"Weighing" black holes from 0 to high-z

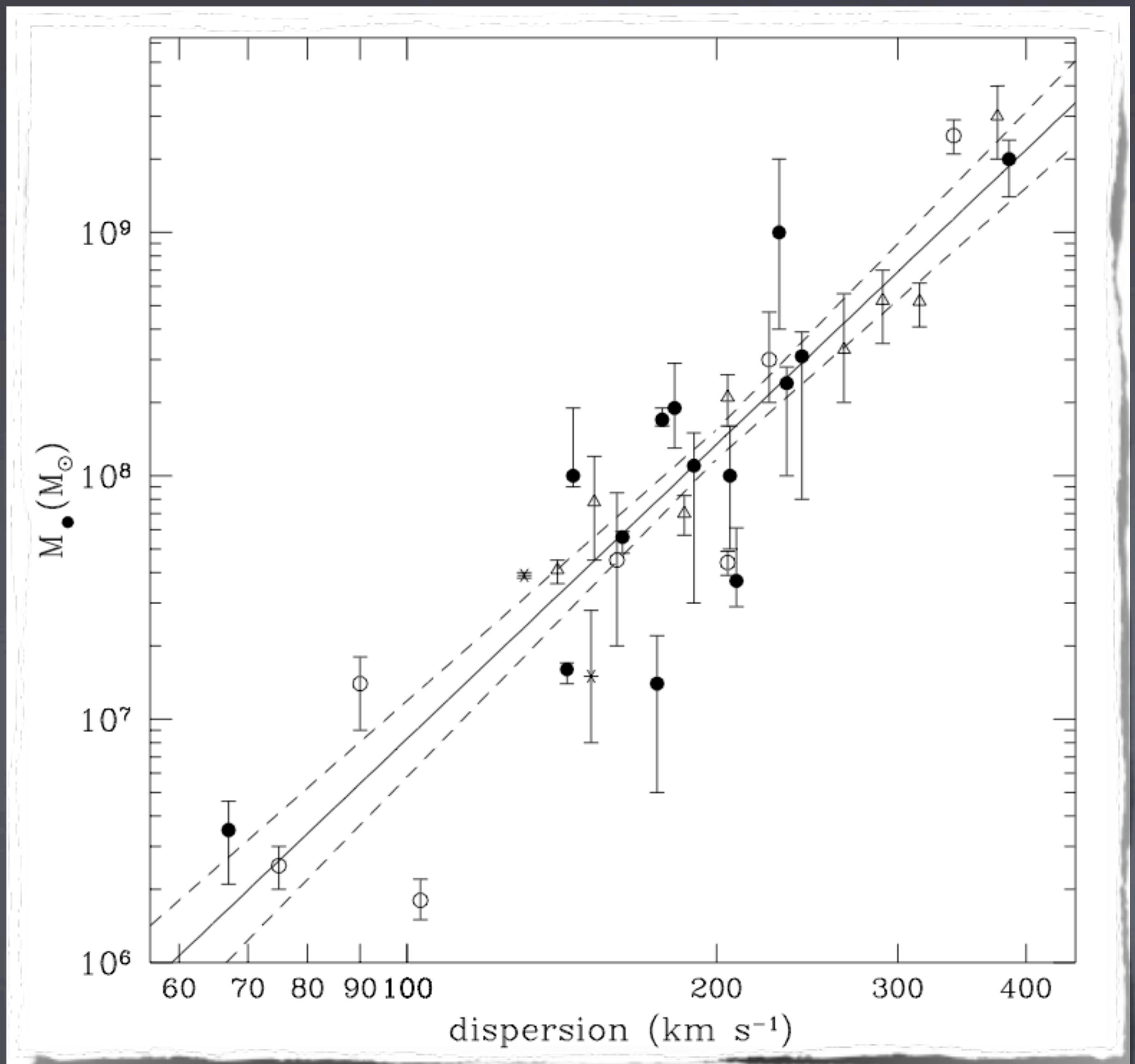
Alessandro Marconi

Dipartimento di Astronomia e Scienza dello Spazio
Università di Firenze

In collaboration with:

David Axon
Roberto Maiolino
Tohru Nagao
Guia Pastorini
Paola Pietrini
Andrew Robinson
Guidetta Torricelli

BH-galaxy scaling relations



Kormendy & Richstone 1995; Magorrian+ 1998; Ferrarese & Merritt 2000, Gebhardt+ 2000; Graham+2001; Tremaine+ 2002; Marconi & Hunt 2003; Haring & Rix 2004; Aller & Richstone 2007; Graham 2008

The discovery of M_{BH}-host spheroid relations (especially M_{BH}-σ) has produced an enormous impact

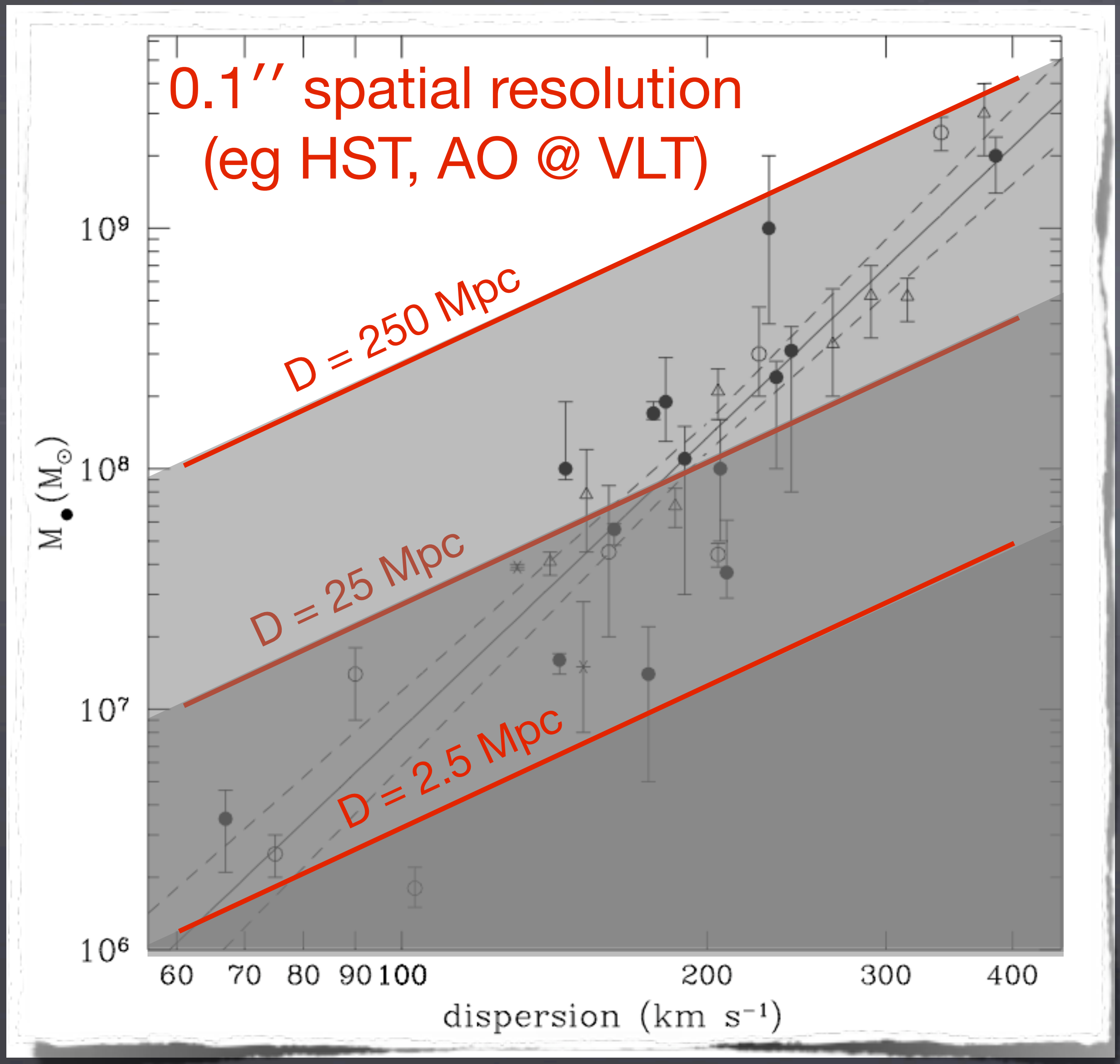
- allowed "census of BHs" (eg ρ_{BH}) → local BHs are AGN "relics";
- indication of a tight link BH - host galaxy → importance of AGN feedback → an AGN (growing BH) is a phase in galaxy life.
- redshift evolution of M_{BH}-galaxy relations can constraint BH growth and galaxy evolutionary models.

Fundamental to measure M_{BH} at ALL redshifts!

