 23    | Berrier et al. 2013 (Indirect method) |
| 7.01±0.07 | 0.171±0.017 | 44    | Davis et al. 2018 (pseudobulges) (Direct method) |
| 8.508 ± 0.02 | 8.525 ± 0.03 | 0.080 ± 0.04 | this work (direct method) |
| 8.525 ± 0.03 | 0.085 ± 0.06 | 10 | this work (Indirect method) |
| 7.875 ± 0.2 | 0.024 ± 0.07 | 14 | this work (direct method) |
| 7.354 ± 0.1 | 0.022 ± 0.05 | 14 | this work (Indirect method) |
| 8.312 ± 0.3 | 0.063 ± 0.05 | 17 | this work (direct method) |
| 8.183 ± 0.2 | 0.051 ± 0.06 | 17 | this work (Indirect method) |

Table 3. Columns: (1) galaxy name. (2) Hubble type taken from the Hyper-Leda catalogue. (3) log(MBH/M\(_{\odot}\)), using reverberation mapping method (RM), mass measurement references: (21) Bentz et al. 2009b; (22) Peterson et al. 2004; (23) Denney et al. 2010; (24) Peterson et al. 2005; (25) Denney et al. 2006. Velocity dispersion in km/s, Velocity dispersion references: (26) Greene et al. 2006; (27) Nowak et al. 2010; (28) Nelson 1995; (29) Oliva et al. 1995; (30) Arribas et al. 1997; (31) Rosario et al. 2010. (5) Pitch angle (P). Most of (P) from Berrier et al. (2013), and Davis et al. (2012). (6) log(MBH/M\(_{\odot}\)) calculated by using MBH\(_{\text{M-}}\) relation.

| Galaxy (1) | Type (2) | log(MBH/M\(_{\odot}\) ) (3) | \(P\) (5) | log(MBH\(_{\text{M-}}\) /M\(_{\odot}\) ) (6) |
|------------|----------|-----------------------------|-------|-----------------------------|
| 3c120      | S0       | 162±24 [20]                 | 10.7±1.4 | 7.76±0.16 |
| Ark120     | So       | 177±20 [27]                 | 5.4±0.6  | 7.91±0.08 |
| Mrk 590    | Sa       | 169±28 [28]                 | 8.5±3.3  | 7.83±0.08 |
| Mrk 79     | Sa       | 130±10 [26]                 | 13.2±3.6 | 7.37±0.13 |
| Mrk817     | S0-a     | 127±12 [26]                 | 9.9±4.2  | 7.33±0.16 |
| NGC3516    | S0       | 144±35 [30]                 | 10.6±4.3 | 7.55±0.09 |
| NGC3783    | SBa      | 152±20 [29]                 | 10.5±4.8 | 7.65±0.07 |
| NGC4051    | SABb     | 60 [31]                     | 29.1±4.9 | 6.71±0.12 |
| NGC4395    | Sm       | 30±5 [26]                   | 35.2±6.8 | 4.81±0.15 |
| NGC4593    | Sb       | 124±29 [28]                 | 20.2±2.7 | 7.29±0.08 |

Table 4. Columns: (1) galaxy name. (2) Hubble type taken from the Hyper-Leda catalogue. (3) log(MBH/M\(_{\odot}\)), using maser method, mass measurement references: (32) Gillessen et al. 2009; (33) Ishihara et al. 2001; (34) Rodríguez-Rico et al. 2006; (35) Lodato & Bertin 2003; (36) Kuo et al. 2011; (37) Kondratko et al. 2008; (38) Greenhill et al. 2003a; (39) Kondratko et al. 2006; (40) Greenhill et al. 2003b; (41) Braatz & Gugliucci 2008. (4) Velocity dispersion in km/s, Velocity dispersion references: (42) Hu 2009; (28) Nelson 1995; (29) Oliva et al. 1995; (43) Terlevich E. et al. 1990; (44) McConnell 2013; (45) Ferrarese 2002. (5) Pitch angle of spiral arm (P). (P) from Berrier et al. (2013), and Davis et al. (2012). Spiral arm pitch angle (P). (P) taken from Berrier et al. (2013), and Davis et al. (2012). NGC 4945 is from Braun (1991), and Levine et al. (2006) (46). (6) log (M_{BH}/M_{\odot}) calculated by using M_{BH}\(_{\text{M-}}\) relation.
### Table 5

