

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



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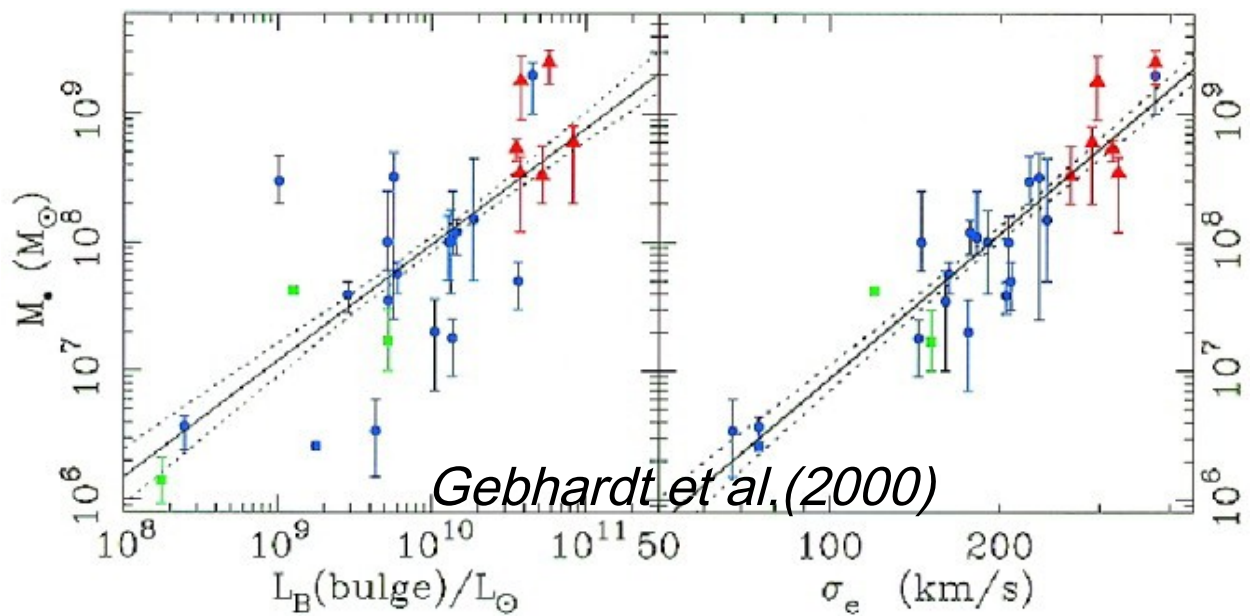
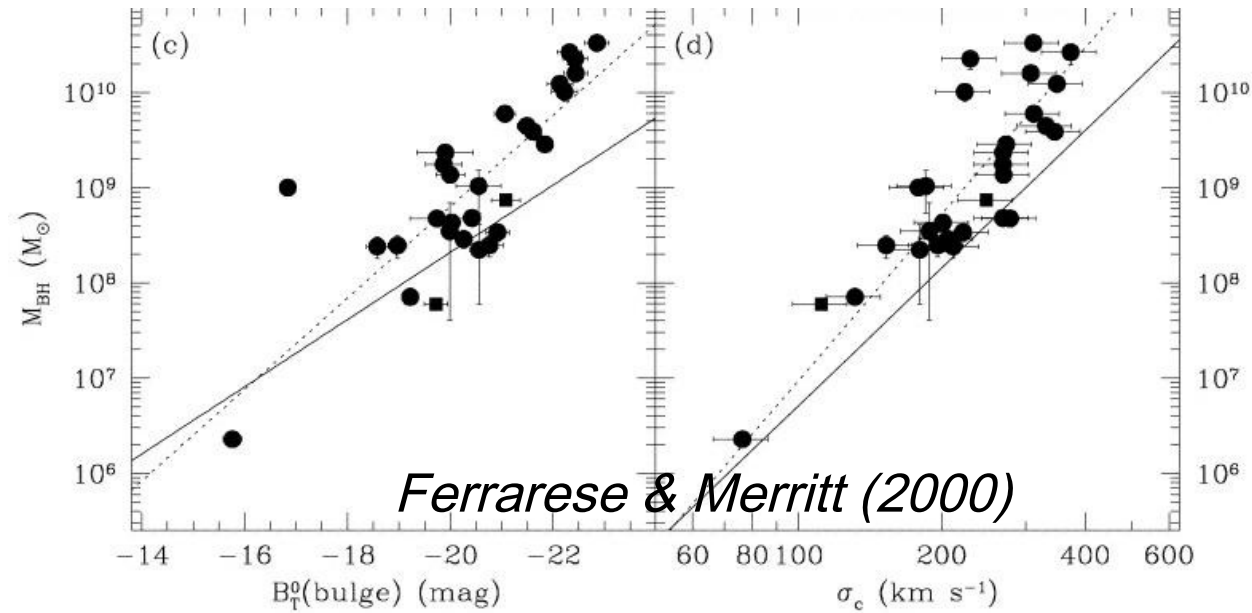


in collaboration with

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What are the 18th and 20th most cited papers
(since 2000)?

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Why are they among the most cited papers?

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Different scales:

μpc -scale of accretion onto BH

pc-scale of BH sphere of influence

kpc-scale of bulge

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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

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Understand evolution: robust baseline

(1) $M(\text{BH})$ - L , $M(\text{BH})$ - σ to 4-6 Gyrs

(Bennert et al. 2010, ApJ, 708, 1507)

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

(Bennert et al. 2011, ApJ, submitted, arXiv:1102.1975)

(3) $M(\text{BH})$ - L , $M(\text{BH})$ - σ , $M(\text{BH})$ - M in local Universe

(Bennert et al. 2011, ApJ, 726, 59; Harris et al. 2011, ApJS, in prep. + ...)