Direct BH mass measurements

BH sphere of influence $$r_{BH} = \frac{G\,M_{BH}}{\sigma_\star^2} = 10.7\,\mathrm{pc}\left(\frac{M_{BH}}{10^8\,M_\odot}\right)\left(\frac{\sigma_\star}{200\,\mathrm{km/s}}\right)^{-2}$$

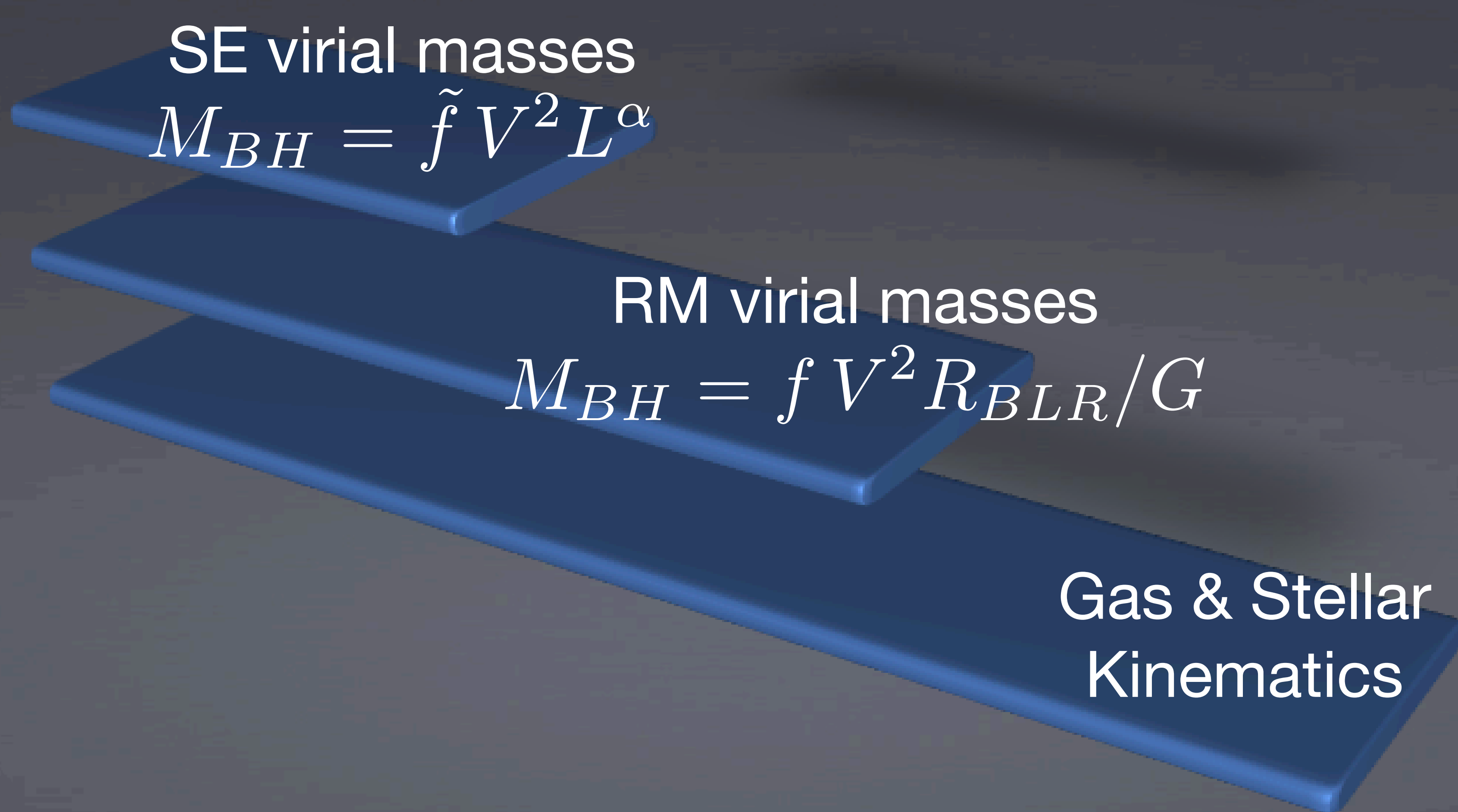
$$\theta_{BH} = 0.11''\left(\frac{M_{BH}}{10^8\,M_\odot}\right)\left(\frac{\sigma_\star}{200\,\mathrm{km/s}}\right)^{-2}\left(\frac{D}{20\,\mathrm{Mpc}}\right)^{-1}$$



BHs are directly detectable with spatially resolved kinematics ONLY in the local universe

Need to calibrate indirect BH mass estimators like for the cosmological distance ladder

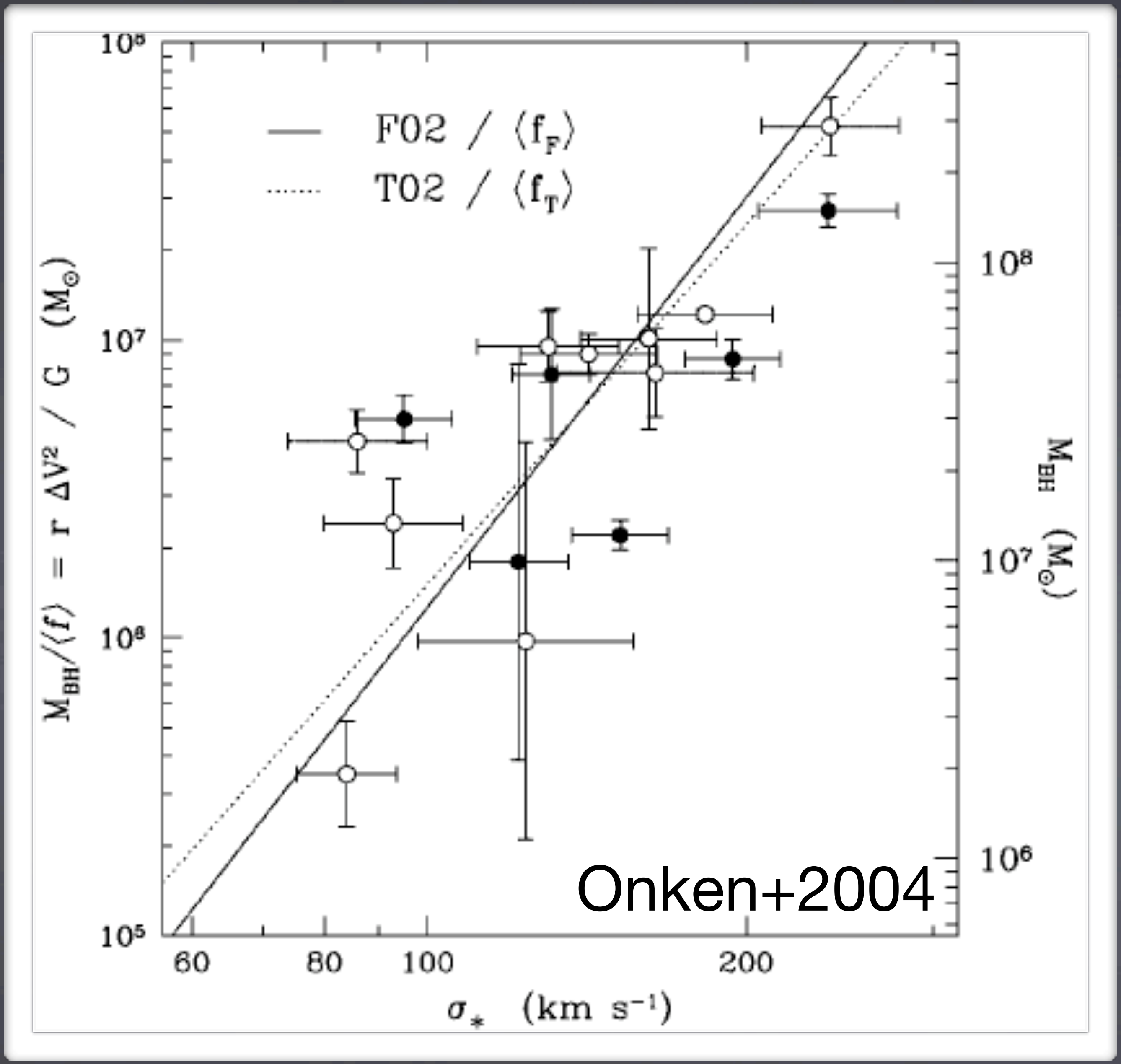
The BH mass ladder (Peterson 2002)



