BH MASS ESTIMATION

for Quasars

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Estimating BH Mass

Broad Emission Lines as virial estimators

FWHM Hbeta $\rightarrow$ virial v

Single epoch FWHM measures? rms? Composites? Or sigma?

$$M_{\mathrm{BH}} = \frac{v^2 r_{\mathrm{BLR}}}{G}$$

$$v = f\mathrm{FWHM}$$

$$v = \sqrt{3}/2\ \mathrm{FWHM}(\mathrm{H}\beta_{\mathrm{BC}})$$

The f factor?

- BLR geometry and kinematics
- Strong inclination dependence
- Of order ~~1-2 (or 5.5 Onken et al. 2009 using sigma)
- Same for Pop. A and B?

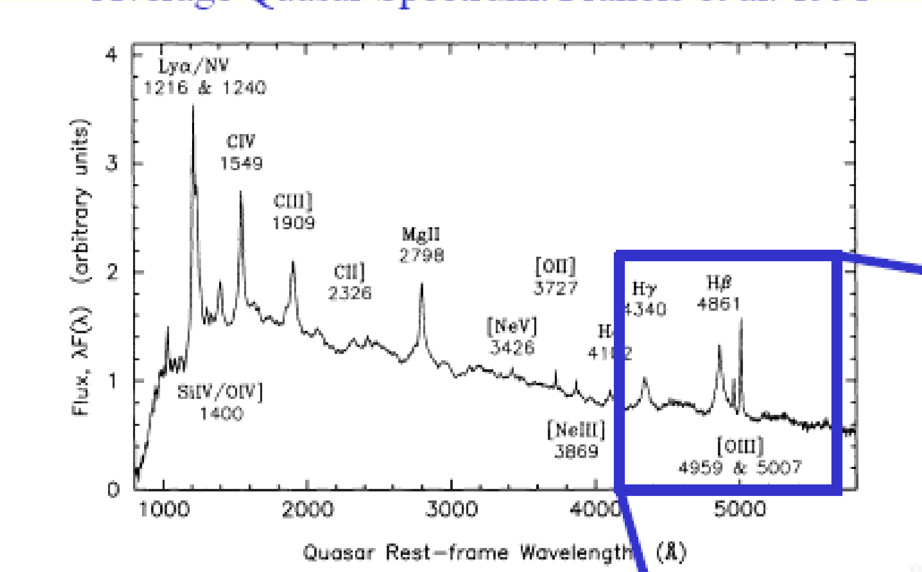
Not all FWHM Hbeta are the same

Sources above and below FWHM Hbeta=4000km/s show different structure (Sulentic et al. 2002)

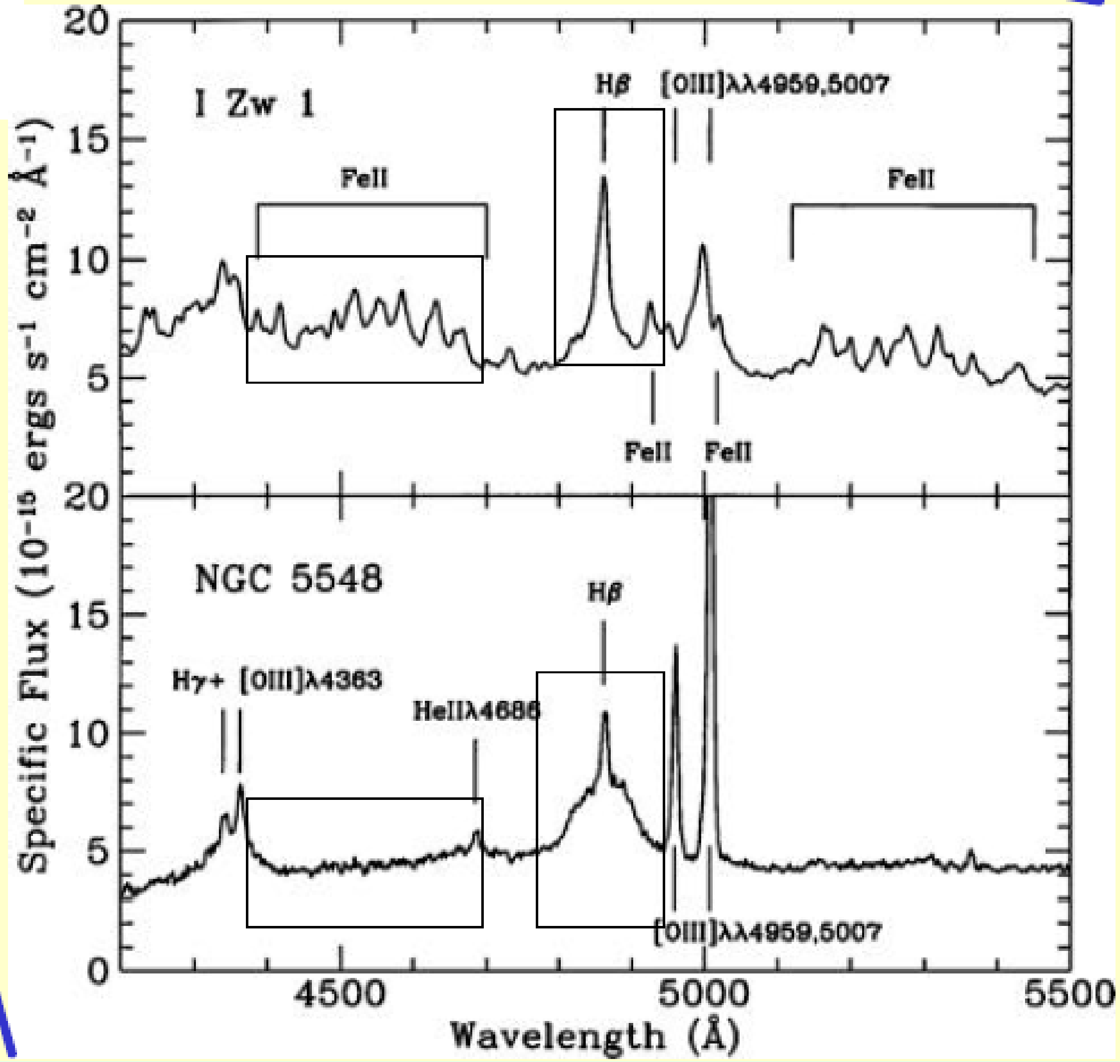
Relationship between FWHM and sigma changes -- reflecting multiple components

