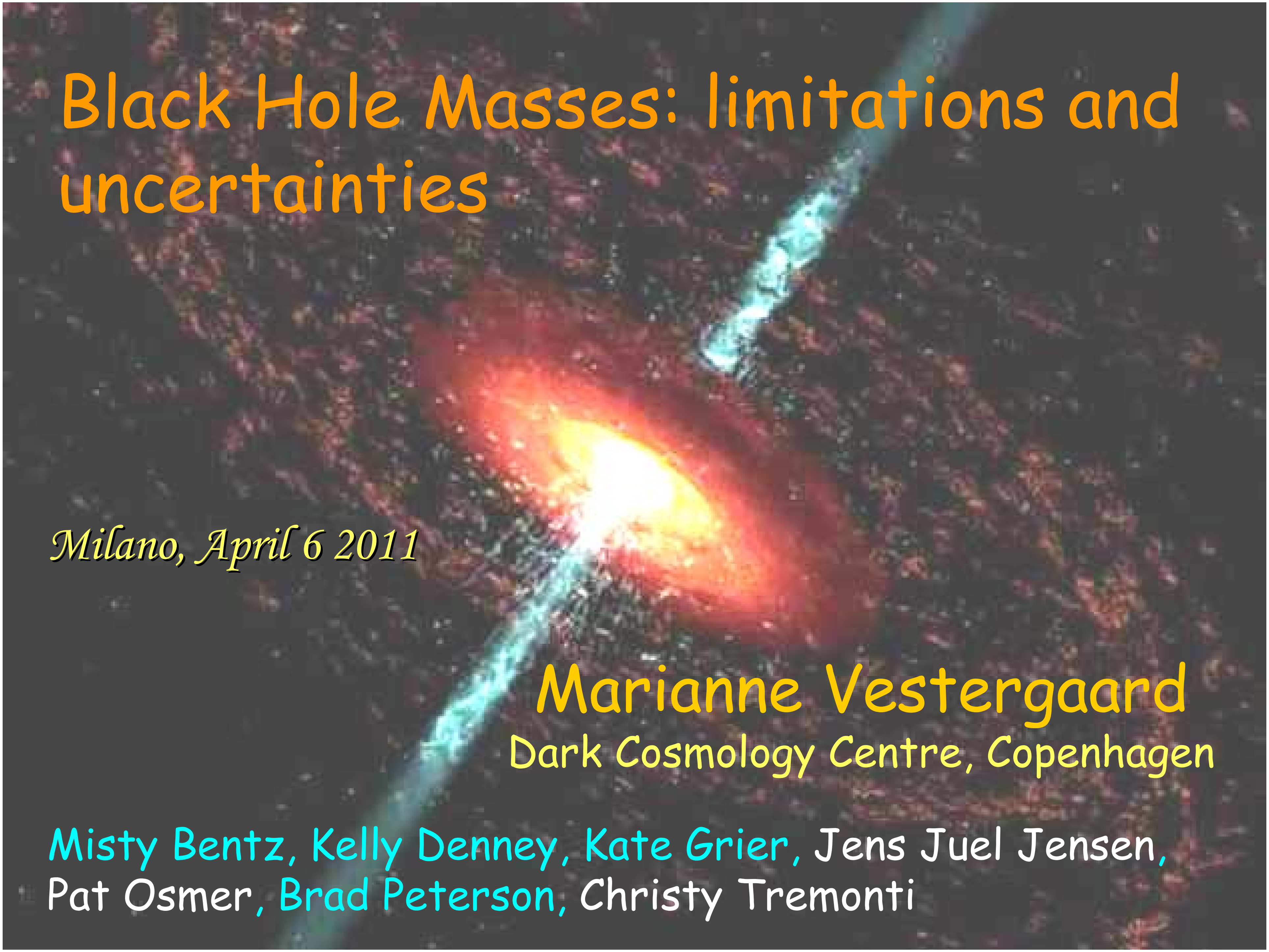


Black Hole Masses: limitations and uncertainties

Milano, April 6 2011

Marianne Vestergaard
Dark Cosmology Centre, Copenhagen

Misty Bentz, Kelly Denney, Kate Grier, Jens Juel Jensen, Pat Osmer, Brad Peterson, Christy Tremonti