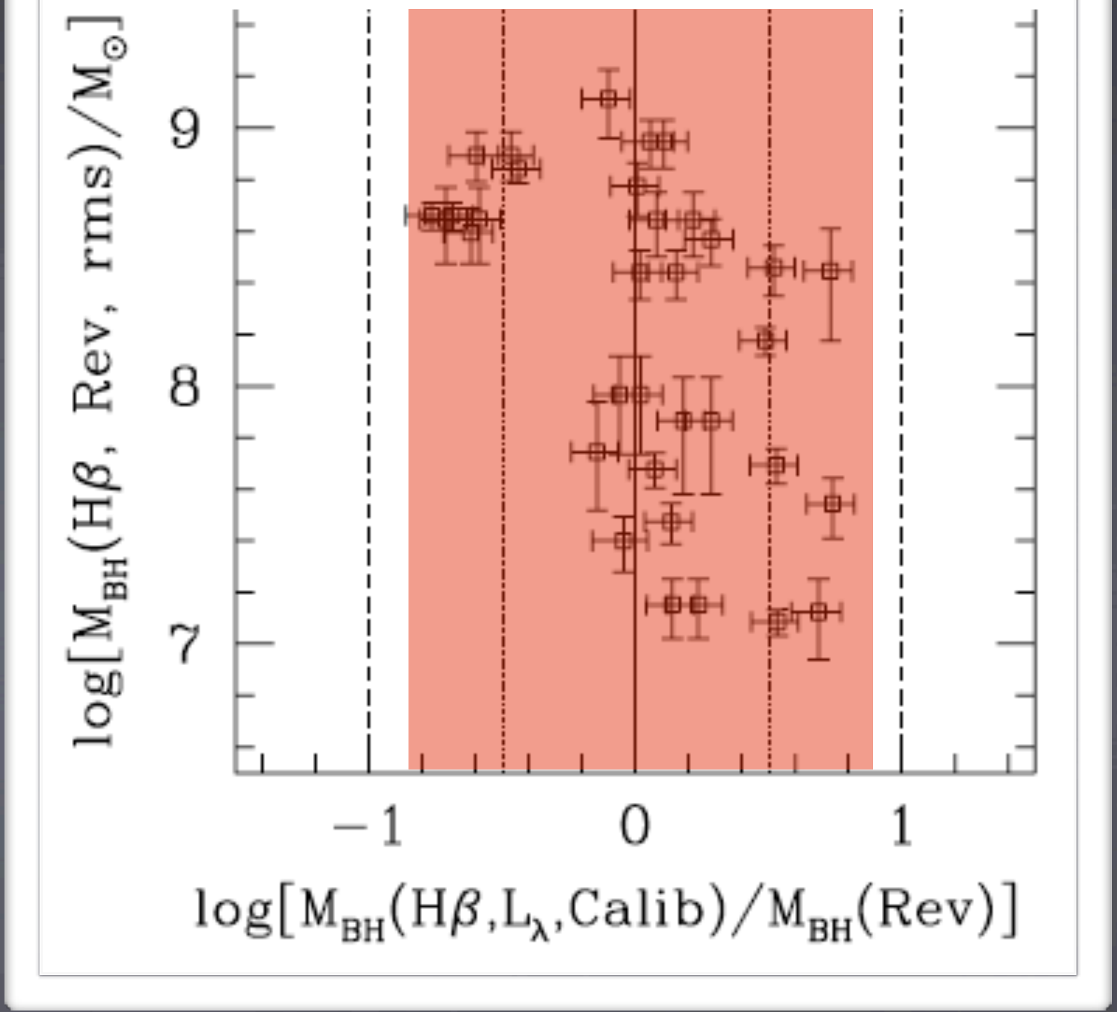
1. Spatially resolved gas & stellar kinematics
2. Virial masses based on Reverberation Mapping (RM) observations (R_{BLR} = c T, T time lag of BLR emission lines, eg. Onken +04)
3. Virial masses based on Single Epoch (SE) spectra (R from continuum luminosity using R_{BLR}-L relation by Kaspi +00, +05, eg Vestergaard & Peterson 06)

Virial M_{BH}: calibration → f

$$M_{BH} = f \frac{V^2 R}{G}$$



Large scatter (~0.4 dex) of M_{BH}(SE)/M_{BH}(RM)



Vestergaard & Peterson 06

Onken +04: calibrate M_{BH} for RM AGNs assuming they lie on M_{BH}-σ

Vestergaard & Peterson 06: M_{BH} for SE AGNs calibrating from RM data

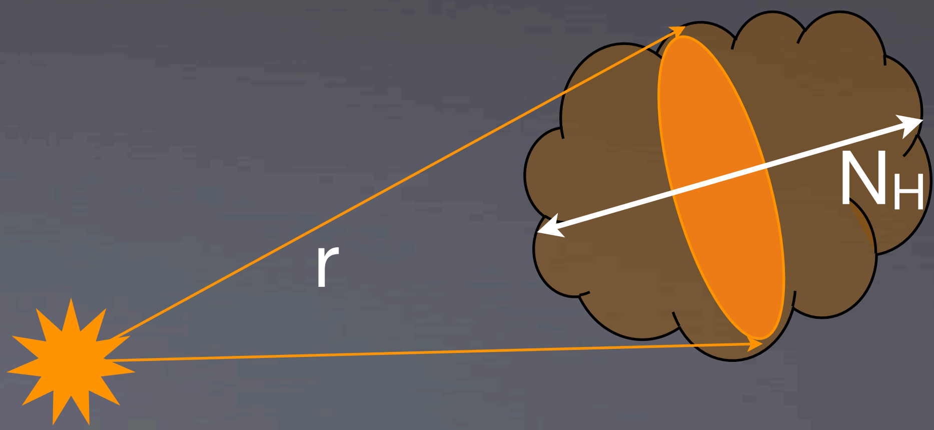
The effect of radiation pressure

Scattering of radiation from free electrons → Eddington limit.

BLR clouds are photoionized → radiation force due to the absorption of ionizing photons much larger than from Thomson scattering.

Consider:

- optically thick BLR clouds;
- Thomson scattering for non-ionizing photons (optically thin);



Then corrected virial mass is:

$$M_{BH} = f\frac{V^2 r}{G} + \frac{L}{L_{\mathrm{Edd}\odot}}\left[1 - a + \frac{a}{\sigma_{\mathrm{T}} N_{\mathrm{H}}}\right] \mathrm{M}_\odot \qquad a = \frac{L_{ion}}{L}$$

Close to L_{Edd}, M_{BH} can increase by factor ~10.
But what is the correction for radiation pressure (eg N_H)?

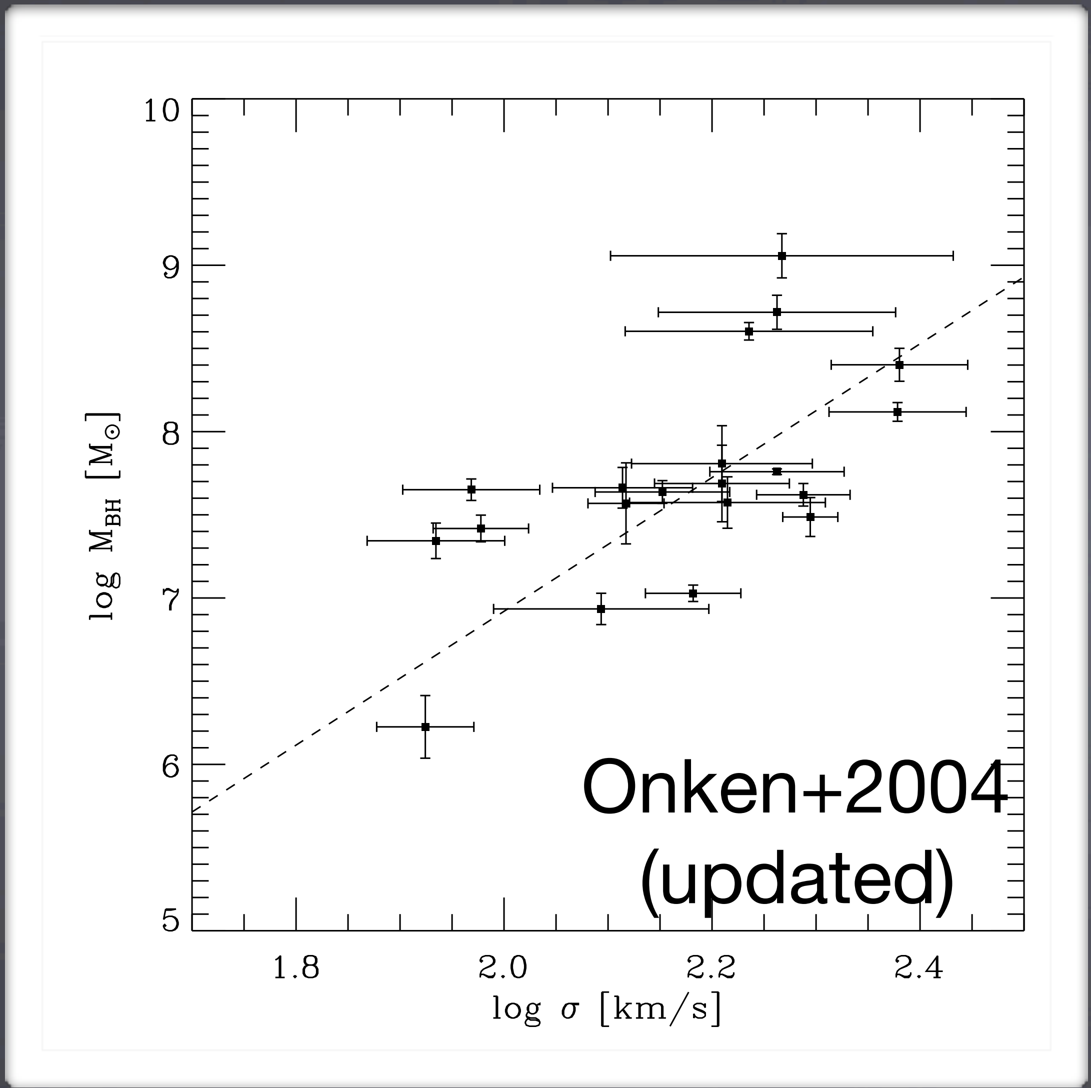
Calibrate virial BH masses using:

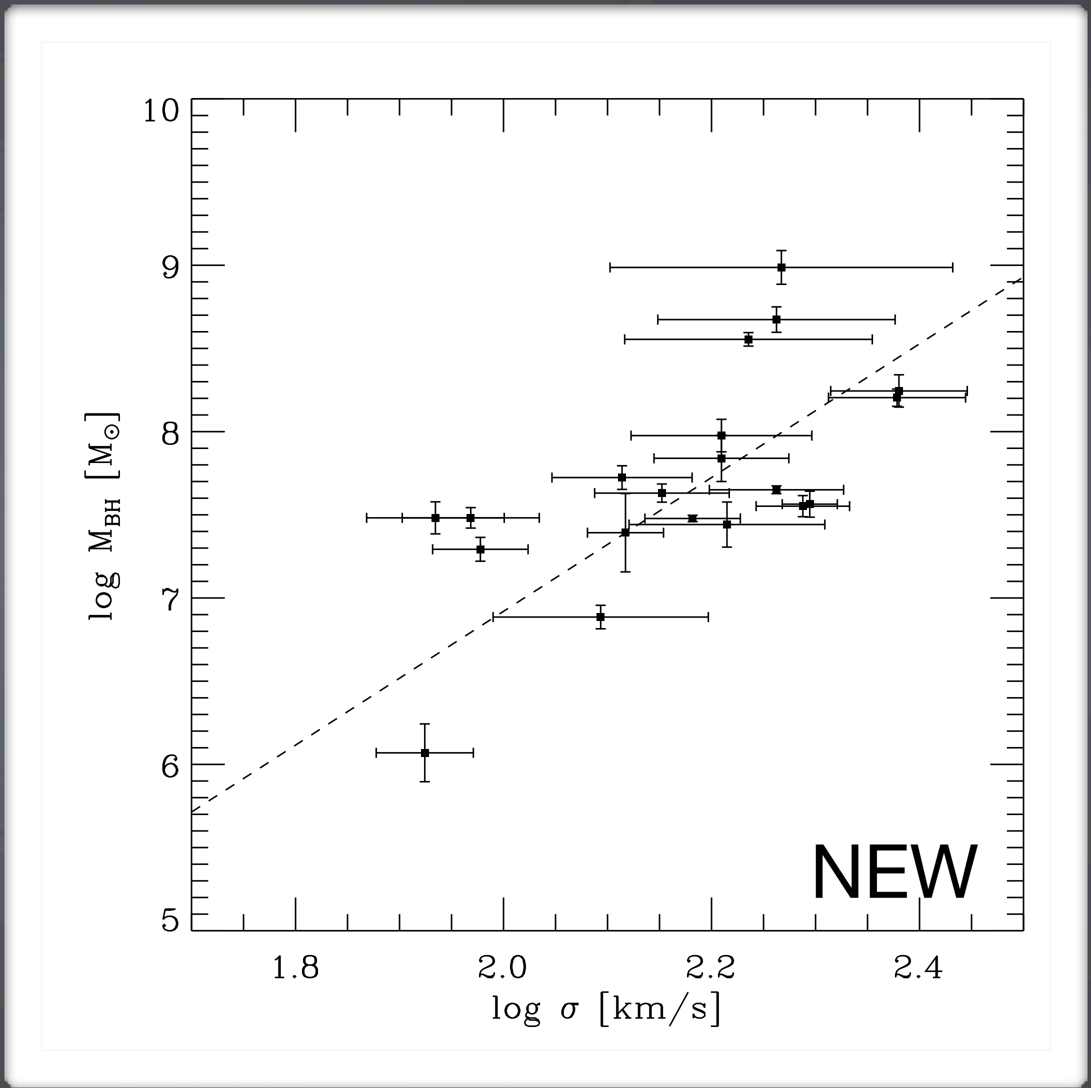
$$M_{BH} = f\frac{V^2 r}{G} + g\left(\frac{\lambda L_\lambda(5100)}{10^{44}\,\mathrm{erg\,s^{-1}}}\right)$$

NEW Calibration of virial M_{BH}: RM

$$M_{BH} = f\frac{V^2 r}{G}$$

$$M_{BH} = f\frac{V^2 r}{G} + g\left(\frac{\lambda L_\lambda(5100)}{10^{44}\,\mathrm{erg\,s^{-1}}}\right)$$





$$f = 4.8 \pm 1.3$$

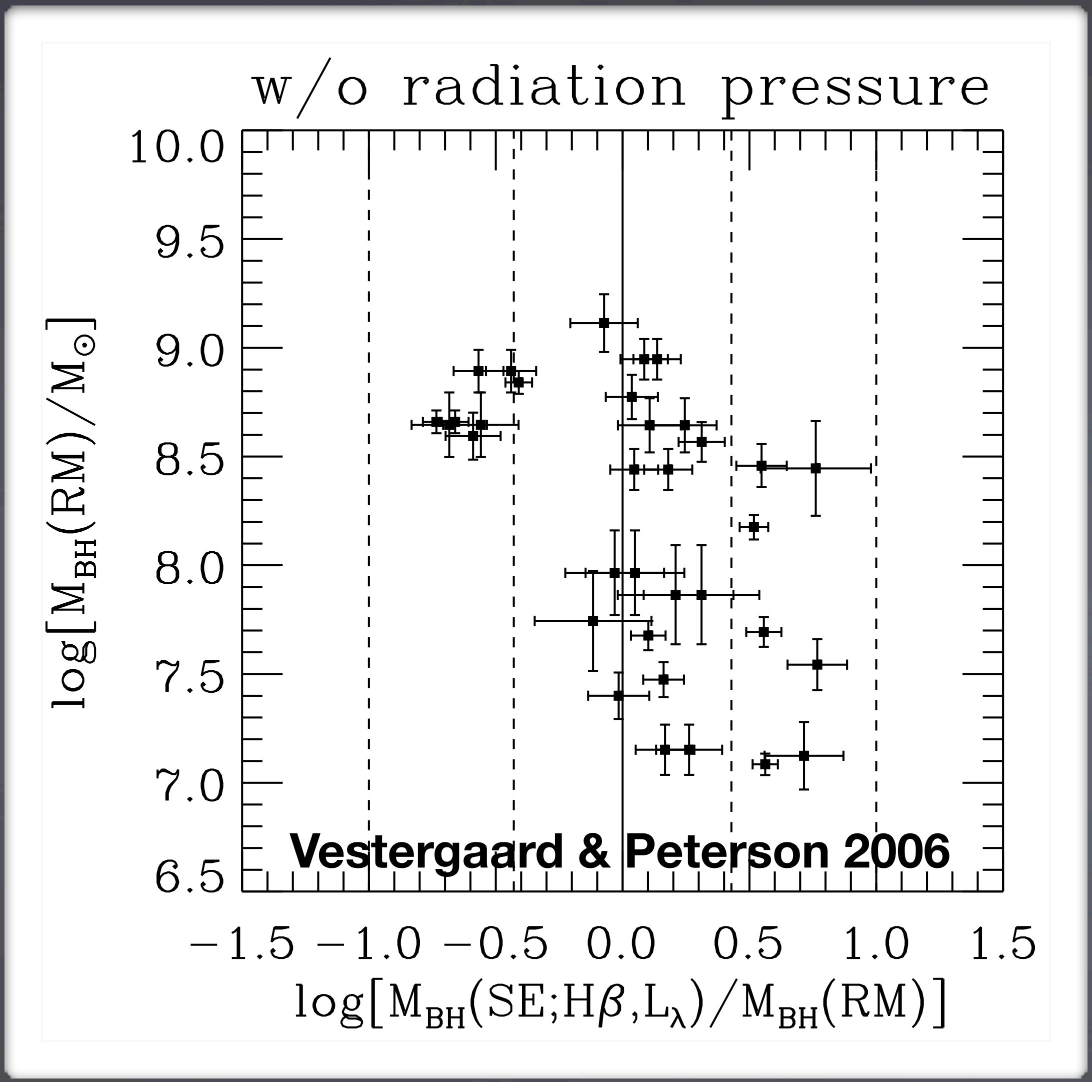
$$f = 3.7 \pm 1.0 \ (L/L_{Edd} < 0.05)$$