(Collin et al. 2006: f(A) ≈ 2.12 f(B) ≈ 0.5-1.0)

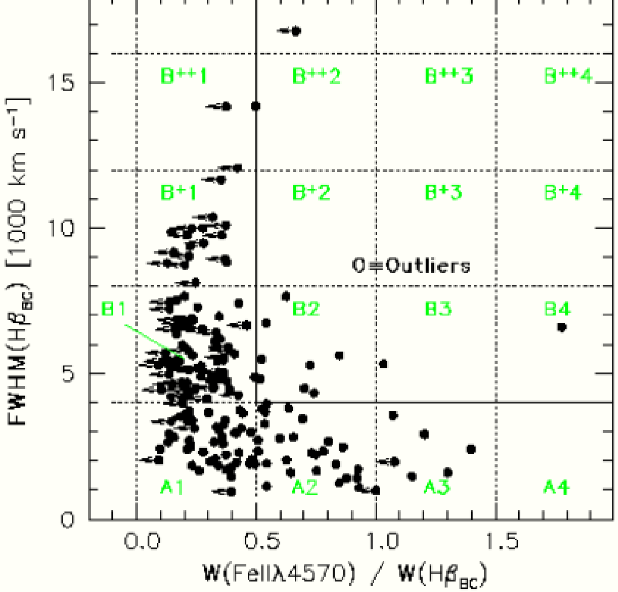
Average Quasar Spectrum: Francis et al. 1991



"Eigenvectors of Quasars"



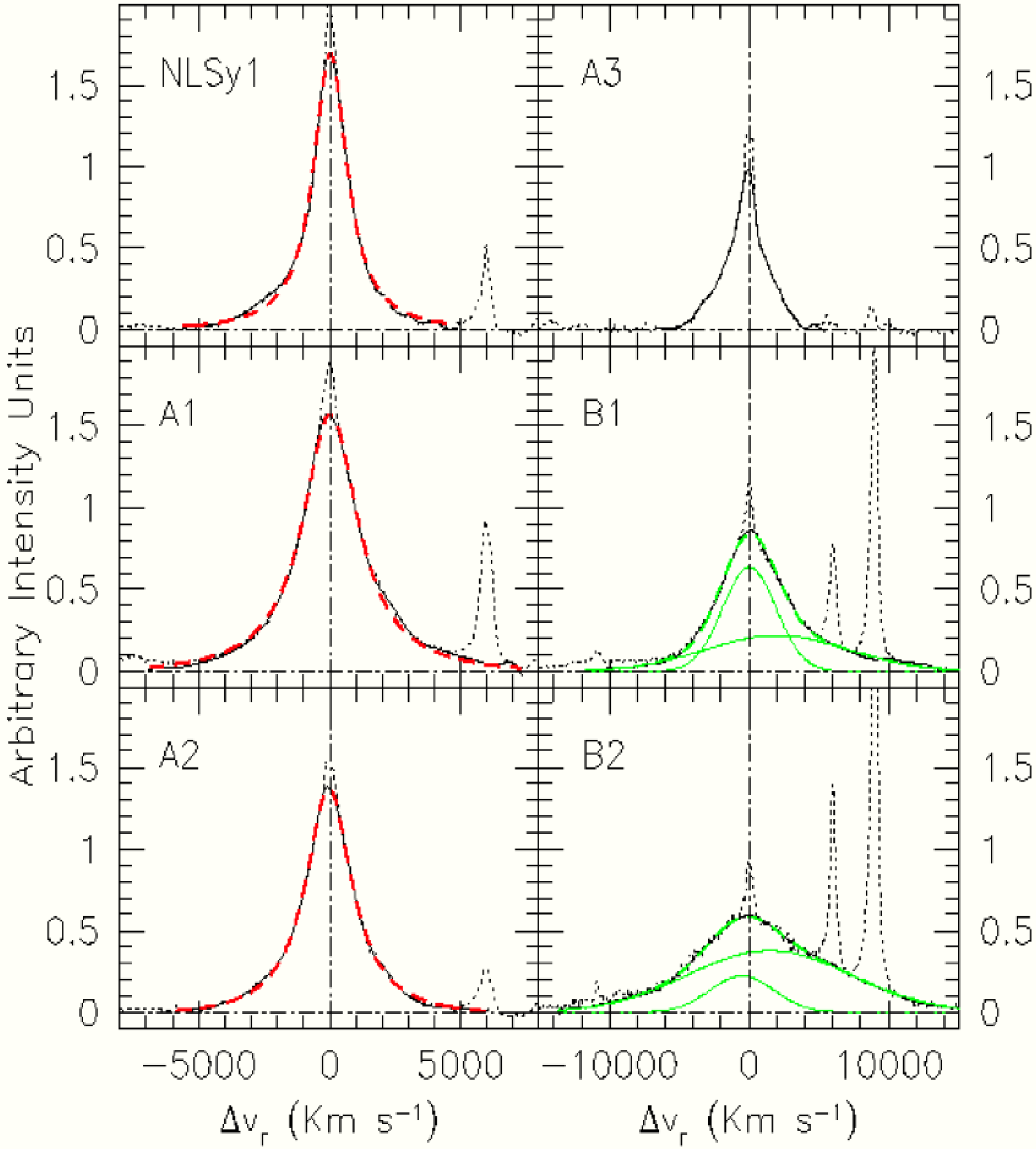
- **Quasar spectra are not similar!**
  - historic inability to explain line ratios via simple photoionization models



Sulentic et al. 2002:

LIL/BLR Structural Difference between Population A and B

(Sample of about 200 Seyfert 1 and low-redshift quasars High S/N and resolution 4 Å FWHM)



