The BH Mass Scaling Relations of Active Galaxies: From the Local Universe out to a Lookback Time of 10 Gyrs

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in collaboration with

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Galaxy Formation, Durham

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What are the 18\textsuperscript{th} and 20\textsuperscript{th} most cited papers (since 2000)?
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Ferrarese & Merritt (2000)

Gebhardt et al. (2000)
Why are they among the most cited papers?
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Different scales:
  \(\mu\text{pc}\)-scale of accretion onto BH
  pc-scale of BH sphere of influence
  kpc-scale of bulge
Why are they among the most cited papers?

Different scales:
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Formation & evolution of galaxies linked to BHs

Theoretical models:
- Mergers, AGN feedback (e.g. Volonteri et al. 2003; Ciotti & Ostriker 2007; Hopkins et al. 2007, 2009; Di Matteo et al. 2008)
What was first?

Look at evolution with redshift – back in time

Are galaxies & BHs constantly on tight correlations by feedback?
Are local relations end product of a more dramatic/stochastic process?
What was first?
What was first?
Approach

Understand relations: evolution

Study evolution: AGNs

Understand evolution: robust baseline
Approach

Understand relations: evolution

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Understand evolution: robust baseline

(1) $M(BH)$-$L$, $M(BH)$-$\sigma$ to 4-6 Gyrs
   \cite{Bennert10ApJ}  

(2) $M(BH)$-$M^*$ to 10 Gyrs
   \cite{Bennert11ApJsubmitted}  

(3) $M(BH)$-$L$, $M(BH)$-$\sigma$, $M(BH)$-$M$ in local Universe
   \cite{Bennert11ApJ, Harris11ApJS}
M(BH)-L, M(BH)-sigma to 4-6 Gyrs

Seyfert-1 galaxies
SDSS DR7: broad Hβ

35 @ z~0.4
6 @ z~0.6

HST images:
Spheroid luminosity
AGN luminosity for M(BH)

Keck spectroscopy:
M(BH)
Sigma
M(BH)–L to 4-6 Gyrs

Including high-z sample (Peng et al. 2006)
0.66 < z < 4.5
27 gravitationally lensed AGNs
17 non-lensed AGNs
M(BH)–L to 4-6 Gyrs

With selection effects: \( M_{\text{BH}}/L_{\text{sph}} \propto (1 + z)^{1.4 \pm 0.2} \)

BH growth precedes bulge assembly

(see also e.g. Merloni et al. 2010, slope 0.7; Decarli et al. 2010, slope 1.5)

Evolution mass dependent?

(e.g. di Matteo et al. 2008; Hopkins et al. 2009)
Mergers (13/40)?

Gas-rich major merger with spiral:
- spheroid grows through disruption of spiral disk
- but no significant BH growth (e.g. Croton 2006)

Large scatter due to different types and time scales?

ACS (Treu et al. 2007)

NICMOS (Bennert et al. 2010)
Mergers (13/40)?

Comparable to fraction in GOODS at same z (Treu et al. 2007)
Cannot infer causal link between merger & AGN activity
(but: e.g. Canalizo & Stockton 2001, Urrutia et al. 2008, Bennert et al. 2008)

ACS (Treu et al. 2007)

NICMOS (Bennert et al. 2010)
Late-type galaxies (>15/40)?
Eventually fall on local relation (downsizing)?
More intrinsic scatter? (e.g. Gueltekin et al. 2009)
Pseudobulges? (e.g. Kormendy & Kennicutt 2004; Kormendy et al. 2011)

ACS (Treu et al. 2007)

NICMOS (Bennert et al. 2010)
The surprise: M(BH)-L(host)

No evolution (z<1)? *(see also Jahnke et al. 2009)*
The surprise: M(BH)-L(host)

No evolution (z<1)? (see also Jahnke et al. 2009)
(a) Growth of bulge through re-distribution of stars?
   Secular evolution or minor mergers?

