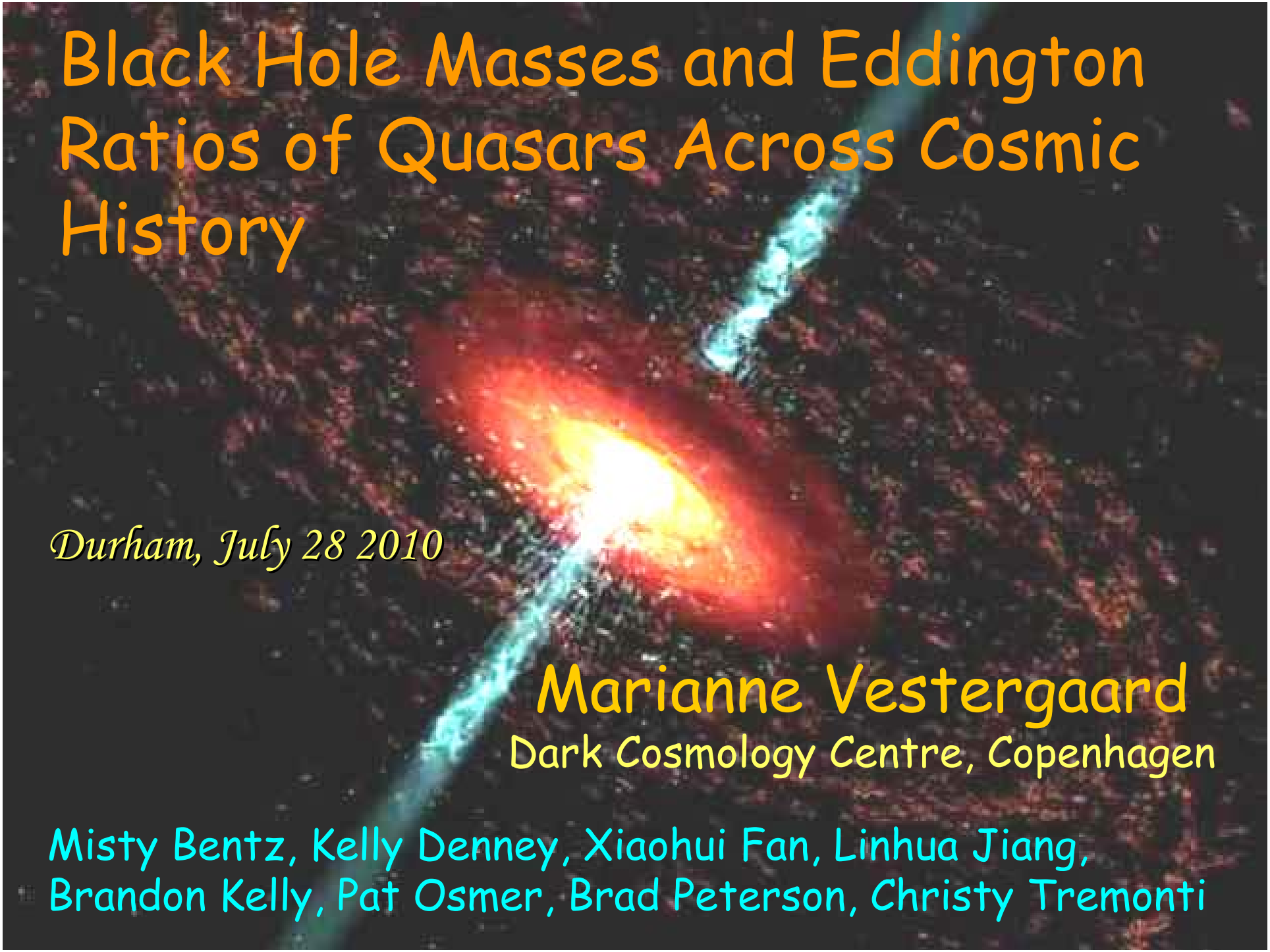
Black Hole Masses and Eddington Ratios of Quasars Across Cosmic History

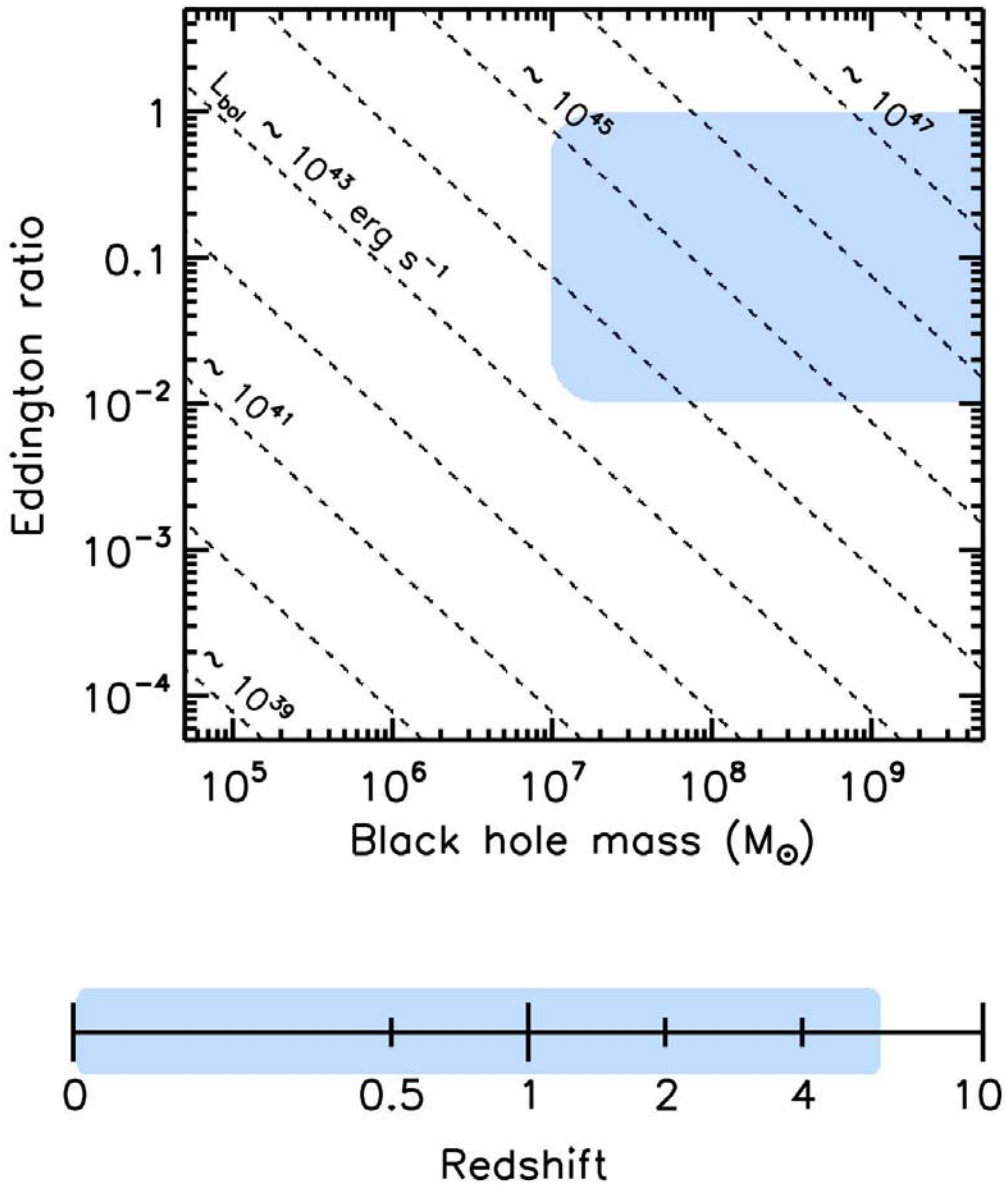


Durham, July 28 2010

Marianne Vestergaard

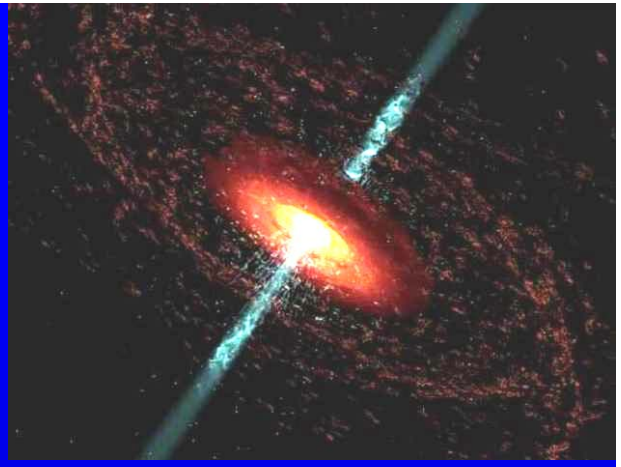
Dark Cosmology Centre, Copenhagen

Misty Bentz, Kelly Denney, Xiaohui Fan, Linhua Jiang, Brandon Kelly, Pat Osmer, Brad Peterson, Christy Tremonti


Eddington ratio
1
0.1
10^{-2}
10^{-3}
10^{-4}
$L_{bol} \sim 10^{43}$ erg s^{-1}
$\sim 10^{45}$
$\sim 10^{47}$
$\sim 10^{41}$
$\sim 10^{39}$
10^5
10^6
10^7
10^8
10^9
Black hole mass ($M_\odot$)
0
0.5
1
2
4
10
Redshift

Virial Mass Estimates

$M_{BH} = v^2 R_{BLR}/G$



- Variability Studies: $R_{BLR}=c\tau$

Radius – Luminosity Relation:

$$R_{BLR} \propto L_{\lambda}(\text{nuclear})^{0.50}$$

(Kaspi et al. 2005; Bentz et al. 2006, 2009, MV et al., in prep.)

See Peterson talk!