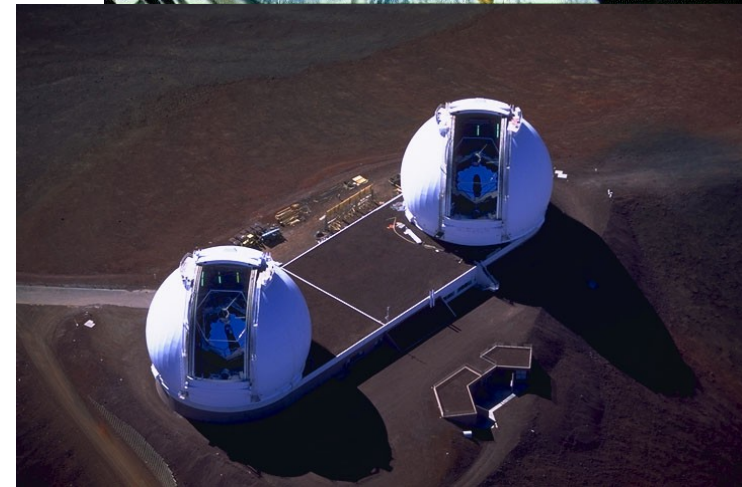
M(BH)-L, M(BH)-sigma to 4-6 Gyrs

Seyfert-1 galaxies
SDSS DR7: broad H β

35 @ $z \sim 0.4$
6 @ $z \sim 0.6$

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

Keck spectroscopy:
M(BH)
Sigma



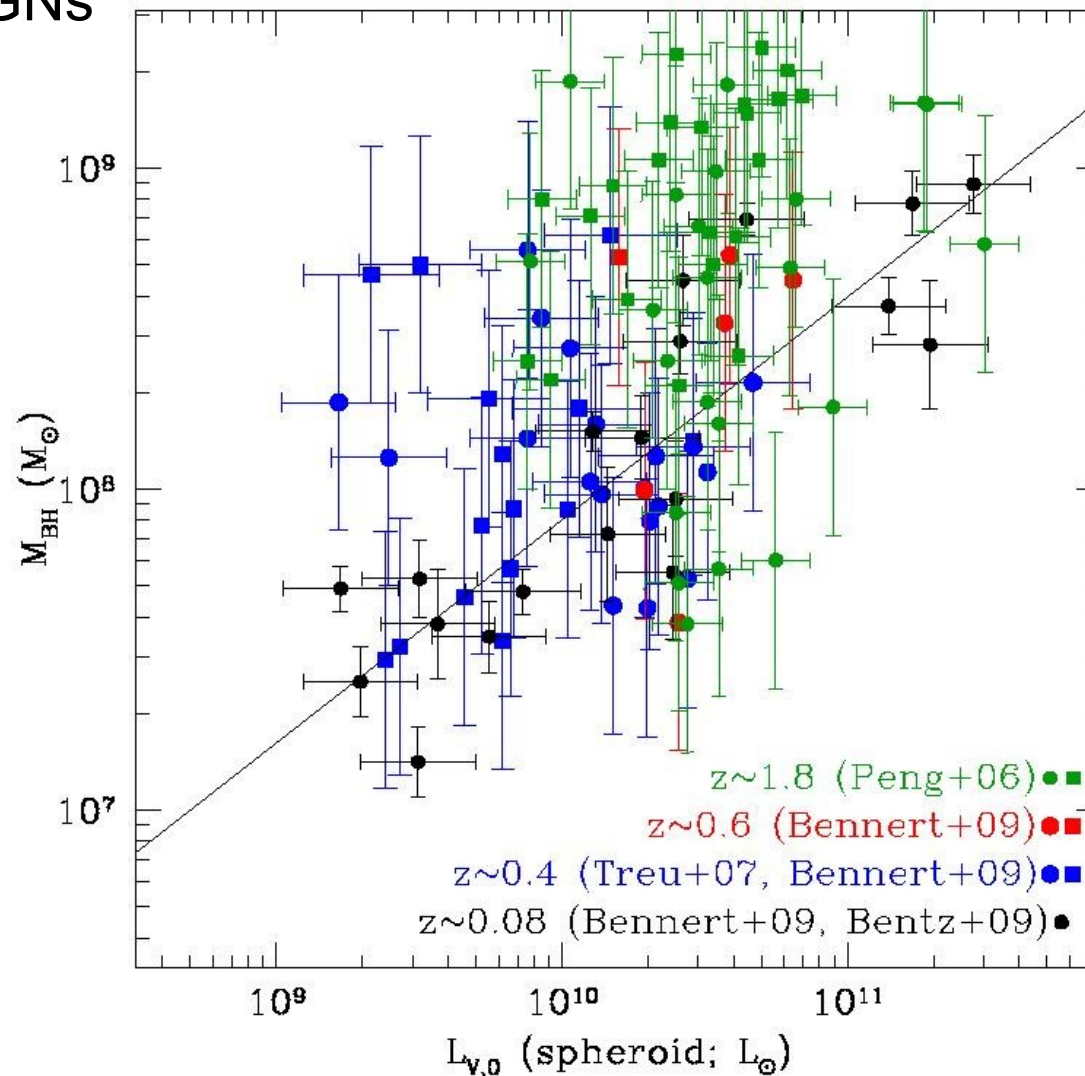
M(BH)–L to 4-6 Gyrs

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

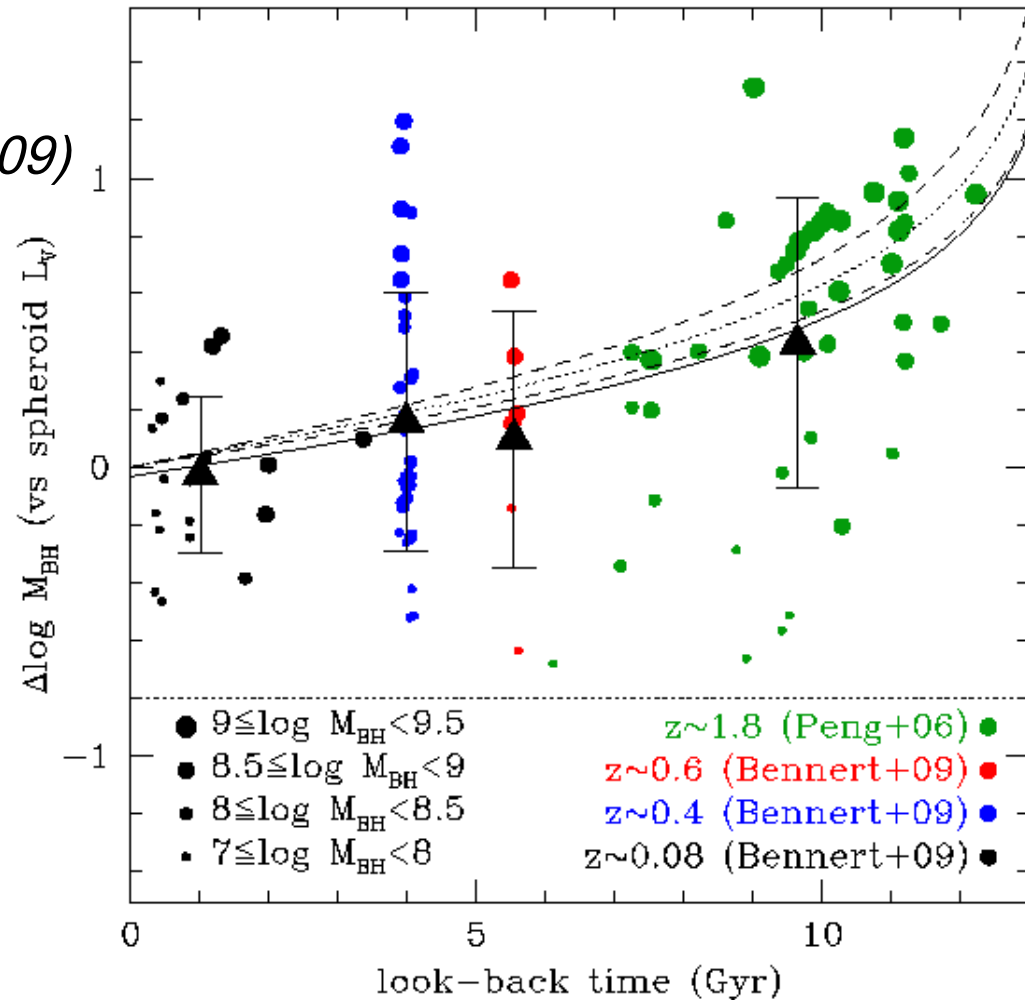
With selection effects: $M_{\text{BH}}/L_{\text{sph}} \propto (1+z)^{1.4 \pm 0.2}$

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)



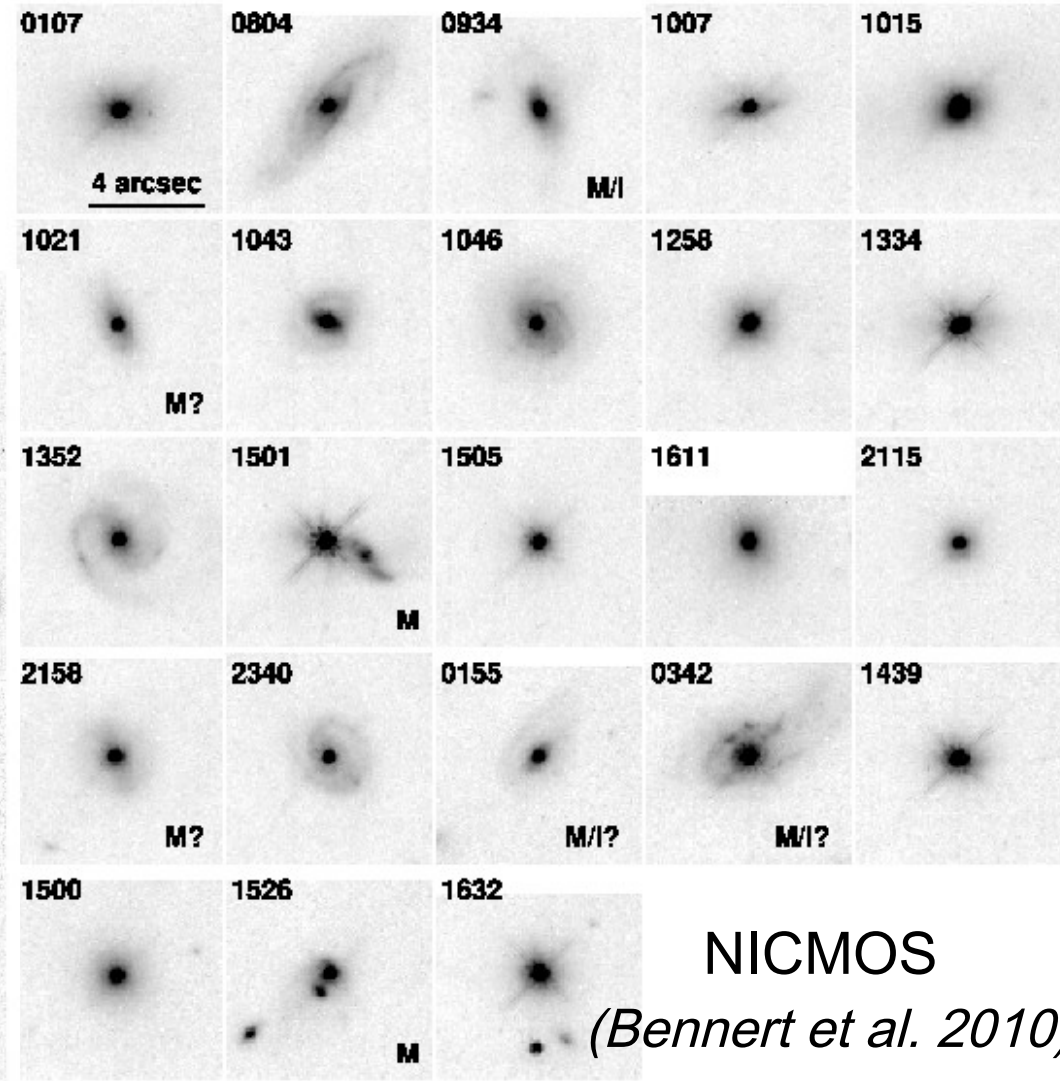
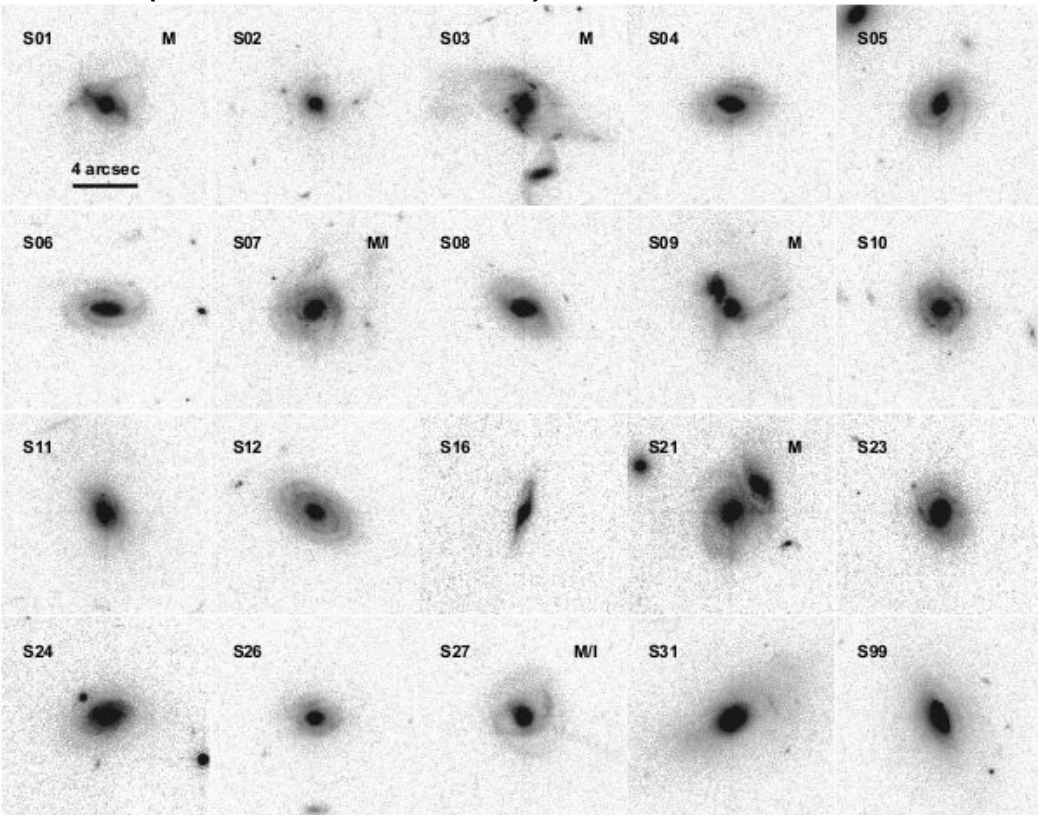
Mergers (13/40)?

