BLACK HOLE MASS SCALING RELATIONS

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Image Credit: James Josephides
Data & Methodology

• The largest to date sample of supermassive black holes (SMBHs) with directly measured masses
  • Independently measured masses via direct measurement techniques:
    • Proper motion of stars orbit a SMBH (i.e., Sgr A*)
    • Stellar dynamics - kinematics of the stellar disk within the sphere of influence of a SMBH
    • Gas dynamics – kinematics of the gaseous disk within the sphere of influence of a SMBH
    • Direct imaging of the shadow (event horizon) of a SMBH (i.e., M87*)
  • 132 SMBHs residing in 84 early-type and 48 late-type galaxies (as distant as ~260 Mpc)
  • We have produced measurements of the bulge, disk, and galaxy stellar masses for all of the sample.
  • For the spiral galaxies, we have measured their spiral-arm pitch angles and estimated their dark matter halo masses via their maximum disk rotational velocities.
The $M_{BH}-\phi$ Relation

Seigar et al. (2008); Berrier et al. (2013); Davis, Graham, & Seigar (2017)
Surface Brightness Profile via Profiler (Ciambur 2016)

Modeling a Lenticular Galaxy from Our Sample

NGC 4371 – SB(r)0
$M_{BH} \sim 7 \times 10^6 \, M_\odot$
Scaling Relations for Early-type Galaxies

$M_{BH} \propto M_{*, sph}^{1.27\pm0.07}$

$M_{BH} \propto M_{*, gal}^{1.65\pm0.11}$

Sahu, Graham, & Davis (2019)
Slow (E) and Fast (ES/S0) Rotators

Offset by 1.12 dex (more than ~13 times) in $M_{BH}$ direction

Both populations tend to follow a single relation

Sahu, Graham, & Davis (2019)
Our conclusions are limited due to a small sample size of only 15 barred galaxies.

We find that barred and non-barred galaxies follow the same $M_{\text{BH}} - M_{\text{gal}}$ relation.

Sahu, Graham, & Davis (2019)
Early-type and Late-type Galaxies

Late-type galaxies follow scaling correlations with slopes twice that of early-type galaxies

\[ M_{BH} \propto M_{sph}^{1.27 \pm 0.07} \]
\[ M_{BH} \propto M_{sph}^{2.16 \pm 0.32} \]
\[ M_{BH} \propto M_{gal}^{1.65 \pm 0.11} \]
\[ M_{BH} \propto M_{gal}^{3.05 \pm 0.70} \]
E, ES/S0, and Sp Type Galaxies

$M_{BH}/M_{*, sph}$ and $M_{BH}/M_{*, gal}$ ratios are not constant
A Consistent Set of Scaling Relations

M*\_{gal} - V_{max}

M_{BH} - V_{max}

M_{DM} - V_{max}

Tully-Fisher Relation

M*\_{gal} - V_{max}

Tiley et al. (2019)

Davis, Graham, & Combes (2019)

Katz et al. (2019)

Davis, Graham, & Combes (2019)

Davis, Graham, & Seigar (2017)

Davis, Graham, & Combes (2019)
Implications

- Estimation of black hole mass in distant galaxies and quasars.

- Prediction of gravitational waves from merging SMBH, actively being searched for by pulsar timing arrays and future space-based interferometers (e.g., PPTA, EPTA, NANOGrav, MeerKat, and LISA).

- Understanding the growth rate of black hole mass relative to the SFR in the host galaxy and AGN feedback models, and constraining AGN virial factor measurements.

- Aids formation and coevolution theories of black holes and the galaxies which harbor them.

- Provides important benchmarks for $N$-body simulations to compare their black hole growth rates.