- For individual spectra:

$$M_{BH} \propto FWHM^2 L^{\beta} ; \beta \approx 0.5$$

(see e.g. MV 2002, McLure & Jarvis 2002, MV & Peterson 2006)

Virial Mass Estimates: $M_{BH} = f\, v^2\, R_{BLR}/G$

Scaling Relationships:

(calibrated to 2004 Reverberation M_{BH})

- Hβ:

$$M_{BH} = 8.3 \cdot 10^6 \left(\frac{FWHM(H\beta)}{10^3\,km/s} \right)^2 \left(\frac{\lambda L_\lambda (5100A)}{10^{44}\,ergs/s} \right)^{0.50} M_\odot$$

- MgII:

$$M_{BH} = 6.2 \cdot 10^6 \left(\frac{FWHM(MgII)}{10^3\,km/s} \right)^2 \left(\frac{\lambda L_\lambda (2100A)}{10^{44}\,ergs/s} \right)^{0.50} M_\odot$$

- CIV:

$$M_{BH} = 4.5 \cdot 10^6 \left(\frac{FWHM(CIV)}{10^3\,km/s} \right)^2 \left(\frac{\lambda L_\lambda (1350A)}{10^{44}\,ergs/s} \right)^{0.53} M_\odot$$

1σ absolute uncertainty: factor ~3.5 – 4

(Vestergaard 2002; Vestergaard & Peterson 2006)

(MgII : MV & Osmer 2009; cf. McLure & Jarvis 2002; Kollmeier et al. 2006)

Mass Scaling Relationships

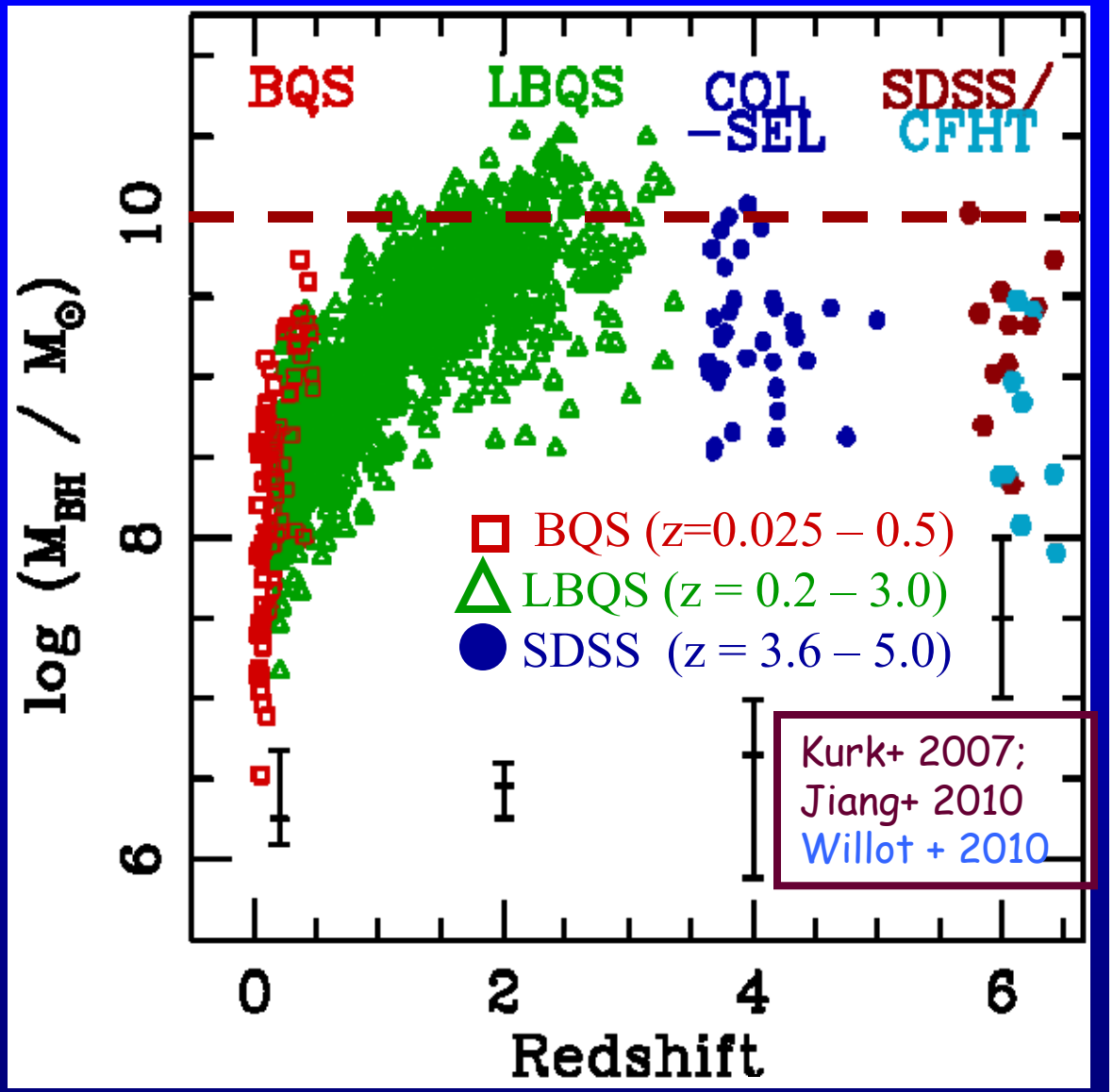
Note:

- Several relations exist in the literature – also for lines such as Hα and for line luminosities
- Not all relations are calibrated well – or to other lines
- So choose the relations with care!

Recent (inter-)calibrated relations:
MV & Peterson 2006/MV & Osmer 2009; McGill et al. 2008; Wang et al. 2009 (empirical/physics limited)

Masses of Distant Quasars

- Ceilings at $M_{BH} \approx 10^{10}\ M_{\odot}$ $L_{BOL} < 10^{48}$ ergs/s
- $M_{BH} \approx 10^{9}\ M_{\odot}$ - even beyond space density drop at $z \approx 3$

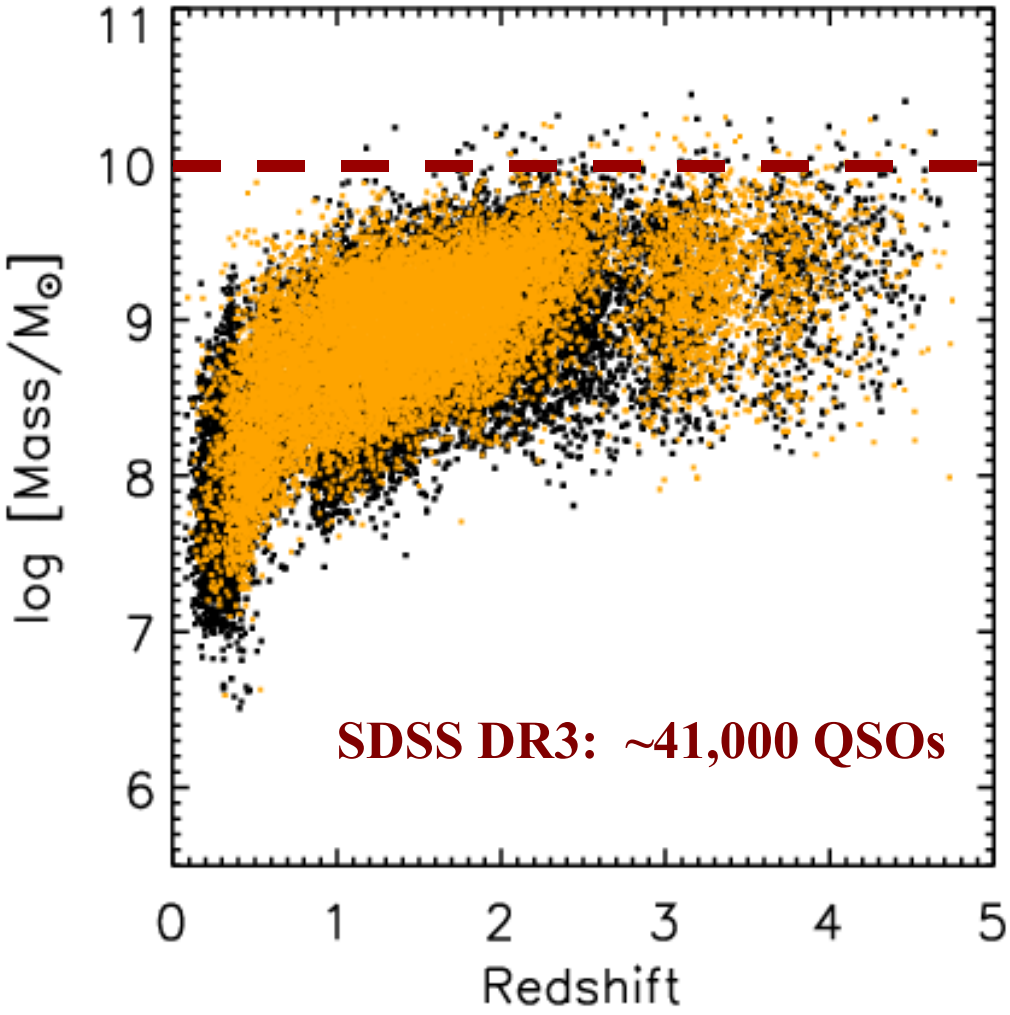


(Vestergaard & Osmer 2009)

(H_0=70 km/s/Mpc; Ω_Λ = 0.7)

Masses of Distant Quasars

- Ceilings at $M_{BH} \approx 10^{10}\ M_{\odot}$ $L_{BOL} < 10^{48}$ ergs/s
- $M_{BH} \approx 10^{9}\ M_{\odot}$ - even beyond space density drop at $z \approx 3$