| Galaxy      | Type | log(M$_{BH}$/M$_{\odot}$) | $\sigma_*$ | P      | log(M$_{BH,*}$/M$_{\odot}$) |
|-------------|------|---------------------------|------------|--------|-----------------------------|
| Circinus    | Sb   | 0.67                      | 75         | 26.7±5 | 6.41±0.1                    |
| IC2560      | SBb  | 0.64                      | 137±14     | 16.3±6.4 | 7.55±0.13                   |
| NGC 253     | SABc | 0.71                      | 109±20     | 17.9±2 | 7.07±0.16                   |
| NGC 1068    | Sb   | 0.72                      | 153±15     | 20.6±4.5 | 7.66±0.17                   |
| NGC 2273    | Sa   | 0.66                      | 124±10     | 17.5±7.5 | 7.295±0.08                  |
| NGC 2986    | Sa   | 0.66                      | 166±15     | 7.5±1.7 | 7.8±0.09                    |
| NGC 3393    | Sb   | 0.65                      | 148±10     | 13.1±2.5 | 7.6±0.06                    |
| NGC 4258    | SABb | 0.65                      | 146±15     | 7.7±4.2 | 7.58±0.08                   |
| NGC 4388    | Sb   | 0.65                      | 107±7      | 26.2±8.2 | 7.037±0.03                  |
| NGC 4494    | SBC  | 0.7                      | 134±20     | 6.1    | 7.43±0.11                   |
| NGC 5495    | Sc   | 0.7                       | 95±12      | 27.8±1.2 | 7.5±0.02                    |
| NGC 6323    | Sab  | 0.67                      | 158±23     | 11.8±3.4 | 7.71±0.29                   |
| NGC 6926    | Sc   | 0.67                      | 110±14     | 17.5±5.5 | 7.66±0.09                   |
| U3789       | SABa | 0.67                      | 107±12     | 10.5±4.8 | 7.03±0.12                   |

Columns: (1) galaxy name. (2) Hubble type taken from the Hyper-Leda catalogue. (3) log(M$_{BH}$/M$_{\odot}$) using for stellar dynamics (S), and gas dynamics (G). Mass measurement references: [47] Ghez et al. (2005); [48] Böker et al. 1999; [49] Bender et al. 2005; [50] Atkinson et al. 2005; [51] Devereux et al. 2003; [52] Davies et al. 2006; [53] Pastorini et al. 2007; [54] Sarzi et al. 2002; [55] Marconi et al. 2003; [56] Okten et al. 2007. (4) Velocity dispersion in km/s. Velocity dispersion references: [42] Hu 2009; [57] Kormondy et al. 2008; [58] Vega Beltrán et al. 2001; [43] Terlevich E. et al. 1990; [59] Whitmore et al. 1985; [44] McConnell 2013; [60] Whitmore 1979; [45] Ferriere 2002; [55] Marconi 2003; [61] Idiart 1996; [62] Barth 2003. (5) Spiral arm pitch angle (P). Most of (P) taken from Berrier et al. (2013), and Davis et al. (2012). The spiral arm pitch angle given for M31, and MW, are taken from Braun (1991), and Levine et al. (2006).(6) log(M$_{BH}$/M$_{\odot}$) using M$_{BH}$- relation.
NGC7582 Slab $f S / S_{22}^{[56]}$ $157\pm20^{[42]}$ $14.7\pm7.4$ $7.696\pm0.07$

5. Conclusion:

There are a variety of methods to measure the SMBHs masses (stellar dynamics, dynamic stellar, reverberation mapping, and $M_{\text{BH}} - \star$). We include 41 galaxies that have direct and indirect measurements.

SMBHs masses in the center of our galaxies are estimated from the (RM, S/G, MM, and $M_{\text{BH}} - \star$) relation. $M_{\text{BH}}-\star$ relation, S/G and RM methods. Although, there is a small difference between the masses values, ($M_{\text{BH}}-\star$) relation using SMBH masses from the $M_{\text{BH}}-\star$ relation are approximately similar to that from the RM and S/G methods. When we compared the ($M_{\text{BH}}-\star$) relation with the different measurements of SMBH masses, results were largely compatible between RM and S/G methods.

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