Measuring black-hole masses and the evolution of the M_{bh}:M_{bulge} relation

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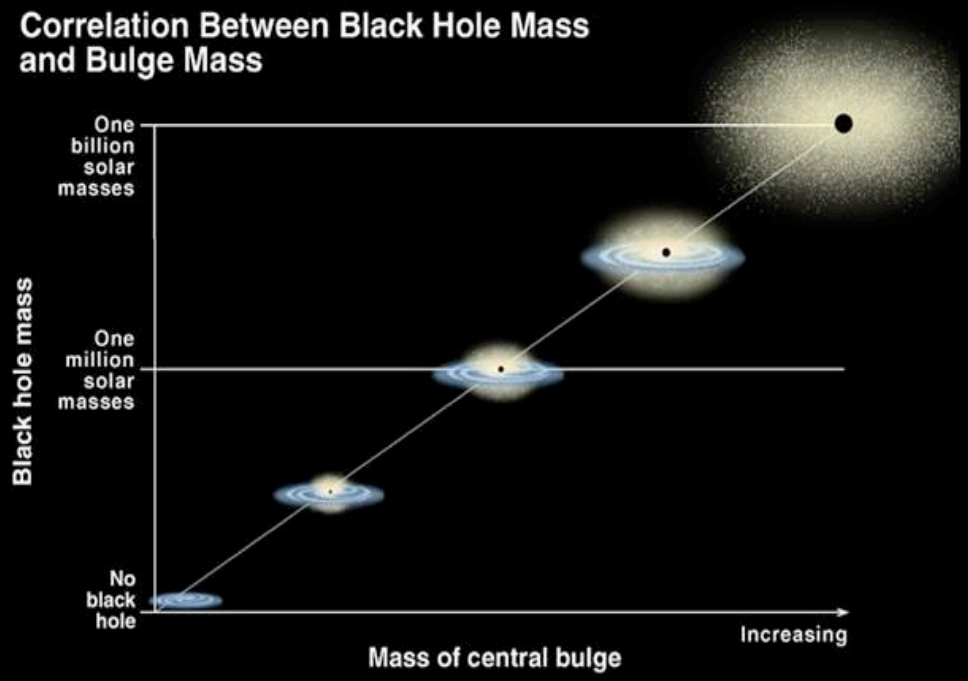
The evolution of the M_{bh}:M_{bulge} relation

Outline

- The M_{bh}:M_{bulge} relation: local galaxies
- The AGN perspective: estimating M_{bh} and possible problems
- Evolution of M_{bh}:M_{bulge} relation $0<z<4$
- Conclusions
- What can we do in the future

The evolution of the M_{bh}:M_{bulge} relation

Now well established fact, at least for massive galaxies, that the central black-hole mass is tightly correlated with galaxy spheroid/bulge mass

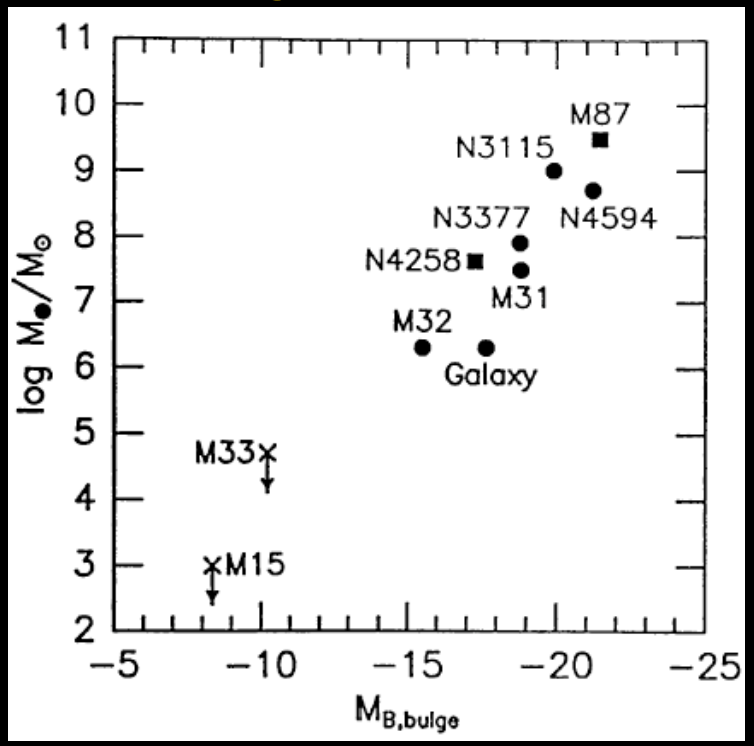


What's the historical background to this ?

The evolution of the M_{bh}:M_{bulge} relation

Historical perspective: Local galaxies

Famous paper by Kormendy & Richstone (1995) first to show from observations that black-hole mass and bulge luminosity were correlated.



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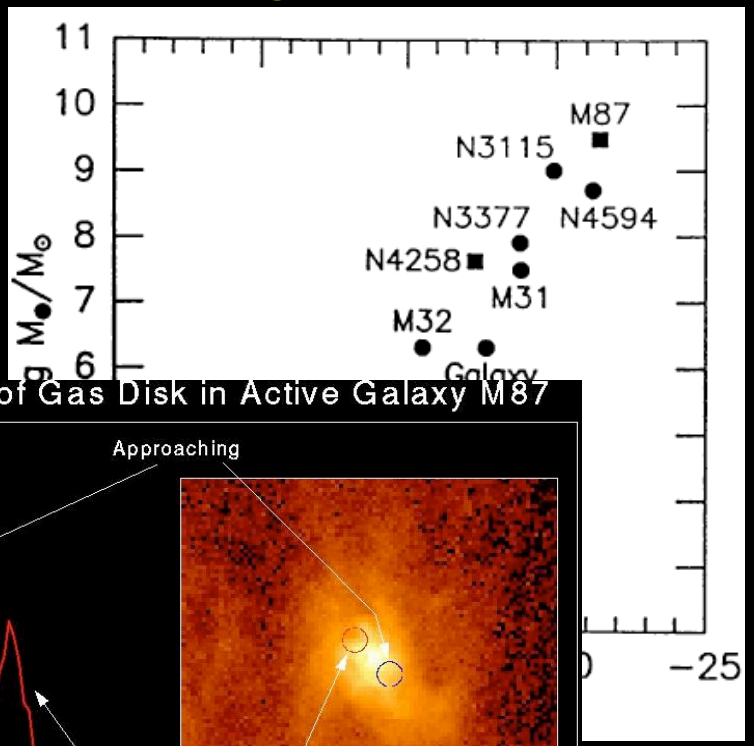
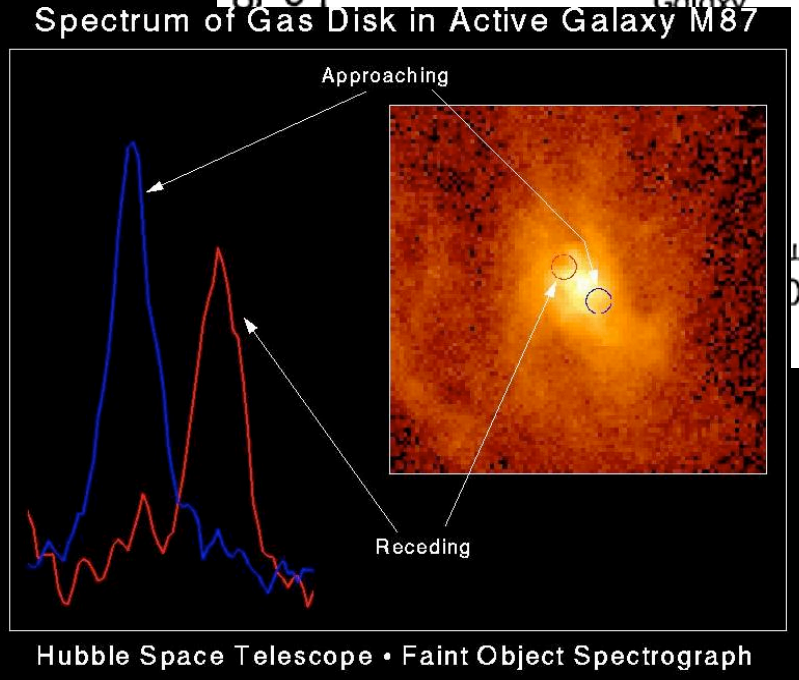


Prompted by refurbishment of HST allowing gas dynamics to studied within black-hole sphere of influence:

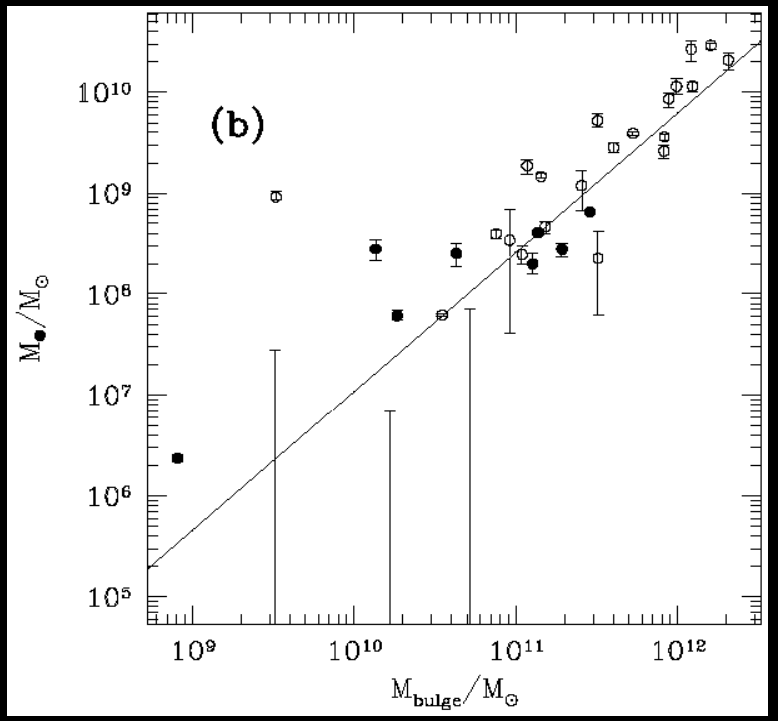


The evolution of the M_{bh}:M_{bulge} relation

Historical perspective: Local galaxies

Step forward to 1998 and second famous paper from Magorrian et al. (1998)