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*)

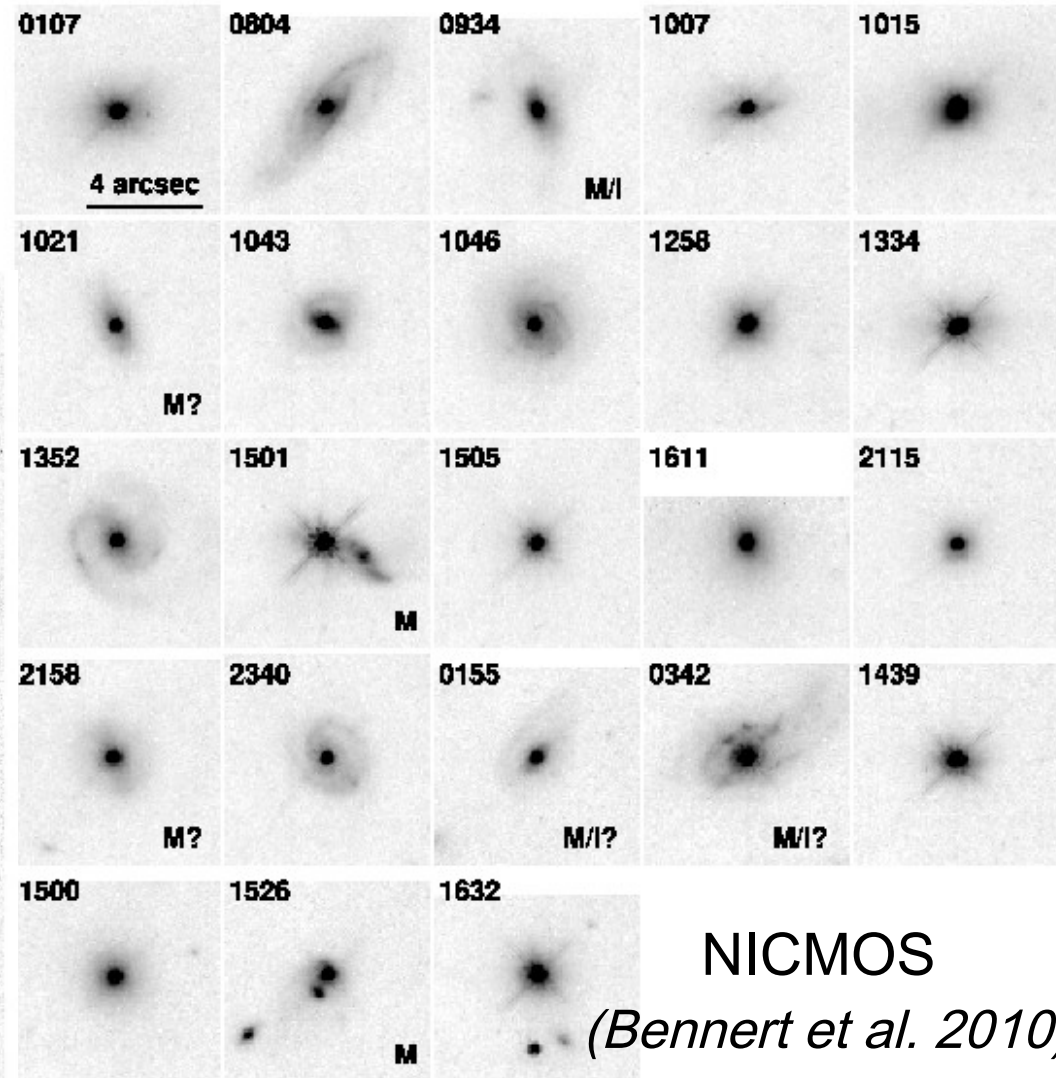
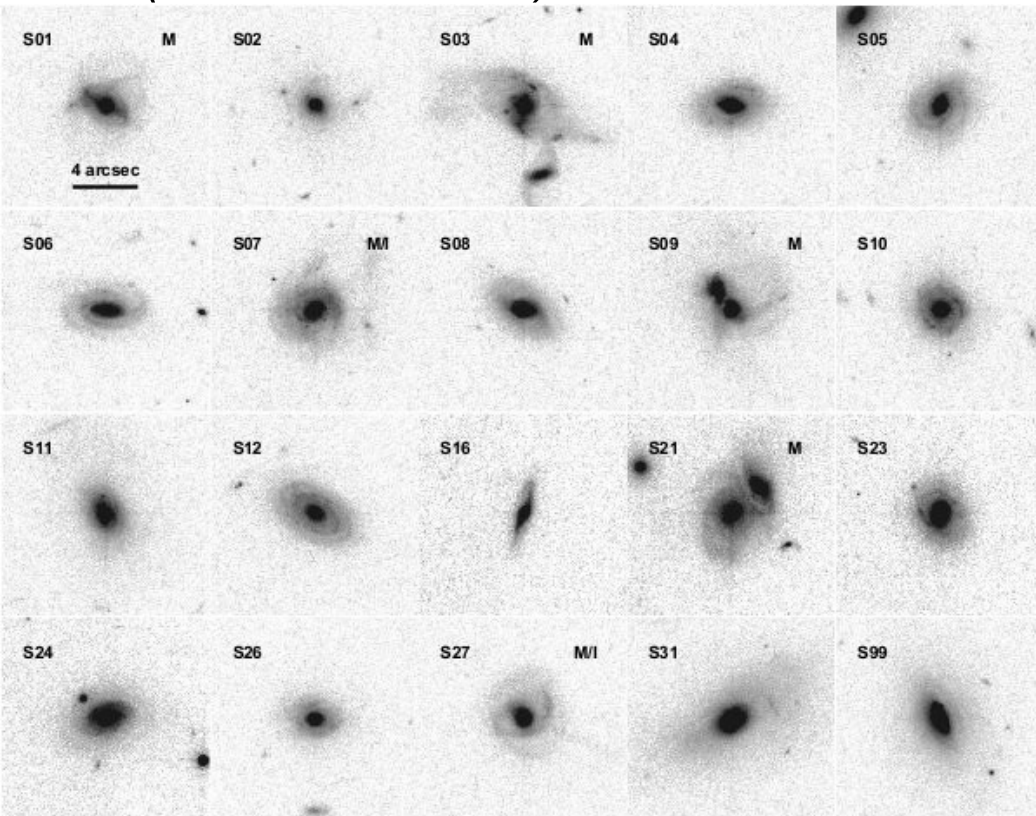
Mergers (13/40)?

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*)



