The Evolution of BH Mass Scaling Relations

Nicola Bennert

UCSB

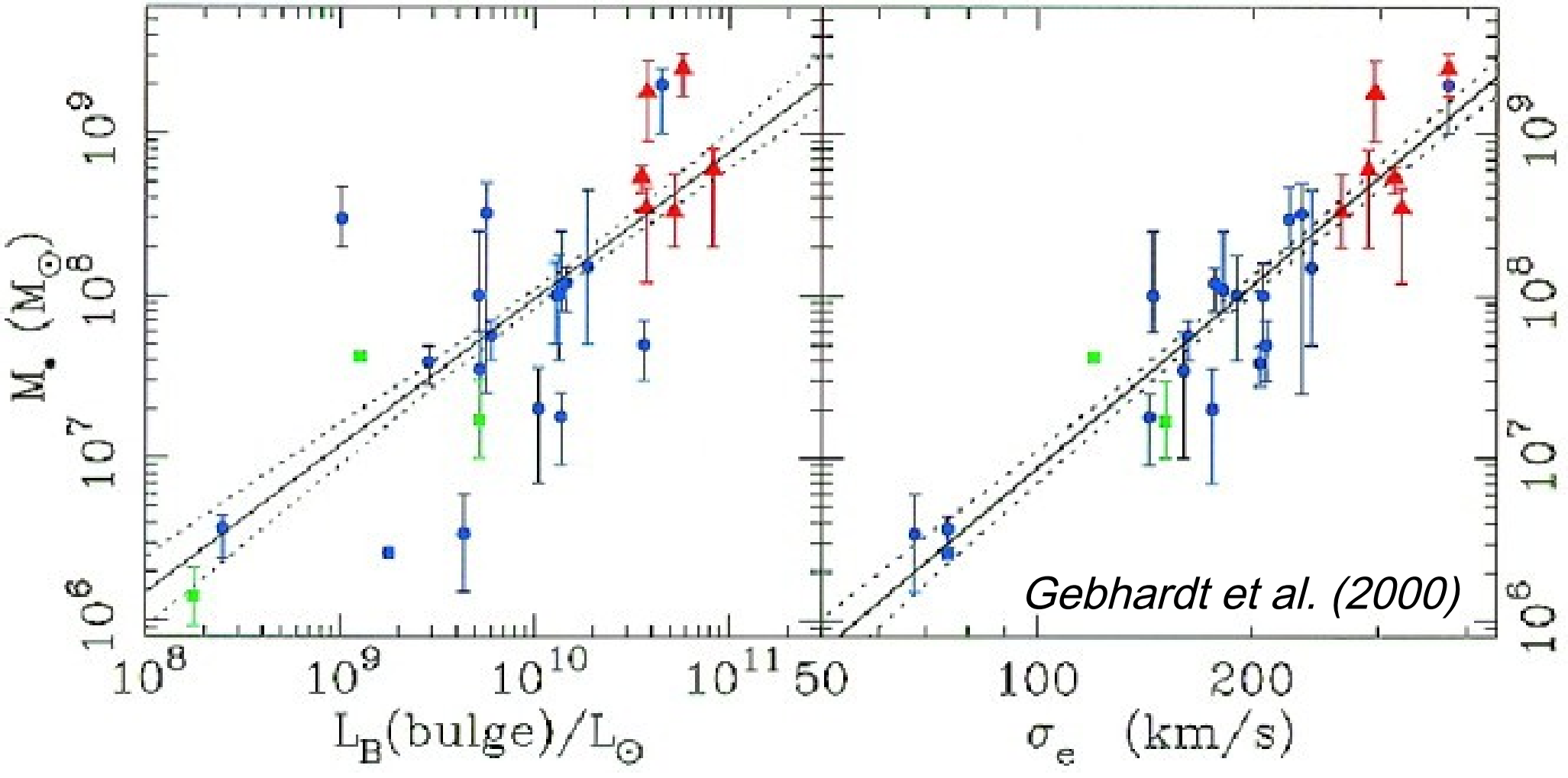
in collaboration with

Tommaso Treu (UCSB), Jong-Hak Woo (UCLA), Alexandre Le Bris (UCSB),
Matthew A. Malkan (UCLA), Matthew W. Auger (UCSB),
Sarah Gallagher (UWO Canada), Roger D. Blandford (Stanford)

Bennert et al. 2009, in preparation

BH mass scaling relations in local universe

Empirical relations between M(BH) and galaxy properties:
Stellar velocity dispersion of bulge sigma, bulge luminosity, bulge mass
(e.g. Gebhardt et al. 2000, Ferrarese & Merrit 2000, Marconi & Hunt 2003)



Why do we care?