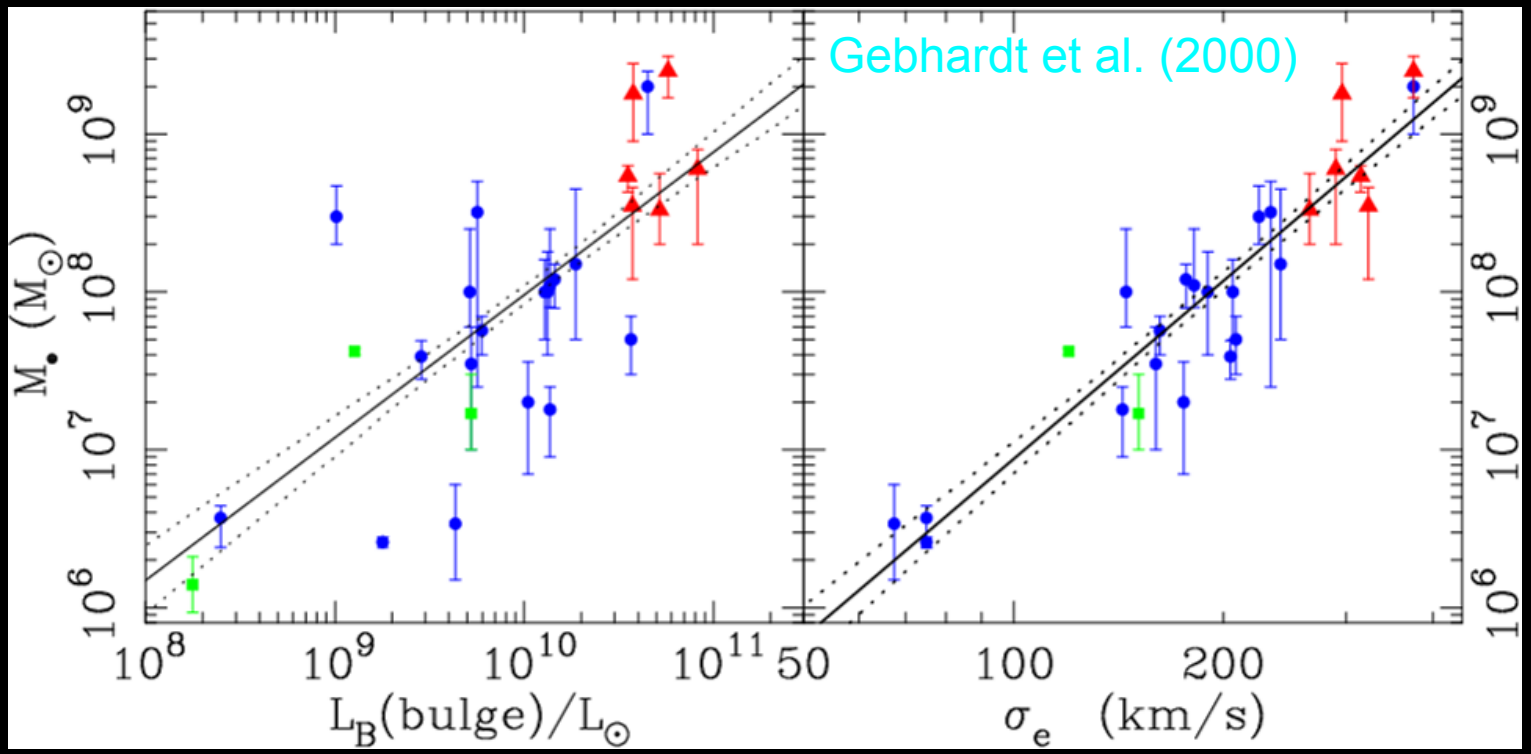
Dynamical modelling of stellar populations of nearby massive galaxies suggested correlation between bulge mass and mass of central "massive dark object"



The M_{bh}:M_{bulge} now often referred to simply as "the Magorrian relation"

The evolution of the M_{bh}:M_{bulge} relation

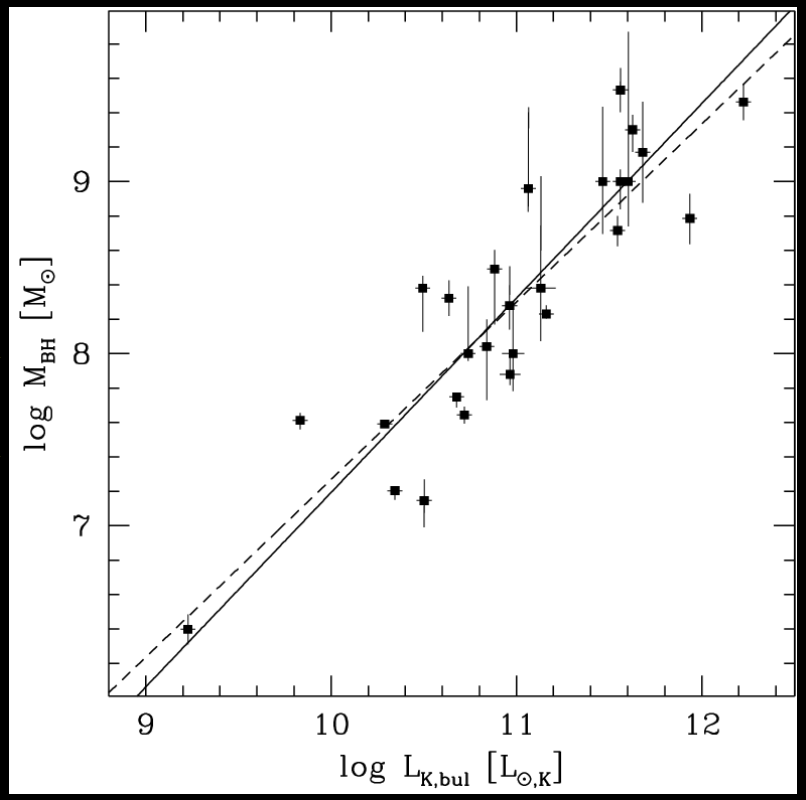
Historical perspective: Local galaxies



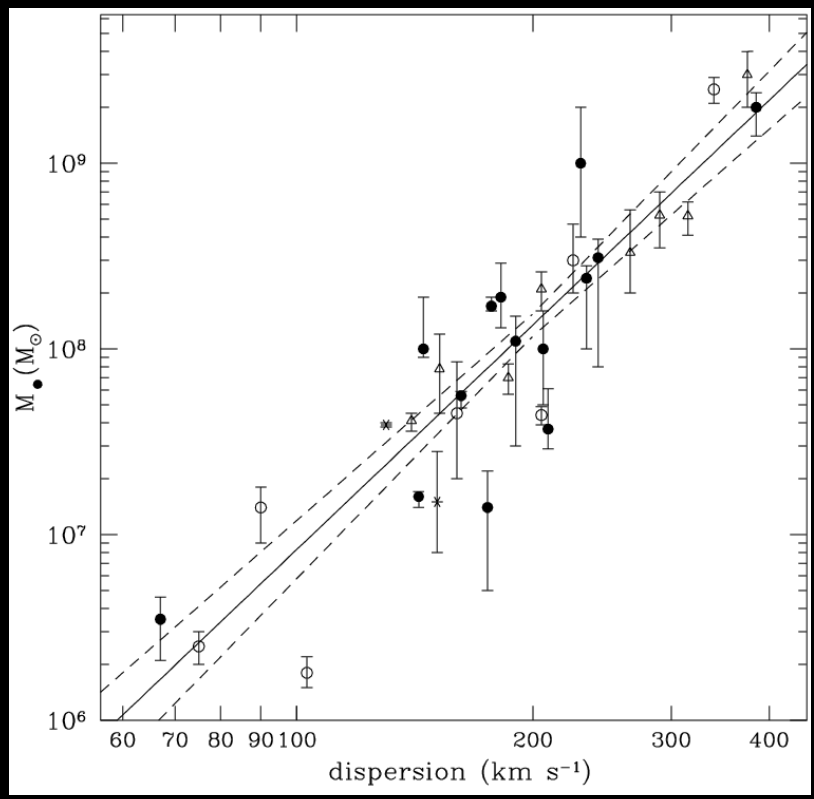
The so-called M_{BH}-σ relation: $M_{BH} \propto \sigma^{3.75\pm0.3}$

The evolution of the M_{bh}:M_{bulge} relation

Marconi & Hunt (2003)



Tremaine et al. (2002)



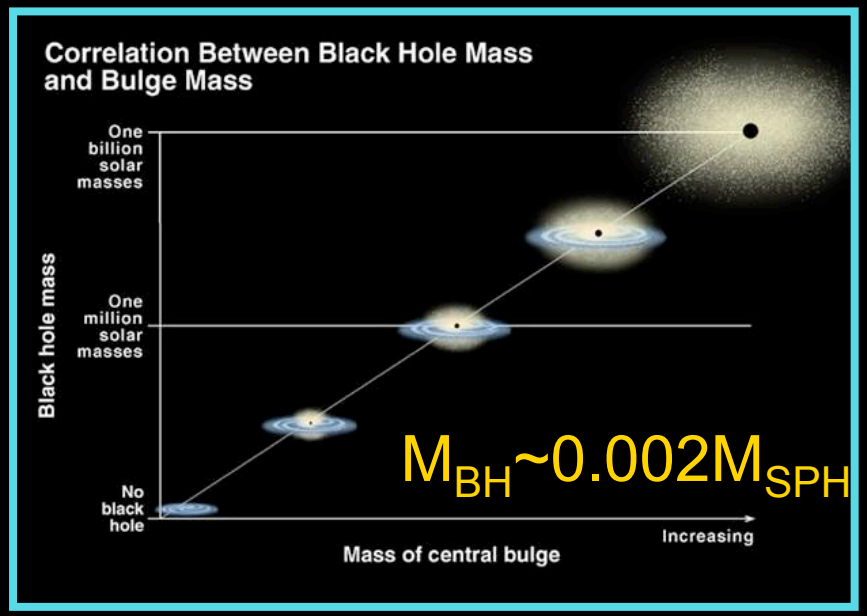
Both correlations have very low associated scatter

Independent of galaxy morphology

M_{BH}~0.002M_{SPH}

The evolution of the M_{bh}:M_{bulge} relation

The black-hole: spheroid relation



Why is this important?