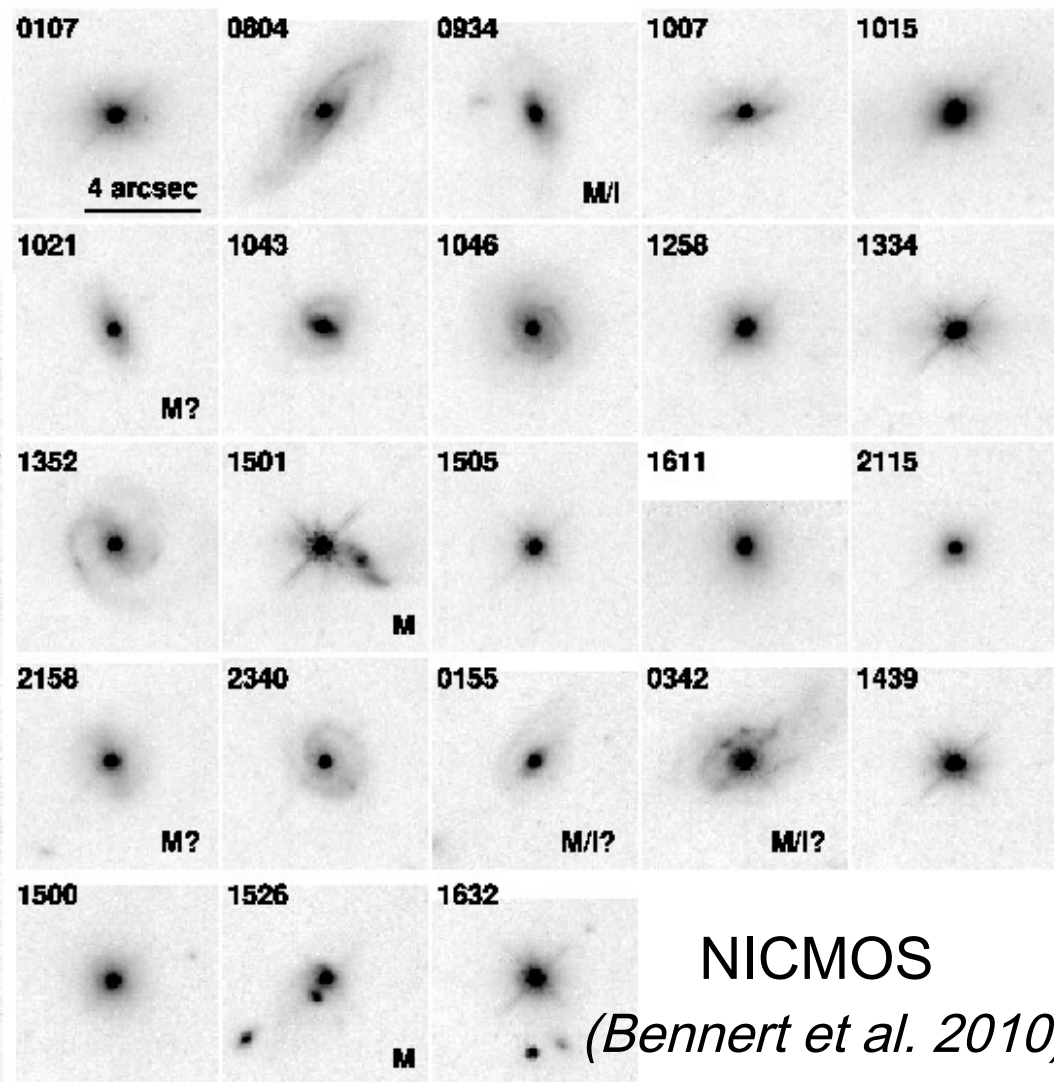
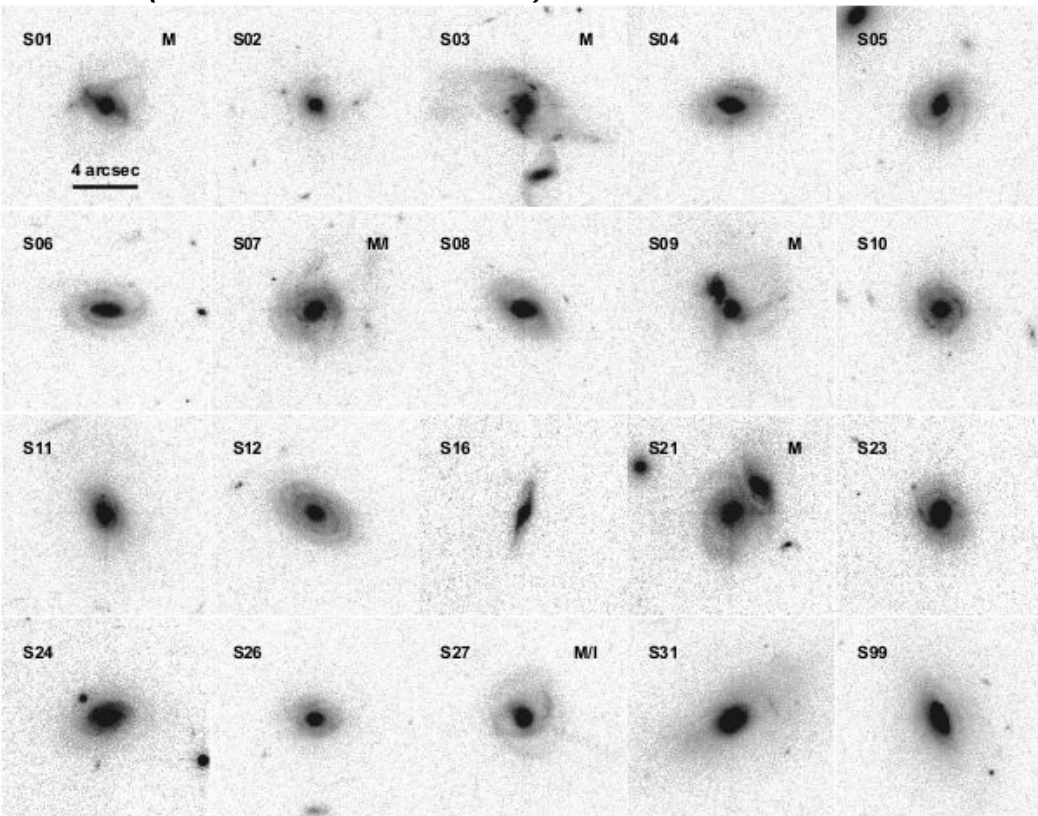
Late-type galaxies (>15/40)?

Eventually fall on local relation (downsizing)?

More intrinsic scatter? (*e.g. Guetekin et al. 2009*)

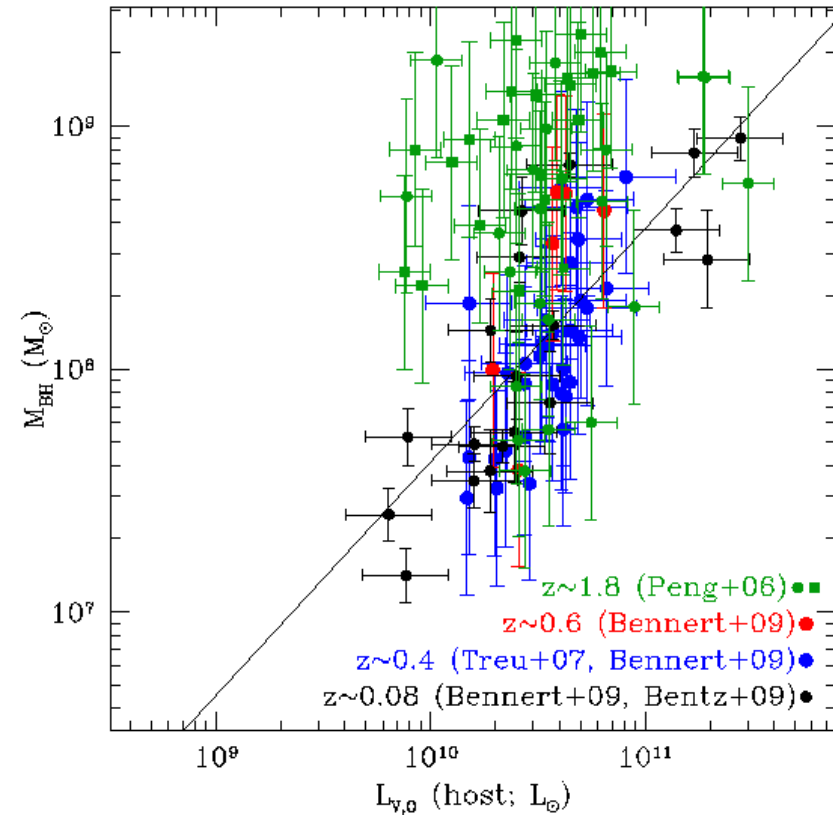
Pseudobulges? (*e.g. Kormendy & Kennicutt 2004; Kormendy et al. 2011*)

ACS (*Treu et al. 2007*)



The surprise: M(BH)-L(host)

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

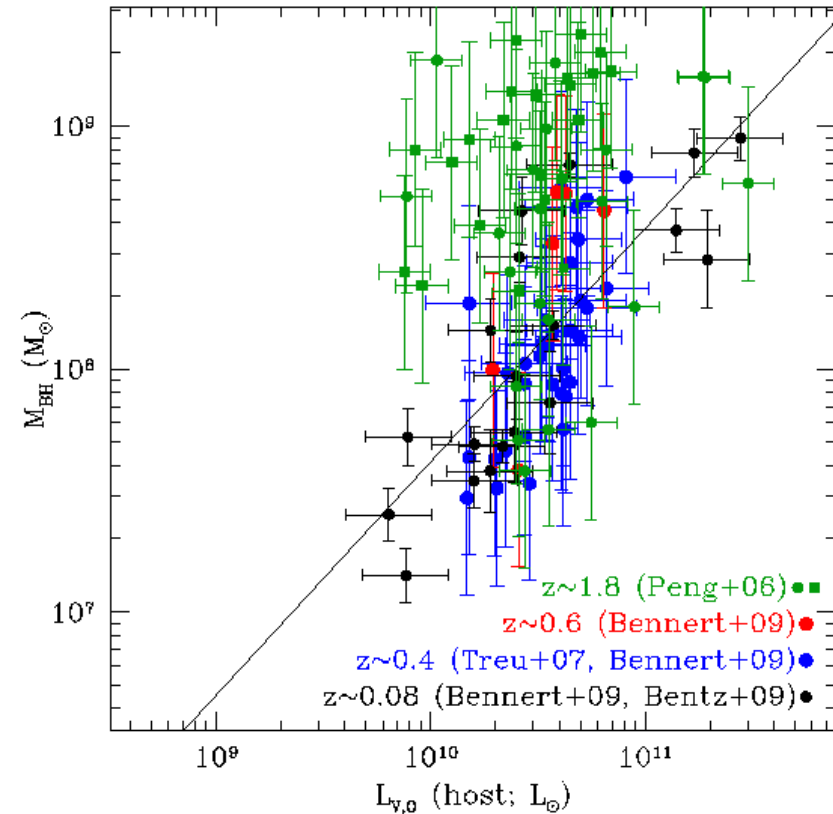


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(a) Growth of bulge through re-distribution of stars?

Secular evolution or minor mergers?