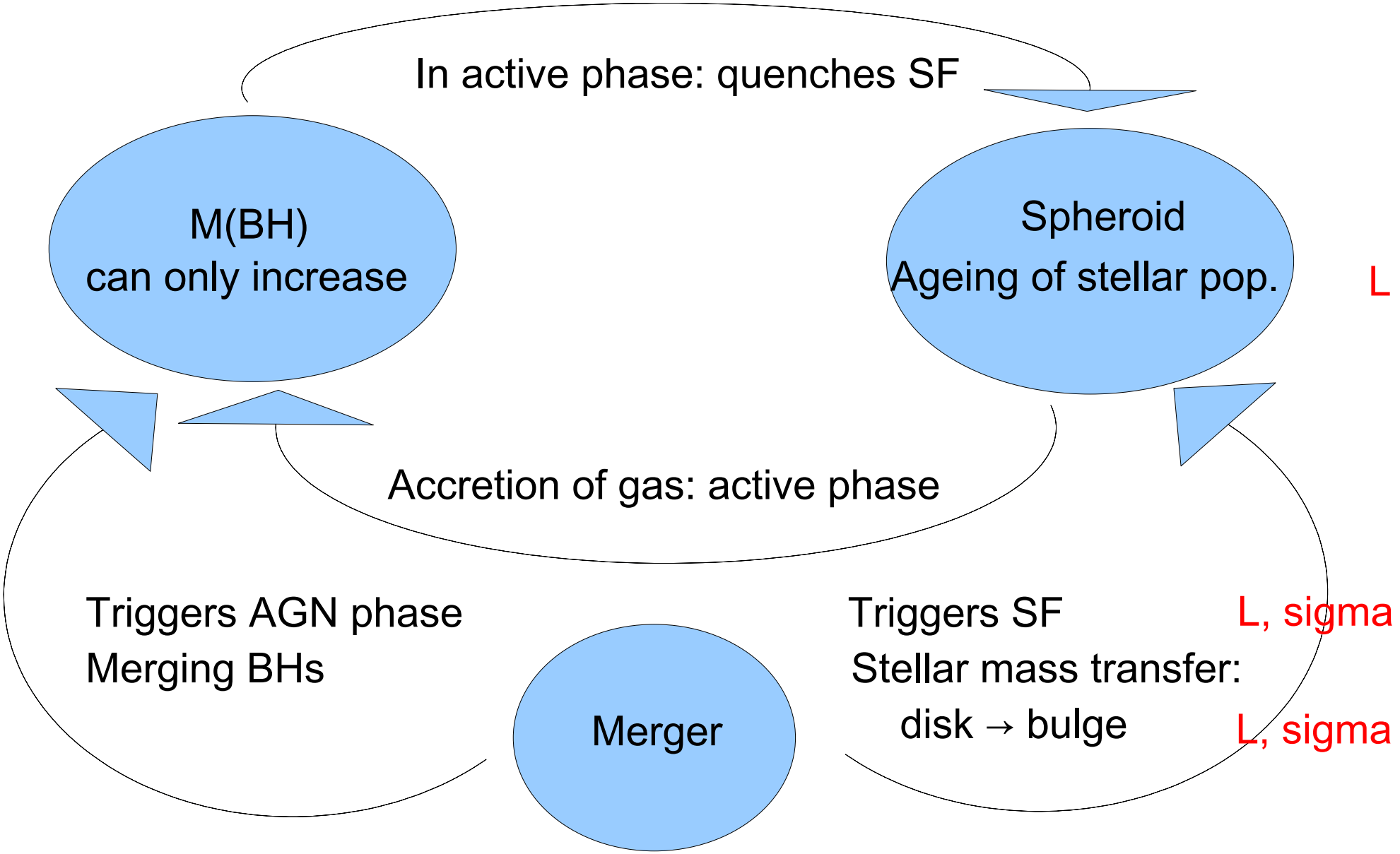
Different scales involved:
µpc-scale of accretion to
pc-scale of BH sphere of influence to
kpc-scale of bulge

Formation & evolution of galaxies linked to BHs

Chicken-and-egg problem:
What was first? What grows faster?

→ Look at evolution with redshift

Do we expect relations to evolve?



→ Relative timing of processes determines evolution of M(BH) relations

→ Study M-L and M-sigma simultaneously to disentangle different effects

BH mass

Resolve BH sphere of influence

(a) Spatially: gas & stellar kinematics → local Universe only

(b) In time: AGN reverberation mapping → time consuming

(c) From single epoch spectra: BLR size-luminosity relation → use AGN

Spheroid: L and sigma

Luminosity: from imaging

Sigma: from spectroscopy

Difficult for high-luminosity AGNs (QSOs)
Contaminated by AGN continuum

Sample selection

Compromise: Seyfert-1 galaxies

Selected from SDSS DR7:
Resolved on images
Broad Hβ
No strong FeII emission

35 @ z=0.36+-0.01
6 @ z=0.57+-0.01

Redshift:
High enough to see evolution
Low enough to allow detailed determination of properties
Clean window in atmosphere

Observations

HST images:
ACS (F775W) and NICMOS (F110W)
→ spheroid luminosity
→ AGN luminosity for M(BH)

Keck spectroscopy
→ M(BH)
→ sigma

Image analysis

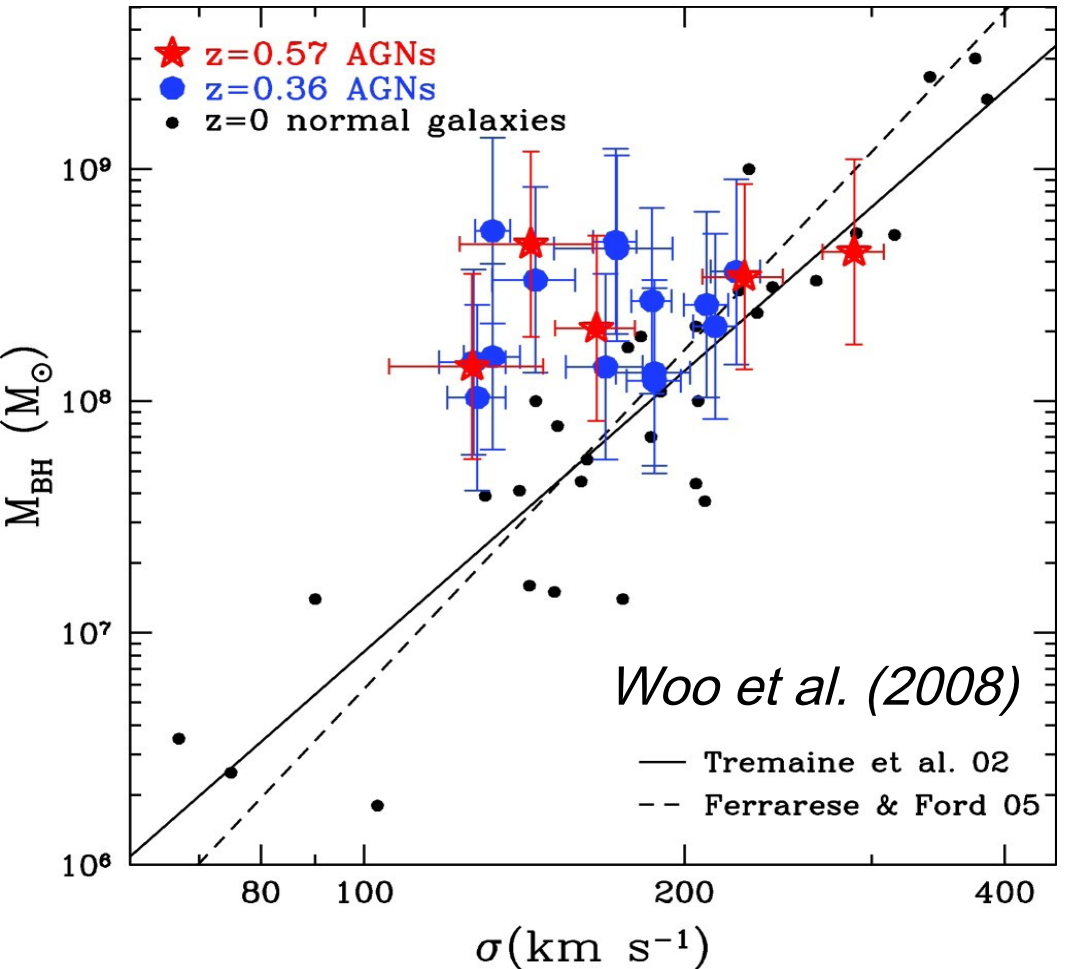
2D image decomposition:
AGN+host using GALFIT *(Peng et al. 2006)*