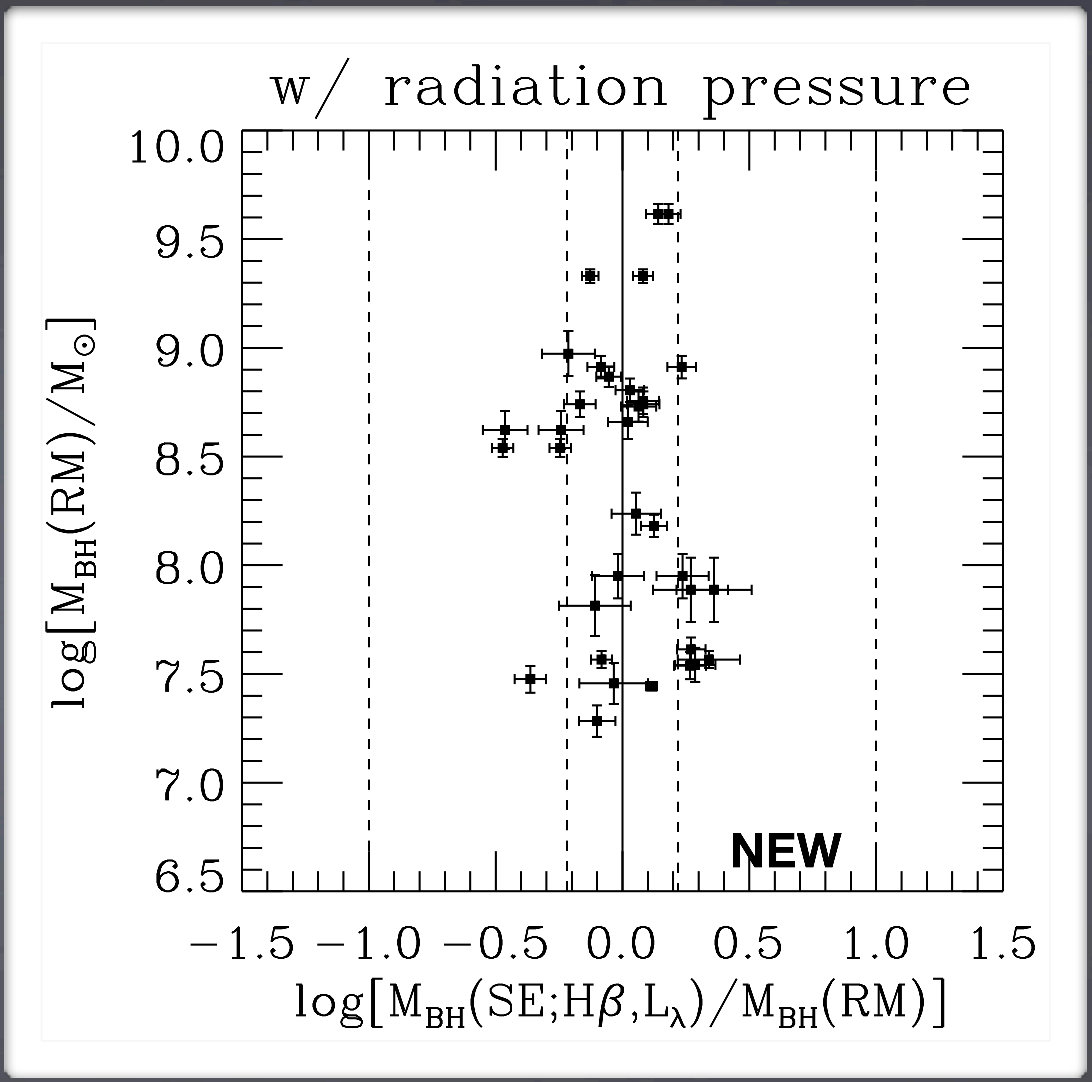
$$f = 3.1 \pm 1.4$$

$$\log g = 7.6 \pm 0.3$$

NEW Calibration of virial M_{BH}: SE

$$M_{BH} = f\, V_{1000}^2\, L_{44}(5100)^{0.5} \qquad = f\, V_{1000}^2\, L_{44}(5100)^{0.5} + g\, L_{44}(5100)$$





r.m.s 0.4 dex

r.m.s 0.2 dex

$$N_{\rm H} \simeq 10^{23}\ {\rm cm}^{-2}$$

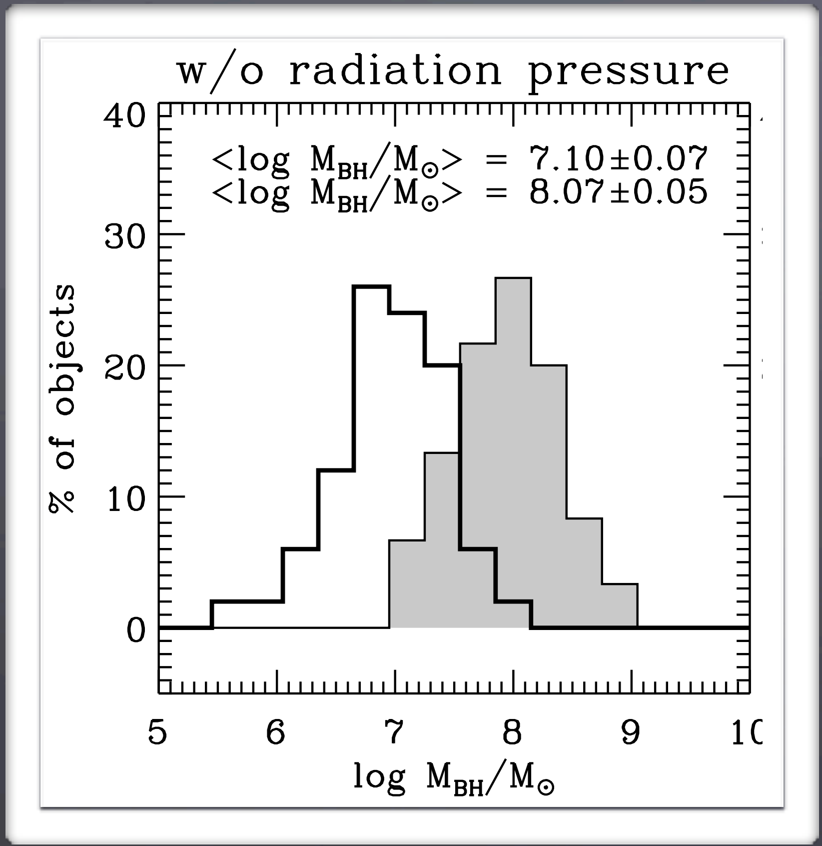
$$\log f = 6.93 \pm 0.1$$

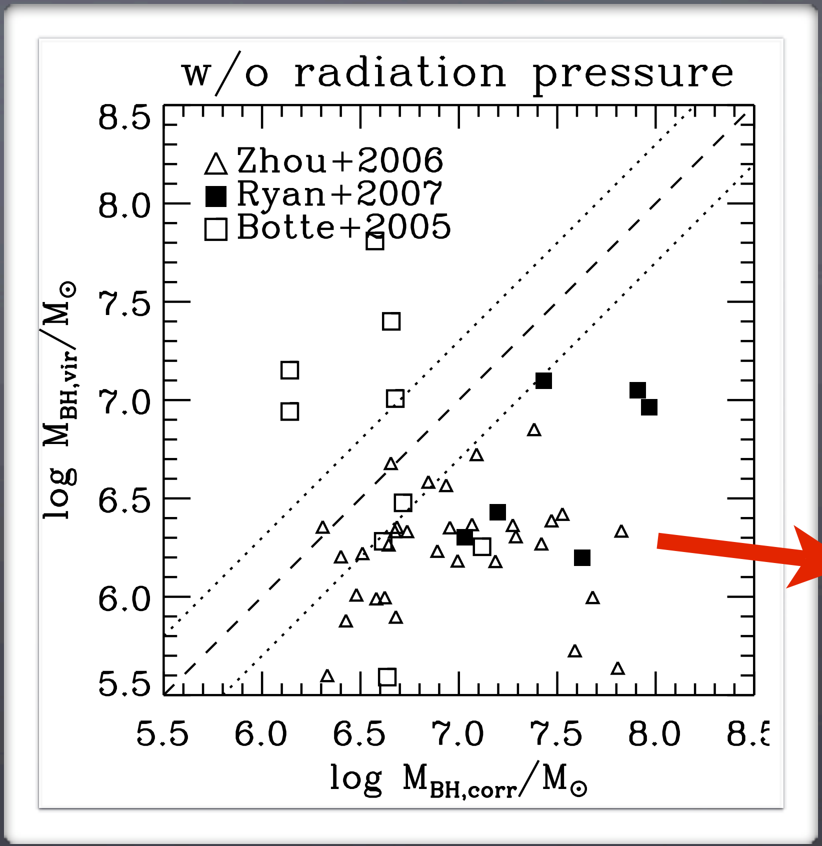
$$\log f = 6.13 \pm 0.2$$
$$\log g = 7.70 \pm 0.05$$

Narrow Line Seyfert 1 Galaxies

Seyfert 1 galaxies with "narrow" broad lines (FWHM<2000 km/s)
They are believed to have:
- high L/L_{Edd};
- small black holes compared to other "normal" AGNs [Grupe 2004];
- small black holes compared to expectations of M_{BH}-σ [Mathur+2001,Grupe & Mathur 2004, Zhou+2006, Ryan+2007, see however Komossa & Xu 2007, Decarli +07].