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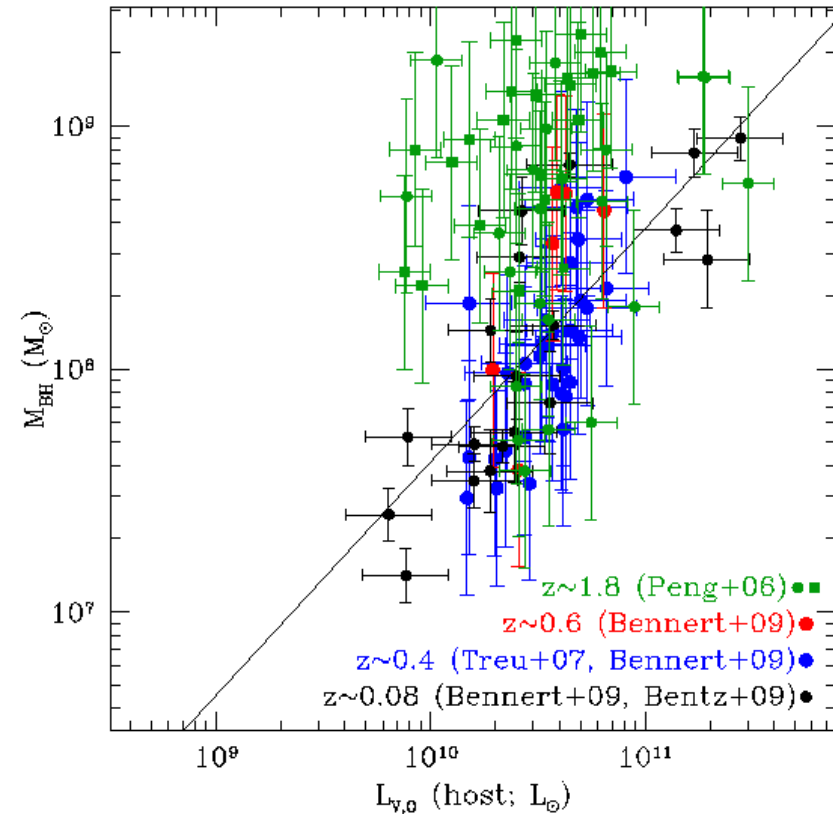
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Secular evolution or minor mergers?

(b) More fundamental relation (late-type galaxies)?

(e.g. Peng 2007, Jahnke & Maccio 2010; Poster 4.14 Laesker)



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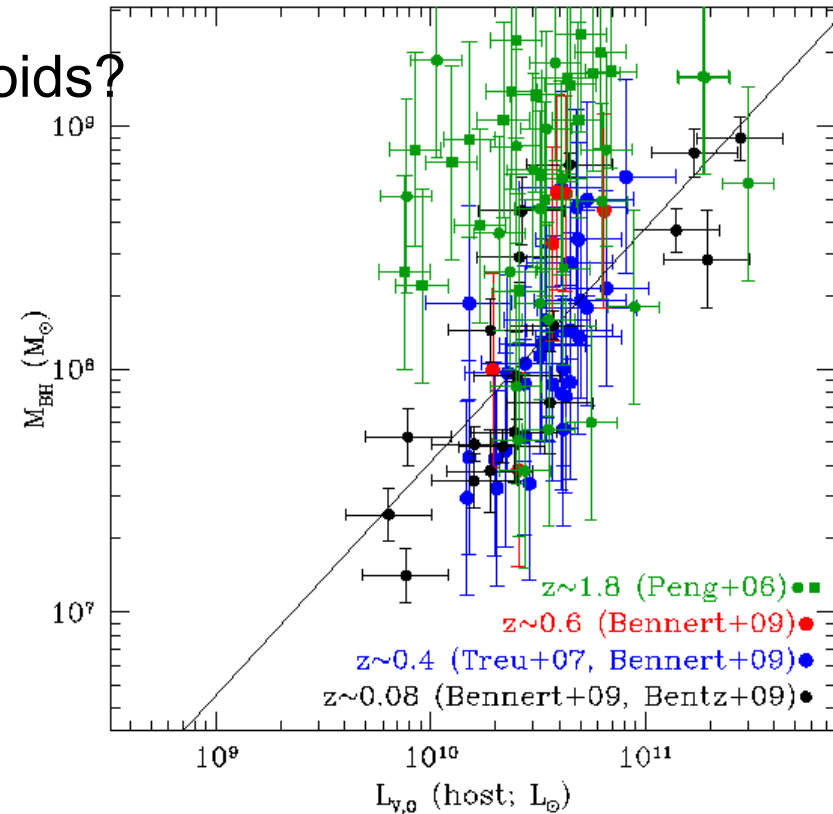
(e.g. *Peng 2007, Jahnke & Maccio 2010; Poster 4.14 Laesker*)

What is dominant mechanism that grows spheroids?

Higher-mass objects, higher z : major mergers

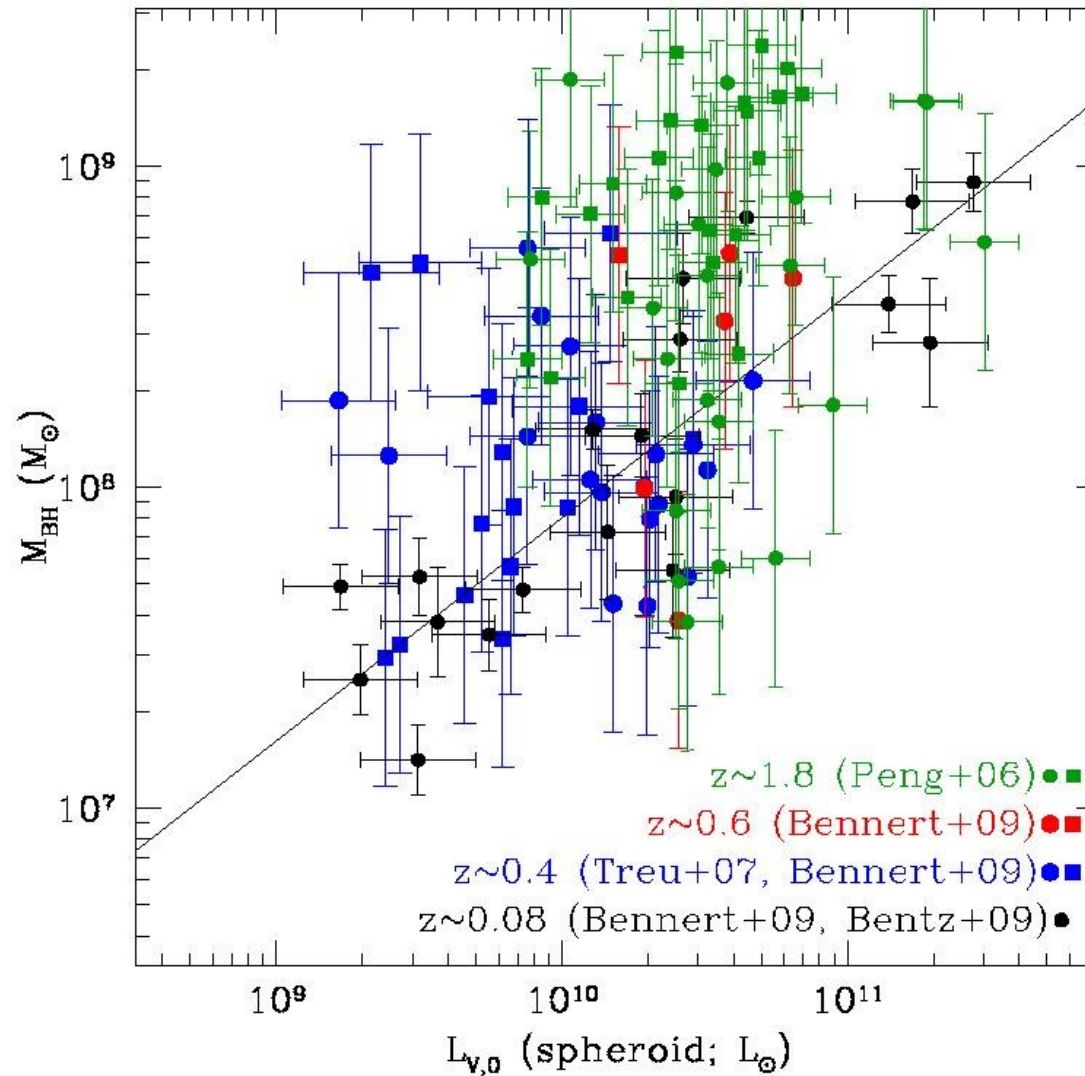
Lower-mass objects, lower z : minor mergers

(*Hopkins et al. 2009*)



Uncertainties

Passive luminosity evolution?