Black hole and galaxy evolution intimately related

All massive galaxies pass through active AGN phase

The evolution of the M_{bh}:M_{bulge} relation

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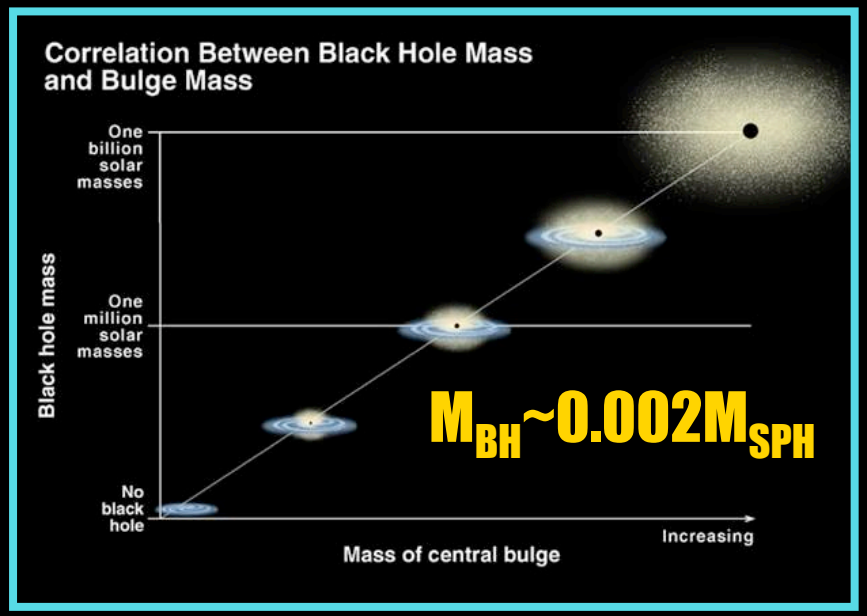

Why is this important?

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All massive galaxies pass through active AGN phase

Clearly some form of feedback relation: black holes regulating starformation

AGN “feedback” now important ingredient of galaxy formation models

How do you study M_{BH}:M_{SPH} evolution?

Active galaxies (AGN) offer the only opportunity for progress
Can estimate both black-hole and galaxy mass

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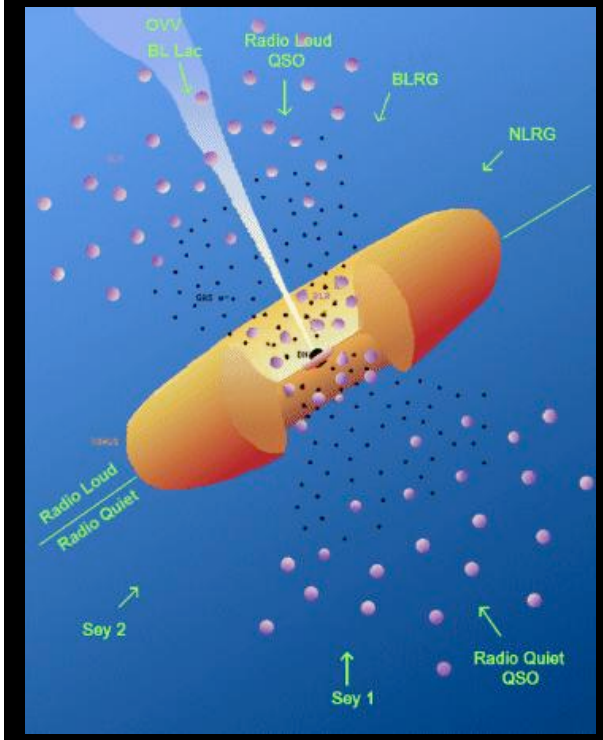

Gas velocity dispersion
from UV/optical spectra

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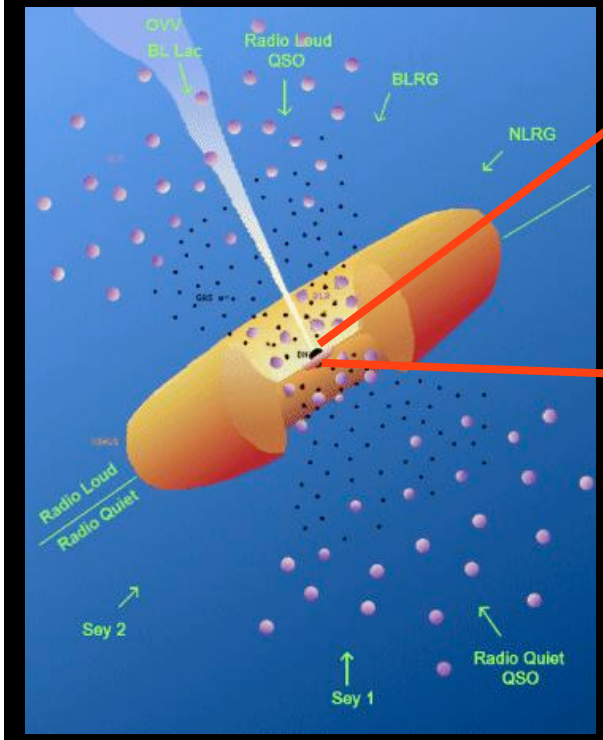

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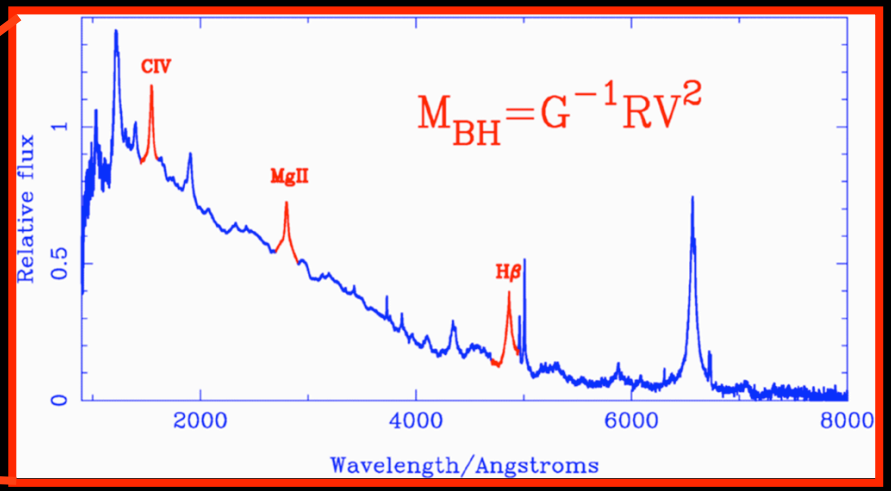
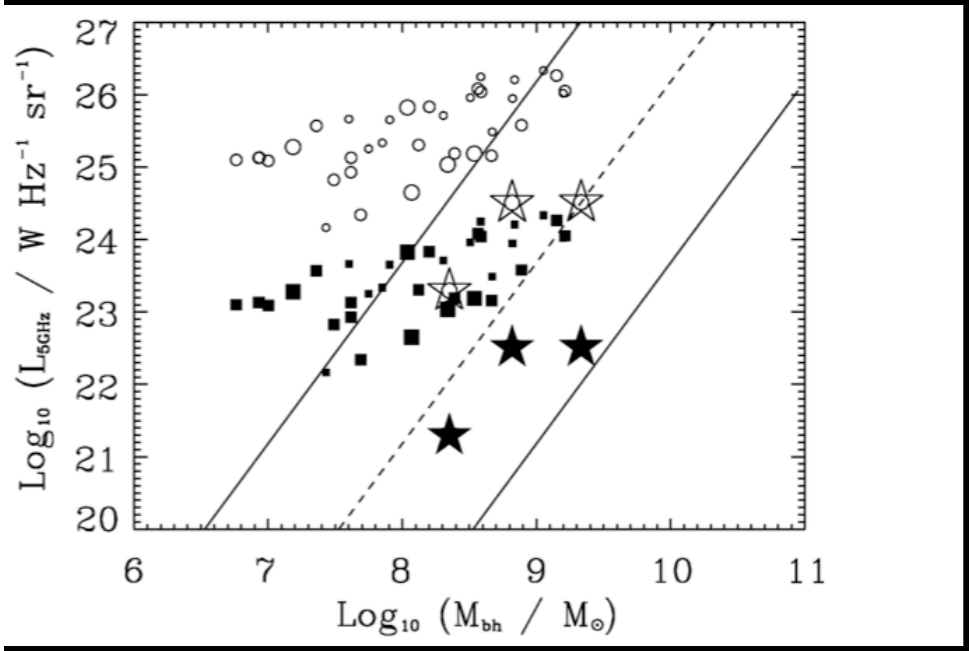


- Assume BLR is virialised
- Velocity from broad-line widths
- Radius from R-L correlation (e.g. Kaspi et al. 2000)

- 0<z<0.8 Hβ line-widths
- 0.8<z<2.0 MgII line-widths (McLure & Jarvis 2002)
- z>2 CIV line-widths (Vestergaard 2002)