Points to Make

- Jungle of mass equations: Use equations on the same mass scale

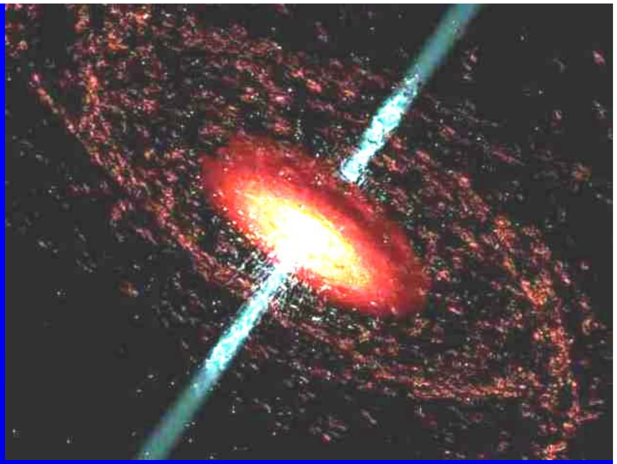
- Use all applicable emission lines.

- Matters ***how*** you measure lines and ***what*** you measure (quality)

- Reminder: CIV not good for high-L NLS1s; MgII calibration not good.

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)

(M. Bentz talk;
K. Grier Poster)

- 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)

Mass Scaling Relationships

Note:

- Several relations exist in the literature – also for lines such as Hα, MgII, 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)

Mass Scaling Relationships

Note:

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

$$M_{BH} \propto FWHM^{\beta} L^{0.5} \; ; \; \beta \approx 1.1$$

2008;

Wang et al. 2009 (empirical; physics limited)

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

Scaling Relationships:

(calibrated to 2004 Reverberation M_{BH})

- Hβ: $$M_{BH} = 8.3 \cdot 10^6 \left(\frac{\text{FWHM(H}\beta\text{)}}{10^3\,\text{km/s}}\right)^2 \left(\frac{\lambda L_\lambda(5100\text{A})}{10^{44}\,\text{ergs/s}}\right)^{0.50} M_\odot$$
- MgII: $$M_{BH} = 6.2 \cdot 10^6 \left(\frac{\text{FWHM(MgII)}}{10^3\,\text{km/s}}\right)^2 \left(\frac{\lambda L_\lambda(2100\text{A})}{10^{44}\,\text{ergs/s}}\right)^{0.50} M_\odot$$
- CIV: $$M_{BH} = 4.5 \cdot 10^6 \left(\frac{\text{FWHM(CIV)}}{10^3\,\text{km/s}}\right)^2 \left(\frac{\lambda L_\lambda(1350\text{A})}{10^{44}\,\text{ergs/s}}\right)^{0.53} M_\odot$$

1σ absolute uncertainty: factor ~3.5 – 4

(Vestergaard 2002; Vestergaard & Peterson 2006)