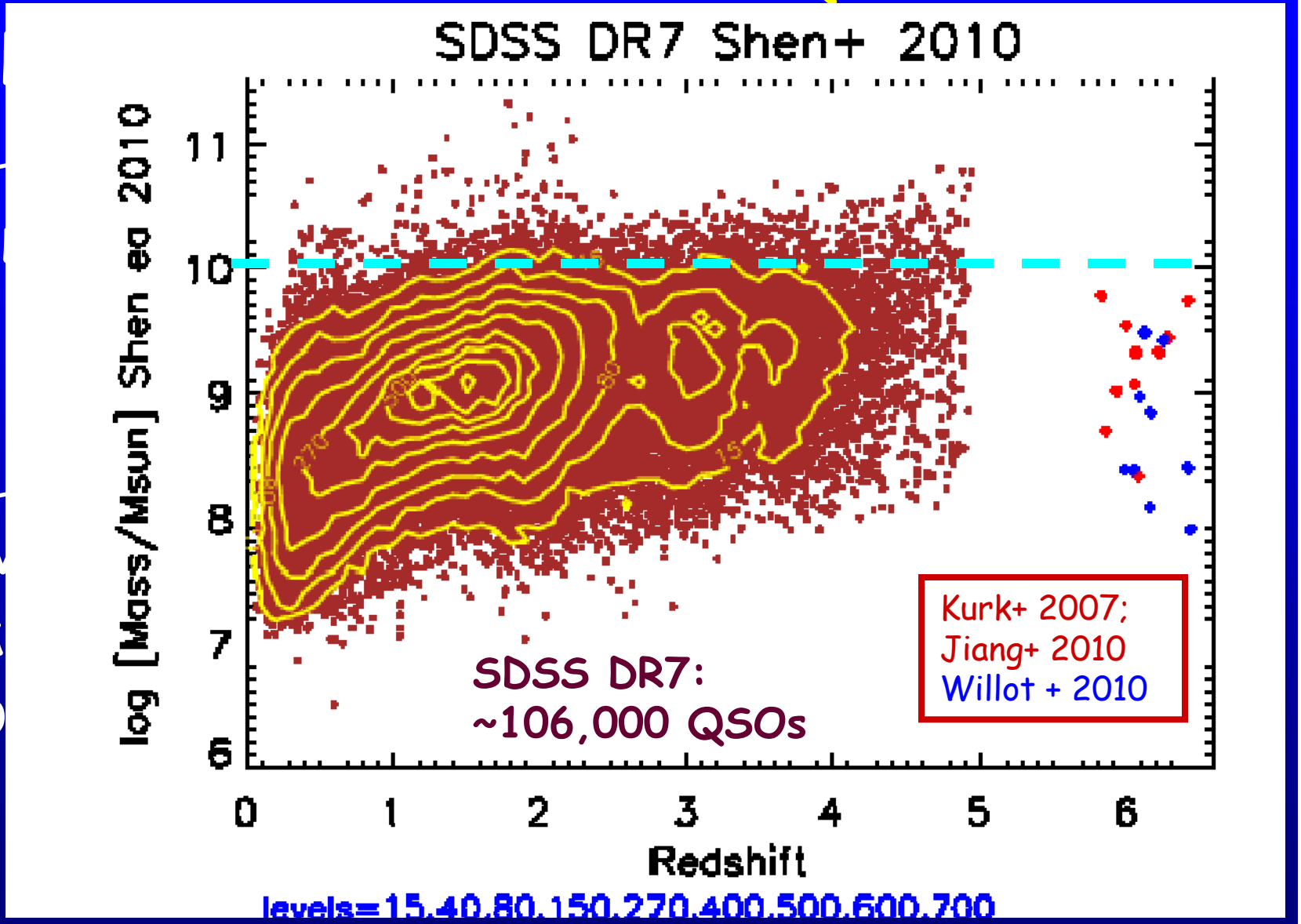
(DR3 Qcat: Schneider et al. 2005)

(MV + 2008, MV+ in prep)

Masses of Distant Quasars

- Cei
  M_{BH}
  L_{BO}

- M_{BH}
  - ev
  spa
  dro



(DR3 Qcat: Schneider et al. 2005)

(MV + 2008, MV+ in prep)

Eddington Luminosity Ratios
$= L_{BOL}/L_{Edd}$

- L_{BOL} = BC1 $\lambda L\lambda(1350\text{Å})$ = BC2 $\lambda L\lambda(4400\text{Å})$
- $L_{Edd} = 1.26\times 10^{38} M_{BH}\ [M_\odot]$

- $L_{BOL}/L_{Edd} \propto BC \times L / L^{1/2}\ FWHM^2$
  $\propto L^{1/2} / FWHM^2$

- Beware of this approximation!
- The only estimate we currently have at high z.

Bolometric Correction Depends on…..?

- L/L_{Edd}
  (Vasudevan & Fabian 2007, Young + 2010)
- Black hole mass
  (Kelly + 2008)

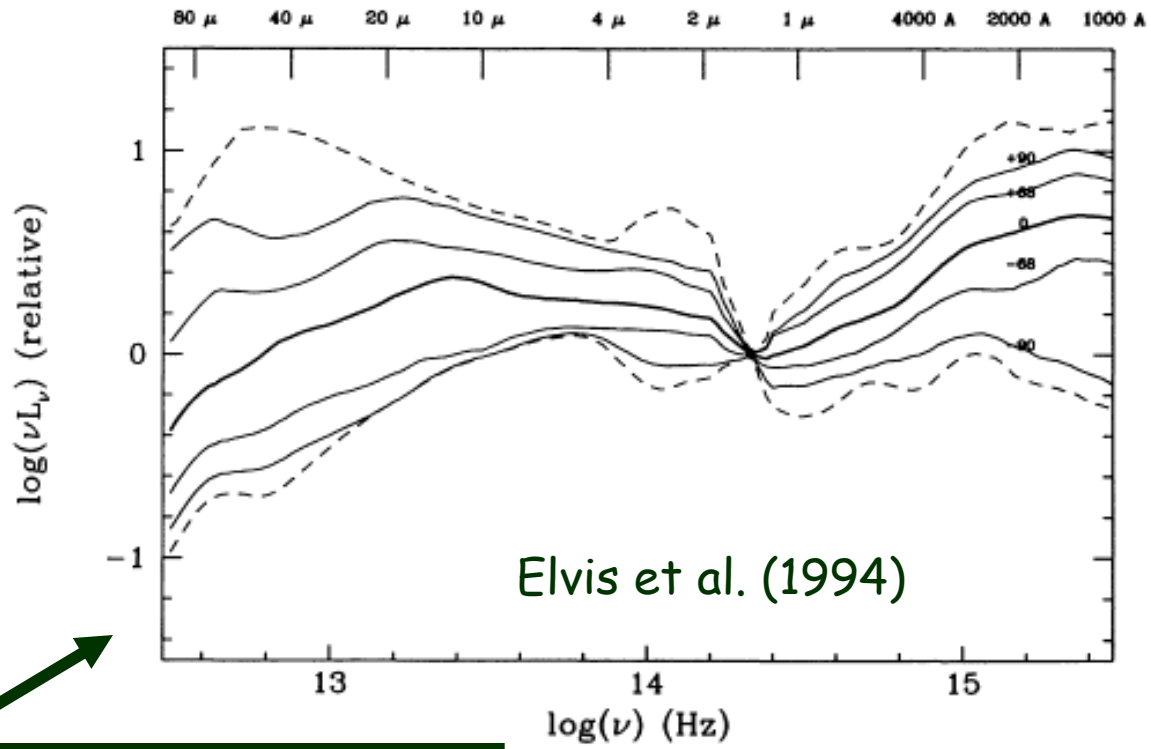
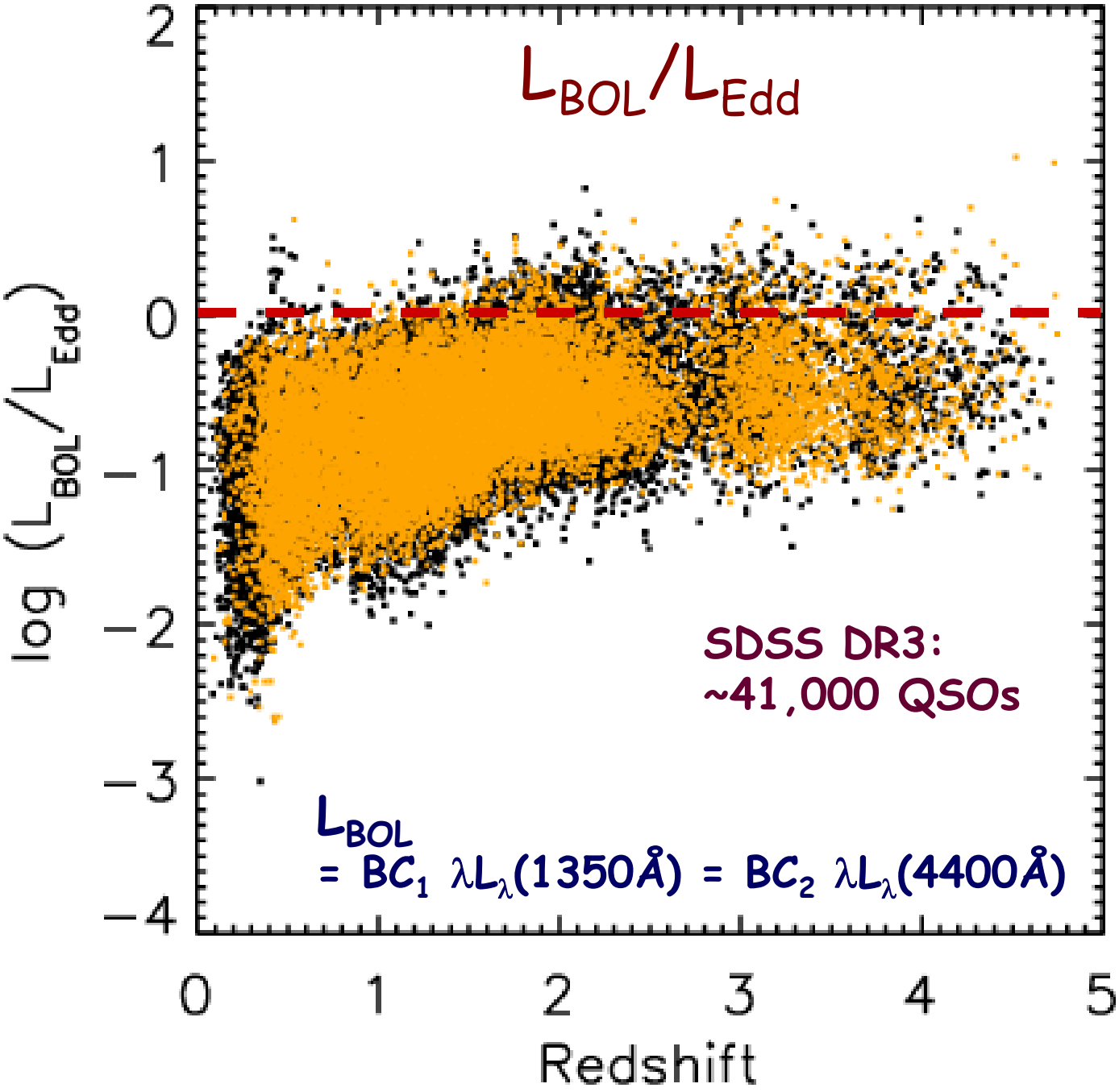
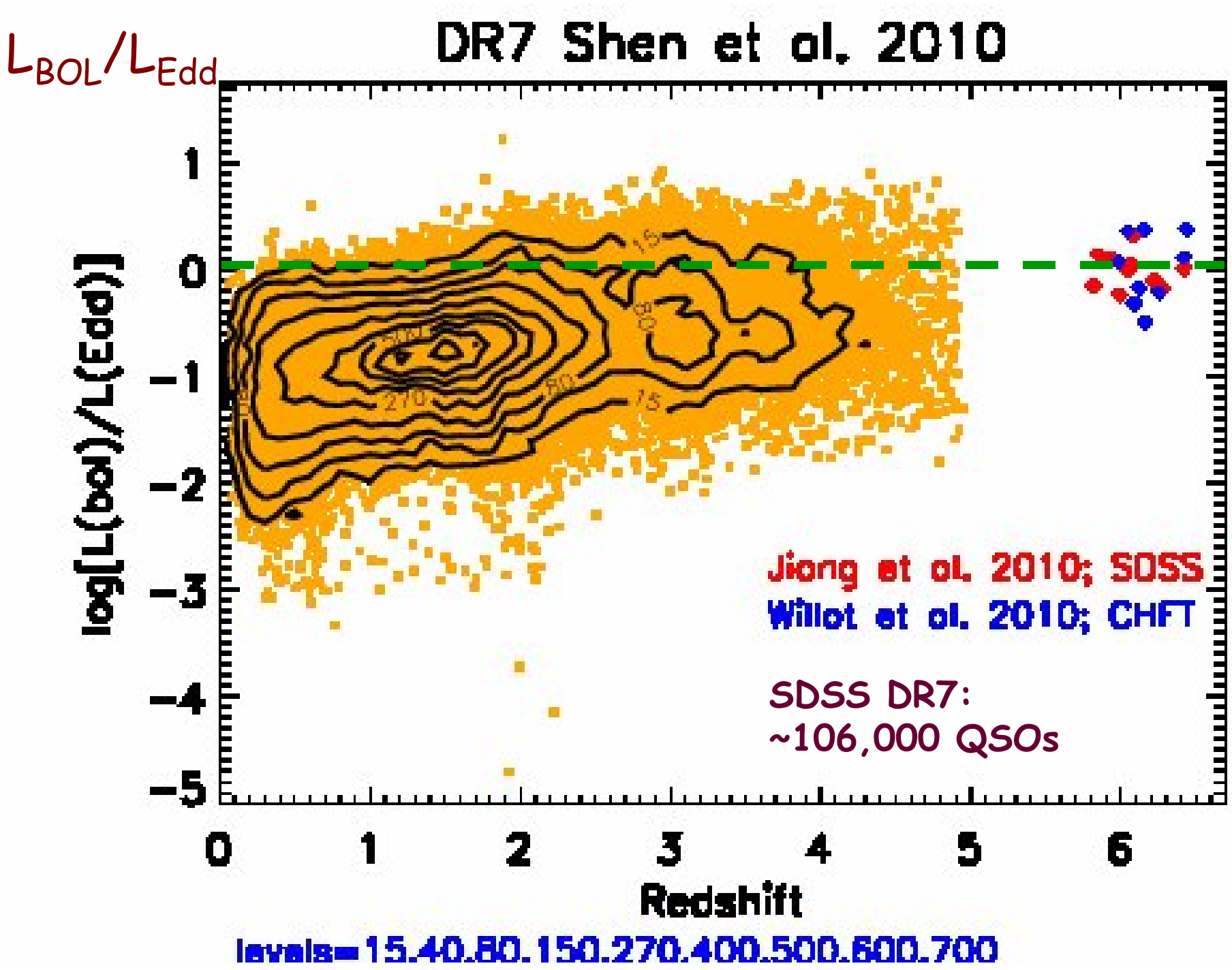