Not all hunkydory with any virial estimator though…

Doppler boosting can disguise real radio power



Jarvis & McLure 2002

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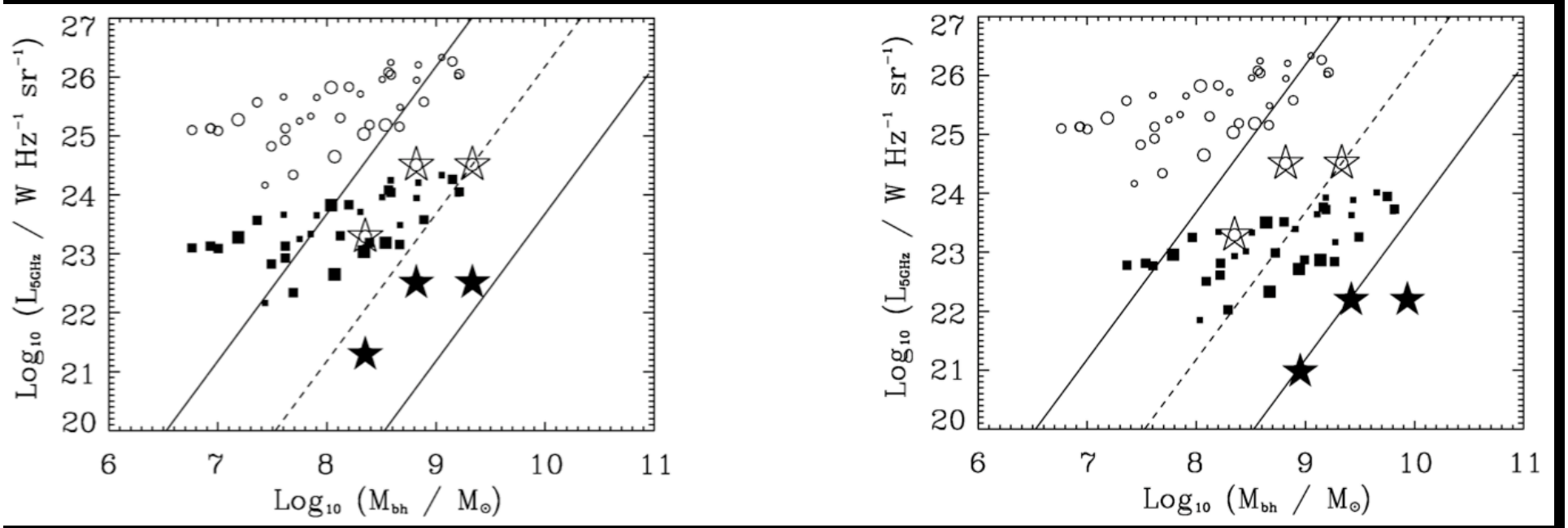
Doppler boosting can disguise real radio power and it has been known for many years that there is a correlation between broad emission-line width and the core-to-lobe ratio of radio-loud source (Wills & Browne 1986; Brotherton 1996; Rokaki et al. 2003)



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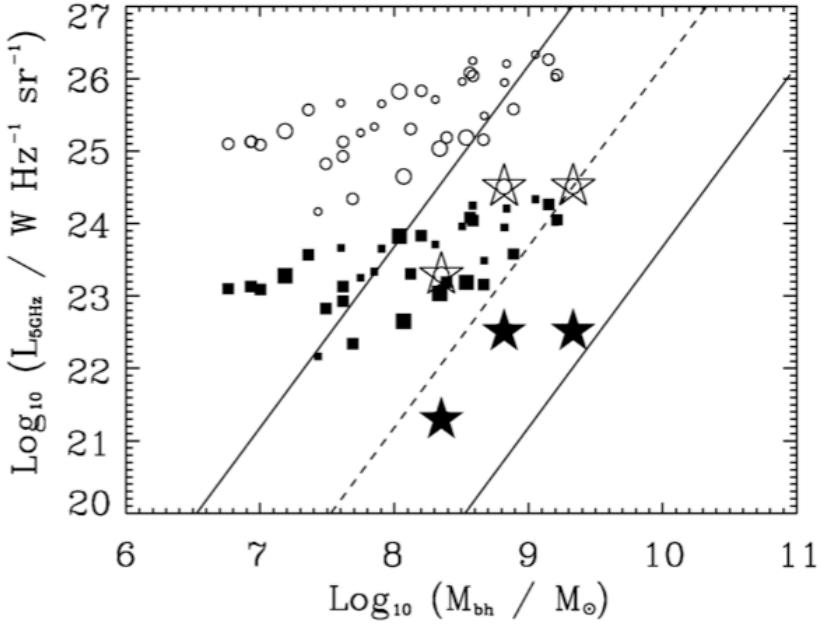
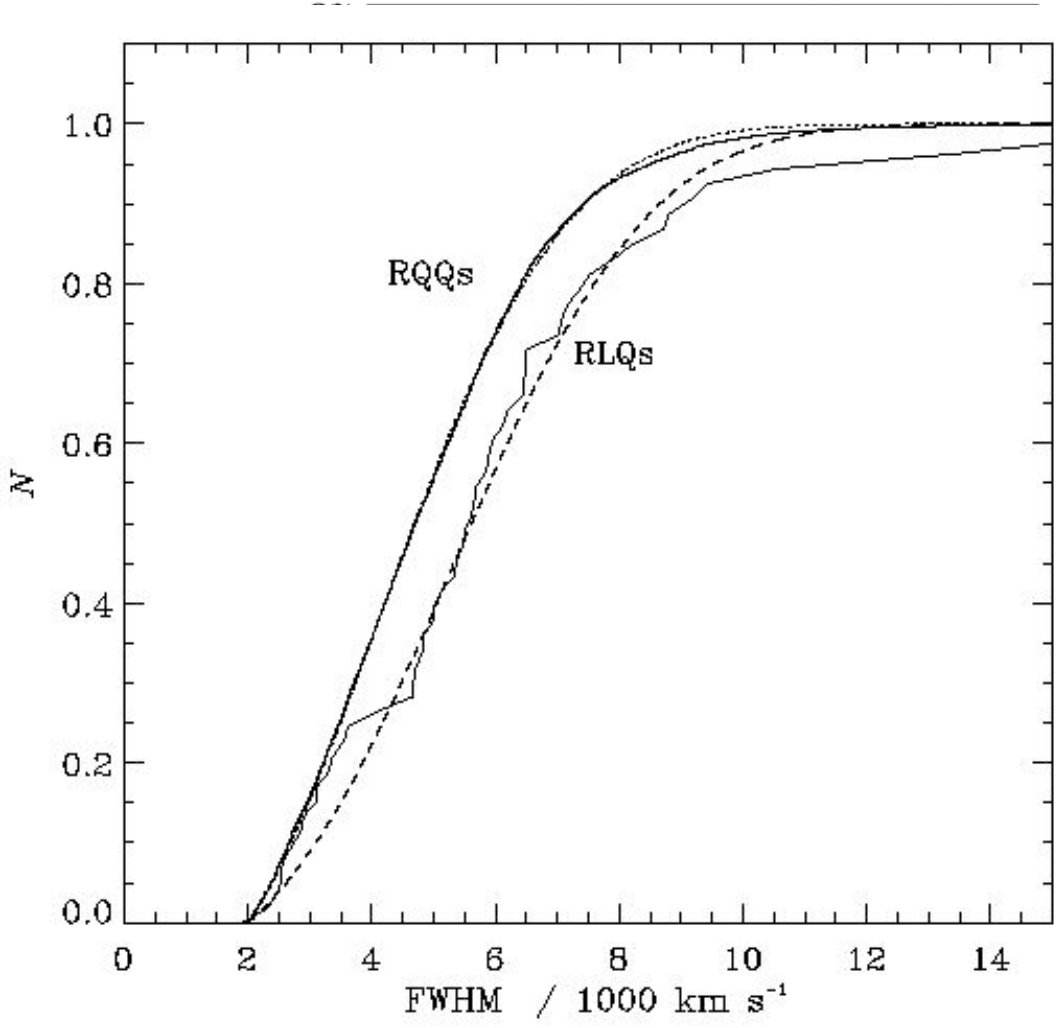


Jarvis & McLure 2002, 2006



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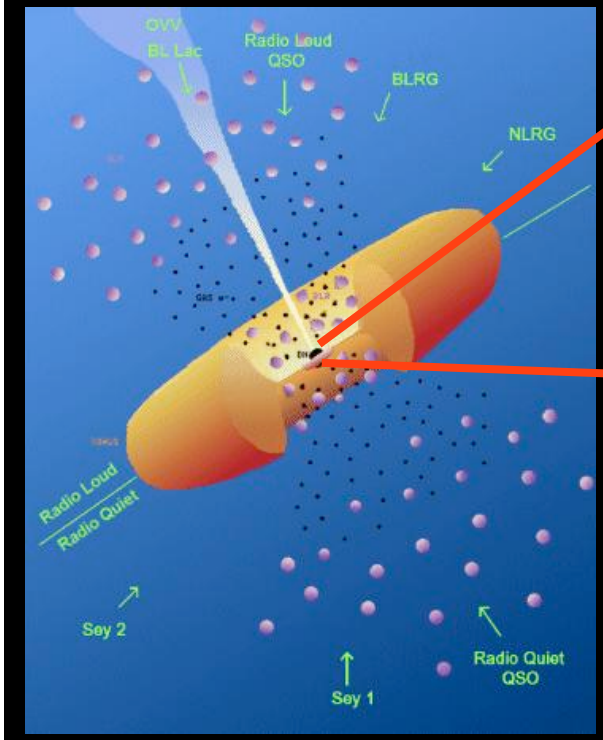
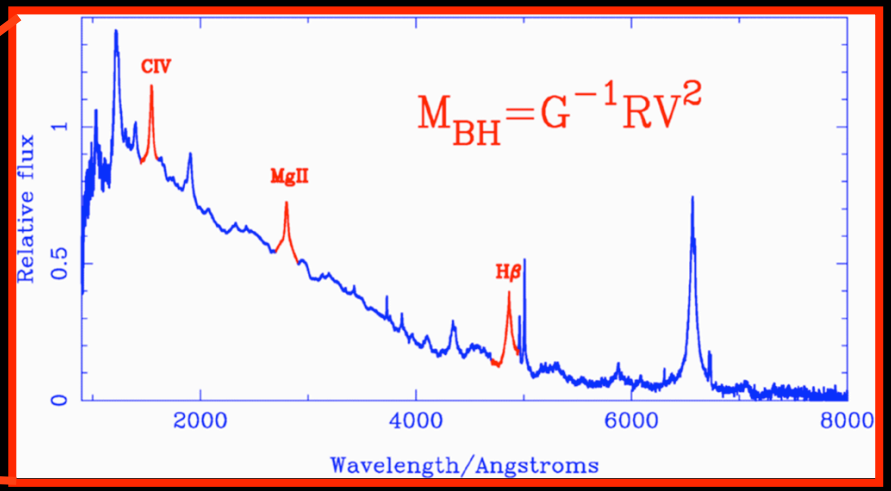


