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The black hole-dark matter halo connection

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Abstract. We explore the connection between the central supermassive blackholes (SMBH) in galaxies and the dark matter halo through the relation between the masses of the SMBHs and the maximum circular velocities of their host galaxies, as well as the relationship between stellar velocity dispersion of the spheroidal component and the circular velocity. We rely on a heterogeneous sample containing galaxies of all types. The only requirement is that the galaxy has direct measurements of its SMBH mass, M_{BH}, circular velocity, v_c, and velocity dispersion, σ. We present a direct observational $M_{BH} - v_c$ relation.

Keywords. black hole physics, dark matter, galaxies: fundamental parameters, galaxies: halo

1. Introduction

Data has been accumulating over the last several years on an increasing number of galaxies in terms of measurements of the bulge velocity dispersion, σ, mass of the central supermassive blackhole (SMBH) M_{BH}, and the circular velocity, v_c, of the host galaxy (e.g., Courteau *et al.* 2007 and refs. therein). It is becoming possible to start asking, and attempting to answer, big questions about the processes that govern the formation of galaxies and their central SMBHs (e.g., Ferrarese 2002; Tremaine *et al.* 2002; Baes *et al.* 2005; Pizzella *et al.* 2005). The aim of this contribution is to approach these issues through studying the observed correlations between v_c, σ, and M_{BH} and comparing with theoretical models (Di Matteo *et al.* 2003; Di Matteo *et al.* 2007).

2. Sample

We built a heterogeneous sample of 339 galaxies of all types for which direct measurements of M_{BH}, v_c, and/or σ exist (see references in the Introduction). The result was 291 galaxies with σ measurements, 221 galaxies with v_c and 75 galaxies with M_{BH}. The intersections between these subsets lead to 193 galaxies that have both σ and v_c, 54 galaxies with both M_{BH} and σ, and 16 galaxies with both M_{BH} and v_c. What we mean by direct measurements of M_{BH} is that masses of the SMBHs have been measured by relying on stellar/gas kinematics (masers, reverberation mapping, etc.) within the sphere of influence of the SMBH; i.e., the mass of the SMBH is measured without any recourse to the host galaxy properties.

3. Analysis

3.1. $M_{BH} - \sigma$ *Relation*

Relying on linear regression analysis (Press *et al.* 1992), we fit a straight line to $\log(M_{BH}/10^6 M_\odot)$ versus $\log(\sigma/200 km\ s^{-1})$ for 54 galaxies:

$$\log(M_{BH}/10^6\ M_\odot) = (4.39 \pm 0.35) \log(\sigma/200\ km\ s^{-1}) + (2.13 \pm 0.06). \quad (3.1)$$

We estimate the intrinsic dispersion to be about 0.25 dex. The relation holds down to $\sigma \approx 76\ km\ s^{-1}$. The slope and normalization derived here agree, within the errors, with those of Merritt & Ferrarese (2001) and Tremaine *et al.* (2002). The relation is also in agreement with theoretical models (Di Matteo *et al.* 2003; Di Matteo *et al.* 2007). The agreement between observations and theory confirms the merger/self-regulated induced growth of the SMBH.

3.2. $v_c - \sigma$ *Relation*

We have 193 galaxies of various types with both v_c and σ. We only fit data for the 179 galaxies with $\sigma > 30\ km\ s^{-1}$ and $v_c > 90\ km\ s^{-1}$, which are comprised of 52 elliptical/lenticulars and 127 spirals:

$$\log(v_c/200\ km\ s^{-1}) = (0.62 \pm 0.03) \log(\sigma/200\ km\ s^{-1}) + (0.153 \pm 0.008). \qquad (3.2)$$

The intrinsic dispersion is about 0.05 dex. Ho (2007) and Courteau *et al.* (2007) find that the zero-point of the powerlaw depends on galaxy properties. The slope we obtain here is slightly shallower than those found in previous studies (Ho 2007; Courteau *et al.* 2007; Pizzella *et al.* 2005; Baes *et al.* 2003; Ferrarese 2002). Our sample for the $v_c - \sigma$ relation is roughly that of Courteau *et al.* (2007). If we apply our fitting procedure for v_c versus σ, i.e., in linear space, then we get a slope of 1.04.

3.3. $M_{BH} - v_c$ *Relation*

We present here an observationally-determined, direct $M_{BH} - v_c$ relation. We apply a linear regression analysis on the 16 galaxies, made up of 7 ellipticals/lenticulars and 9 spirals, in our sample that have directly measured M_{BH} and v_c. The result of fitting is:

$$\log(M_{BH}/10^6\ M_{\odot}) = (6.75 \pm 0.80) \log(v_c/200\ km\ s^{-1}) + (1.21 \pm 0.14), \qquad (3.3)$$

with an intrinsic scatter of 0.25 dex. This relation is steeper than that reported by Baes *et al.* (2003) where the slope was 4.21 ± 0.60. Baes et al. (2003) followed the indirect approach in which they used the $M_{BH} - \sigma$ to calculate M_{BH}. Similarily, we can compare with Ferrarese (2002) by using the relations in her paper to calculate a slope to of 5.5. To compare with theoretical models, we use the information in Di Matteo *et al.* (2003) to derive a theoretical $M_{BH} - v_c$ relation and find its slope to be 4.12, shallower than that of eq. (3.4). Evidently, the sample of galaxies possessing direct measurements of both M_{BH} and v_c must be increased to better constrain the $M_{BH} - v_c$ relation.

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