![Graph showing M(BH)-L(host) relationship](image-url)
The surprise: $M(\text{BH})$-$L(\text{host})$

No evolution ($z<1$)? *(see also Jahnke et al. 2009)*

(a) Growth of bulge through re-distribution of stars?
   Secular evolution or minor mergers?
(b) More fundamental relation (late-type galaxies)?
   *(e.g. Peng 2007, Jahnke & Maccio 2010; Poster 4.14 Laesker)*
The surprise: $M(BH)$-$L$ (host)

No evolution ($z<1$)?  
(see also Jahnke et al. 2009)
(a) Growth of bulge through re-distribution of stars?
   Secular evolution or minor mergers?
(b) More fundamental relation (late-type galaxies)?
   (e.g. Peng 2007, Jahnke & Maccio 2010; Poster 4.14 Laesker)

What is dominant mechanism that grows spheroids?
Higher-mass objects, higher $z$: major mergers
Lower-mass objects, lower $z$: minor mergers
(Hopkins et al. 2009)
Uncertainties

Passive luminosity evolution?

![Graph showing the relationship between $M_{HI} (\log N_\odot)$ and $L_{V,0}$ (spheroid; $L_\odot$).]

- $z \sim 1.8$ (Peng+06)
- $z \sim 0.6$ (Bennert+09)
- $z \sim 0.4$ (Treu+07, Bennert+09)
- $z \sim 0.08$ (Bennert+09, Bentz+09)
M(BH)–M* to 10 Gyrs

AGNs in GOODS: 1<z<2
Lookback time: 8-10 Gyrs
Deep multi-color HST images
Evolutionary trend confirmed
M(BH)–M* to 10 Gyrs

4/11 clear spirals: bulge+disk
3 no bulge?
M(BH)–sigma to 4-6 Gyrs

Same sample *(Woo et al. 2011, in prep.)*

Advantage: no „passive luminosity evolution”

Distinguish different scenarios
(passive luminosity evolution, dissipational/dissipationless mergers)
A local baseline of the BH mass scaling relations

(i) Understand evolution = understand local relations
A local baseline of the BH mass scaling relations

(i) Understand evolution = understand local relations

(ii) True bulge dispersion

Wide range of morphologies (majority late-types):
Disk is kinematically cold but rotation
Questions "global" sigma measurements (high z & fiber-based SDSS)
A local baseline of the BH mass scaling relations

(i) Understand evolution = understand local relations

(ii) True bulge dispersion
Wide range of morphologies (majority late-types):
Disk is kinematically cold but rotation
Questions „global“ sigma measurements (high z & fiber-based SDSS)

(iii) Measure sigma from three different spectral ranges (e.g. Greene & Ho 2006)

CaHK region (~3735-4300 A)  Mglb, Fe region (~5100-5300 A)  Call triplet (~8500-8700 A)
A local baseline of the BH mass scaling relations

Selected from SDSS:
z=0.02-0.08; M(BH) > 10^7 M(sun)
Majority spirals (~65%)

Keck spectroscopy:
Spatially resolved along major axis
111 objects
M(BH)
sigma

SDSS images:
Spheroid luminosity
Spheroid mass
AGN luminosity for M(BH)
Spatially resolved sigma and velocity

Effect of disk present but negligible

Spectral regions interchangeable
M(BH)-L, M(BH)-sigma, M(BH)-M in local Universe

Inactive galaxies and active galaxies follow same relations
Approach

Understand relations: evolution

Study evolution: AGNs

Understand evolution: robust baseline

(1) M(BH)-L, M(BH)-sigma to 4-6 Gyrs

(2) M(BH)-M to 10 Gyrs

(3) M(BH)-L, M(BH)-sigma, M(BH)-M in local Universe
Approach

Summary

Understand relations: evolution

Study evolution: AGNs

Understand evolution: robust baseline

(1) M(BH)-L, M(BH)-sigma to 4-6 Gyrs

* BH growth precedes bulge assembly
* M(BH)-total L not evolving?

(2) M(BH)-M to 10 Gyrs

* Evolutionary trend confirmed

(3) M(BH)-L, M(BH)-sigma, M(BH)-M in local Universe

* Active = inactive galaxies
* Effect of disk/spectral region negligible


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And from Sep 1st 2011 on?
Teaching teaching teaching teaching teaching:
Teaching research teaching teaching teaching

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