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

Word of Caution

- Comparing masses from different lines?
  Use equations on the same mass scale

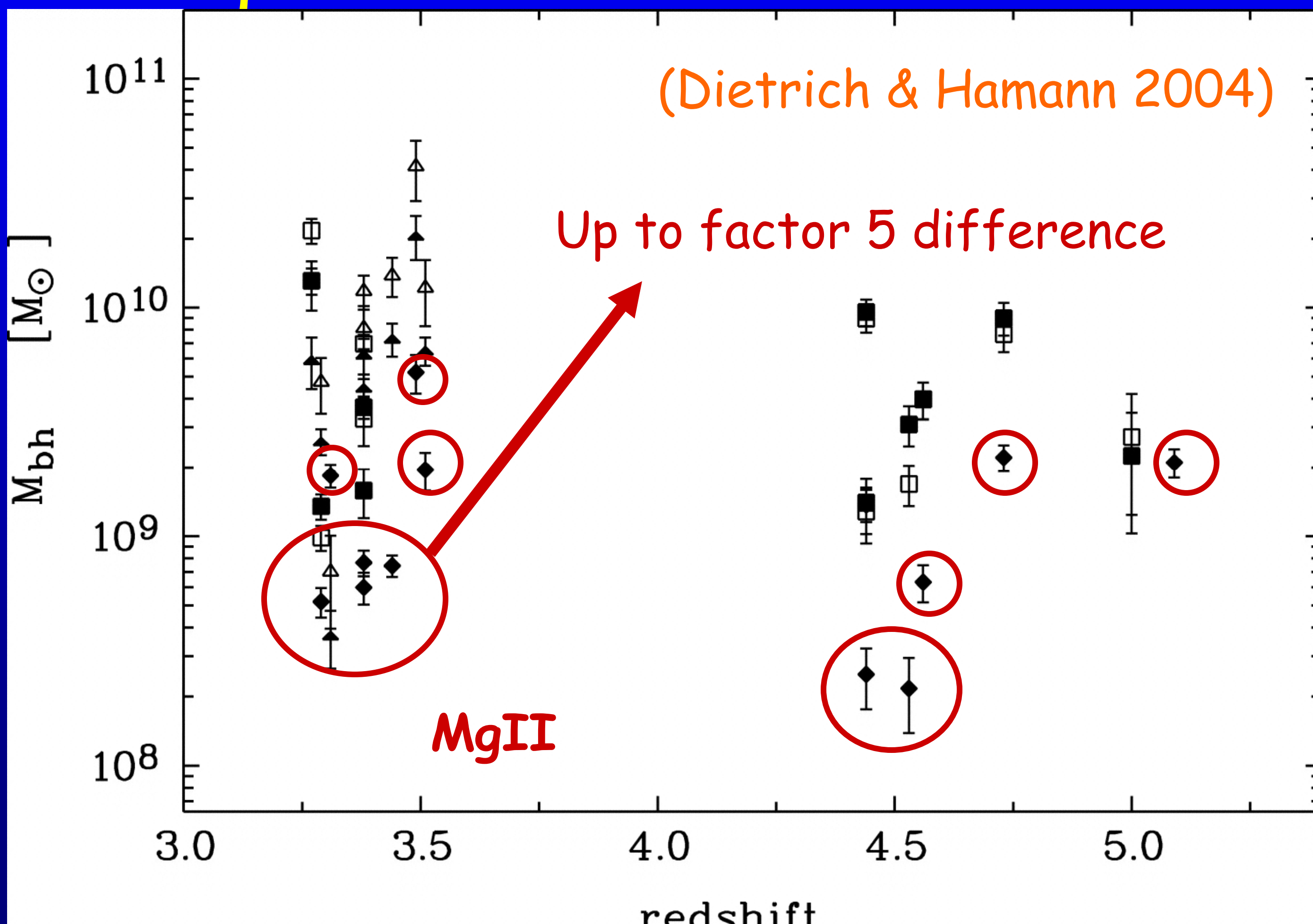
- Have multiple lines?

  - Use equations on the same mass scale
  - Use all applicable emission lines.

- Discard bad data (see later)