Gas velocity dispersion
from UV/optical spectra



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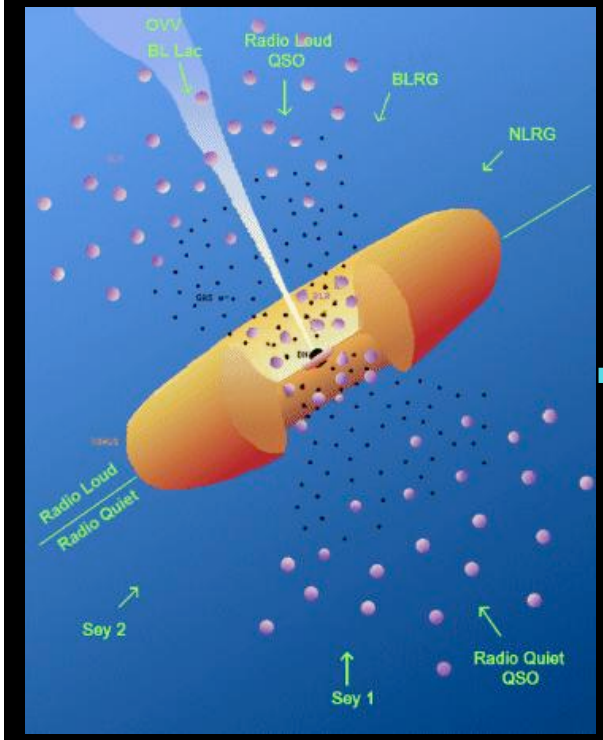
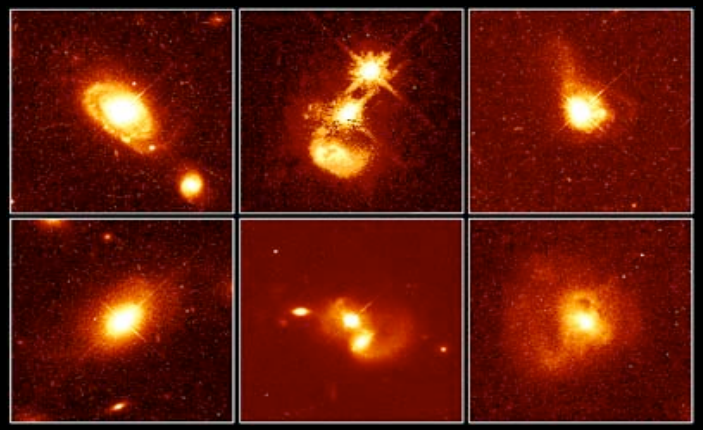


Gas velocity dispersion
from UV/optical spectra

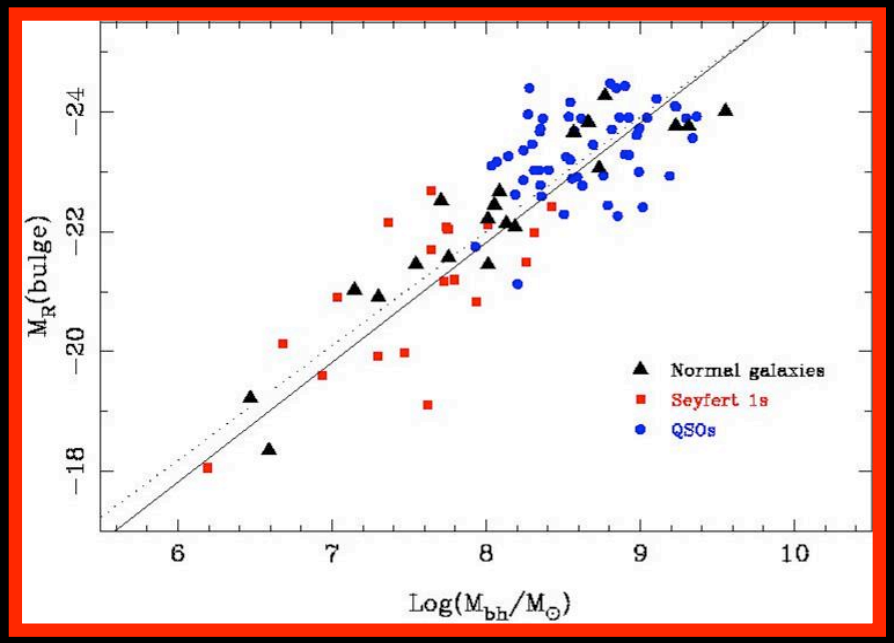
+

Galaxies provide spheroid mass

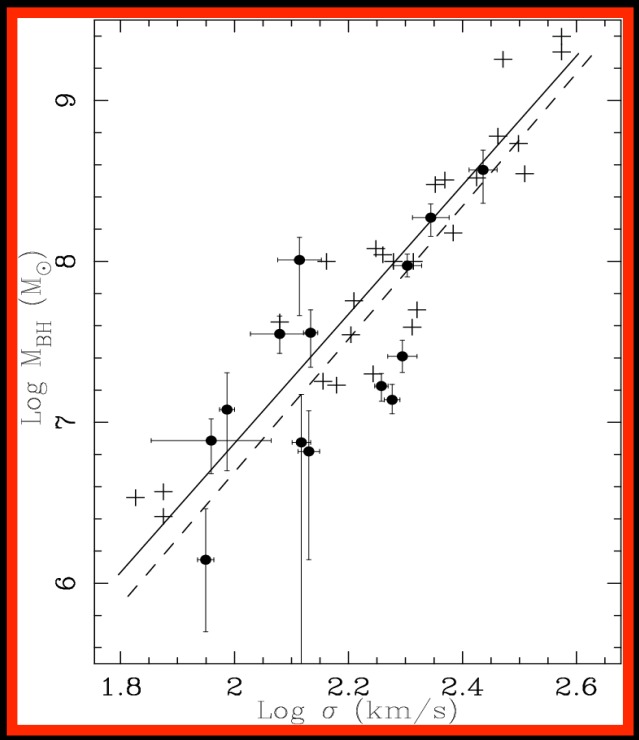


$$\frac{M_{BH}}{M_{SPH}}(z)$$

Do AGN follow the M_{bh}:M_{bulge} relation?



(McLure & Dunlop 2002)



(Nelson et al. 2004)

Low-redshift quasars/Seyferts follow standard M_{bh}-L_{bulge} correlation (McLure & Dunlop 2002)

Low-redshift Seyferts follow standard M_{bh}-σ correlation (Nelson et al. 2004)

AGN appear to be unbiased tracer of M_{bh}:M_{bulge} relation

Recent studies: Seyfert galaxies

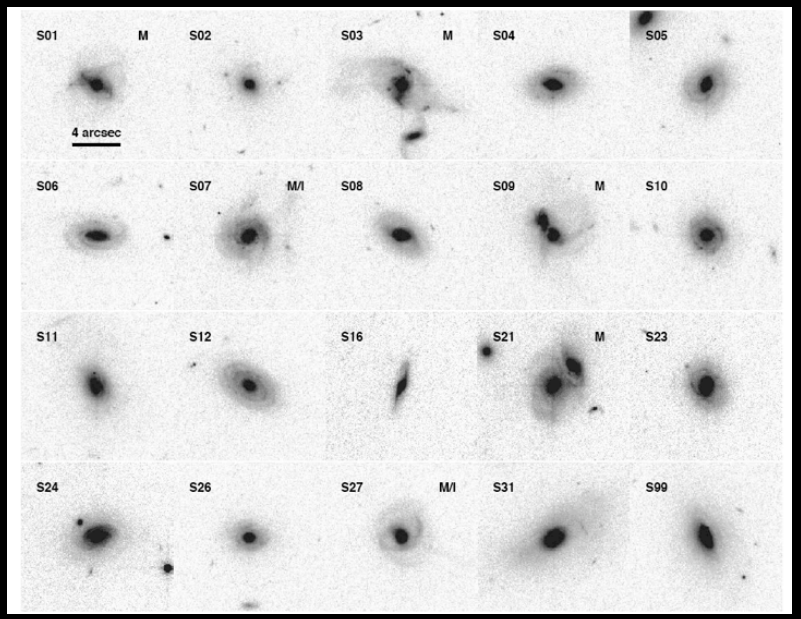
Woo et al. (2008), Treu et al. (2007)

latest results of on-going study of M_{bh}-σ and M_{bh}-L_{bulge} relations using sample of broad-line Seyferts at z~0, z~0.4 and z~0.6