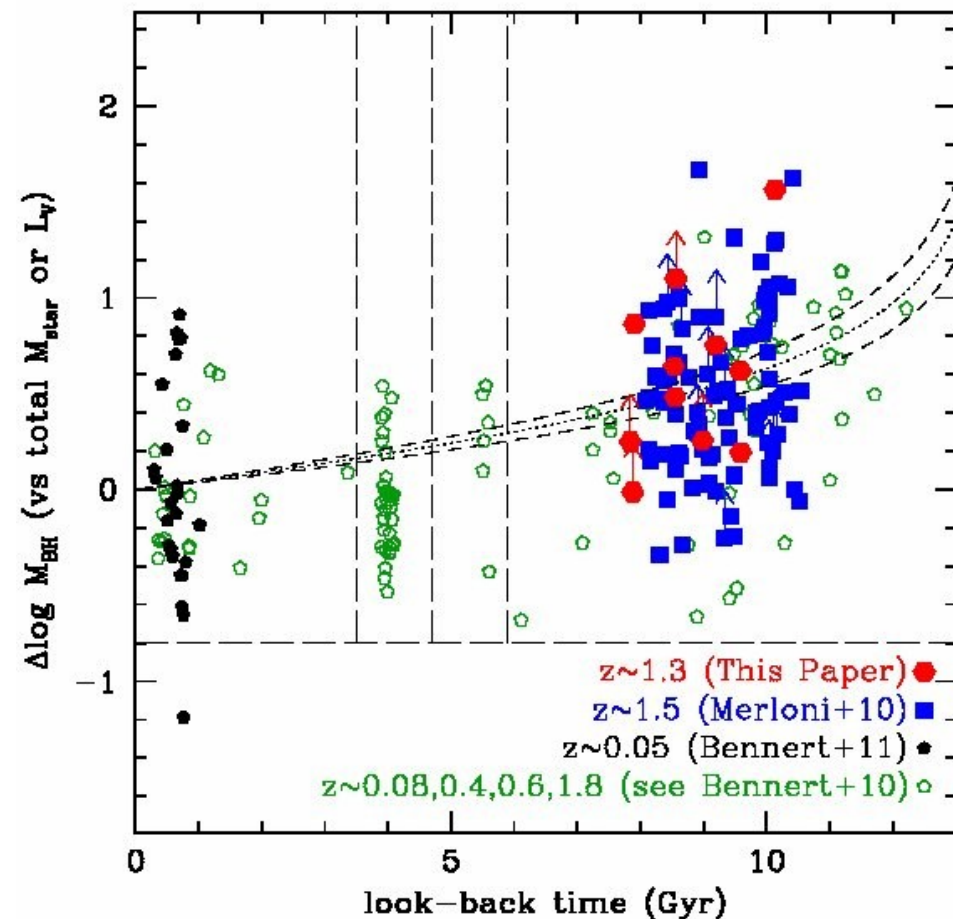
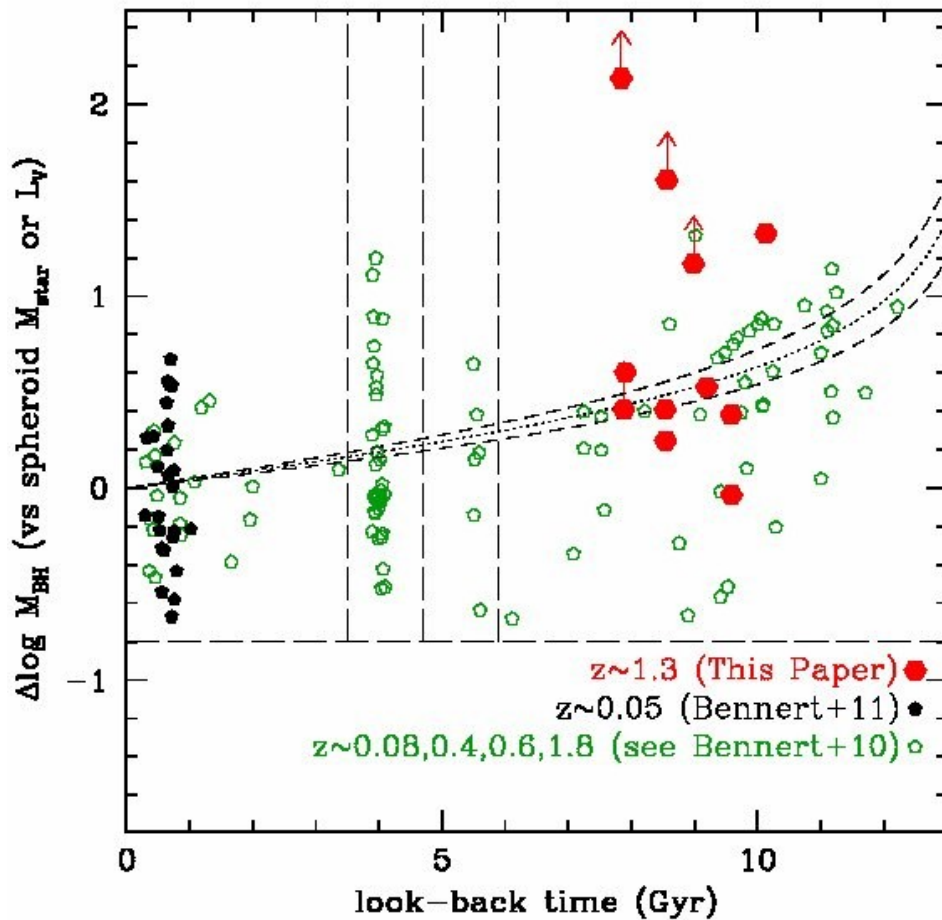
M(BH)–M* to 10 Gyrs

AGNs in GOODS: $1 < z < 2$

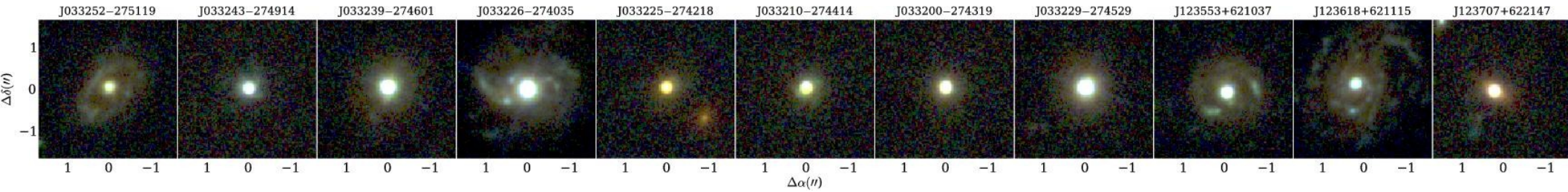
Lookback time: 8-10 Gyrs

Deep multi-color HST images

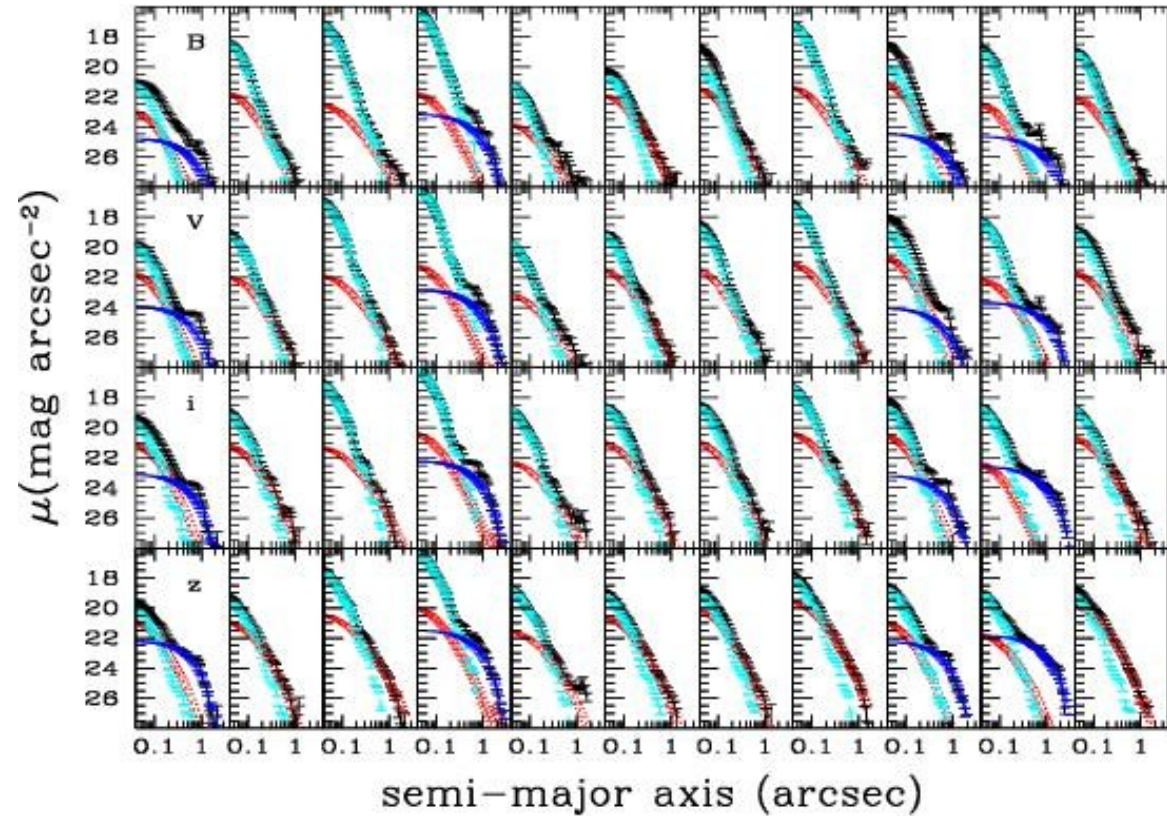
Evolutionary trend confirmed



M(BH)–M* to 10 Gyrs



4/11 clear spirals: bulge+disk
3 no bulge?