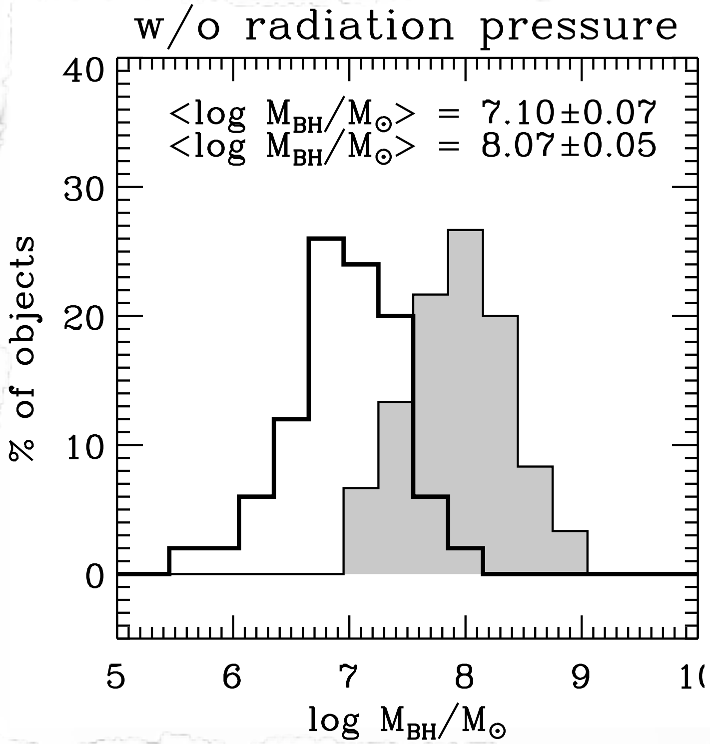
Hence, these galaxies are now rapidly building their BHs.
However ... high L/L_{Edd} suggest that radiation pressure is important!

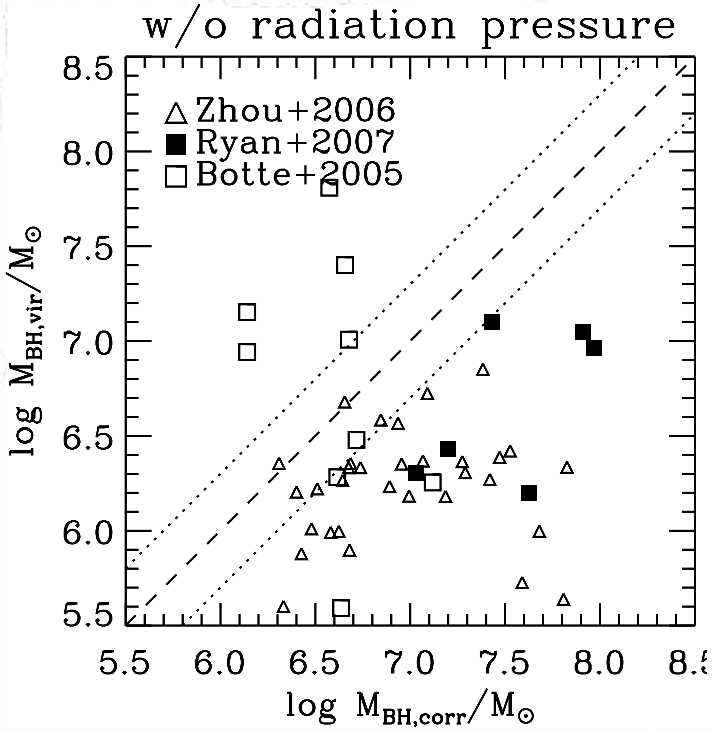


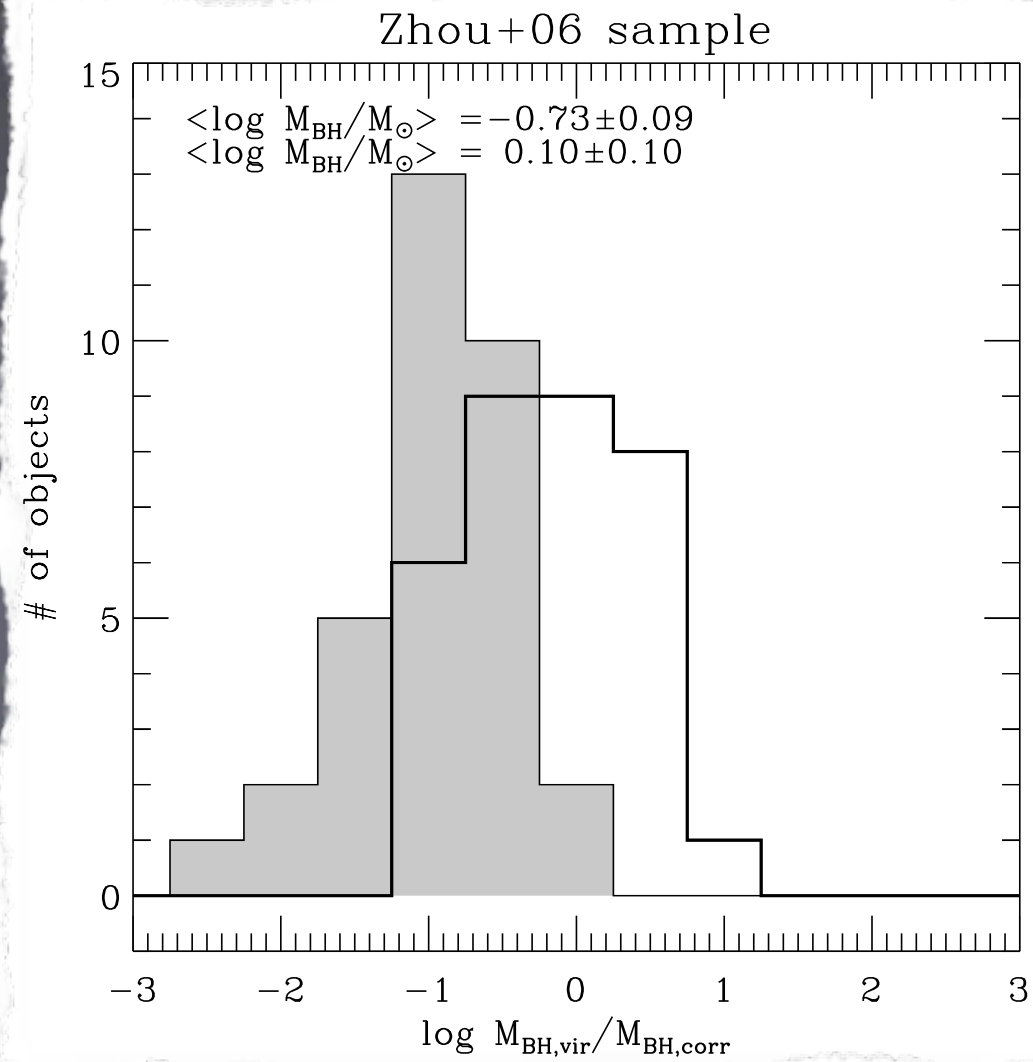


Bulge luminosity or "real" σ, no [OIII], [SII] surrogates!