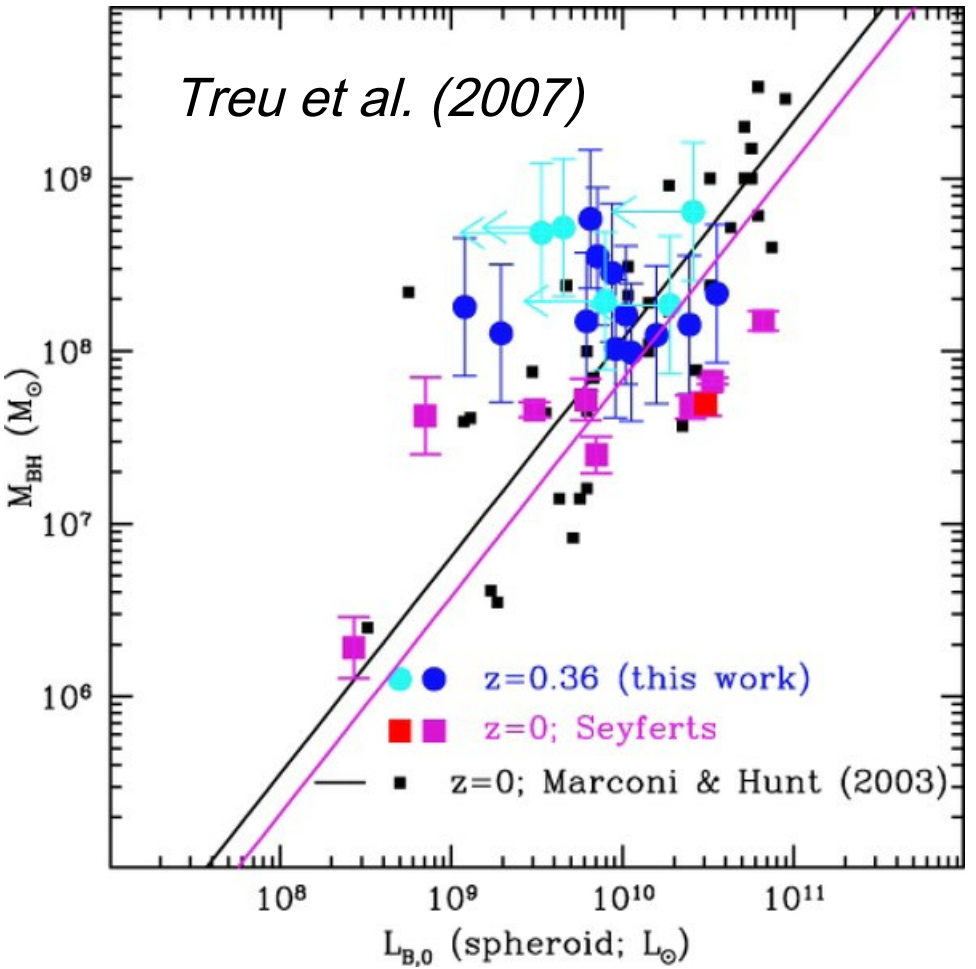
Host:
DeVaucouleurs
DeVaucouleurs+Exp.
DeVaucouleurs+Exp.+Bar

Correct for luminosity evolution:
$\log L(V,0) = \log L(V) - 0.62 * z$
(Treu et al. 2001)

Evidence for evolution?

First results: offset from local relation (*Woo et al. 2006, 2008, Treu et al. 2007*)
Distant spheroids (4-6 Gyrs ago) have smaller bulges than local ones
BH growth predates bulge assembly





Improvements

Sample doubled:
from 20 to 40

M(BH) range expanded:
from log M(BH)= 8-9 to log M(BH)=7.5-9 (selection effects!)

Better local comparison sample:
From inactive galaxies to reverberation-mapped AGNs

Local comparison sample

Reverberation-mapped AGN sample *(Peterson et al. 2004, Bentz et al. 2009)*
35 objects; HST images (ACS/HRC and WFPC2/PC)

Bentz et al. (2009):
More than one PSF
More than one bulge component
Sersic index free for bulge component

Do image analysis again:
Comparable to our approach
Improved PSF
Include luminosity evolution