FIG. 11*a*

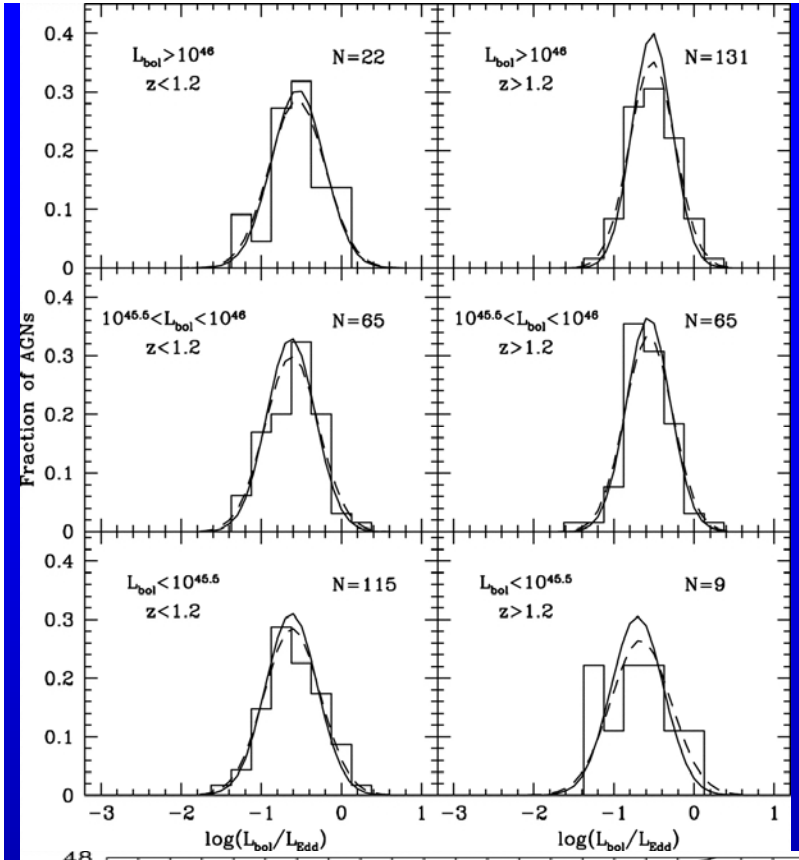
SEDs of quasars: Mean SED and observed range

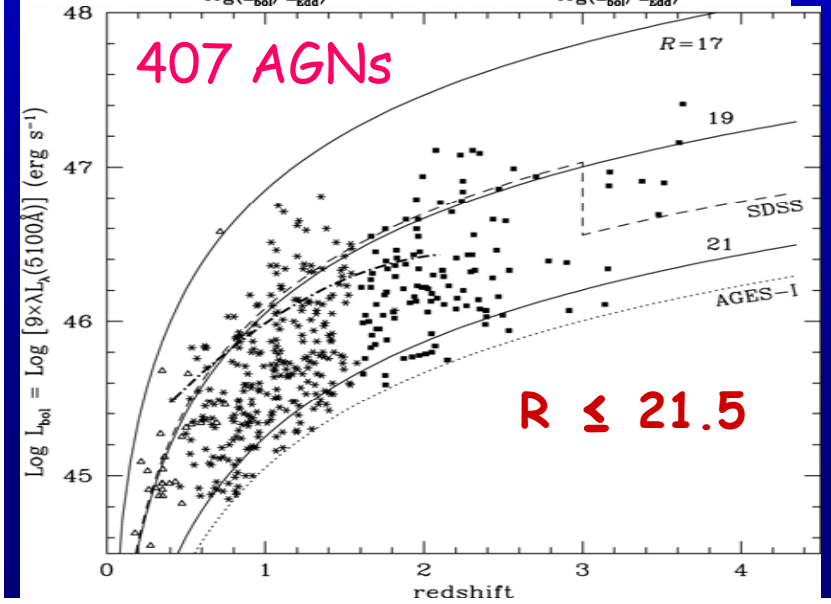

L_{BOL}/L_{Edd}
SDSS DR3:
~41,000 QSOs
L_{BOL}
= BC_1 $\lambda L_\lambda(1350Å)$ = BC_2 $\lambda L_\lambda(4400Å)$
log (L_{BOL}/L_{Edd})
Redshift
2
1
0
−1
−2
−3
−4
0
1
2
3
4
5