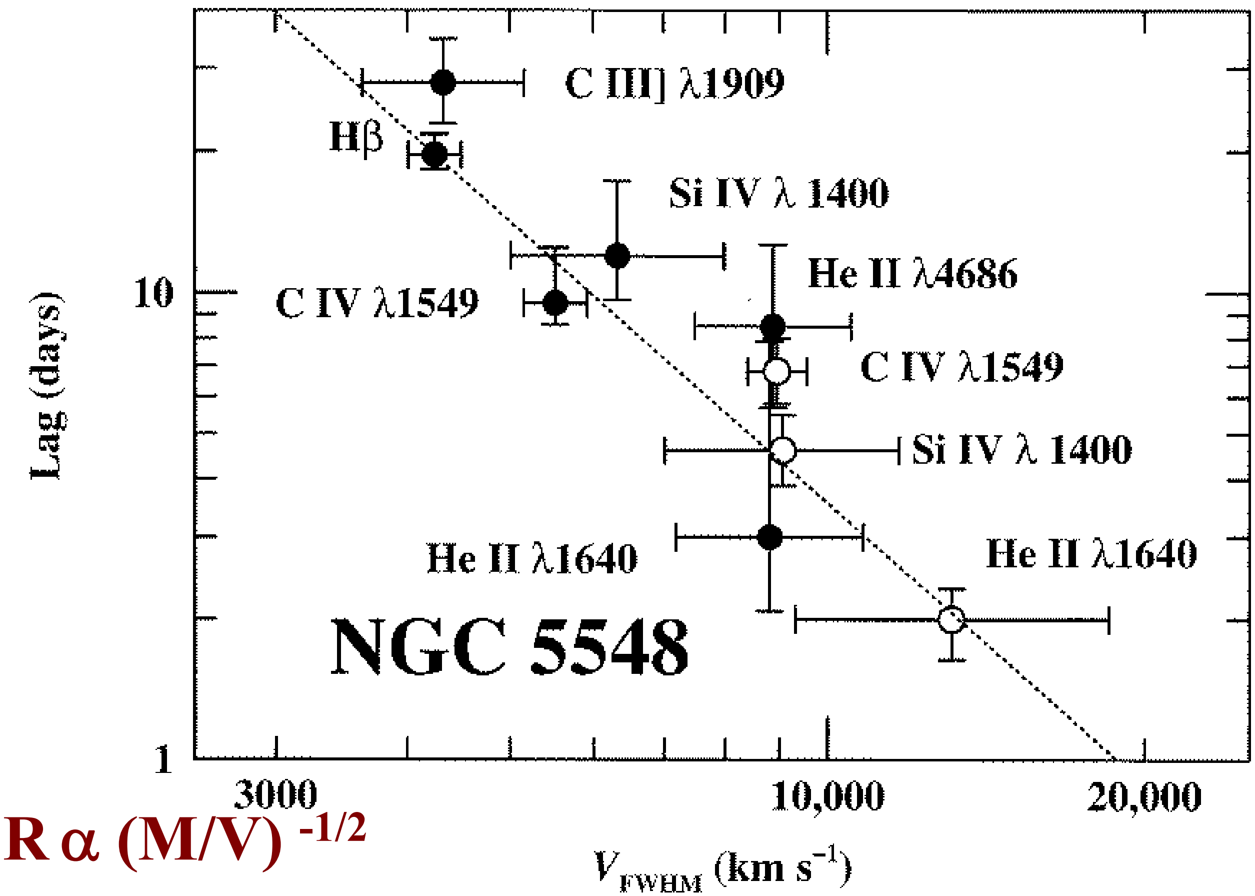
Word of Caution

- Comparing masses from different lines?
  Use equations on the same mass scale
- scale



Virialized BLR

The power of multiple lines for mass estimates!



$R \alpha (M/V)^{-1/2}$

- ● Filled circles: 1989 data from *IUE* and ground-based telescopes.
- ○ Open circles: 1993 data from *HST* and *IUE*.
- … Dotted line corresponds to virial relationship with $M = 6 \times 10^7 M_{\odot}$.