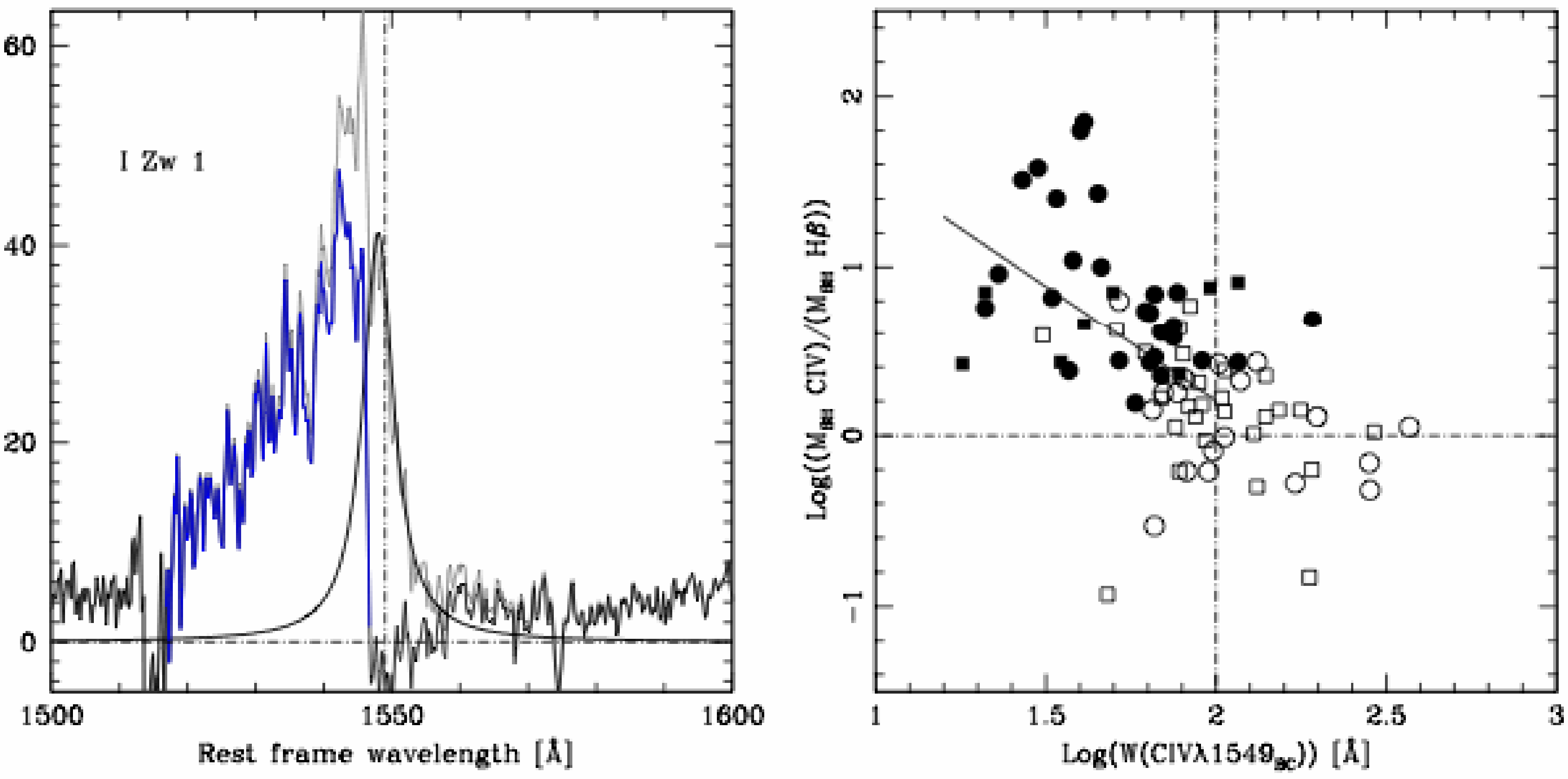
Extreme M_BH

- Pop. A extremely narrow profiles lead to underestimates of MBH

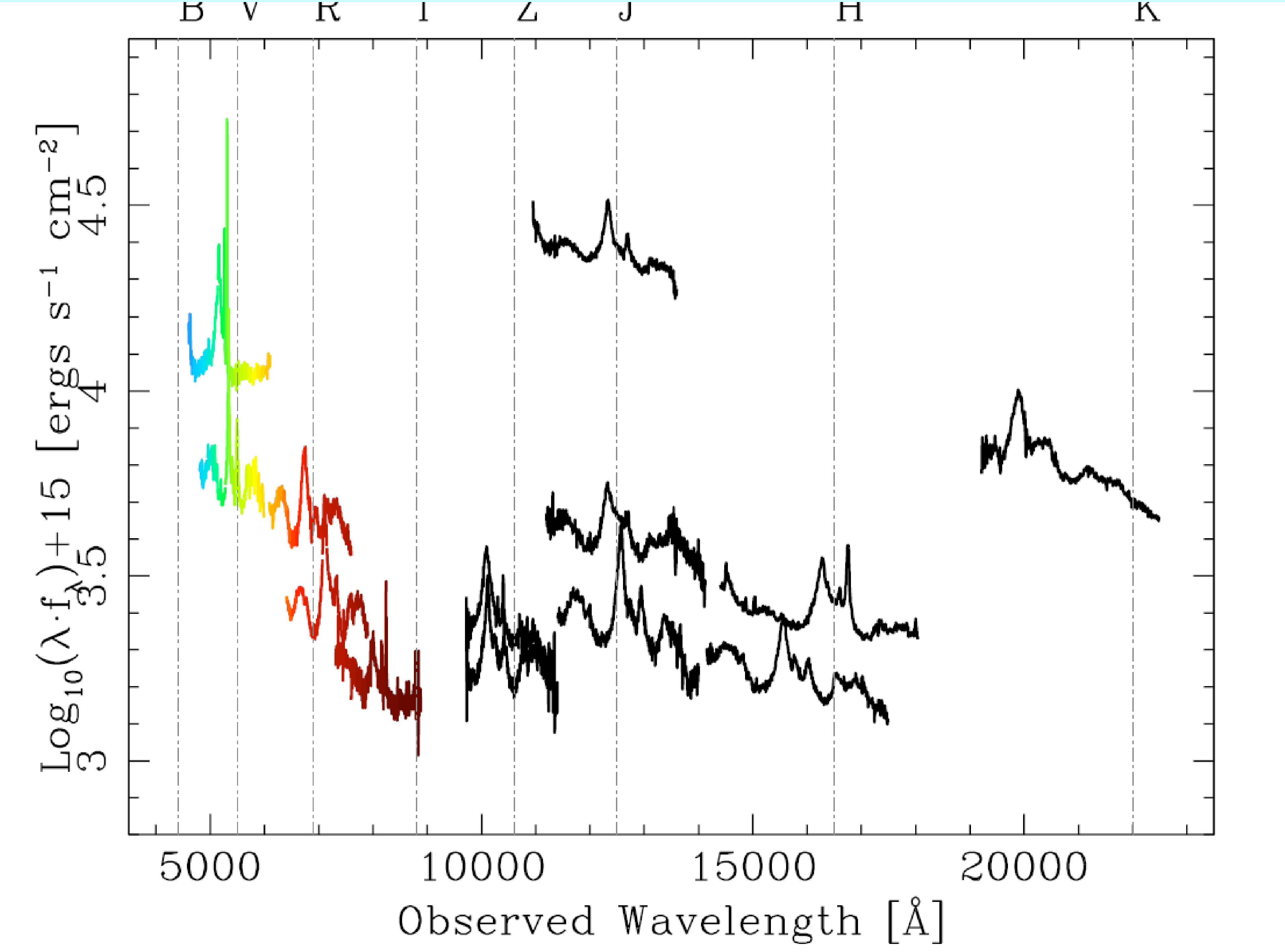
- Most extreme MBH values came from pop B sources using FWHM Hbeta uncorrected for the extra very broad component.