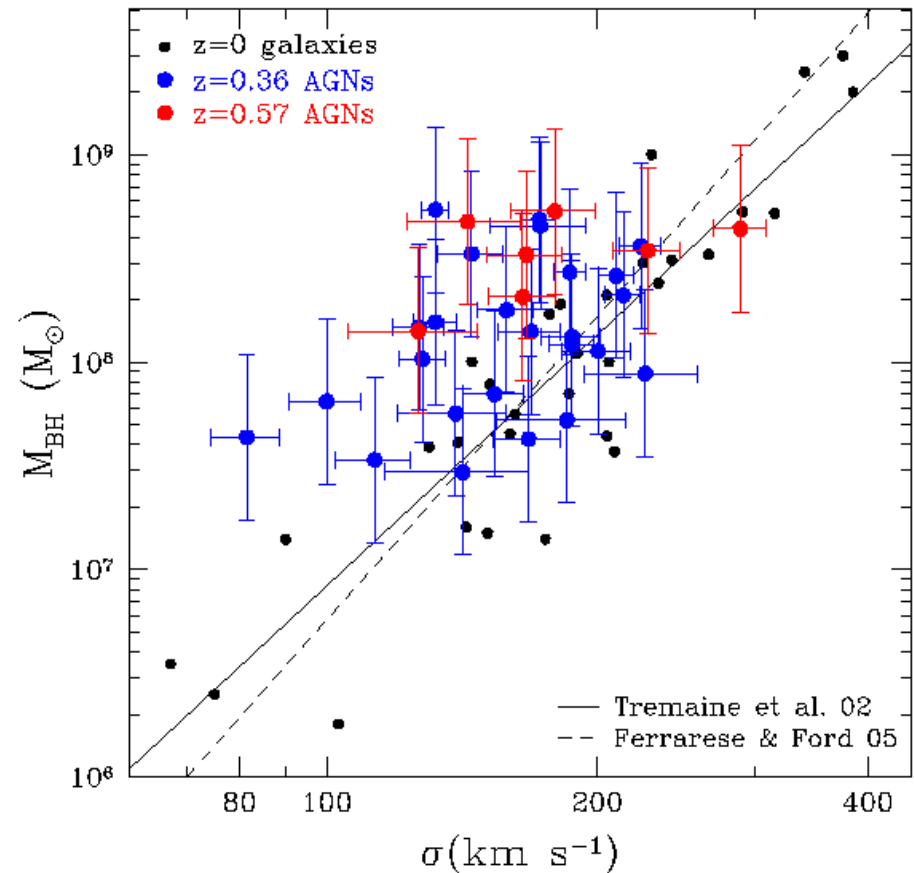
M(BH)–sigma to 4-6 Gyrs

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

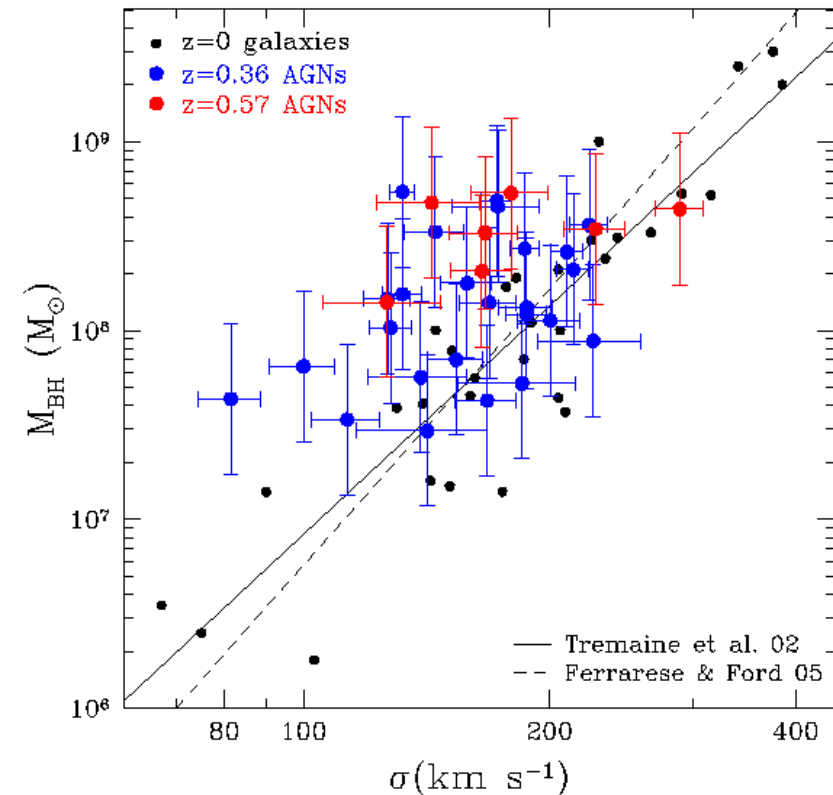
(i) Understand evolution = understand local relations

(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)



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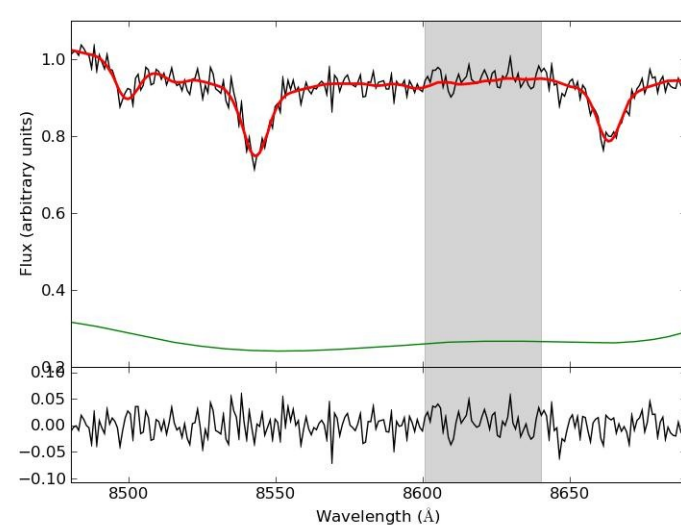
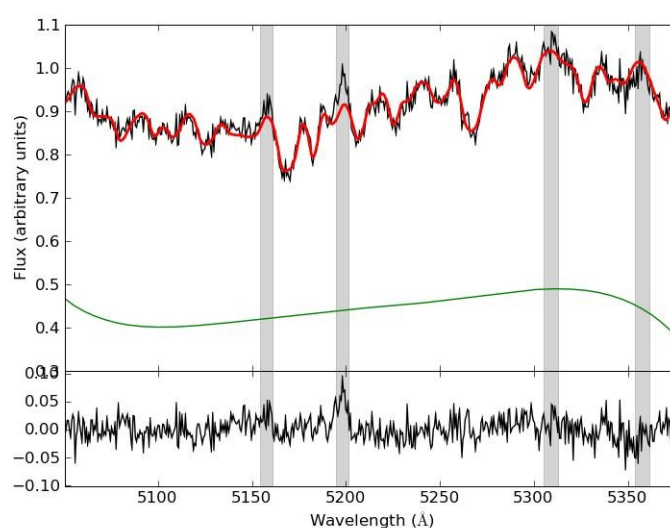
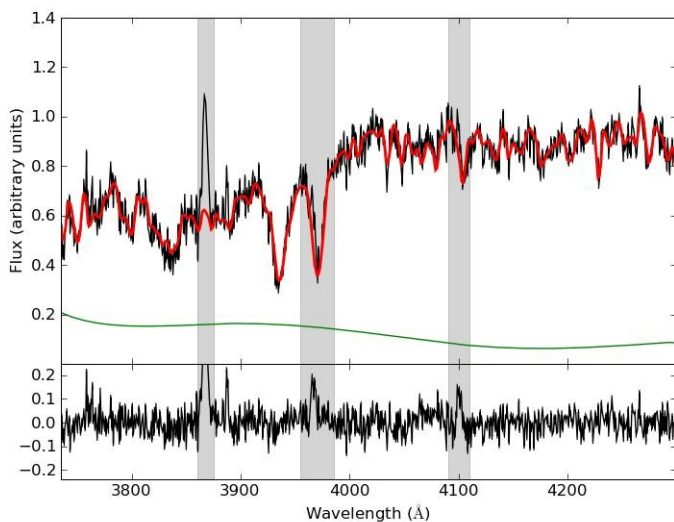
Questions „global“ sigma measurements (high z & fiber-based SDSS)

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

CaHK region (~3735-4300 Å)

MgIb, Fe region (~5100-5300 Å)

Call triplet (~8500-8700 Å)



A local baseline of the BH mass scaling relations

Selected from SDSS:

$z=0.02-0.08$; $M(\text{BH}) > 10^7 M(\text{sun})$

Majority spirals ($\sim 65\%$)

Keck spectroscopy:

Spatially resolved along major axis

111 objects

$M(\text{BH})$

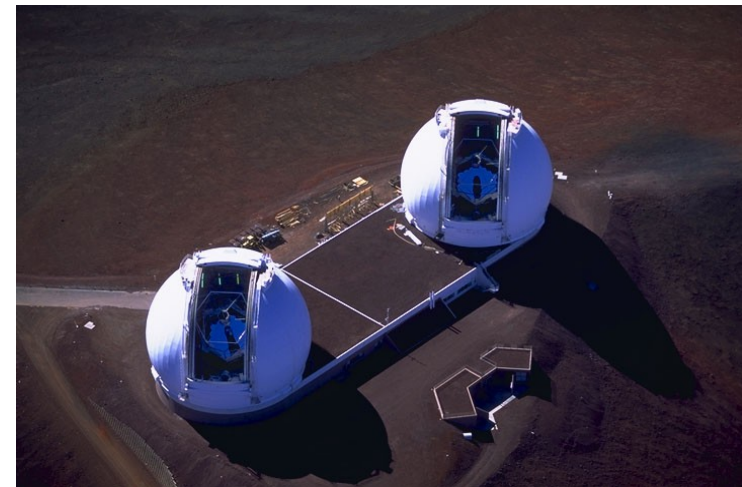
σ

SDSS images:

Spheroid luminosity

Spheroid mass

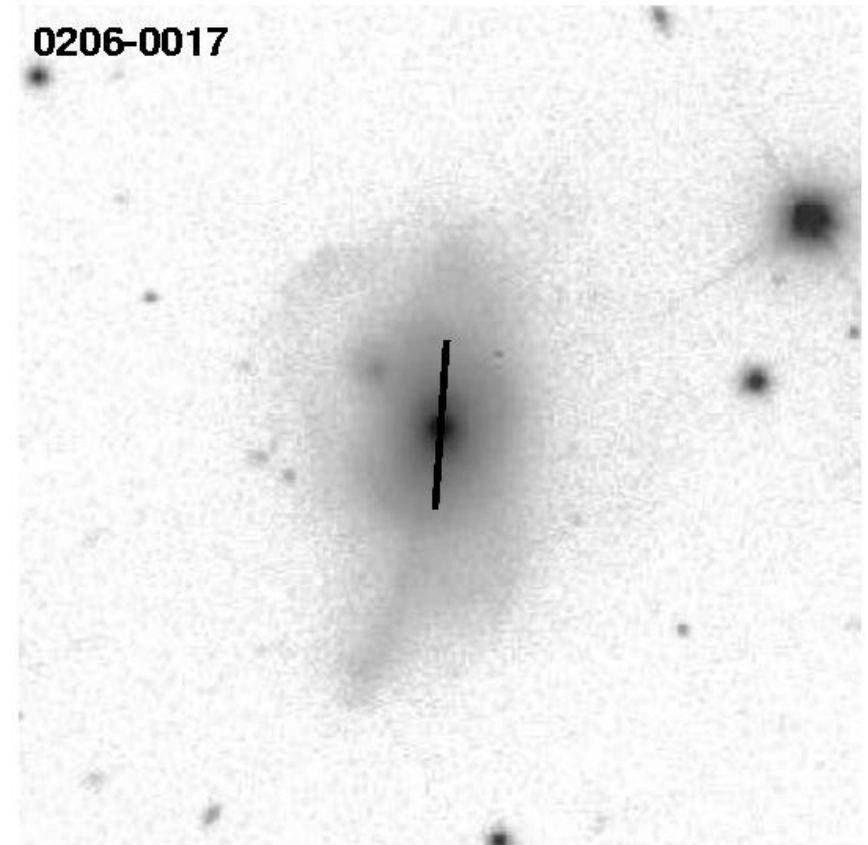
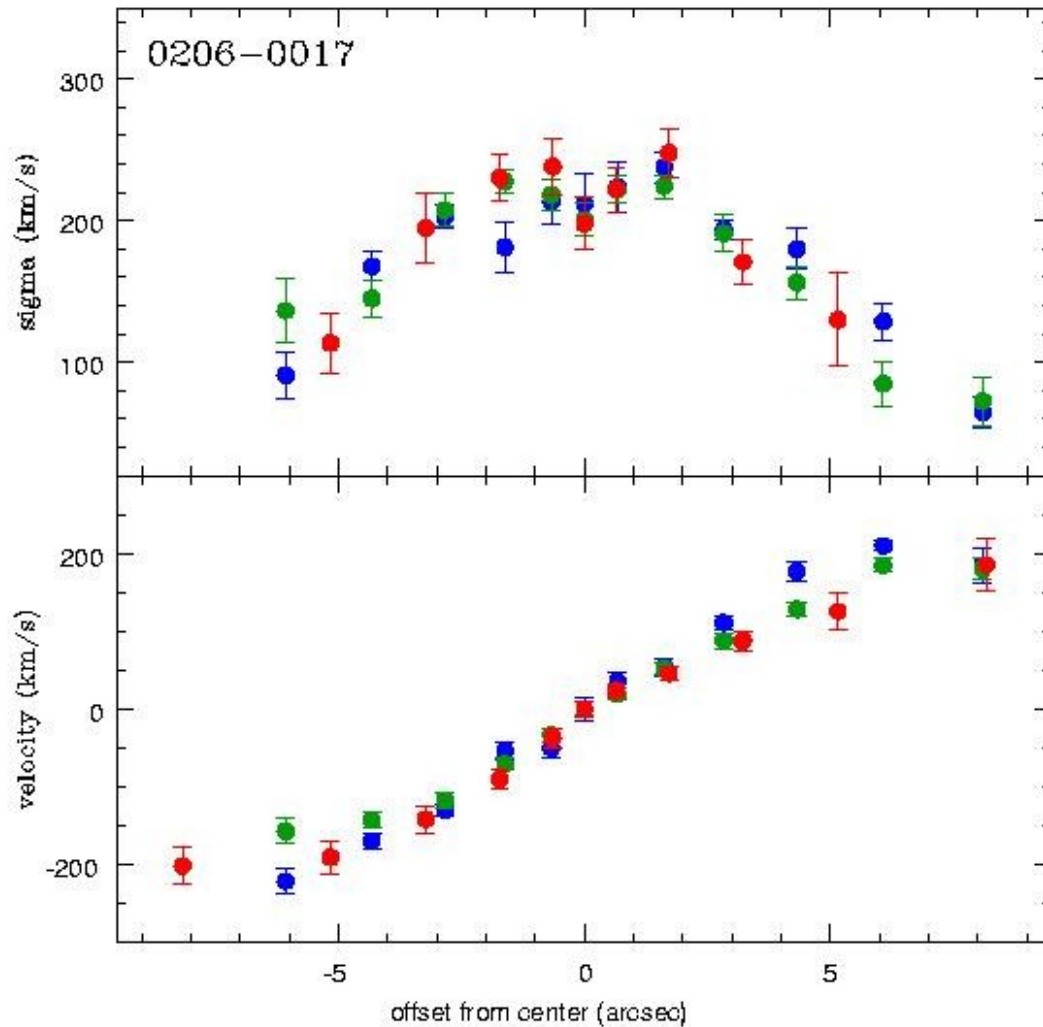
AGN luminosity for $M(\text{BH})$



Spatially resolved sigma and velocity

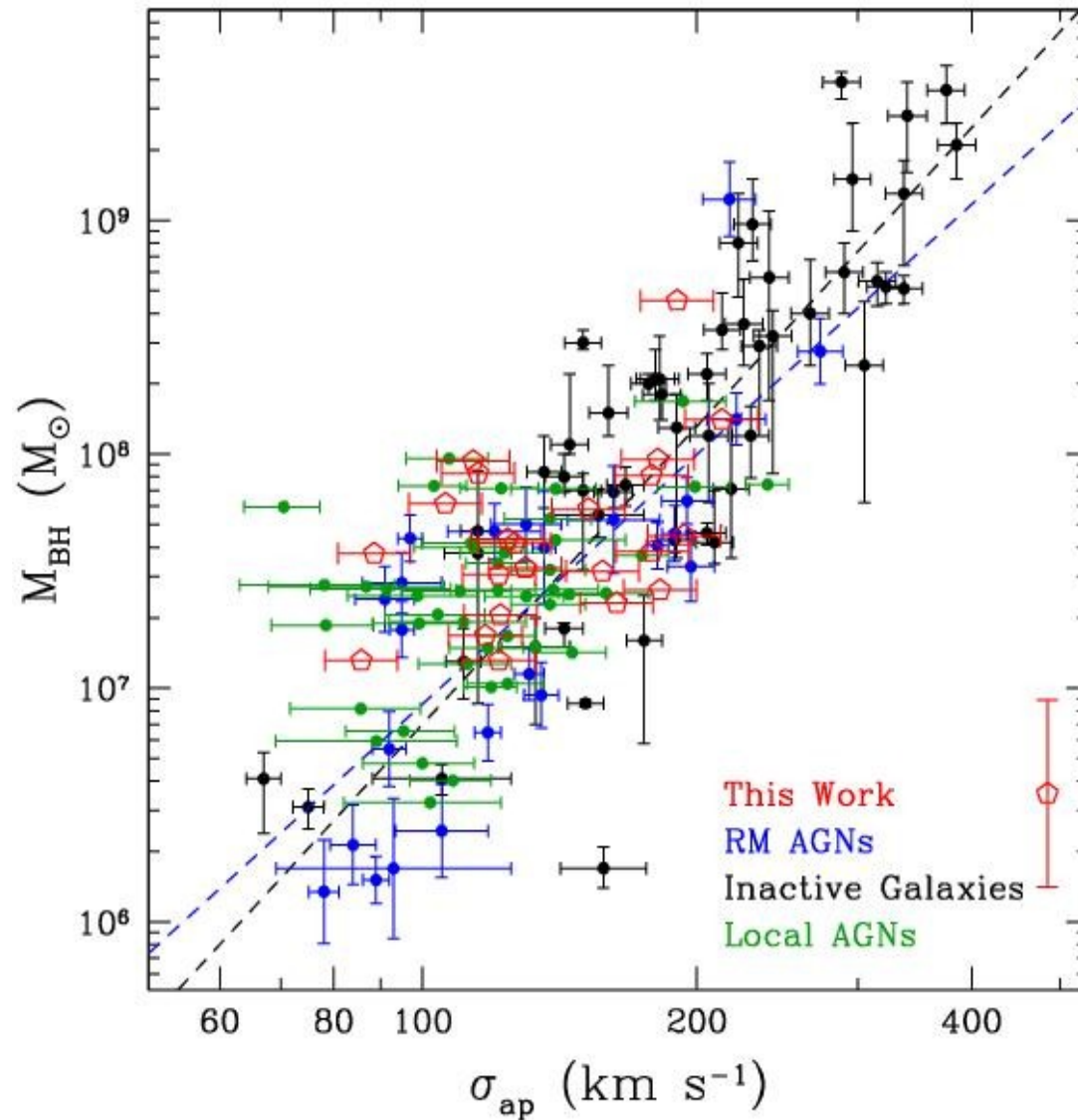
Effect of disk present but negligible

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

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(2) $M(\text{BH})$ -M to 10 Gyrs

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(3) $M(\text{BH})$ -L, $M(\text{BH})$ -sigma, $M(\text{BH})$ -M in local Universe

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Approach

Summary

Understand relations: evolution

Study evolution: AGNs

Understand evolution: robust baseline

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

(Bennert et al. 2010, ApJ, 708, 1507)

BH growth precedes bulge assembly
 $M(\text{BH})\text{-total L}$ not evolving?

(2) $M(\text{BH})\text{-M}$ to 10 Gyrs

(Bennert et al. 2011, ApJ, submitted, arXiv:1102.1975)

Evolutionary trend confirmed

(3) $M(\text{BH})\text{-L}$, $M(\text{BH})\text{-sigma}$, $M(\text{BH})\text{-M}$ in local Universe Active = inactive galaxies

(Bennert et al. 2011, ApJ, 726, 59; Harris et al. 2011, ApJS, in prep. + ...)

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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