Narrow Line Seyfert 1 Galaxies





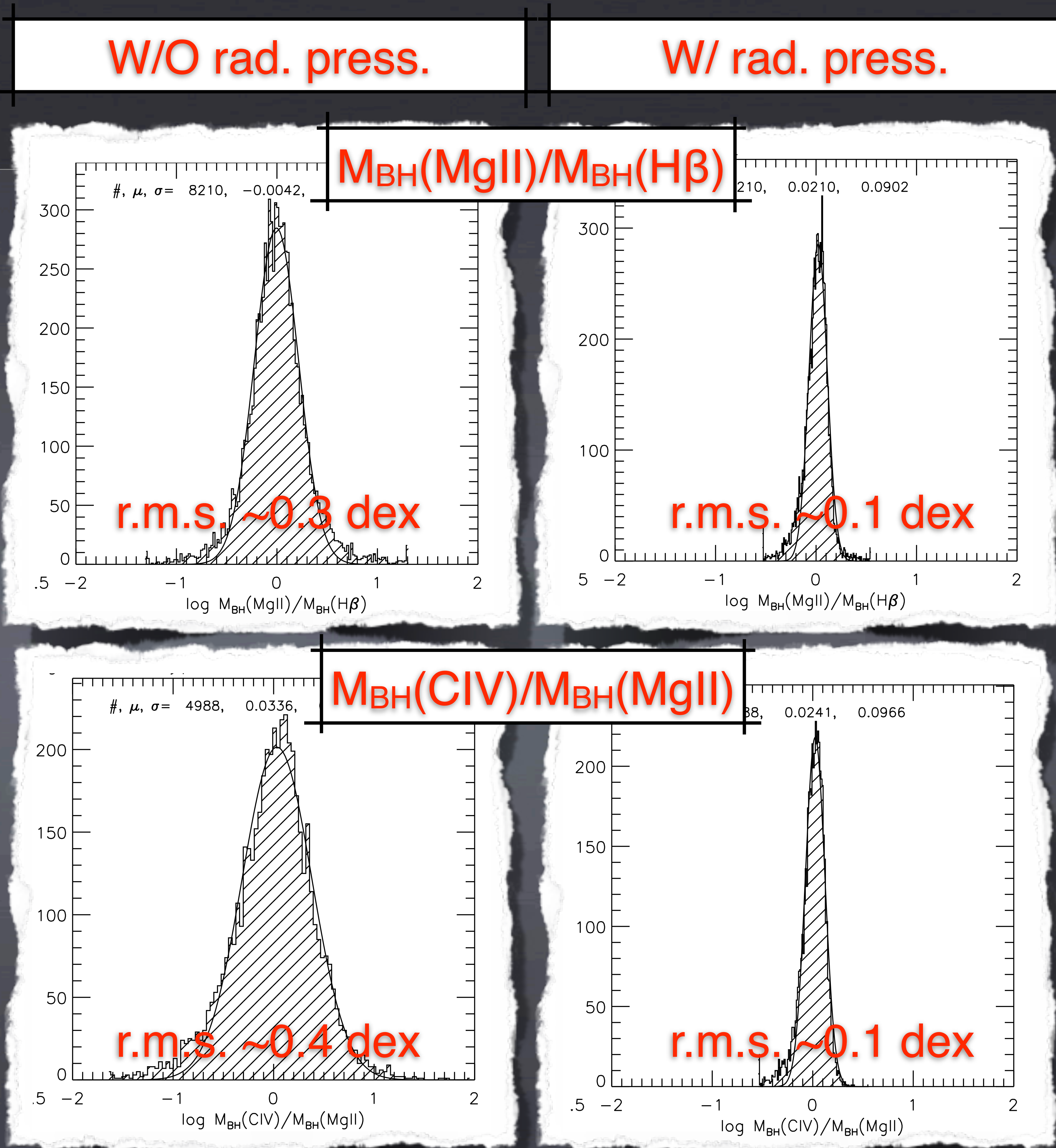


MgII and CIV

Broad UV lines to estimate BH masses at high z: MgII λ2800 Å, CIV λ1550 Å (eg. McLure & Jarvis 2002, McLure & Dunlop 2004, Netzer+2007, Vestergaard & Peterson 2006).

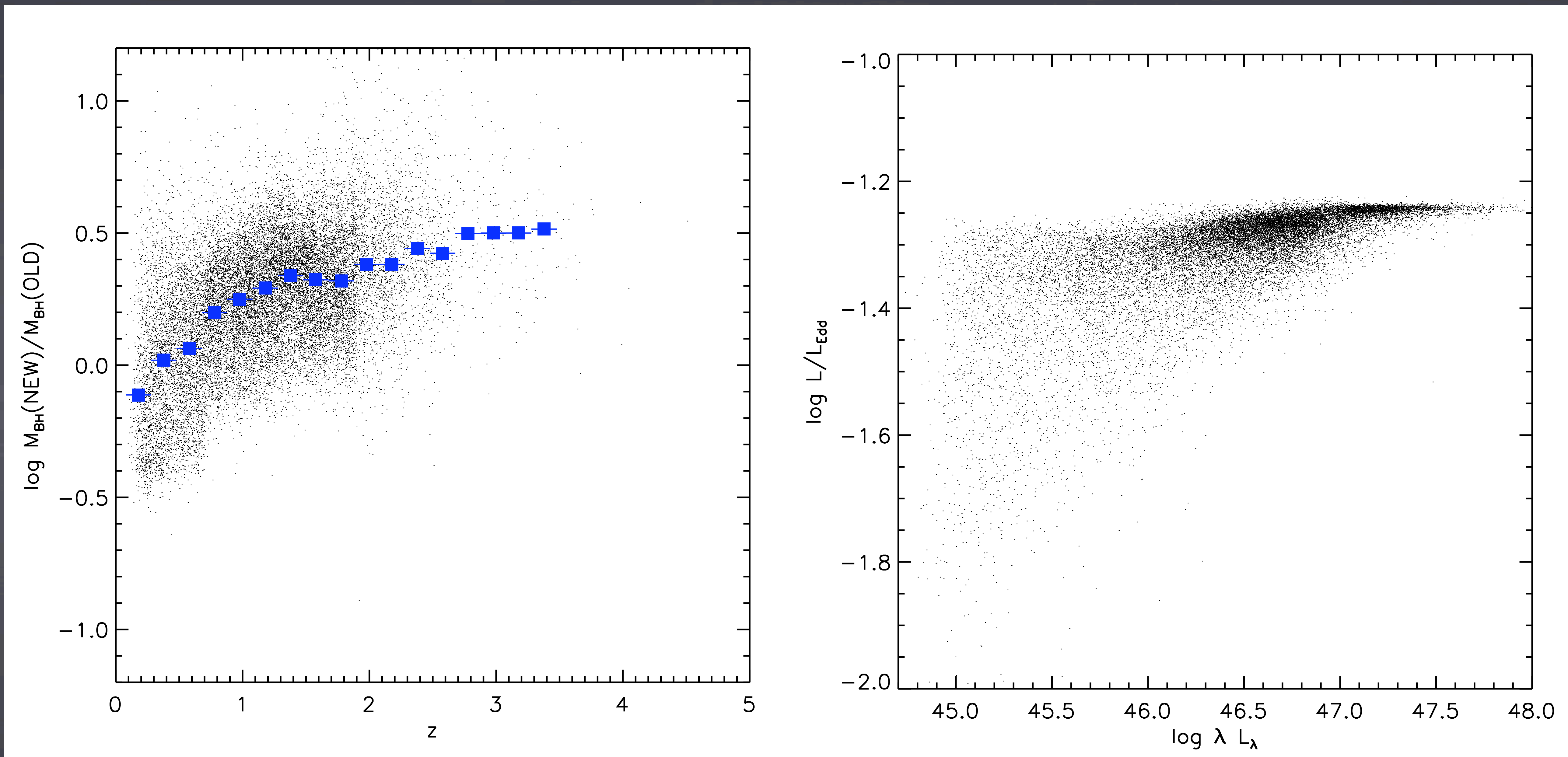
CIV is believed to be a bad M_{BH} estimator (winds, outflows ...)

Calibrate using samples of QSOs from SDSS with both Hβ and MgII λ2800 Å or MgII and CIV λ1550 Å in their spectra (from Shen +08).



Two important points ...