AGN broad lines provide black-hole masses

SDSS+Keck spectra provide velocity dispersions

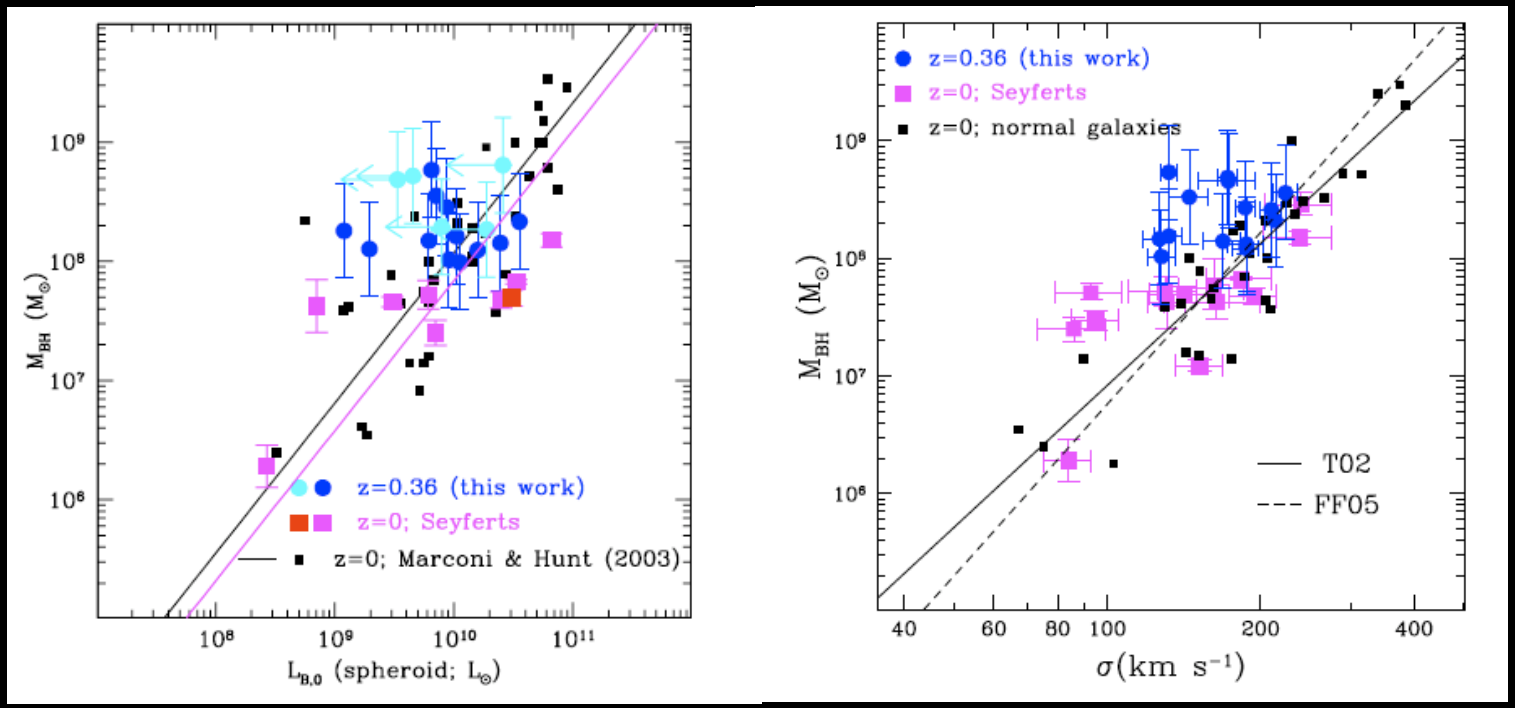
ACS imaging provide bulge luminosities at z~0.4



HST ACS i-band imaging

Recent studies: Seyfert galaxies

Results of study of M_{bh}-σ and M_{bh}-L_{bulge} relations at z~0.4:

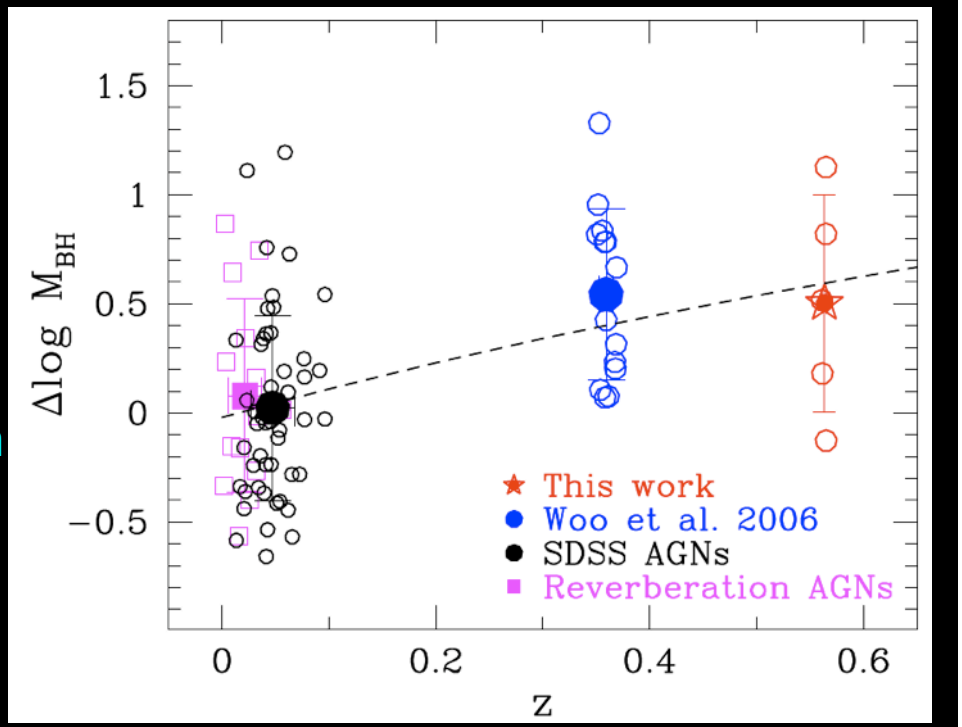


Claim is that results are inconsistent with no evolution at 95% CL

Recent studies: Seyfert galaxies

Latest results from Woo et al. (2008)

- Addition of comparison sample of Seyferts at z=0 drawn from the SDSS
- Small sample (5 objects) added at z=0.57
- z=0 Seyferts sit on standard M_{bh}-σ relation
- z>0.3 samples are off-set



Dashed line is evolution of the form: $\Delta M_{BH} \propto (1+z)^{3.1\pm1.5}$

Recent studies: Quasars

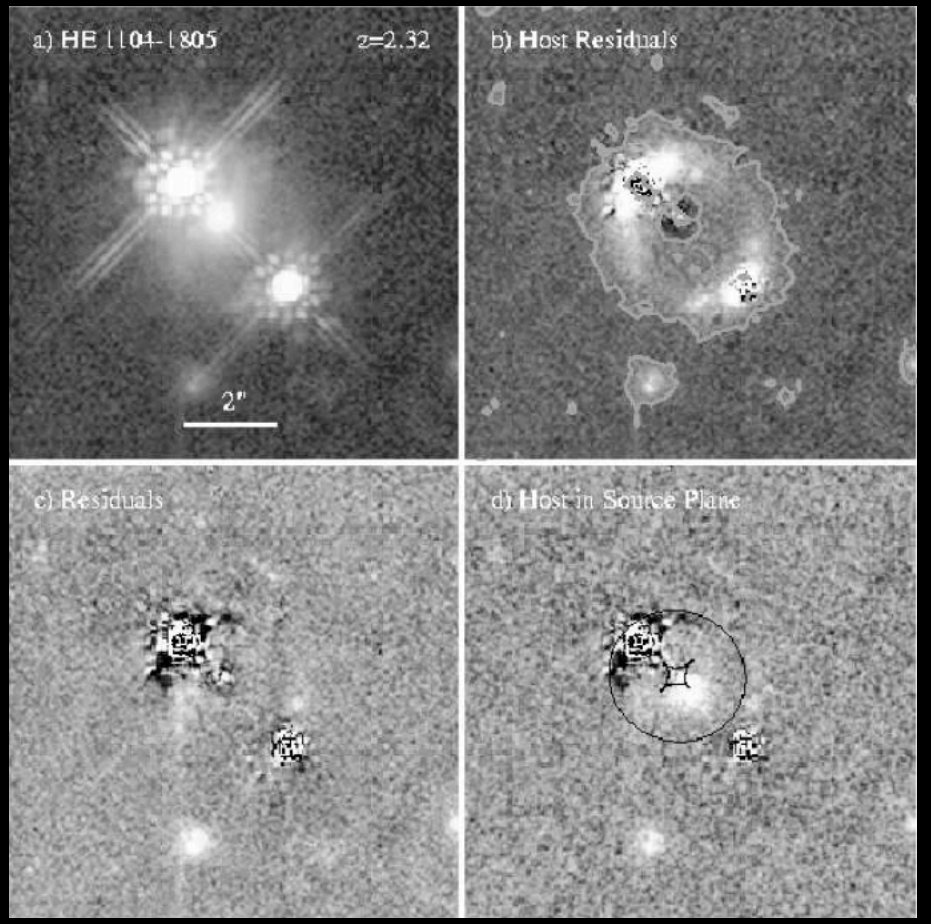
Peng et al. (2006)

Doing things the hard way

Study of the evolution of the M_{bh}-L_{bulge} relation using literature sample of quasars with HST imaging at 1<z<3

Plus, modelling of host galaxies in lensed quasar systems.....

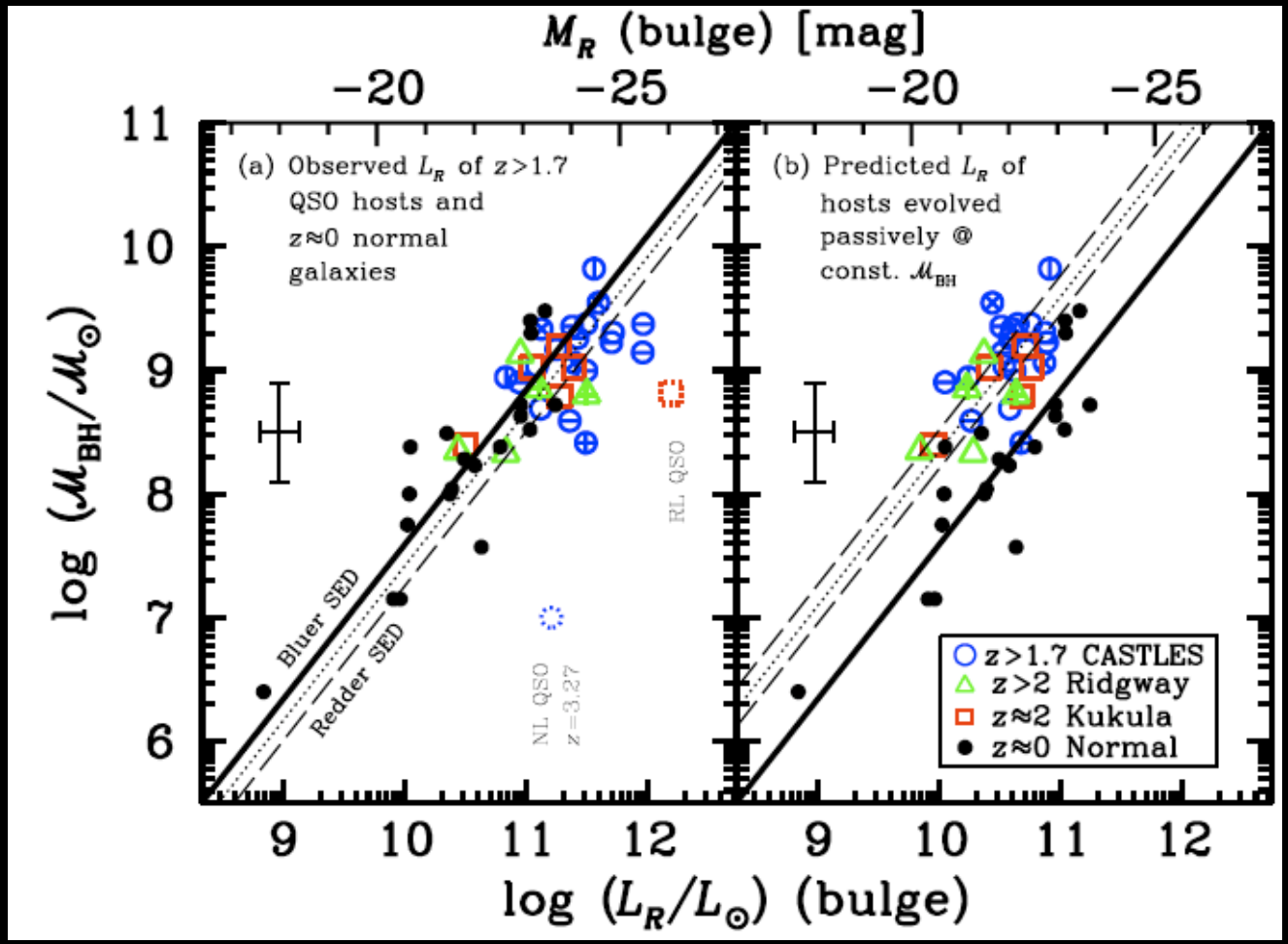
- 31 objects from the CASTLES survey
- 15 objects from the literature