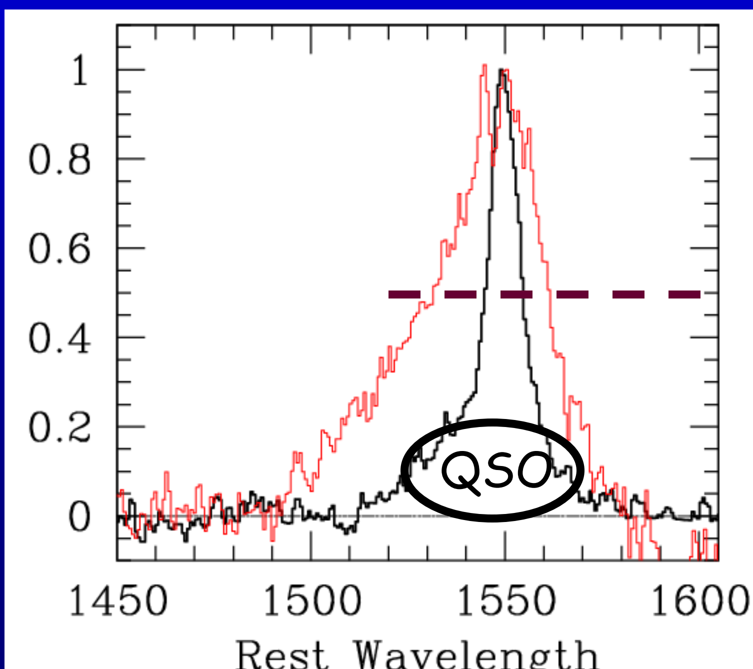
Peterson and Wandel 1999

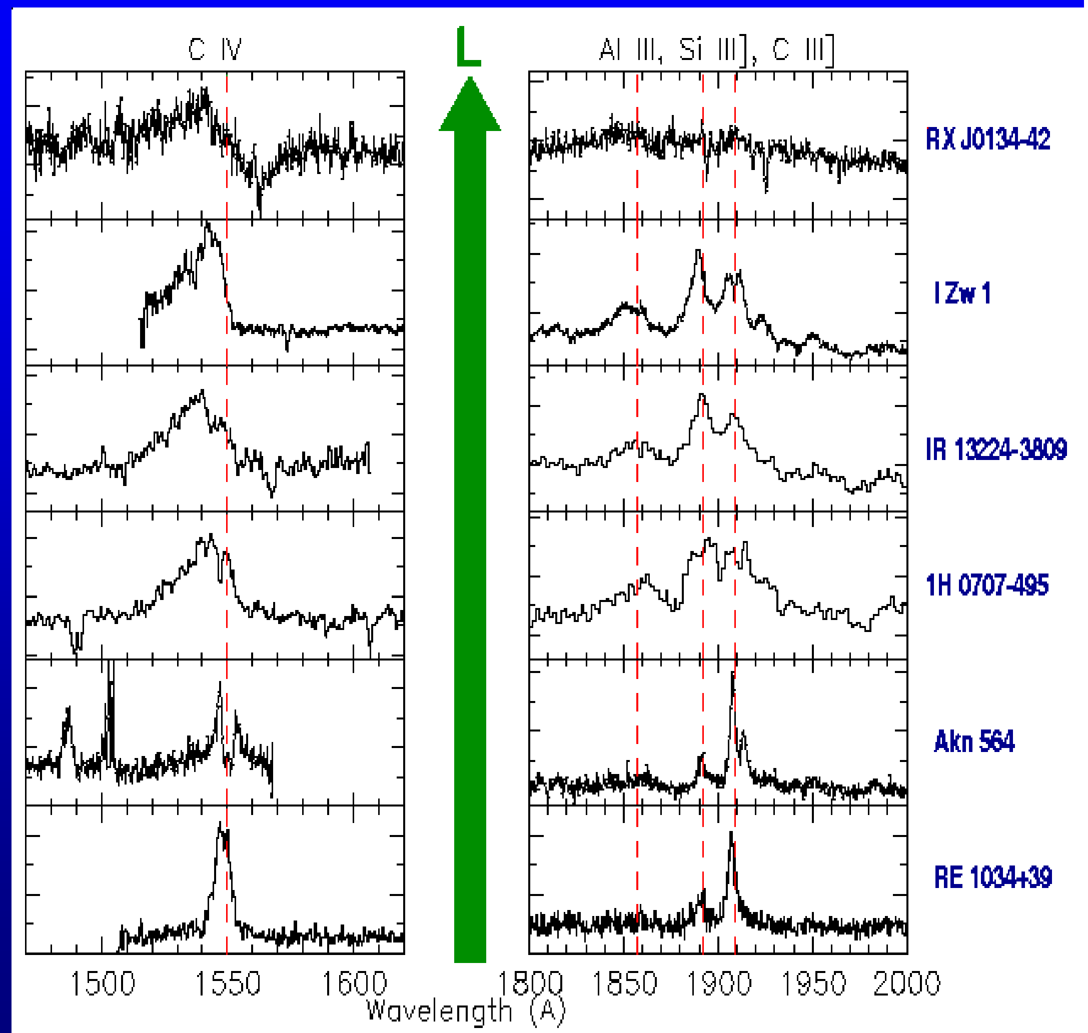
CIV line of NLS1s