Above z ~ 0.7?

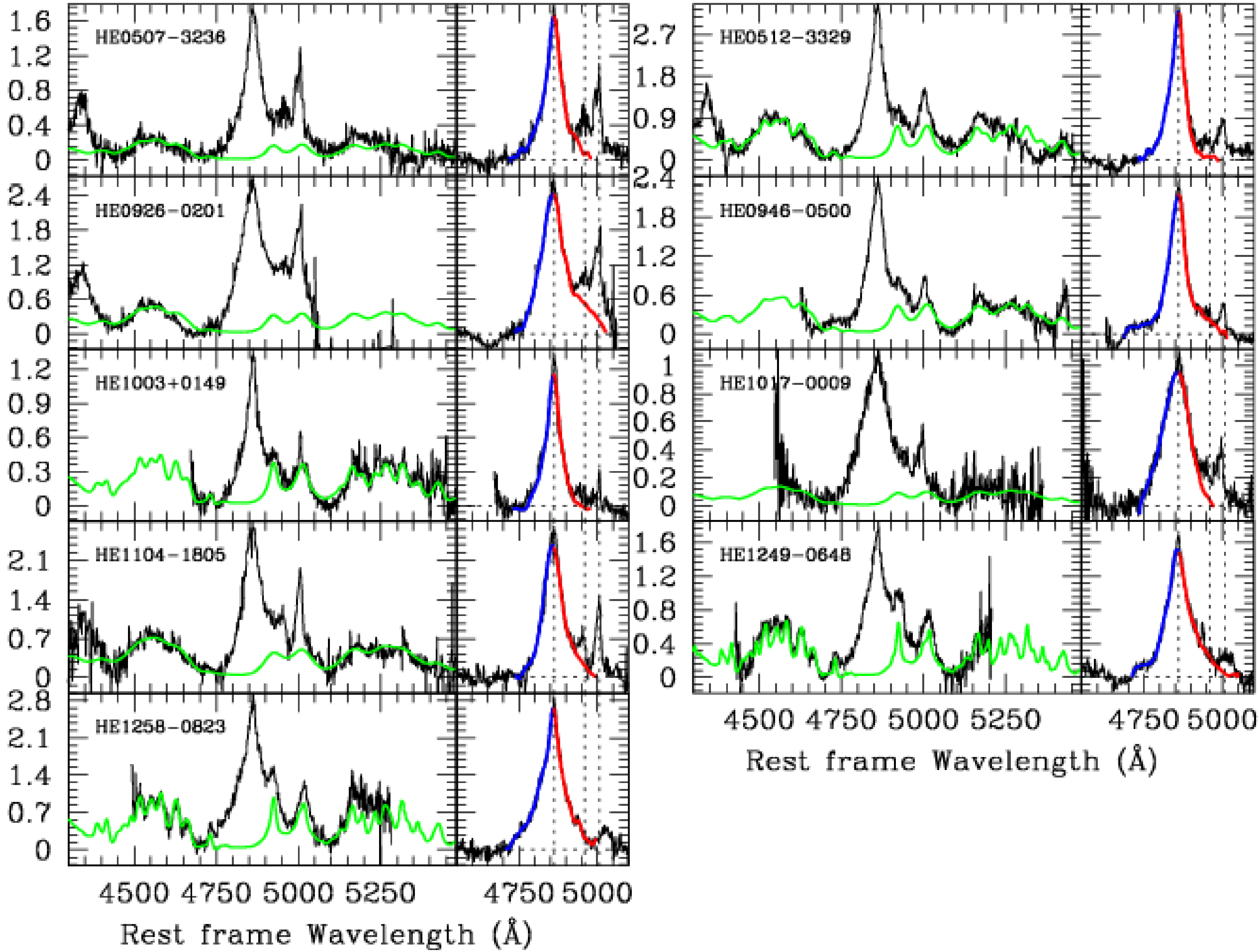
- Follow Hbeta into the IR to z = 3.8
- MgII2798 with suitable corrections to z > 6
- CIV1549 dangerous



I Zw 1
60
40
20
0
1500
1550
1600
Rest frame wavelength [Å]
Log((M_BH CIV)/(M_BH Hβ))
2
1
0
−1
1
1.5
2
2.5
3
Log(W(CIVλ1549_BC)) [Å]



B
V
R
I
Z
J
H
K
$Log_{10}(\lambda \cdot f_\lambda)+15$ [ergs s^{-1} cm^{-2}]
3
3.5
4
4.5
5000
10000
15000
20000
Observed Wavelength [Å]


HE0507-3236
HE0512-3329
HE0926-0201
HE0946-0500
HE1003+0149
HE1017-0009
HE1104-1805
HE1249-0648
HE1258-0823
Rest frame Wavelength (Å)
Rest frame Wavelength (Å)

So we have "v" – ways to estimate BLR size

- Directly: reverberation mapping

  (Peterson & Horne 2006)

- Using r_BLR vs. Luminosity relation

(Marziani et al. 2009: Trachtenbrot et al. 2011)

- Photoionization Method

  (Dibai 1984; Wandel & Yahil 1985; Padovani & Rafanelli 1989; Wandel et al. 1999; Negrete et al. 2011)