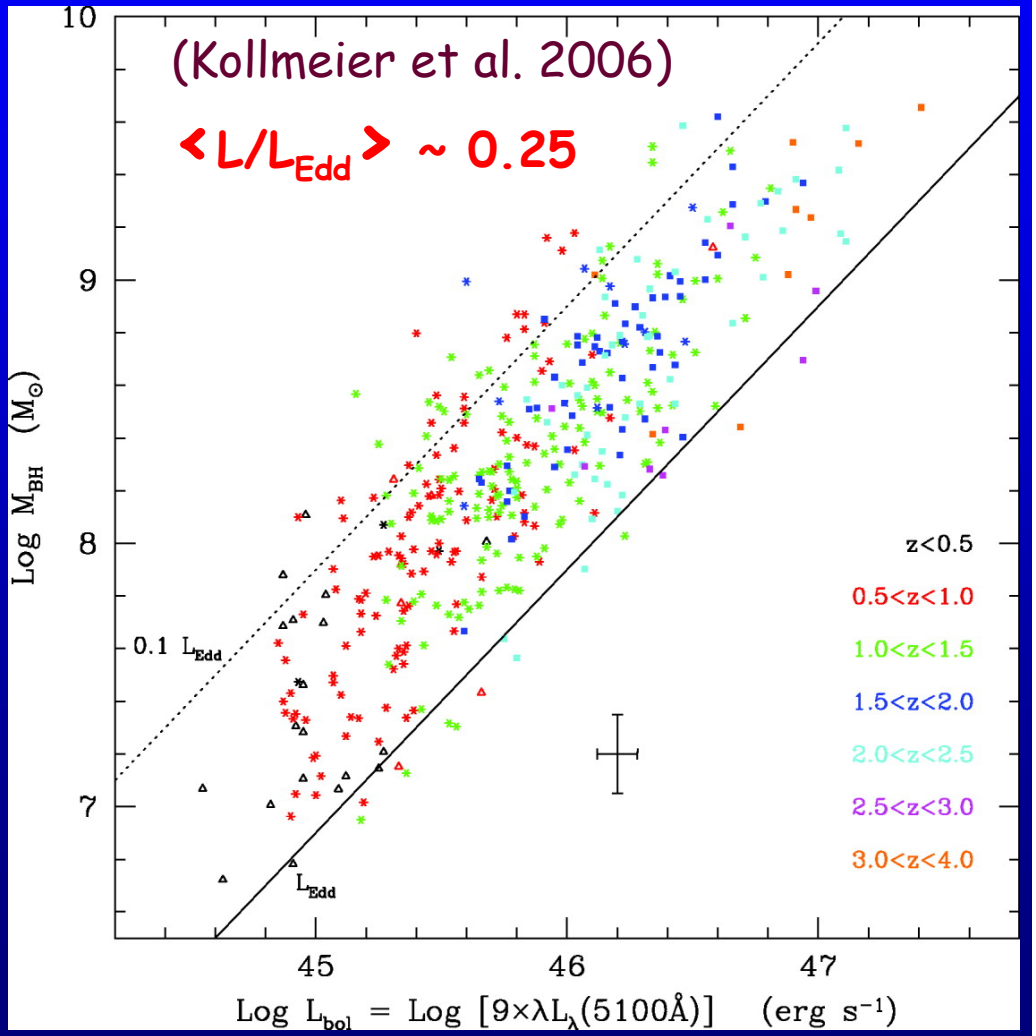

L_{BOL}/L_{Edd}
DR7 Shen et al. 2010
log[L(bol)/L(Edd)]
1
0
−1
−2
−3
−4
−5
0
1
2
3
4
5
6
Redshift
Jiang et al. 2010; SDSS
Willot et al. 2010; CHFT
SDSS DR7:
~106,000 QSOs
levels=15.40.80.150.270.400.500.600.700