SDSS quasars from Shen +08:



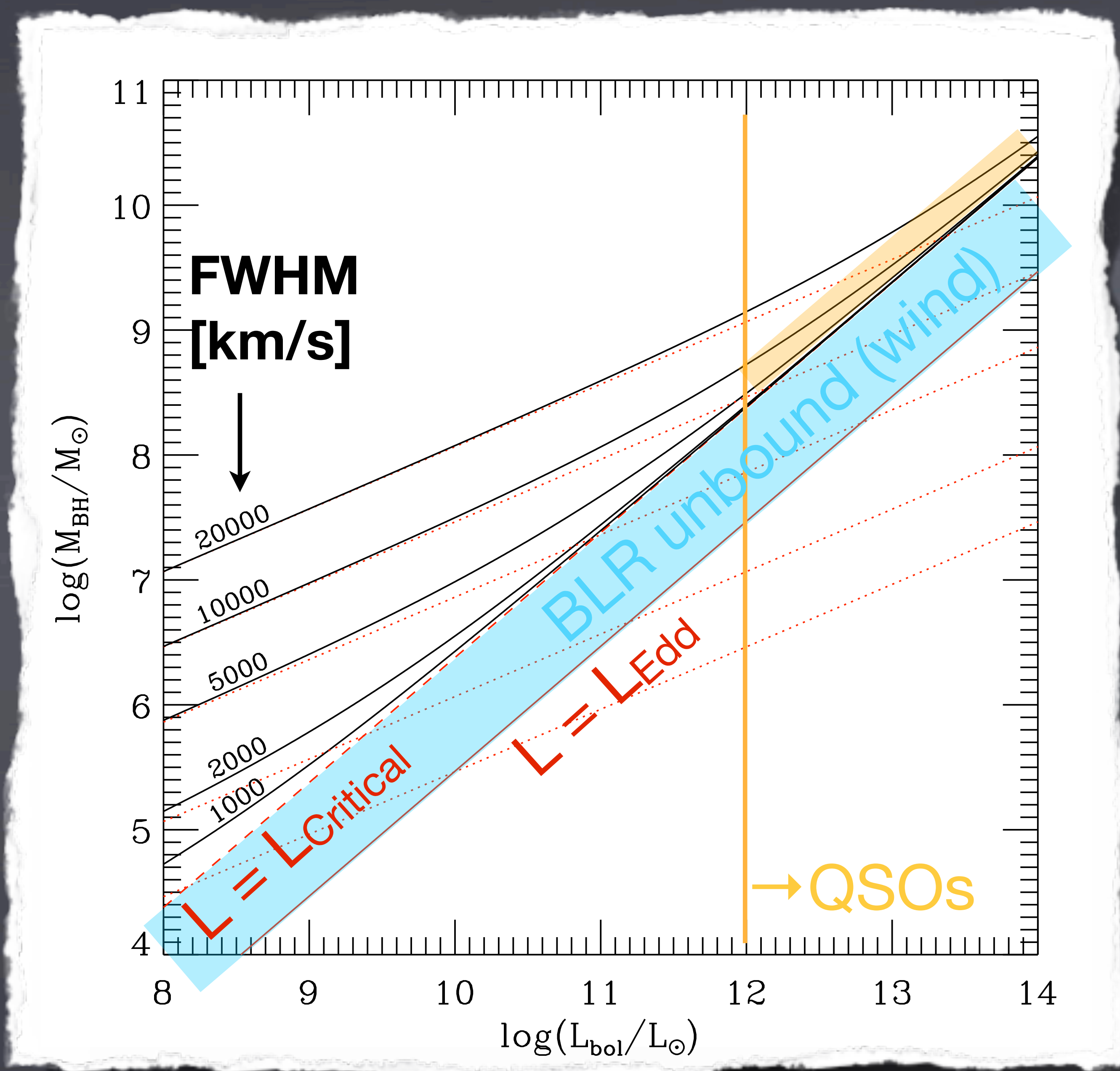
On average, M_{BH} is at most a factor ~3 larger

L/L_{Edd} saturates at high luminosities (M_{BH}~gL)

Why is the scatter reduced?

Virial theorem provides: $$f\frac{V^2 r}{G} = M_{\rm BH} - \frac{L}{L_{\rm Edd,\odot}}\left[1 - a + \frac{a}{\sigma_{\rm T} N_{\rm H}}\right] {\rm M_\odot}$$

$$= M_{\rm BH} - 2.9\times10^8\,{\rm M_\odot}\left(\frac{L}{10^{12}\,{\rm L_\odot}}\right)$$



$L/L_{\rm Edd}$ saturates at $L_{\rm crit}/L_{\rm Edd}$

Effective BH mass seen by BLR is much smaller than real one in high L sources; $M_{\rm BH}$ ~ L, scatter is due to scatter in luminosity ratio!

PROBLEM:

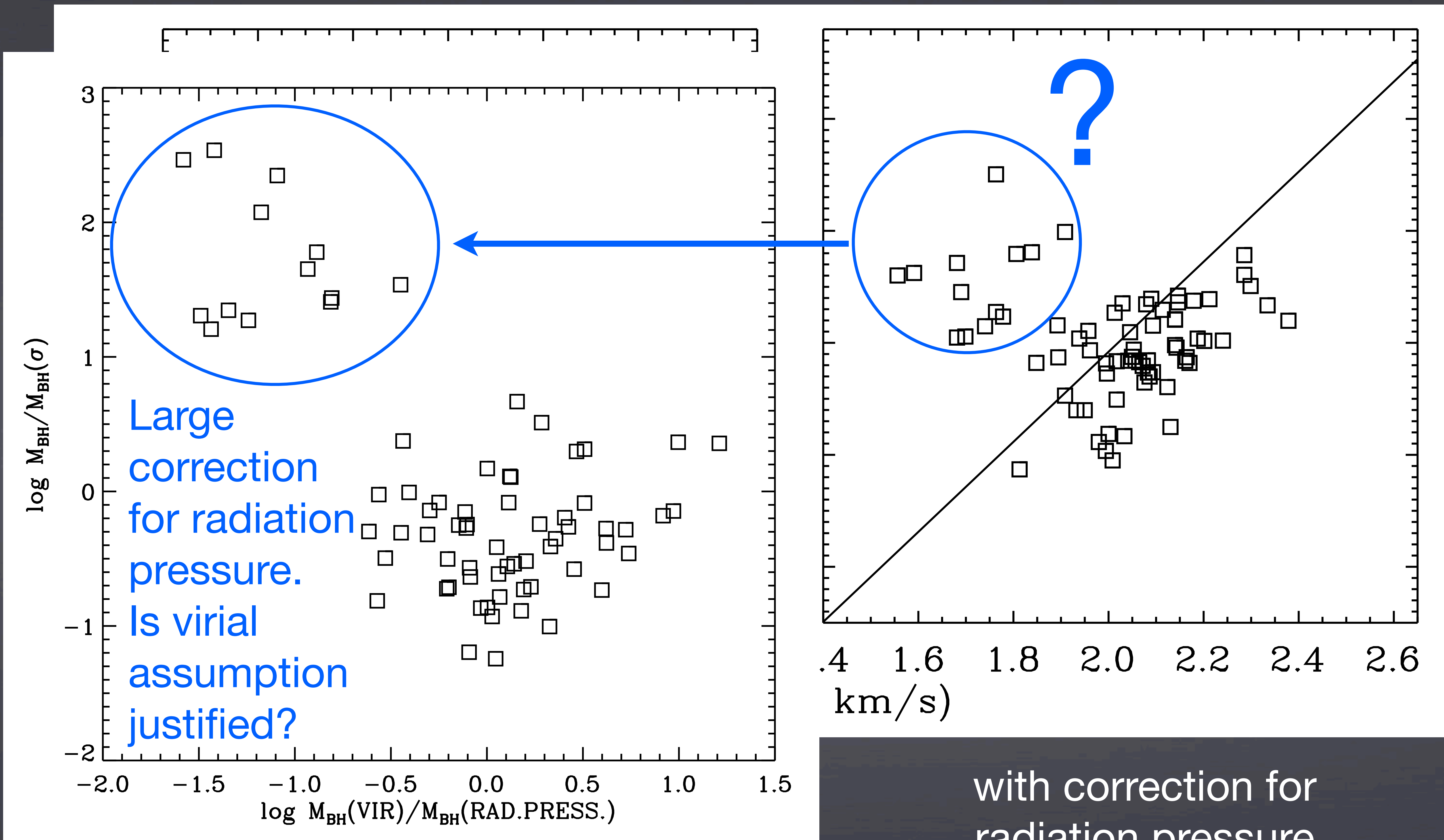
in high L objects radiation pressure shields > 90% of $M_{\rm BH}$ gravitational field, is virial assumption still viable?

UNLESS:

Anisotropy of continuum emission

Or very large column densities of BLR clouds at high L (N_H ~10^{25} cm^{-2})

M_{BH}-σ relation of local AGN



with correction for radiation pressure

Conclusions

Marconi +08 (ApJ and in prep)

- Virial BH masses can be severely underestimated if the radiation pressure by ionizing photons is neglected.
- A "tentative" calibration suggests optically thick BLR clouds with average $N_H \sim 10^{23}$ cm^{-2} consistent with independent estimates.
- A better database is needed.
- RM BH masses have ~0.5 dex average error.
- Discrepancy between RM BH masses and SE BH masses is much lower than previously thought (0.2 dex vs 0.4 dex rms).
- Radiation pressure can explain the low BH masses in NL Seyfert 1 galaxies.
- Little changes in M_{BH} except for objects close to "classical" Eddington limit.
- Is L/L_{Edd} meaningful in high luminosity objects?
- At high L, BLR appear to see only a tiny fraction of gravitational field, is radiation pressure effect overestimated (i.e. N_H larger at high L) or BLR unbound (a wind)?