Determination of central compact object mass

$c\tau_{max}$ provides an emissivity weighted estimate of the BLR linear distance (size) from central continuum source

$$r_{BLR} \approx c\tau_{\max} \approx 33\left(\frac{\lambda L_{5100}}{10^{44}\, erg\, s^{-1}}\right)^{0.7} l.d.$$

Kaspi et al. 2000

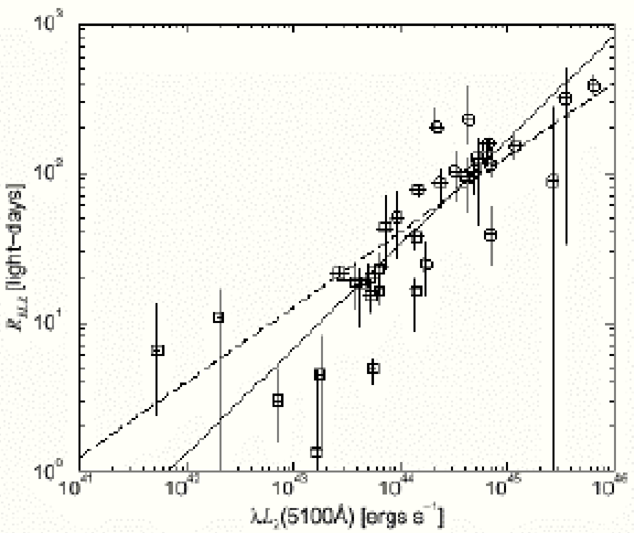


FIG. 6.—BLR size–luminosity relation. The solid line is the best fit to the data. The dashed line is a fit with a slope of 0.5.

More recent work indicates exponent ≈ 0.5

Bentz et al. 2009

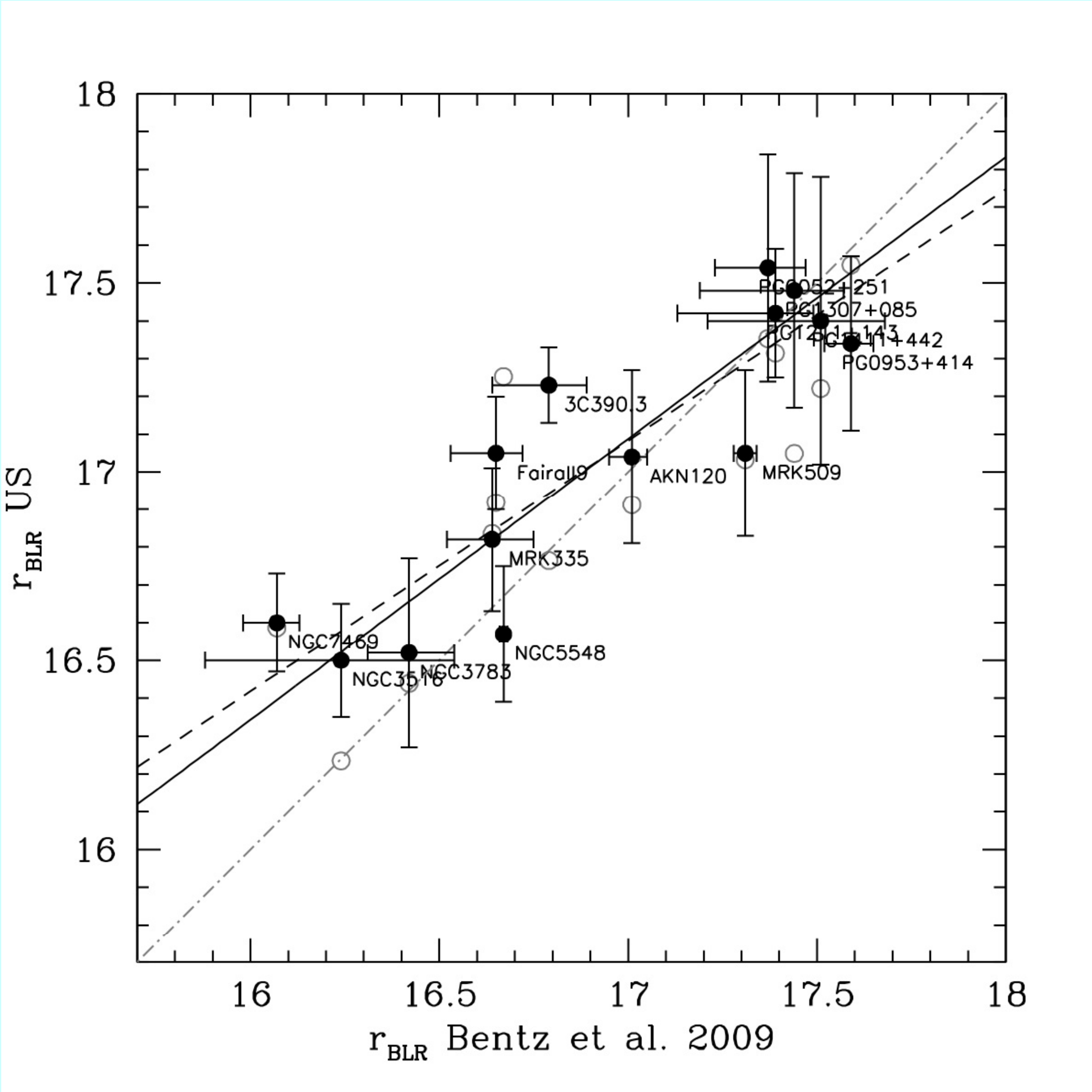
Paves the road to easy mass estimates

Bolometric luminosity estimated from bolometric correction ≈ 9 - 10 times the optical luminosity (at 5100 Å)

Elvis et al. 1994; see Nemmen & Brotherton 2010 for a more modern approach

$$U = \frac{\int_{\nu_0}^{+\infty} \frac{L_\nu}{h\nu} d\nu}{4\pi n_{\mathrm{H}} c r^2}$$

$$r_{\mathrm{BLR}} = \underbrace{\frac{1}{(4\pi c)^{\frac{1}{2}}}}_{\text{const.}} \underbrace{(U n_{\mathrm{H}})^{-\frac{1}{2}}}_{\text{diagnostics}} \left(\underbrace{\int_{\nu_0}^{+\infty} \frac{L_\nu}{h\nu} d\nu}_{\text{\# ionizing photons}} \right)^{\frac{1}{2}}$$