NLS1s: low M_{BH}

high L_{BOL}/L_{Edd}

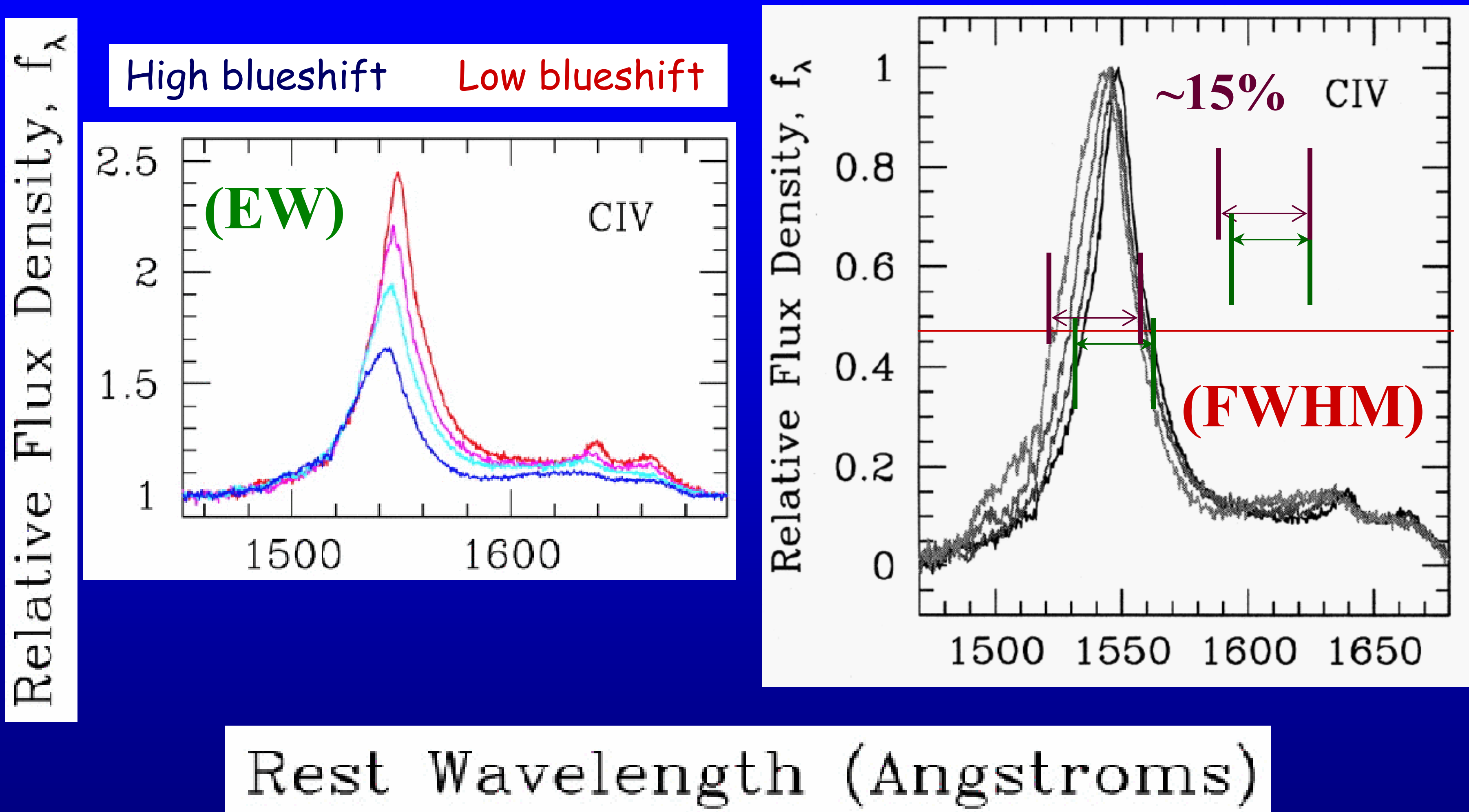
Possible outflow component to CIV?





(Leighly 2001)