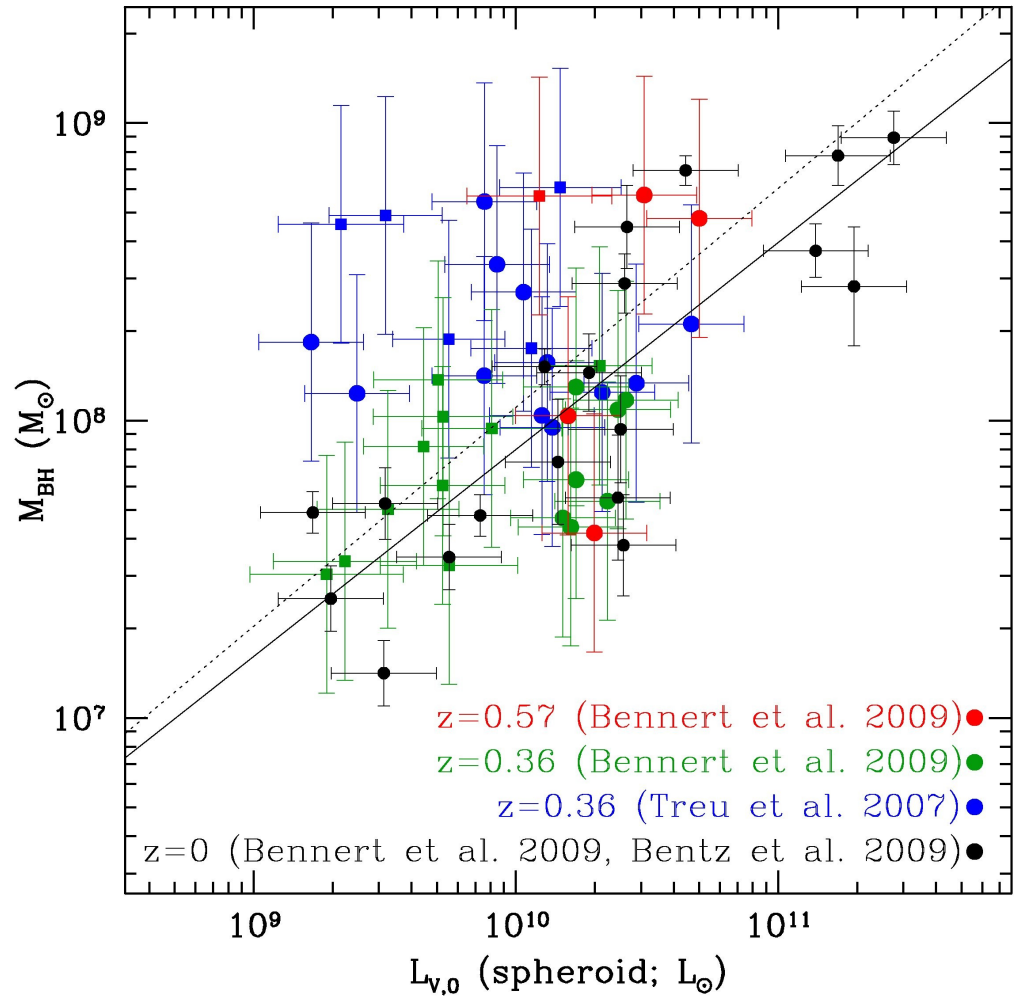
Exclude NGC* objects: fill FOV & dusty
Exclude WFPC2/PC objects: data quality too low
→ 19 objects

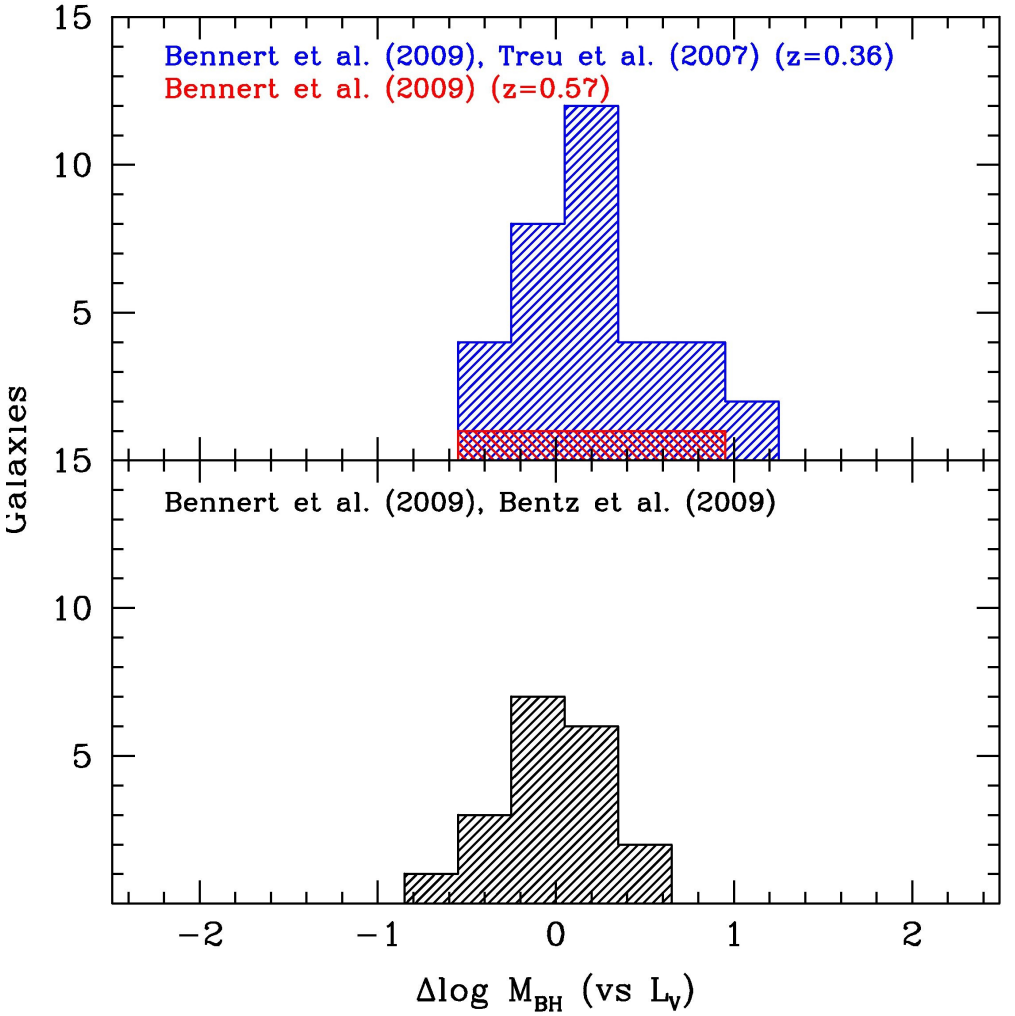
Less offset, large scatter

Offset: 0.3 dex (0.5 dex before)

The larger the higher M(BH)?