AGES Survey

L/L_{Edd} dispersion ~ 0.3dex

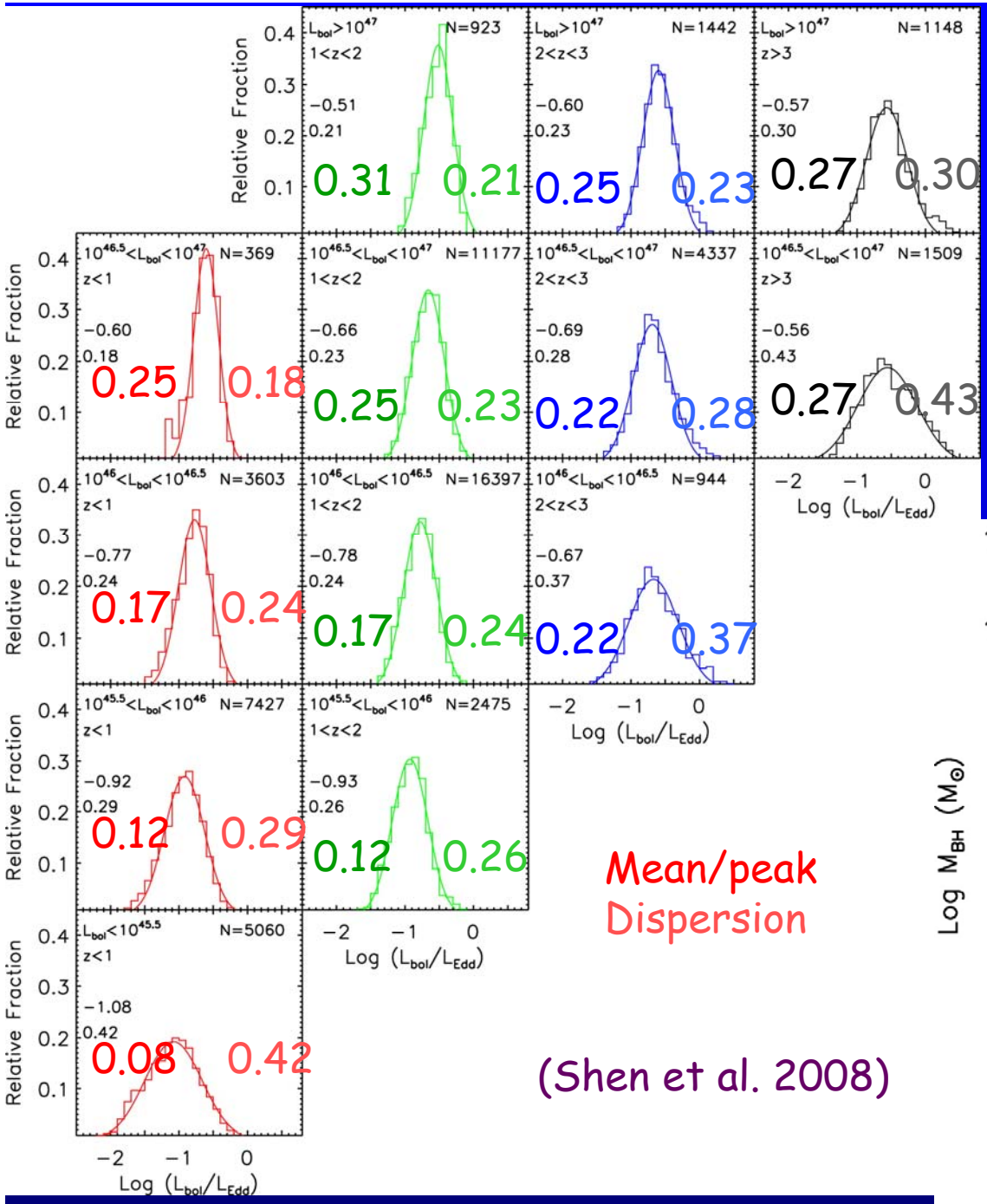






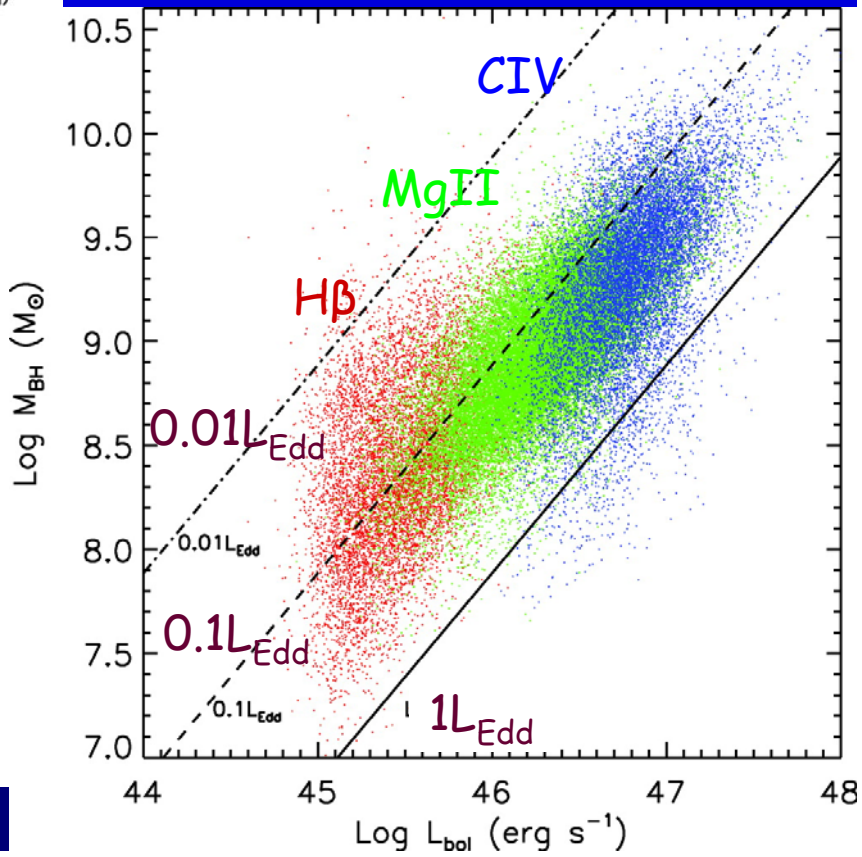
SDSS DR5

57,000 quasars

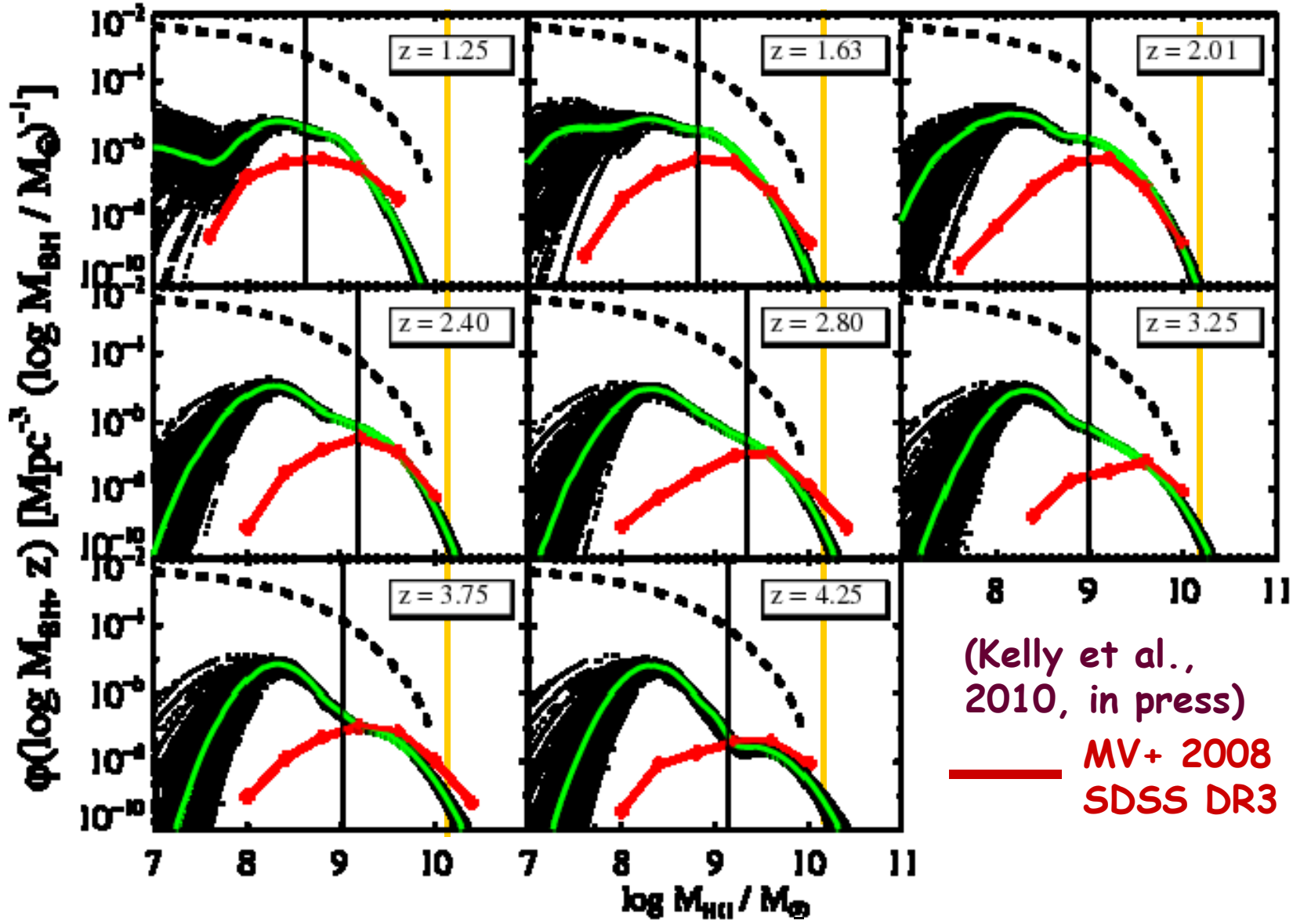


Mean/peak
Dispersion

(Shen et al. 2008)



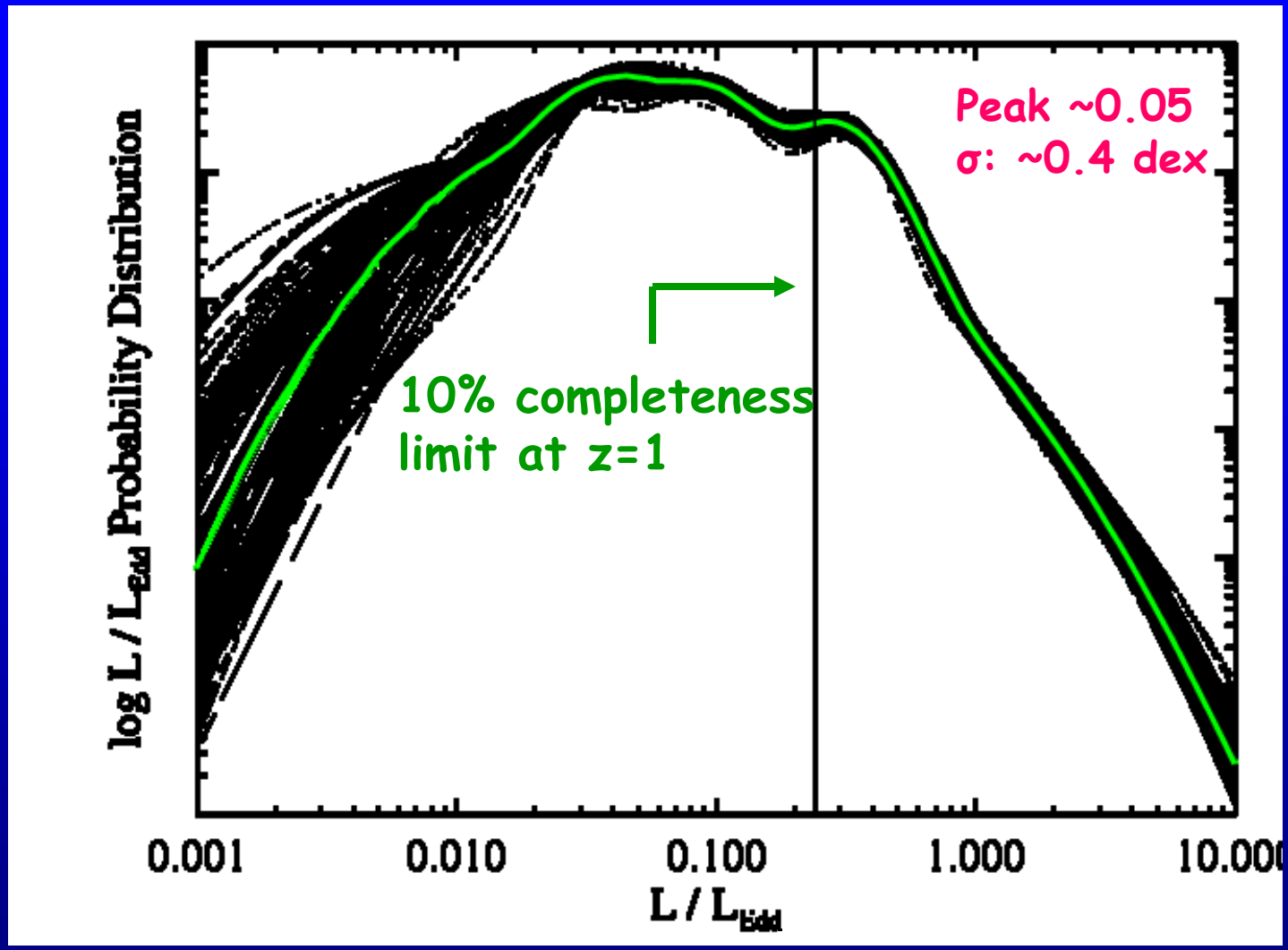
Mass Functions: Bayesian Approach



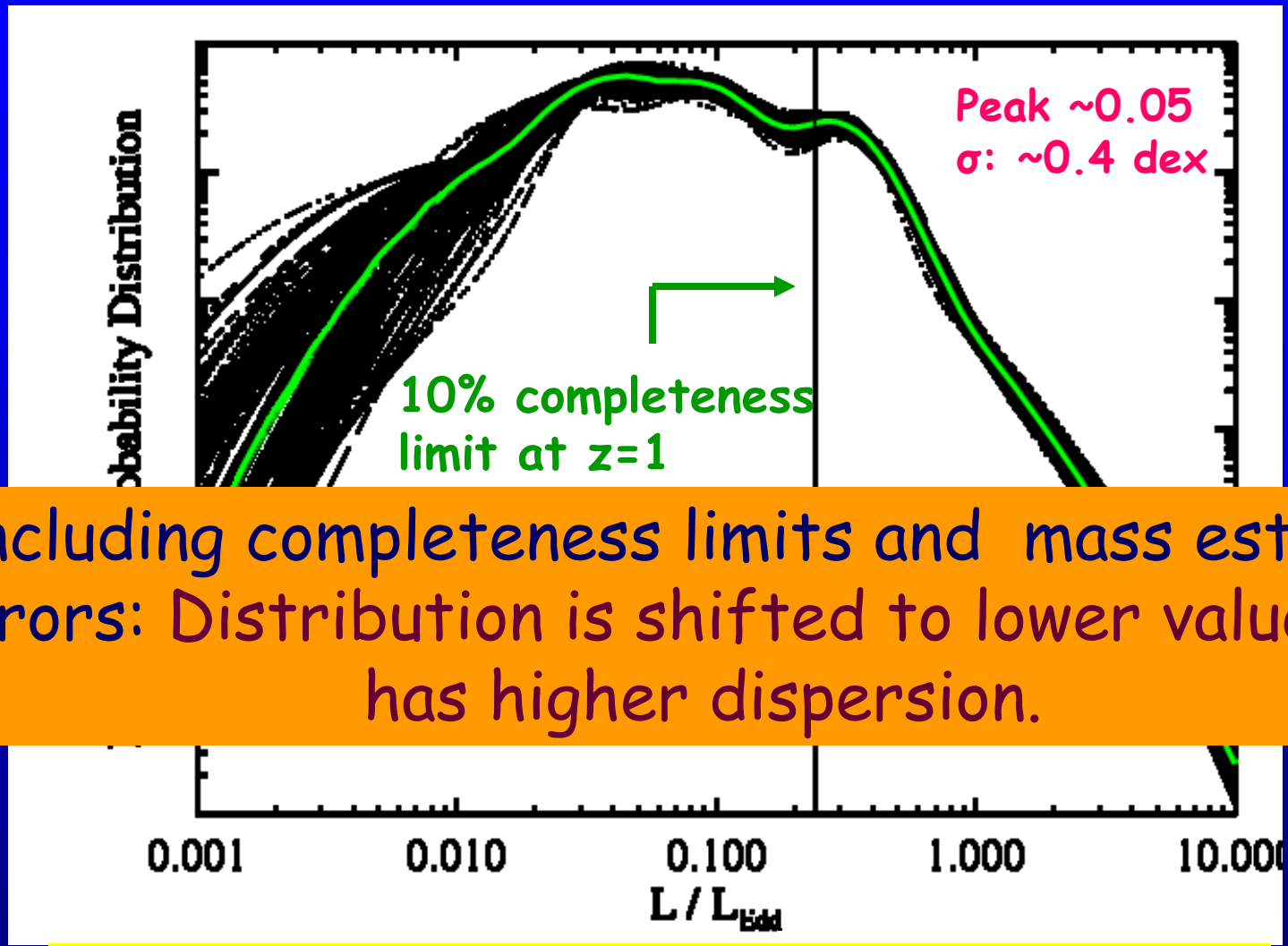
(Kelly et al., 2010, in press)