18
17.5
17
16.5
16
r BLR US
PG0052+251
PG1307+085
PG0953+414
3C390.3
Fairall9
AKN120
MRK509
MRK335
NGC7469
NGC5548
NGC3516
NGC3783
16
16.5
17
17.5
18
r BLR Bentz et al. 2009

$$M_{\mathrm{BH}} = \frac{3}{4}\frac{r_{\mathrm{BLR}}\mathrm{FWHM}(\mathrm{H}\beta_{\mathrm{BC}})^2}{G}$$

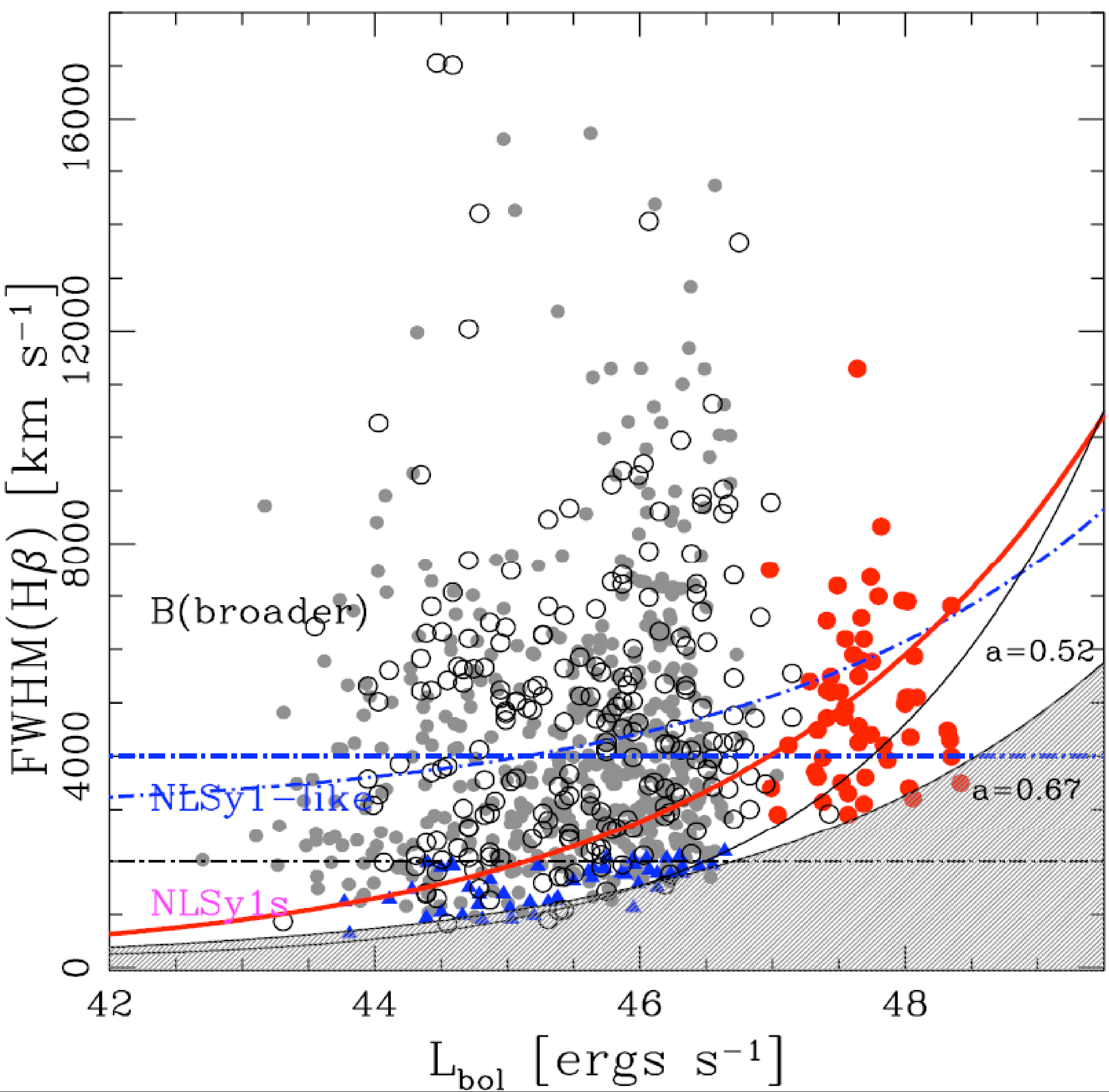
$$r_{\mathrm{BLR}} \propto (L_{5100})^{\alpha}$$

(Kaspi et al., 2000; 2005)