Scatter large





M(BH): Selection effects? *(e.g. Lauer et al. 2007)*

Populate local scaling relation according to spheroid LF *(Driver et al. 2007)*

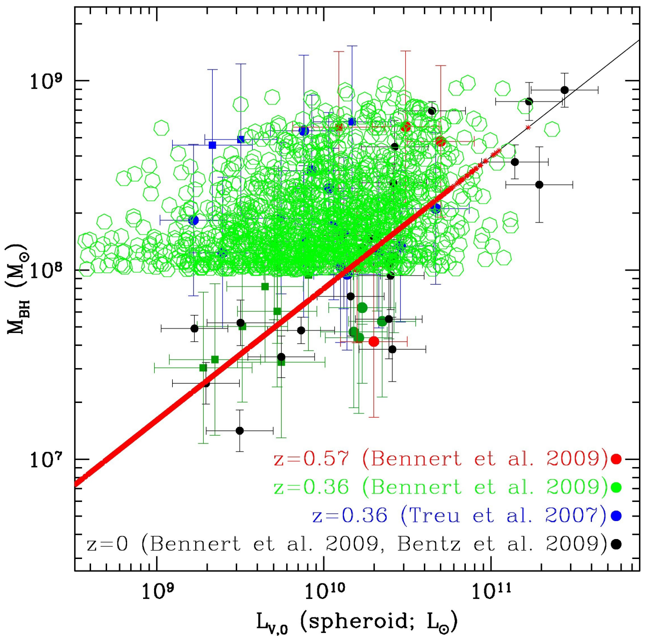
Add errors (0.2/0.4 dex) in montecarlo fashion

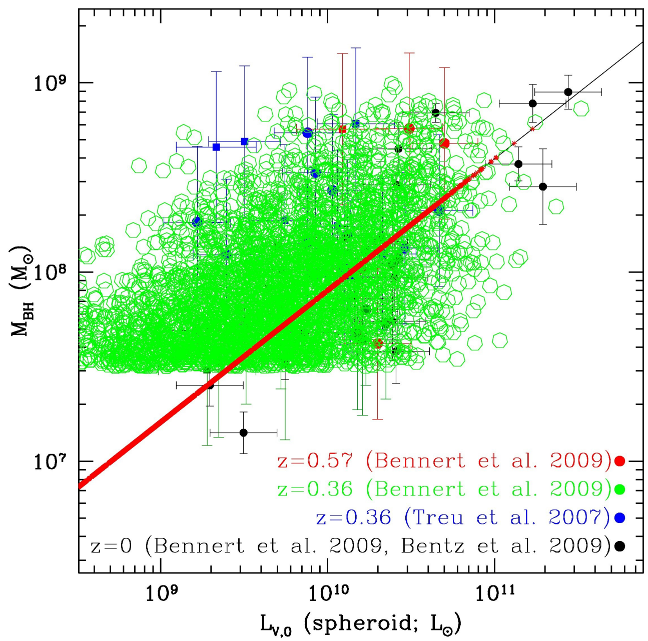
Cut at log M(BH) = 8, 7.5, 7

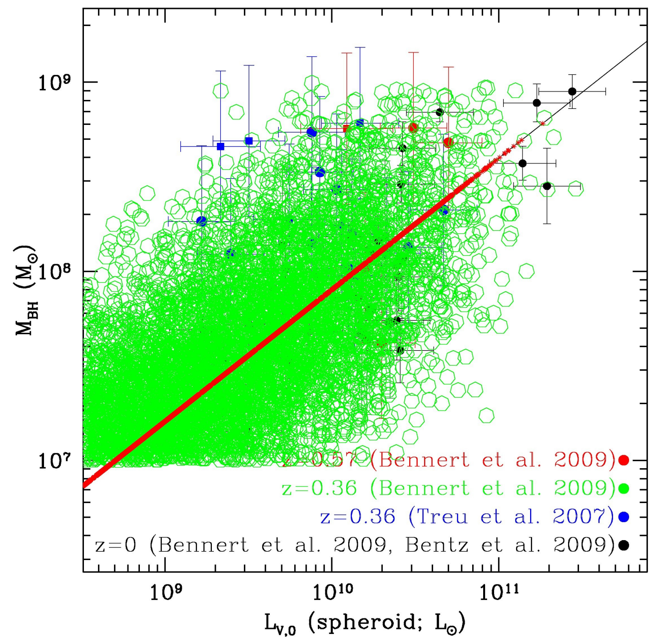
Up to 0.2 dex (difference Treu et al./now)