MV+ 2008 SDSS DR3

Bayes Stats: Eddington Ratio Distribution



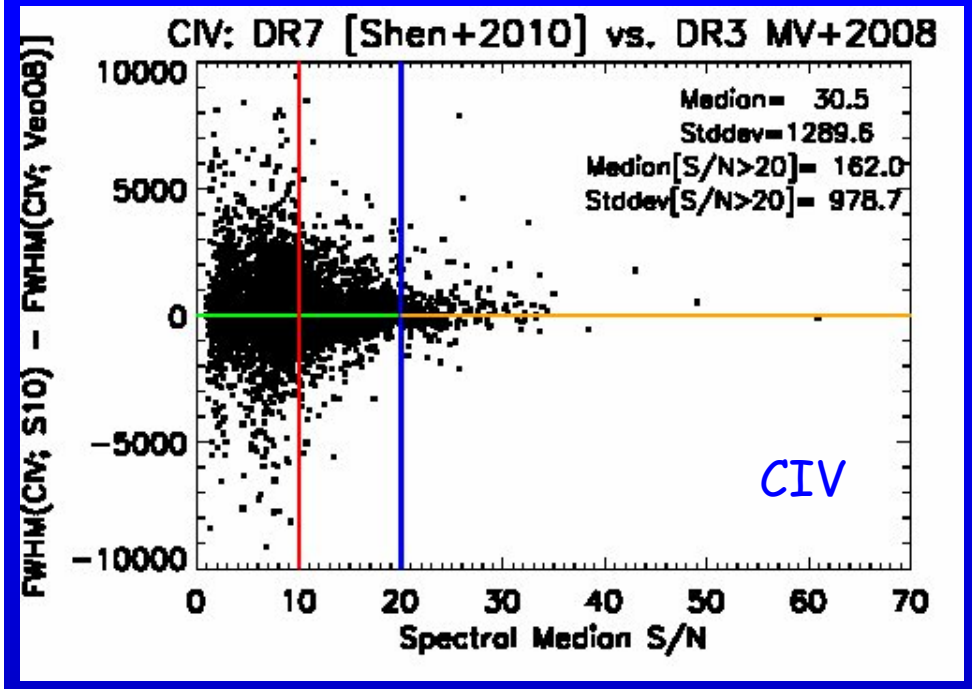
Bayes Stats: Eddington Ratio Distribution

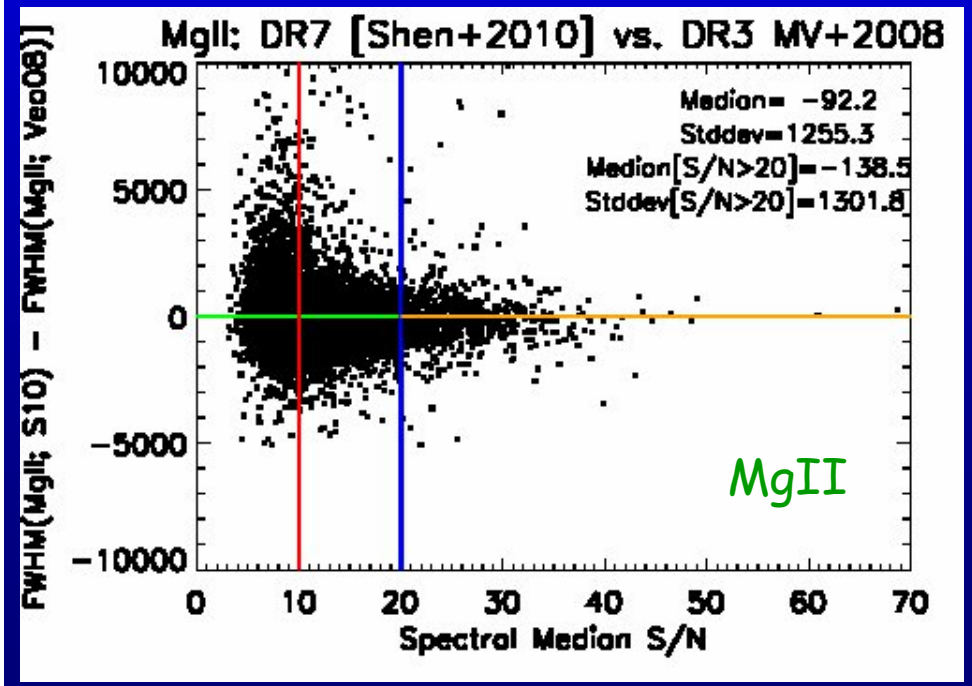


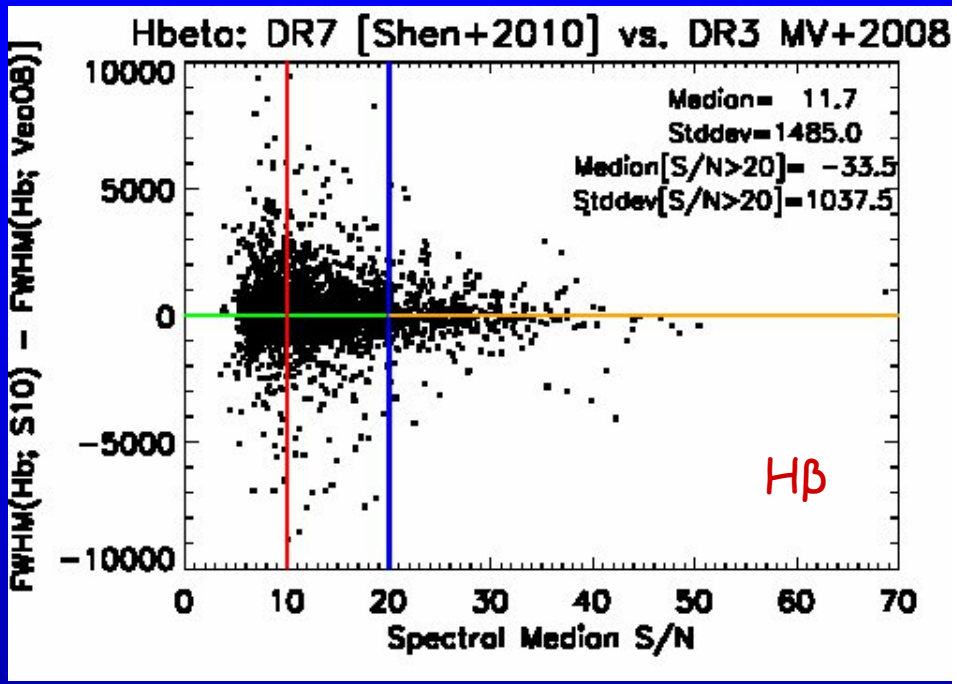
Including completeness limits and mass estimate errors: Distribution is shifted to lower values and has higher dispersion.

Consistent with deeper samples of BLQs [Gavignaud + 2008; Trump + 2009]

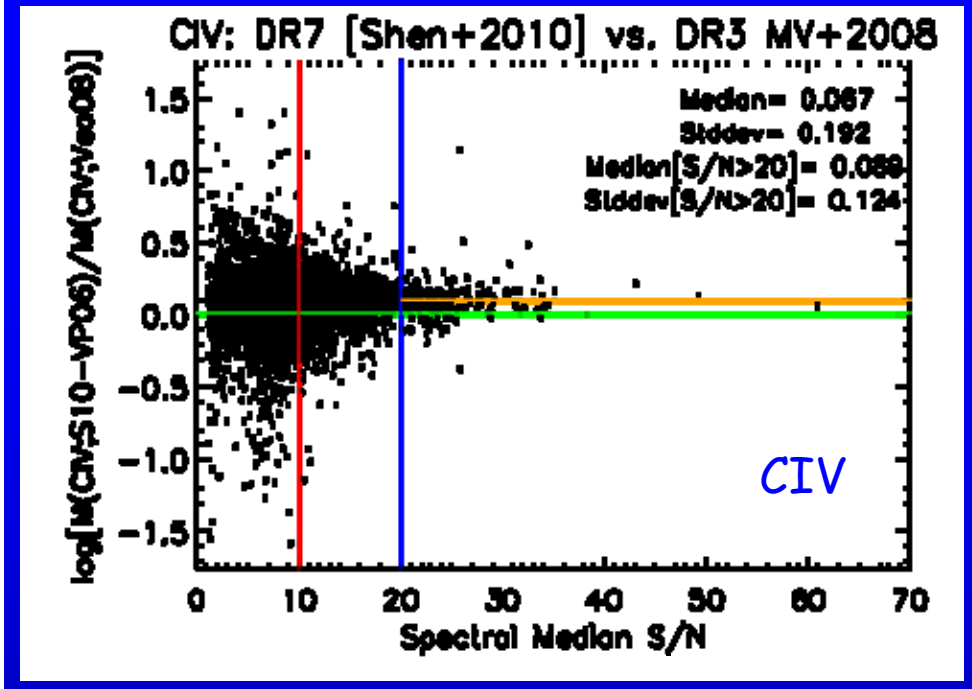
S/N Matters!