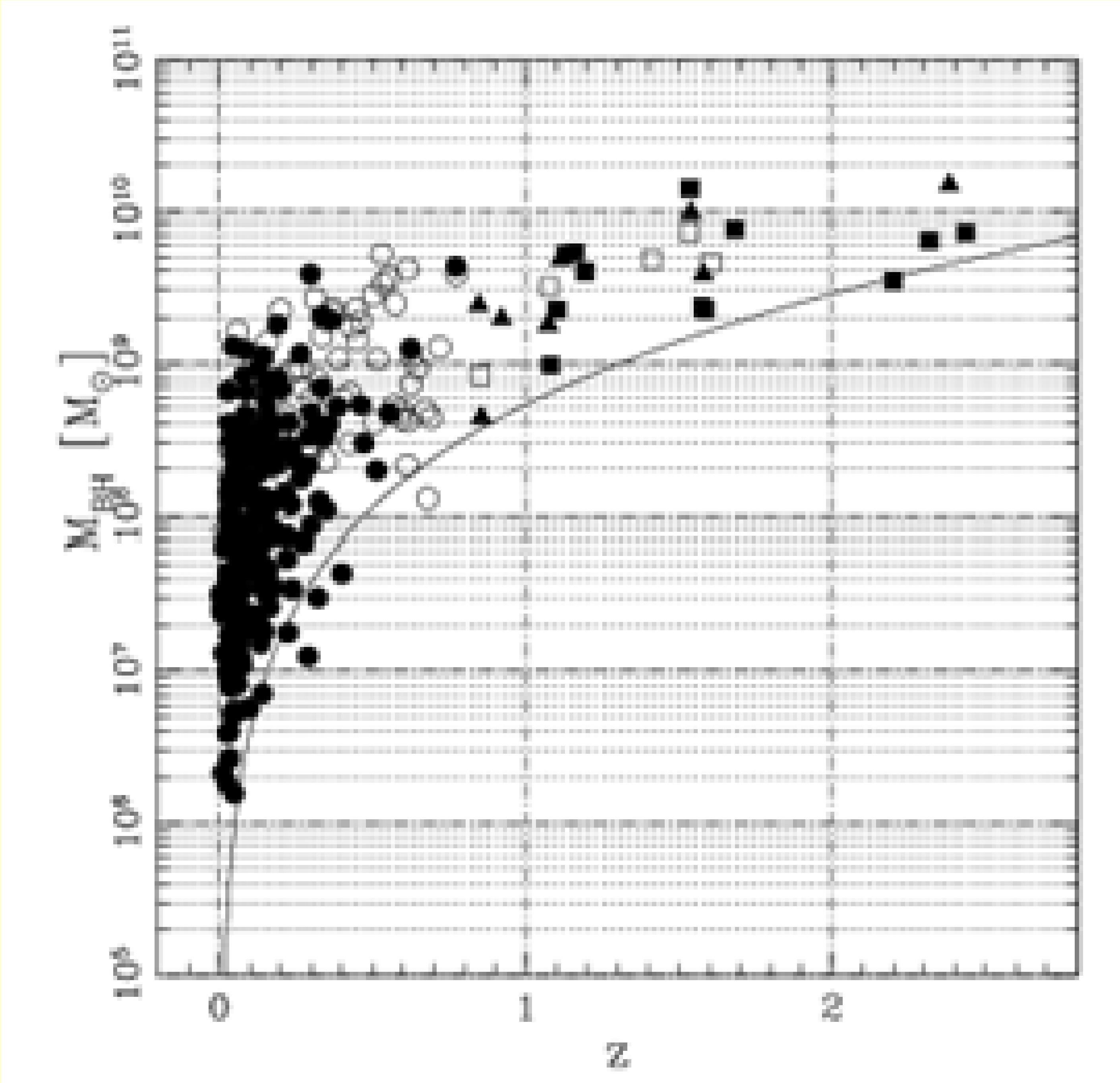
$$r_{BLR} = 0.85 \cdot 10^{17} \cdot \left[\frac{\lambda L_\lambda \left(5100\text{Å}\right)}{10^{44}\,\mathrm{erg\,s^{-1}}} \right]^{0.7} \mathrm{cm}$$

$$\lambda L_\lambda \left(5100\text{Å}\right) = 3.14 \cdot 10^{35-0.4(M_B)}$$

$$\lambda L_\lambda \left(5100\text{Å}\right) = 4\pi d_{\mathrm{P}}^2 \lambda f_\lambda \mathrm{ergs\ s}^{-1}$$



FWHM(Hβ) [km s⁻¹]
L_bol [ergs s⁻¹]
B(broader)
NLSy1-like
NLSy1s
a=0.52
a=0.67
0
4000
8000
12000
16000
42
44
46
48

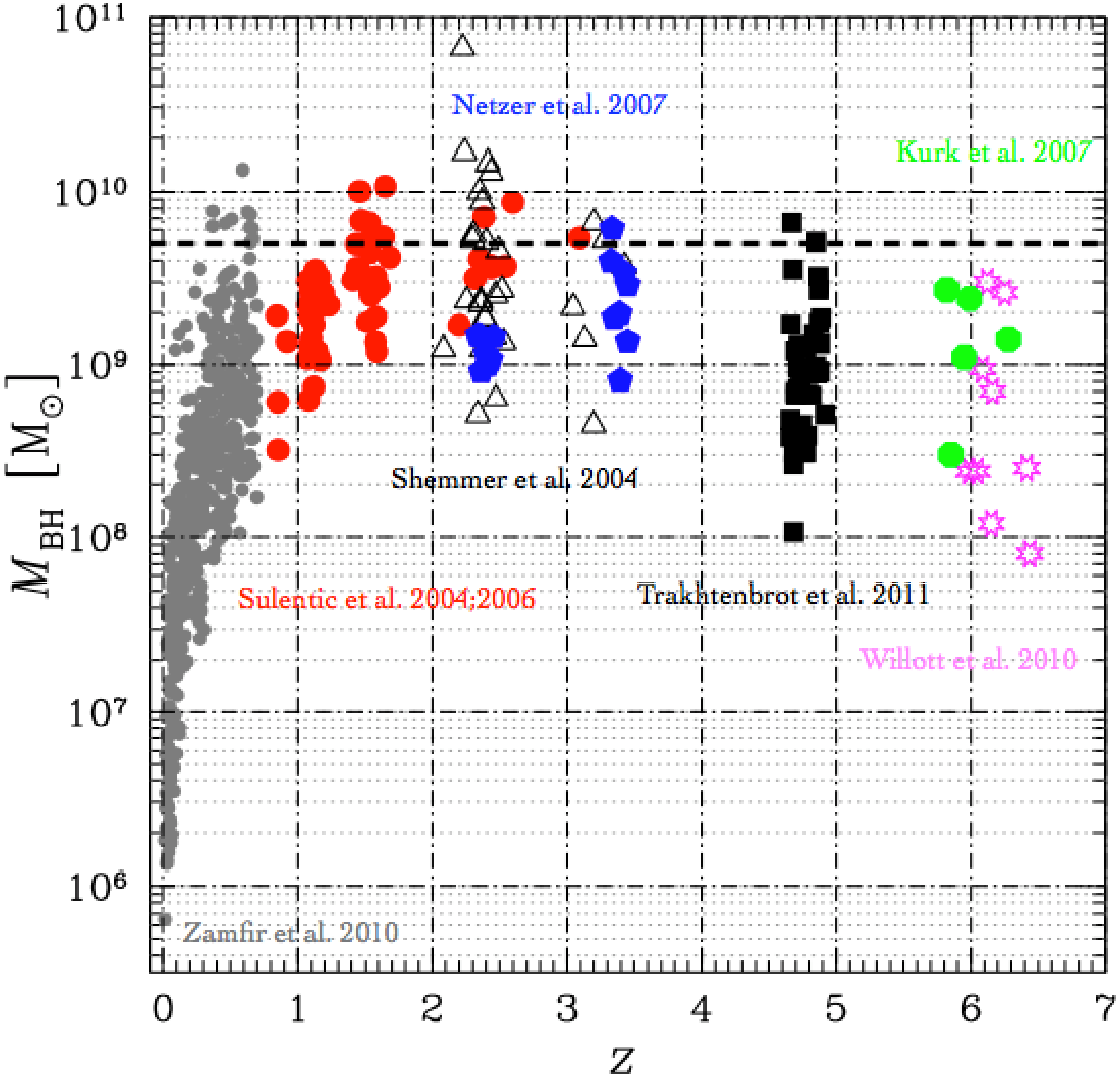


M_{BH} $[M_\odot]$
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
0
1
2
z

Table 6. Measurements on the broad lines of median spectra.