Now: less selection effect with larger M(BH) range

Ideally: extend even further





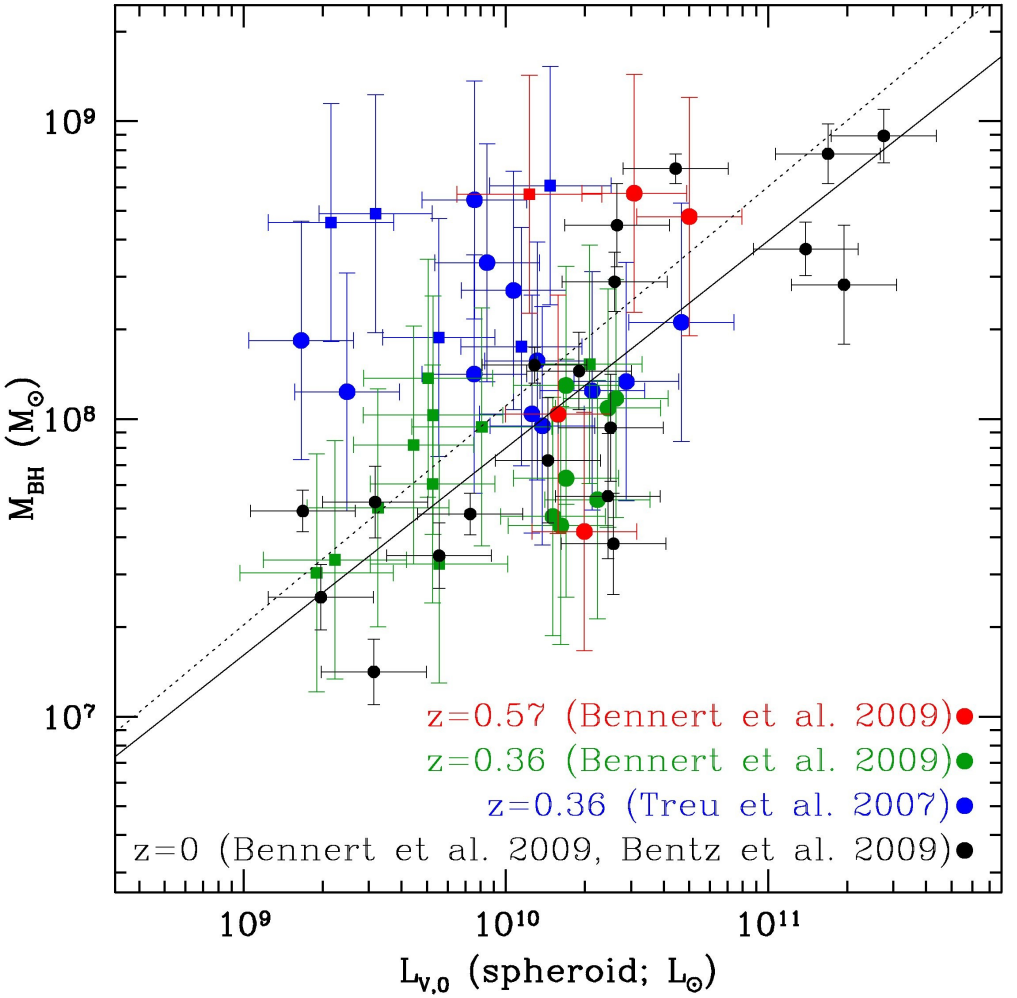


L: Selection effects?

Narrow range in spheroid luminosity:

Selected from SDSS: low lum. excluded?

No QSO-like objects: high lum. excluded?



Including high-z sample

Peng et al. (2006):

0.7 < z < 1.5

28 gravitationally lensed AGNs

18 non-lensed AGNs

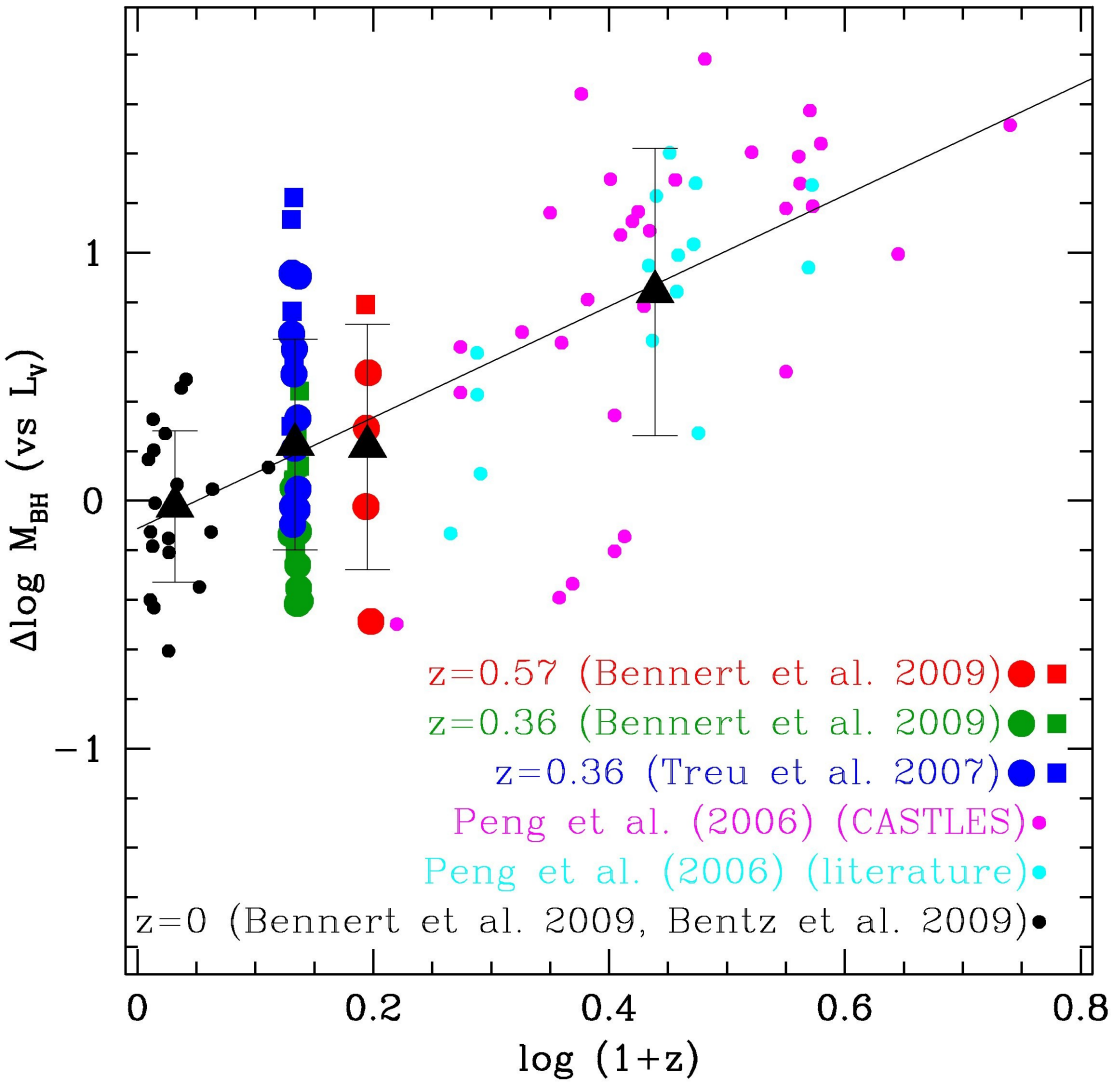
M(BH) (vs. L)

propto (1+z)^(2.2+/-0.2)

Without high-z sample:

M(BH) (vs. L)

propto (1+z)^(1.9+/-1)