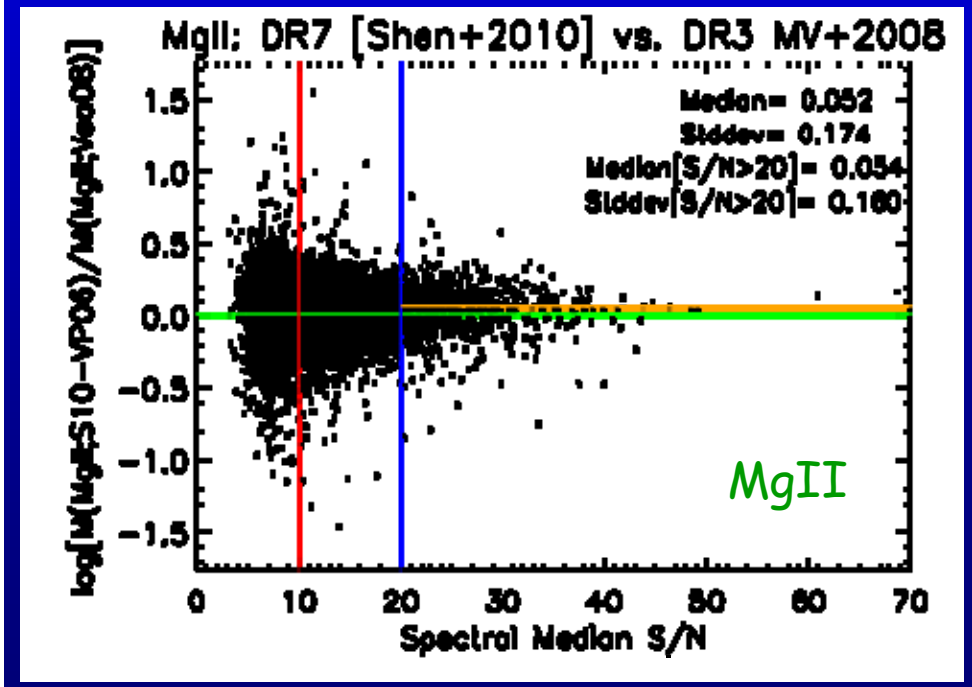

CIV: DR7 [Shen+2010] vs. DR3 MV+2008
Median= 30.5
Stddev=1289.6
Median[S/N>20]= 162.0
Stddev[S/N>20]= 978.7
CIV
FWHM(CIV; S10) - FWHM(CIV; Vea08)
Spectral Median S/N

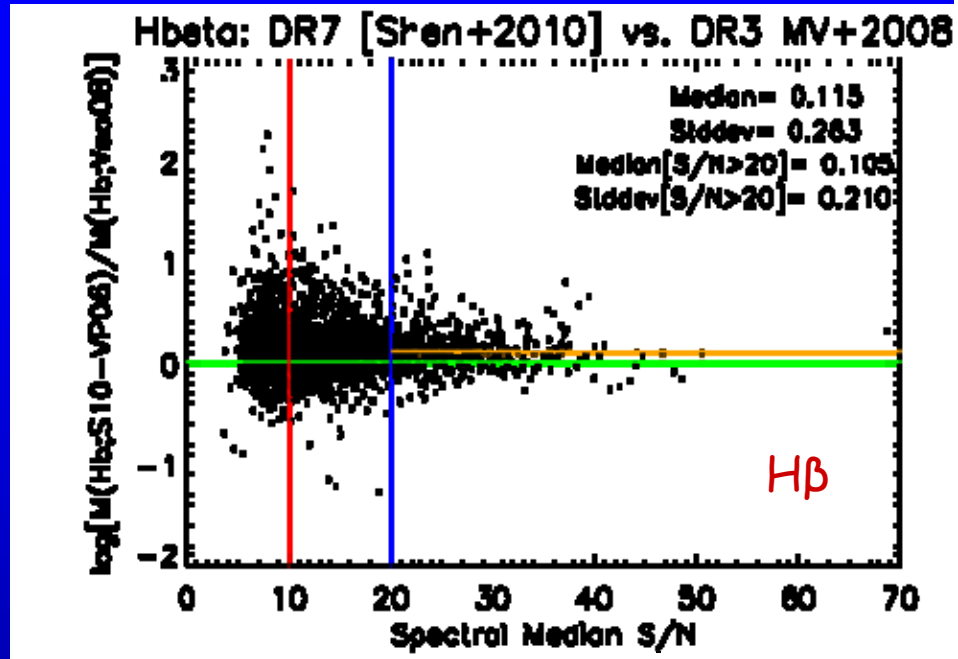

MgII: DR7 [Shen+2010] vs. DR3 MV+2008
Median= -92.2
Stddev=1255.3
Median[S/N>20]=-138.5
Stddev[S/N>20]=1301.8
MgII
FWHM(MgII; S10) - FWHM(MgII; Vea08)
Spectral Median S/N


Hbeta: DR7 [Shen+2010] vs. DR3 MV+2008
Median= 11.7
Stddev=1485.0
Median[S/N>20]= -33.5
Stddev[S/N>20]=1037.5
Hβ
FWHM(Hb; S10) - FWHM(Hb; Vea08)
Spectral Median S/N

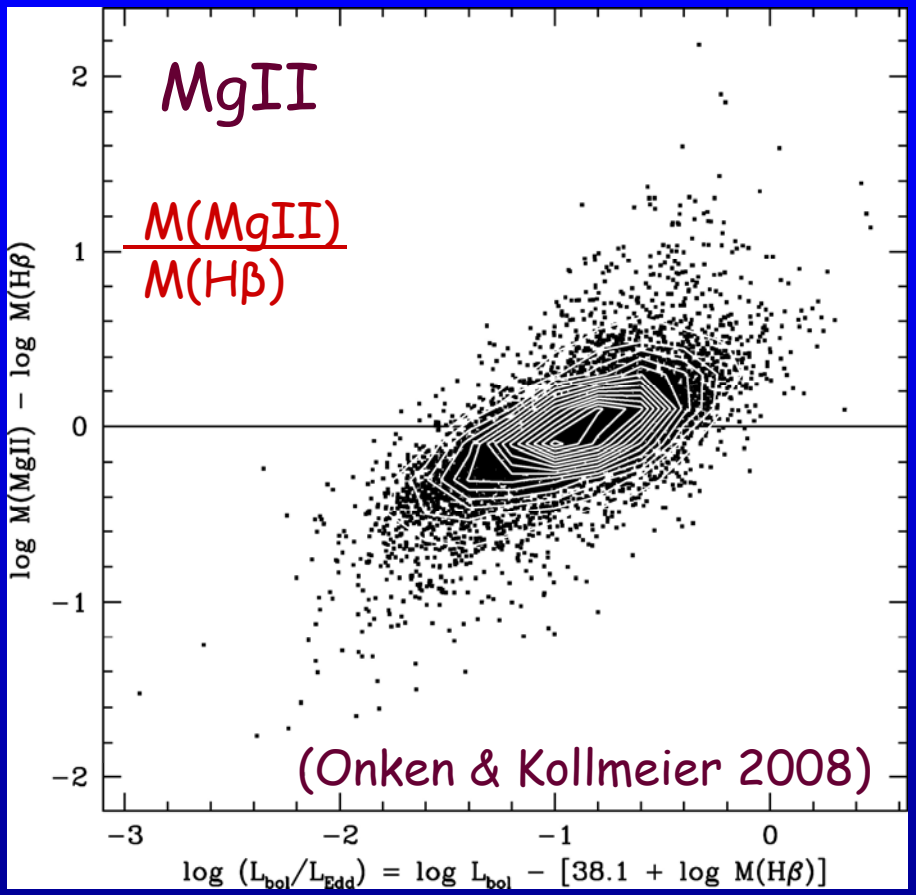
S/N Matters!


CIV: DR7 [Shen+2010] vs. DR3 MV+2008
Median= 0.067
Stddev= 0.192
Median[S/N>20]= 0.069
Stddev[S/N>20]= 0.124
CIV
log[M(CIVS10−VP06)/M(CIV;Vea08)]
Spectral Median S/N


MgII: DR7 [Shen+2010] vs. DR3 MV+2008
Median= 0.052
Stddev= 0.174
Median[S/N>20]= 0.054
Stddev[S/N>20]= 0.160
MgII
log[M(MgIIS10−VP06)/M(MgII;Vea08)]
Spectral Median S/N


Hbeta: DR7 [Shen+2010] vs. DR3 MV+2008
Median= 0.115
Stddev= 0.263
Median[S/N>20]= 0.105
Stddev[S/N>20]= 0.210
Hβ
log[M(HbS10−VP06)/M(Hb;Vea08)]
Spectral Median S/N

Radiation Pressure Effects?

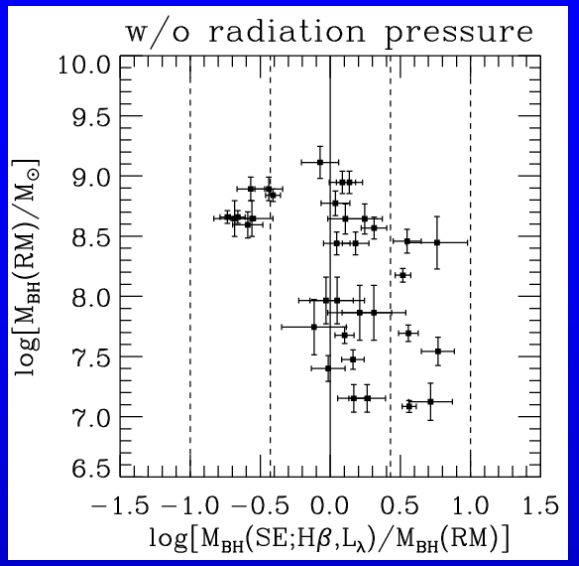


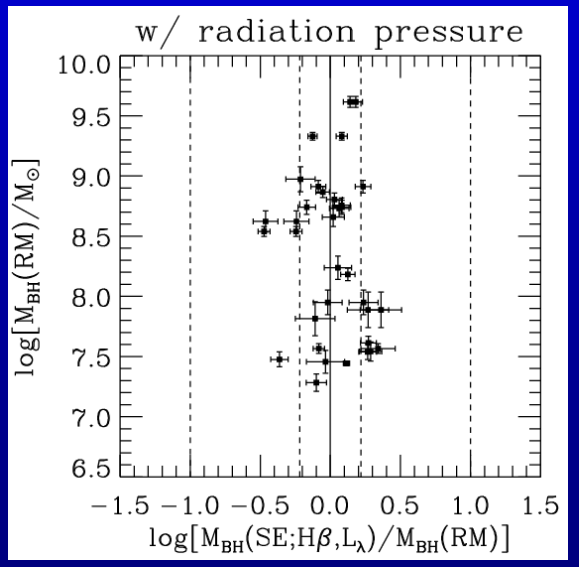
$L/L_{EDD} = \log L_{BOL} - 38 - \log M(H\beta)$

0.4 dex

Hβ

0.2 dex





(Data from MV & Peterson 2006, Marconi et al. 2008)

Main Points to Take Away

- Single-epoch mass estimates: accurate to within a factor of 3.5 – 4
- Apparent Eddington Ratios: $L_{bol}/L_{Edd} \sim 0.3$
- Intrinsic ratios: $L_{bol}/L_{Edd} \sim 0.05$
- Edd. Ratio increases with black hole mass
- Caution 1: Ratio is ONLY a crude approximation at present.
- Caution 2: S/N of data matters!!
- Mass function is not simple scaling of the LF