Example modelling of one CASTLES quasar

Recent studies: Quasars

Peng et al. (2006)

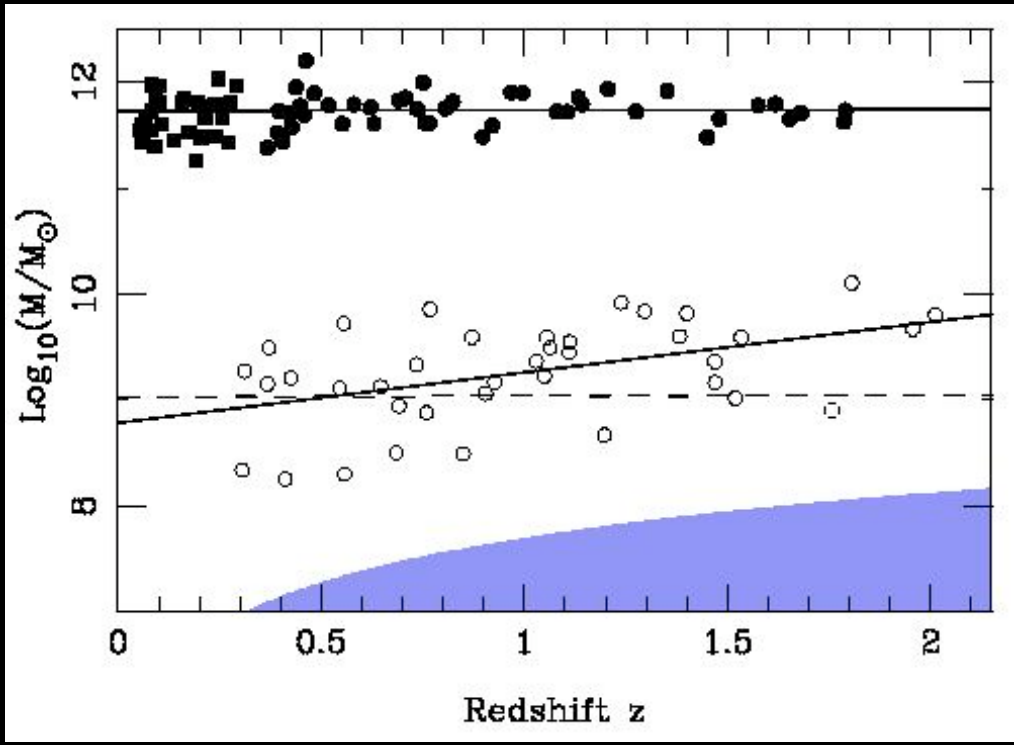


- Conclude that black-holes are a factor 5-6 more massive at z~2
- Quasar hosts cannot be fully assembled at these redshifts

Recent studies: Radio-loud AGN

McLure, Jarvis et al. (2006)
Doing things the quick and dirty way...

- 3CRR sample of radio-loud AGN
- Rely on radio-loud unification: Radio galaxies and radio-loud quasars drawn from same underlying population
- Bulge masses from radio galaxies
- Black-hole masses from quasars



- No apparent evolution of bulge masses: RGs fully assembled?
- Black-hole masses increase with redshift

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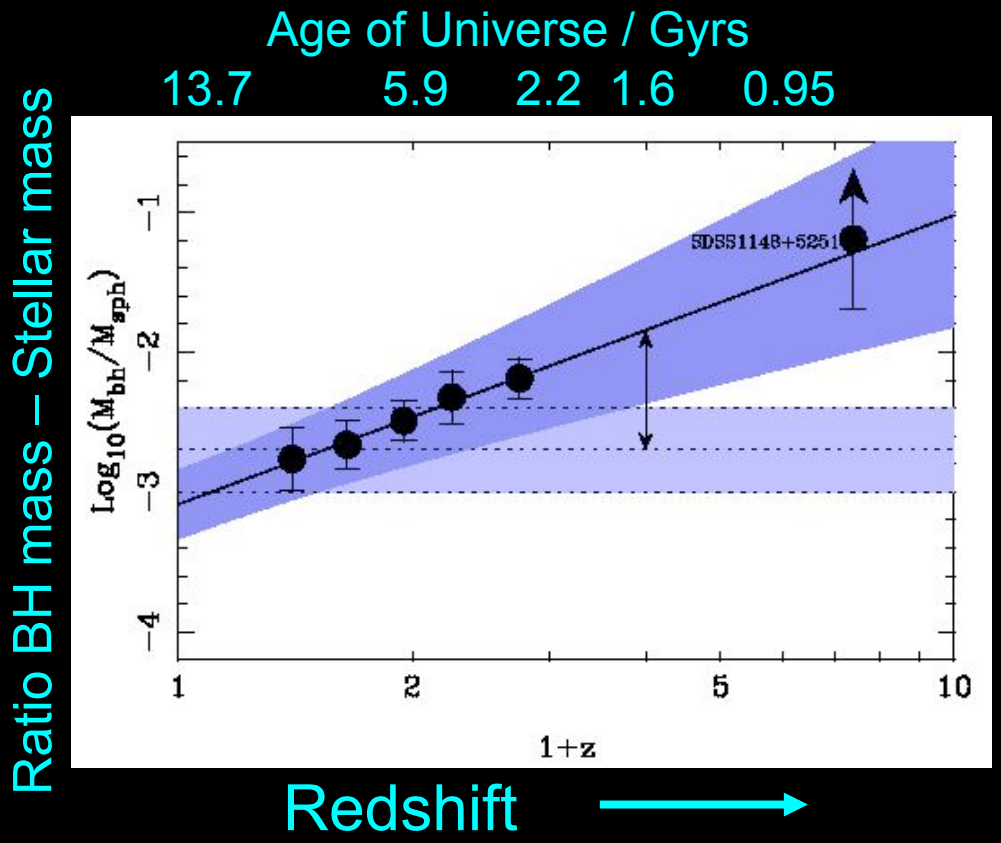


Solid line is evolution of the form: $\Delta M_{BH} \propto (1+z)^{2.1\pm0.7}$

Within the uncertainties, good agreement with Woo et al. (2008) and Peng et al. (2006)

Conclusions

◉ Redshift evolution of M_{bh}:M_{bulge} relation key constraint on galaxy evolution models

◉ AGN provide the only practical method for tracing evolution

◉ Tests suggest that AGN are unbiased tracers at low redshift

◉ Various studies of luminous AGN suggest M_{bh}:M_{bulge} ratio evolves with redshift

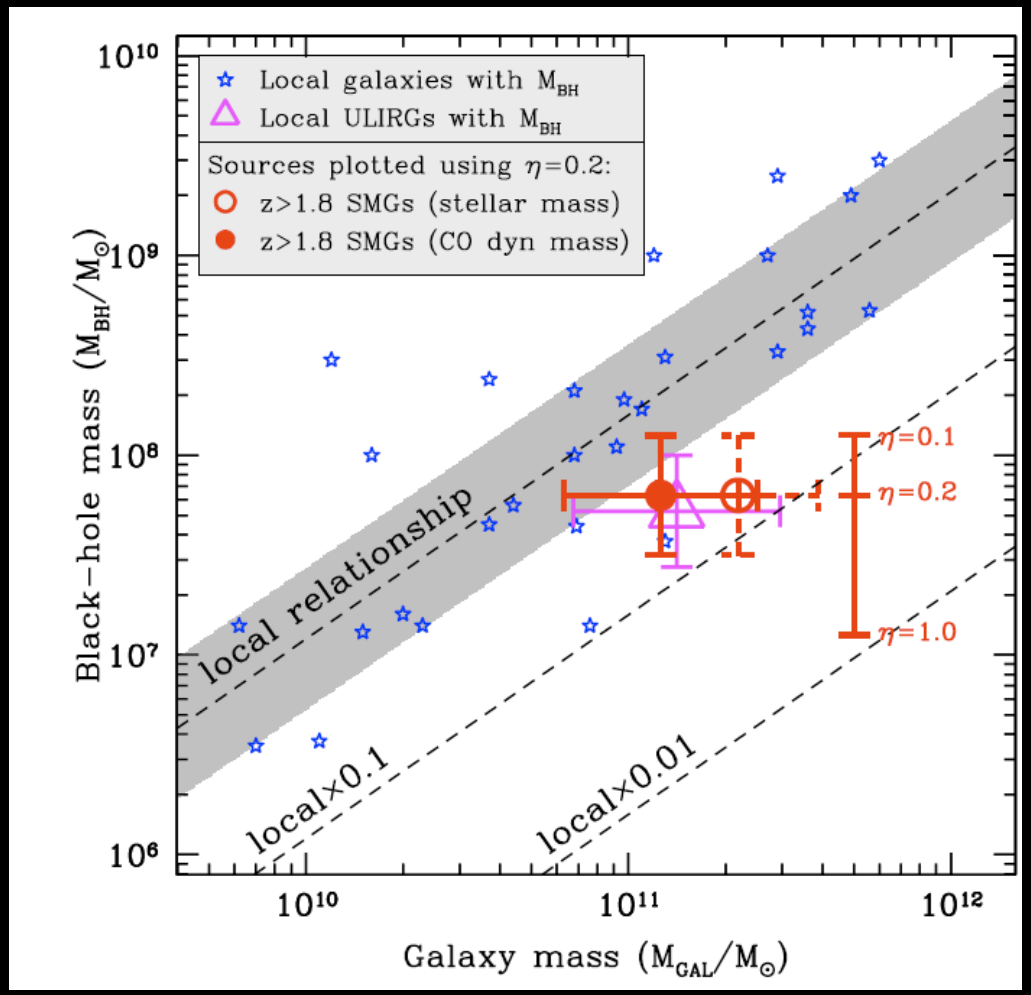
(although this does not appear to be true for Sub-mm galaxies)