M(BH)-M(bulge) relation

Use SDSS colors to determine stellar bulge mass

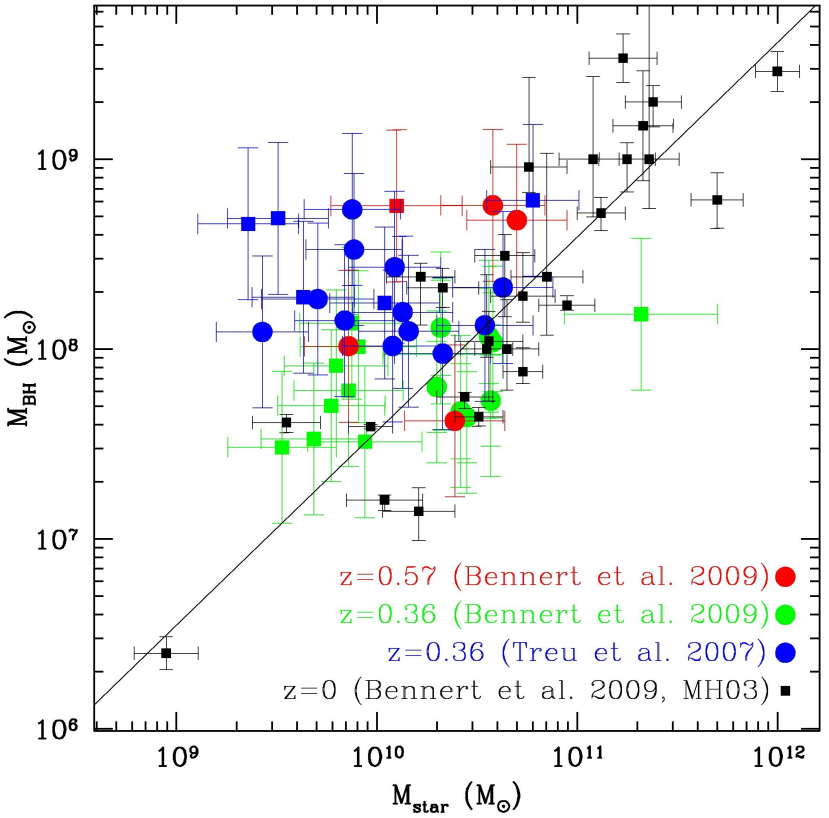
Subtract PSF magnitude (extrapolated from NICMOS)

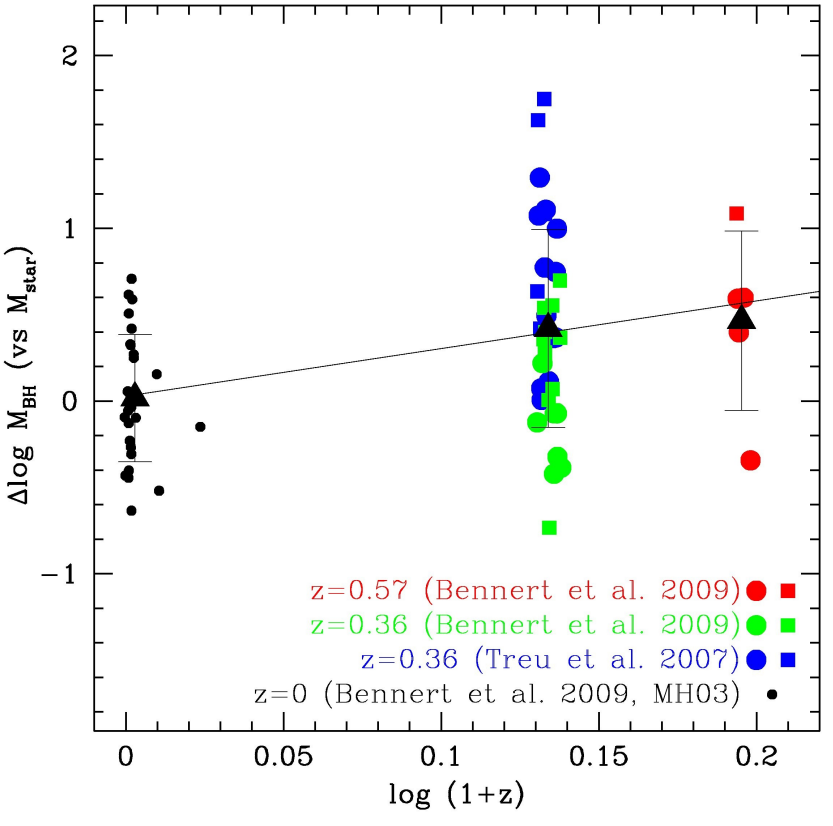
Local comparison sample from Marconi&Hunt (2003)

Offset 0.4 dex

M(BH) (vs M(bulge)) propto (1+z)^(2.8+/-0.9)

in agreement with z=6.4 QSO from Walter et al. (2004)





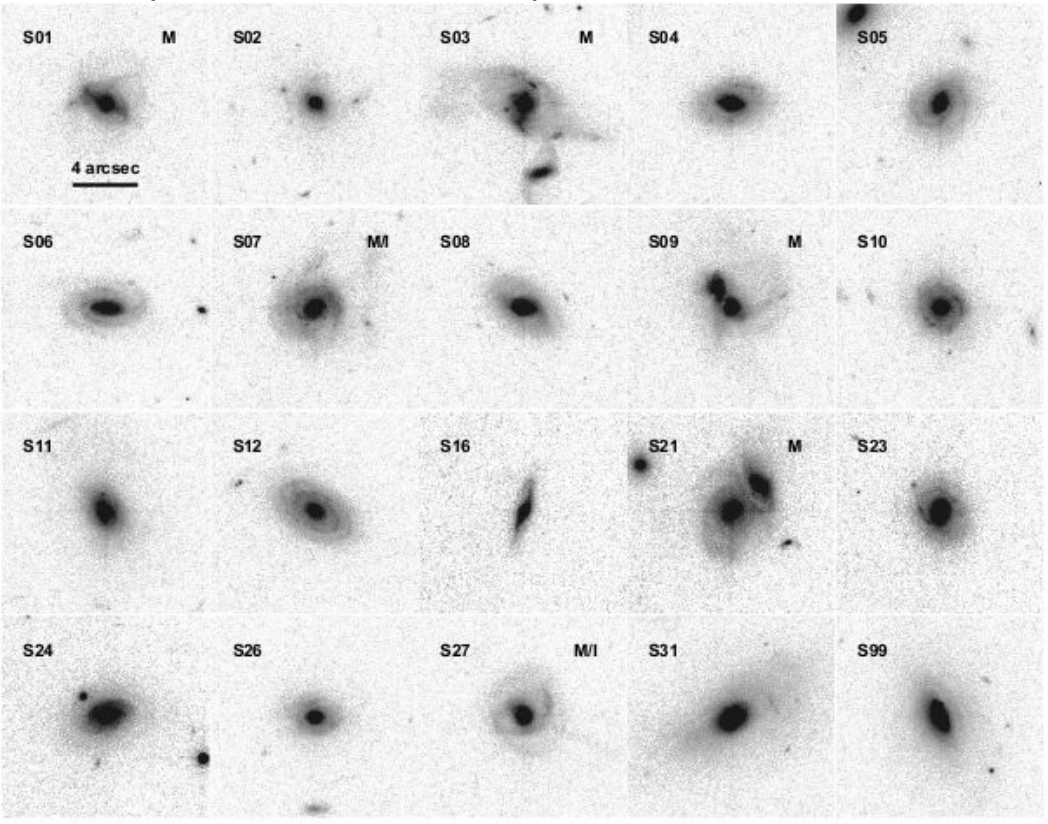
Observations: Mergers?

