Probing black hole-galaxy co-evolution from de-biased scaling relations

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With: V. Allevato, M. Bernardi, A. Lapi, R. Sheth, P. Grylls, C. Marsden, L. Zanisi, and many more...
WHAT I WILL DISCUSS:

Local Scaling Relations:
Slopes, Normalizations, Scatters

Discussion of biases:
Observed vs ‘Intrinsic’ relations

Consequences:
Basic models, AGN feedback, Accretion, Gravitational waves
Local Scaling Relations:
Slopes, Normalizations, Scatters
BH-galaxy scaling relations

$M_{BH} \sim M_{\text{star}}$

$M_{BH} \sim \sigma^{4-5}$

$M_{BH} \sim L_K, \text{bulge (Lsun)}$

$\sigma \text{ (km/s)}$

Kormendy & Ho 13
The $M_{\text{BH}}-\sigma$: The most fundamental?
The $M_{\text{BH}}-\sigma$: The most fundamental?

Repeated for $R_e$, $n$, $M_{\text{bulge}}$, and also in hosts of AGN

Shankar+16, 17, 19
Take-home message I: Stellar velocity dispersion is more fundamental!
Discussion of biases: Observed vs ‘Intrinsic’ relations
One major problem!

$M_{BH}/M_{\odot}$

$L_{K,\text{bulge}} (L_{\odot})$  $\sigma \,(\text{km/s})$

Kormendy & Ho 13
A case study: The Illustris simulation (Horizon also!)
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Another major problem!

Hosts of SMBHs are OUTLIERS!!

SDSS, early-type galaxies

Shankar+16
The ‘sphere of influence’ of a SMBH

\[ r_h \sim \frac{G M_{BH}}{\sigma^2} \sim 11 \left( \frac{M_{BH}}{10^8 M_{\text{Sun}}} \right) \left( \frac{\sigma}{200 \text{ km/s}} \right)^2 \text{ pc} \]

“...defined as the region of space within which the gravitational potential of the SMBH dominates over that of the surrounding stars.”

Implications?
As an example, a SMBH of \( M_{BH} \sim 3 \times 10^7 \text{ M}_{\text{Sun}} \) placed at the distance of the Virgo cluster (\( \sim 15 \text{ Mpc} \)), would shrink to a projected radius of 0.07”, beyond the reach of even HST (\( \sim 0.1" \))!

Ferrarese 06
Assume BHs’ hosts follow SDSS
- 1- Assume BHs’ hosts follow SDSS
- 2- Assume underlying $M_{BH} - \sigma$ (residuals)
- 3- Cut above the resolution limit

$r_{lim} < r_{h} \sim \frac{GM_{BH}}{\sigma^2}$
\[ \log \sigma \quad \left[ \text{km s}^{-1} \right] \]

\[ \log M_{\text{STAR}} \quad [M_\odot] \]

Shankar+16

BIASED

INTRINSIC

\[ \Delta M_{\text{BH}} \]
BIASED

Δ$M_{BH}$

INTRINSIC

Shankar+16
Take-home message II:
Be cautious with ‘raw’ scaling relations!
Consequences:
Basic models, AGN feedback, Accretion, Gravitational waves
AGN feedback? Which one?
Thermal AGN feedback does not work!

Barausse, FS, et al. 2017
\[ \log M_{\text{BH}} = (\log M_{\text{BH}} - \sigma) + (\sigma - M_{\text{star}}) \]

Shankar+19
X-ray/Optical AGN from Krumpe+15

Shankar+16 (observed, All)
Shankar+16 (unbiased)
Reines&Volonteri15 (AGN)
Davis+18 (spirals)

Shankar+19b, Nature Astronomy, resubmitted
AGN ARE NOT (GRAVITATIONALLY) BIASED!!

Shankar+19
\[ \langle \log M_{BH}(z) \rangle [M_\odot] \]

\[ \dot{M}_{BH} \propto \frac{1 - \epsilon}{\epsilon} L \]
Local ratio from K&H

Shankar+19 in prep, Suh+19 submitted, Carraro+19 submitted, ...
Take-home message III: From de-biased scaling relations more radiative efficiency, less evolution, less GWs!