◉ At present evolution appears to be : $\Delta M_{BH} \propto (1+z)^{2\pm1}$

Uncertainties and potential sources of bias are still large/unknown

Evolution (if it exists) only demonstrated at ~2σ level

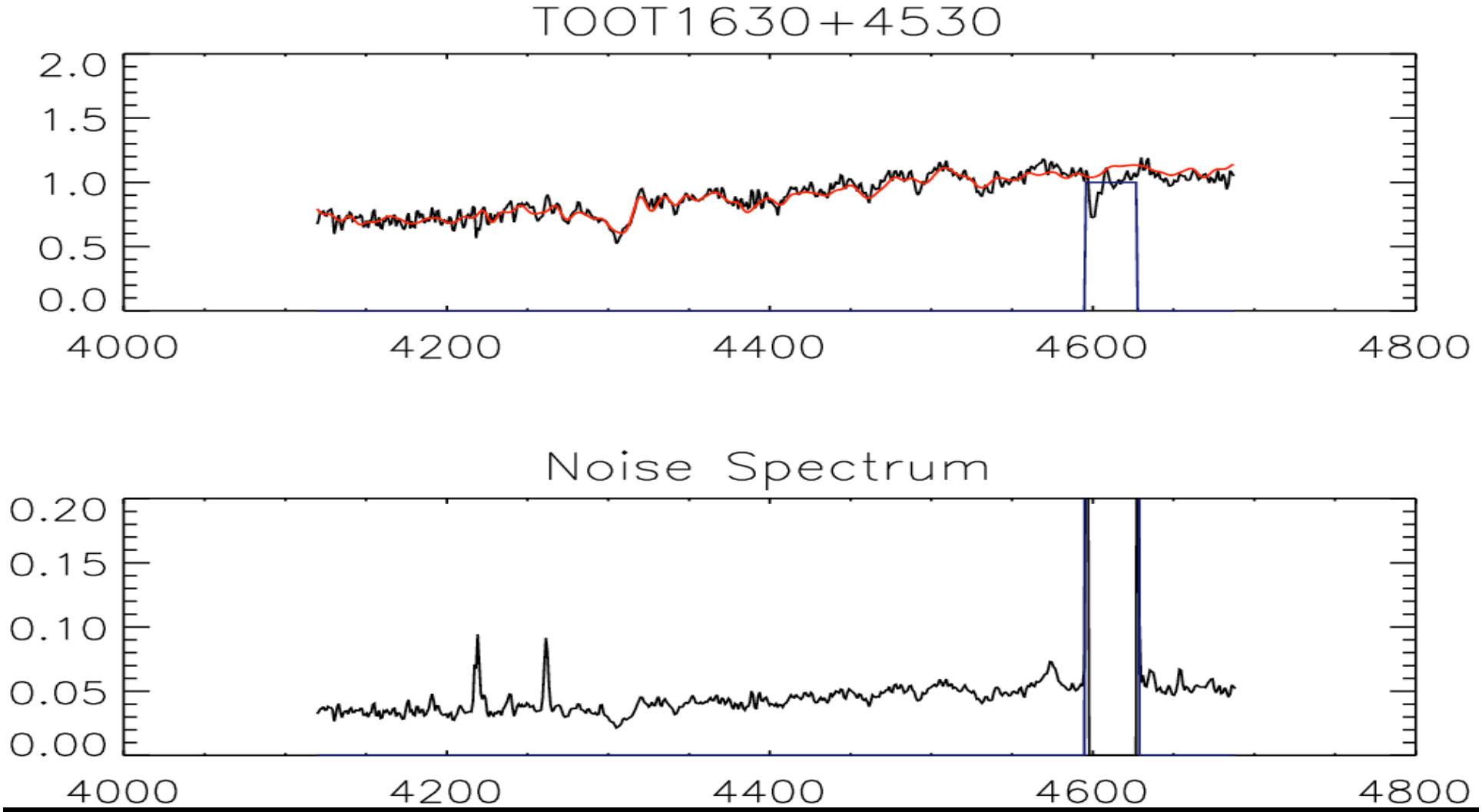
Recent studies: Sub-mm galaxies



Alexander et al. (2008)

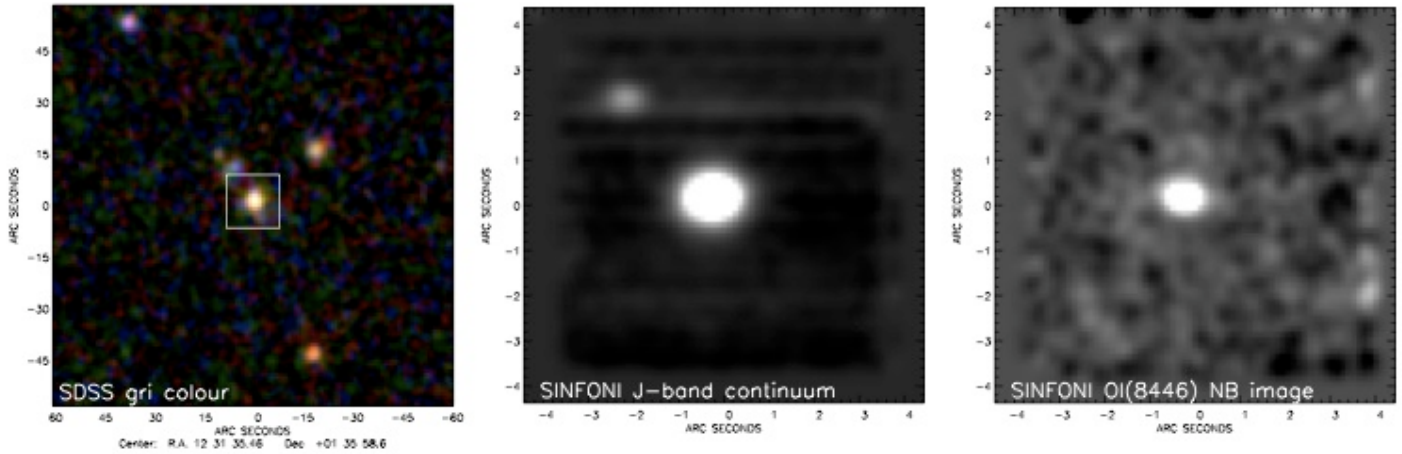
Sub-mm galaxies at z~2 appear to lie factor of 3-5 below local relation

Evolution of the M_{bh}- σ relation: the future

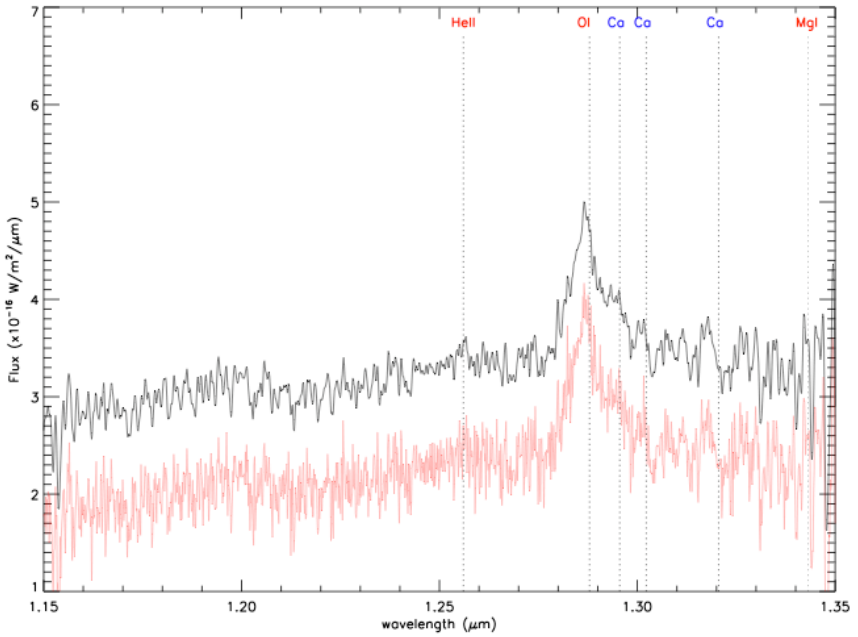


Herbert, Jarvis , Willott, McLure in prep.

Evolution of the M_{bh}- σ relation: the future



Jarvis, McLure & Swinbank in prep.



EUCLID (2017)

- Merger of SPACE and DUNE for the ESA Cosmic Visions Programme
- Satellite able to carry out both imaging and spectroscopy over 20000sq.deg
- (RIZ)+YJH filters for imaging at 0.2arcsec resolution
- near-IR spectroscopy of 1/5 of all sources in 20000 sq.deg to H_{AB}=23
- Deep survey of 10sq.deg with spectroscopy of ~2million galaxies to AB=26

Design study bid to STFC last month. Currently exploring links between the spectroscopic science and with SKA