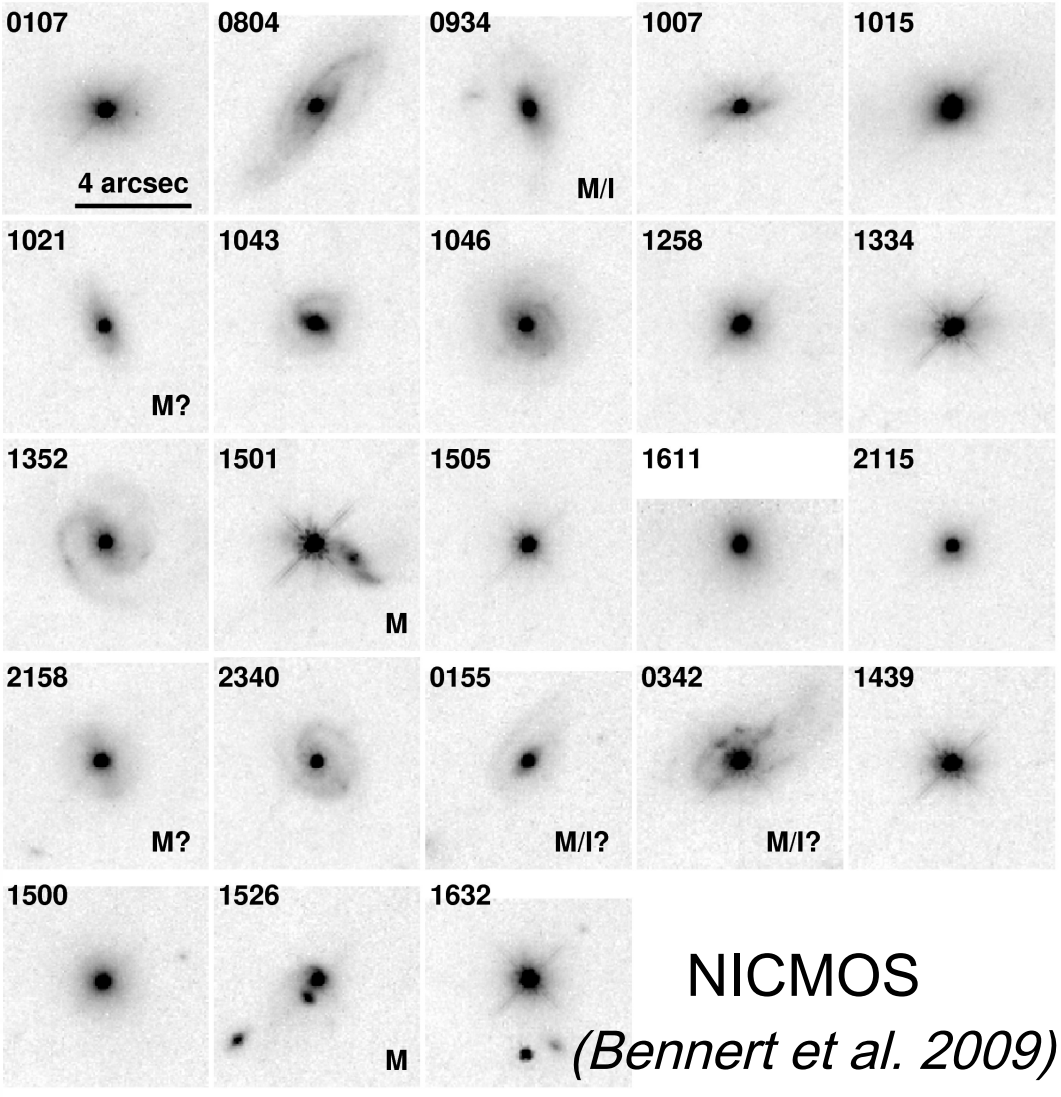
13/40 with signs of interaction/mergers

Comparable to fraction in GOODS at same z *(Treu et al. 2007)*

Larger than in local universe *(e.g. Patton et al. 2002)*

ACS *(Treu et al. 2007)*





NICMOS *(Bennert et al. 2009)*

Theory: Mergers?

Grow both BH and spheroids, but:

(a) different timescales involved

(b) different types of mergers
e.g. dry vs. wet mergers, evolution in progenitor properties

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

→ large scatter
eventually fall on local relation?

Observed evolution (slope of 2.2 or 2.8) faster than theoretical predictions:
Slope: 0.5-1.5
(e.g. Wyithe & Loeb 2003, Merloni et al. 2004, Croton 2006, Hopkins et al. 2009)

Caveats

Small local comparison sample

M(BH):
(a) Based on BLR size-lum relation
(b) Virial coefficient f – convert size & vel. into mass
Onken et al. (2004): M(BH) – sigma: AGN=local quiescent galaxies
Cancels out if f does not evolve with z
Or: cosmic evolution of f? = geometry/kinematics of BLR
But: AGN spectra look similar over wide range of redshifts
(c) Radiation pressure ignored *(Marconi et al. 2008, 2009; but Netzer 2009)*
But: would further increase M(BH)

L overestimated?
But: Error on K-correction & lum. evolution negligible (0.02/0.03 dex)
Using Sersic n<4 instead of n=4 (de Vaucouleurs) increases offset

Outlook

More objects (9 @ z=0.57, 3 @ z=0.36 with WFC3)

M(BH) – sigma relation for same sample (Woo et al. 2009, in preparation)

Wide range of morphologies (majority are spirals):
Likely degree of rotational support
Questions e.g. fiber-based SDSS measurements of sigma

→ 100 galaxies selected from SDSS
z=0.02-0.1; M(BH) > 10^7.5 M(sun)
Spatially resolved spectra: determine true bulge dispersion