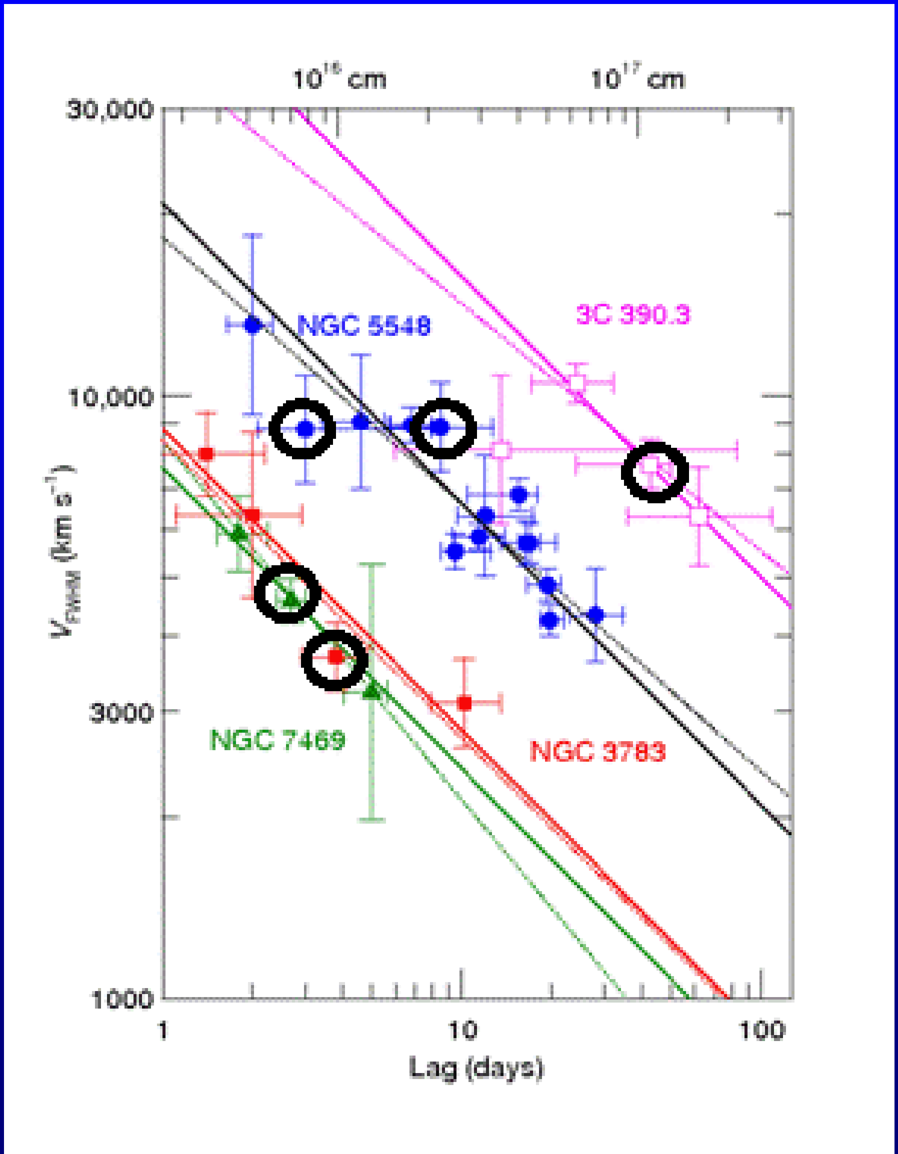
Are Quasar CIV Profiles Problematic?

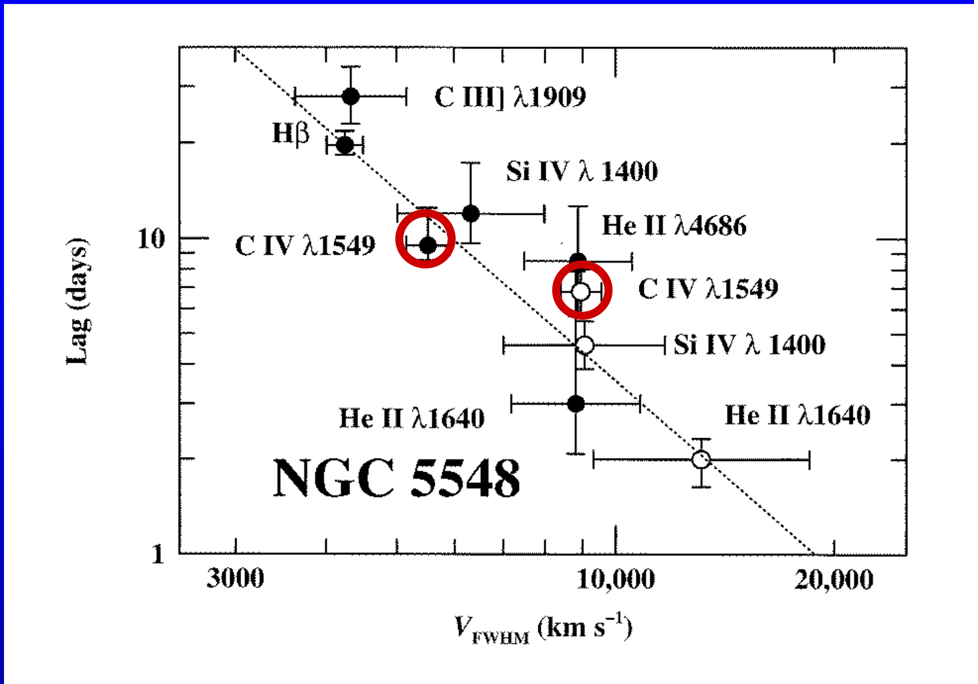


Further investigation needed!