Object name (1)	$W(\mathrm{H}\beta)^a$ (2)	$W(\mathrm{Fe II}\lambda4570)^a$ (3)	$FWHM(\mathrm{Fe II})^b$ (4)	$F(\mathrm{H}\beta_{\mathrm{BC}})/F(\mathrm{H}\beta)^c$ (5)	$FWHM(\mathrm{H}\beta_{\mathrm{BC}})^d$ (6)	$\log M_{\mathrm{BH}}$ $\mathrm{H}\beta_{\mathrm{BC}}{}^e$ (7)	$\log L_{\mathrm{bol}}/L_{\mathrm{Edd}}$ $\mathrm{H}\beta_{\mathrm{BC}}{}^e$ (8)
A1	72^{+11}_{-11}	26^{+3}_{-4}	2700^{+1100}_{-1100}	1.00	...	...	...
A2	65^{+10}_{-52}	49^{+13}_{-11}	3700^{+2000}_{-1400}	1.00	...	...	...
B1	86^{+13}_{-13}	26^{+5}_{-6}	5200^{+2400}_{-2300}	0.27	4000	...	...
B2	70^{+11}_{-11}	44^{+8}_{-14}	5000^{+800}_{-1700}	0.32	4000	...	...
A	61^{+10}_{-13}	25^{+7}_{-7}	2700^{+1500}_{-1200}	1.00	...	...	...
M	67^{+10}_{-11}	35^{+7}_{-6}	3800^{+1450}_{-1200}	1.00	...	...	...
MB	86^{+10}_{-13}	31^{+6}_{-7}	5000^{+1600}_{-1800}	0.27	4100	...	...
43A	91^{+10}_{-20}	36^{+7}_{-7}	3000^{+500}_{-750}	1.00	...	6.1	–0.74
44A	69^{+15}_{-15}	38^{+10}_{-10}	2600^{+500}_{-750}	1.00	...	6.8	–0.47
45A	86^{+10}_{-20}	43^{+10}_{-10}	2800^{+750}_{-500}	1.00	...	7.8	–0.43
46A	80^{+10}_{-10}	47^{+10}_{-10}	3000^{+600}_{-600}	1.00	...	8.6	–0.26
47A	68^{+10}_{-11}	30^{+8}_{-8}	3000^{+1400}_{-1200}	1.00	...	9.6	–0.20
48A	60^{+11}_{-11}	27^{+3}_{-8}	3800^{+1500}_{-1100}	1.00	...	10.3	+0.11
43B	130^{+20}_{-20}	8^{+10}_{-7}	...[f]	0.59	4600	7.1	–0.68
44B	125^{+10}_{-30}	38^{+5}_{-20}	5600^{+600}_{-1800}	0.49	4700	7.7	–1.37
45B	111^{+15}_{-20}	29^{+5}_{-15}	4900^{+500}_{-800}	0.35	4400	8.4	–0.98
46B	93^{+10}_{-20}	22^{+5}_{-10}	5900^{+350}_{-1200}	0.37	4800	9.1	–0.73
47B	92^{+13}_{-14}	38^{+7}_{-7}	4900^{+1600}_{-2000}	0.27	4000	9.6	–0.24
48B	75^{+9}_{-11}	12^{+3}_{-3}	4600^{+1200}_{-1700}	0.23	4300	10.3	+0.03

[a] Equivalent width of Hβ ($\mathrm{H}\beta_{\mathrm{BC}}$+ $\mathrm{H}\beta_{\mathrm{VBC}}$) and FeIIλ4570in Å ±2σ confidence level uncertainty. Note that those values have been computed on median spectra with flux normalized to unity at $\lambda = 5100$ Å. Considering that the continuum shape is not flat, but that there is however little dispersion in continuum shape across the median spectra, it is $W(\mathrm{H}\beta) \approx I(\mathrm{H}\beta)/1.1$, and $W(\mathrm{Fe II}\lambda4570) \approx I(\mathrm{Fe II}\lambda4570)/1.25$ Å. [b] *FWHM* of lines in the blend in units of km s^{-1} computed by `specfit` as for the individual sources. Uncertainty is at ±2σ confidence level. See text for details. [c] Intensity ratio of the $\mathrm{H}\beta_{\mathrm{BC}}$ to total Hβ line emission i.e., $\mathrm{H}\beta_{\mathrm{BC}}$ and $\mathrm{H}\beta_{\mathrm{VBC}}$. [d] *FWHM* of the $\mathrm{H}\beta_{\mathrm{BC}}$ component i.e., after removing $\mathrm{H}\beta_{\mathrm{VBC}}$. [e] Logarithm of M_{BH}, in solar masses, and of $L_{\mathrm{bol}}/L_{\mathrm{Edd}}$. Values have been computed following Paper II, using the $FWHM(\mathrm{H}\beta_{\mathrm{BC}})$ reported in Col. (6), and assuming the average bin luminsosity. Values are therefore only indicative. No M_{BH} or $L_{\mathrm{bol}}/L_{\mathrm{Edd}}$ has been computed for median in spectral types since they are normalized median spectra made regardless of their luminosity. [f] $\mathrm{Fe II}_{\mathrm{opt}}$ too faint for *FWHM* to be meaningfully constrained.



Netzer et al. 2007
Kurk et al. 2007
Shemmer et al. 2004
Sulentic et al. 2004;2006
Trakhtenbrot et al. 2011
Willott et al. 2010
Zamfir et al. 2010
M_{BH} [$M_\odot$]
z