(Richards et al. 2002)

Virialized CIV line gas





$R \alpha (M/V)^{-1/2}$

R-L relation for CIV include high-z QSOs (Denney talk)

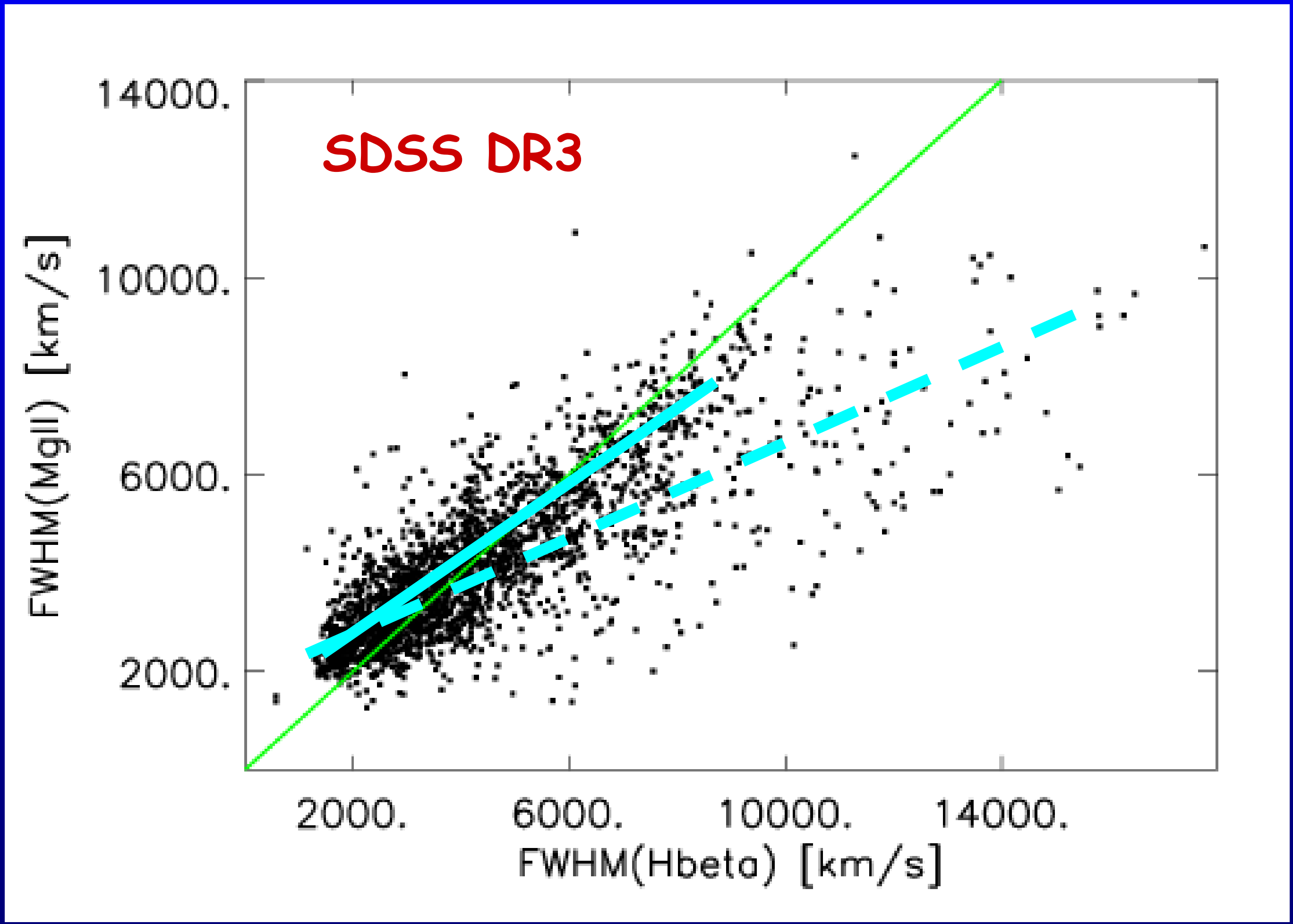
(Peterson & Wandel 1999, 2002)

Other Issues

- Radiation pressure (Marconi Talk)
- Host galaxy contamination – R-L relation (Bentz talk)
- Mass estimation uncertainties (Denney and Woo talks)
- Mass Calibration OK for NLS1s?
- S/N issues (Also Denney talk)

No Broad Emission Line is Perfect!

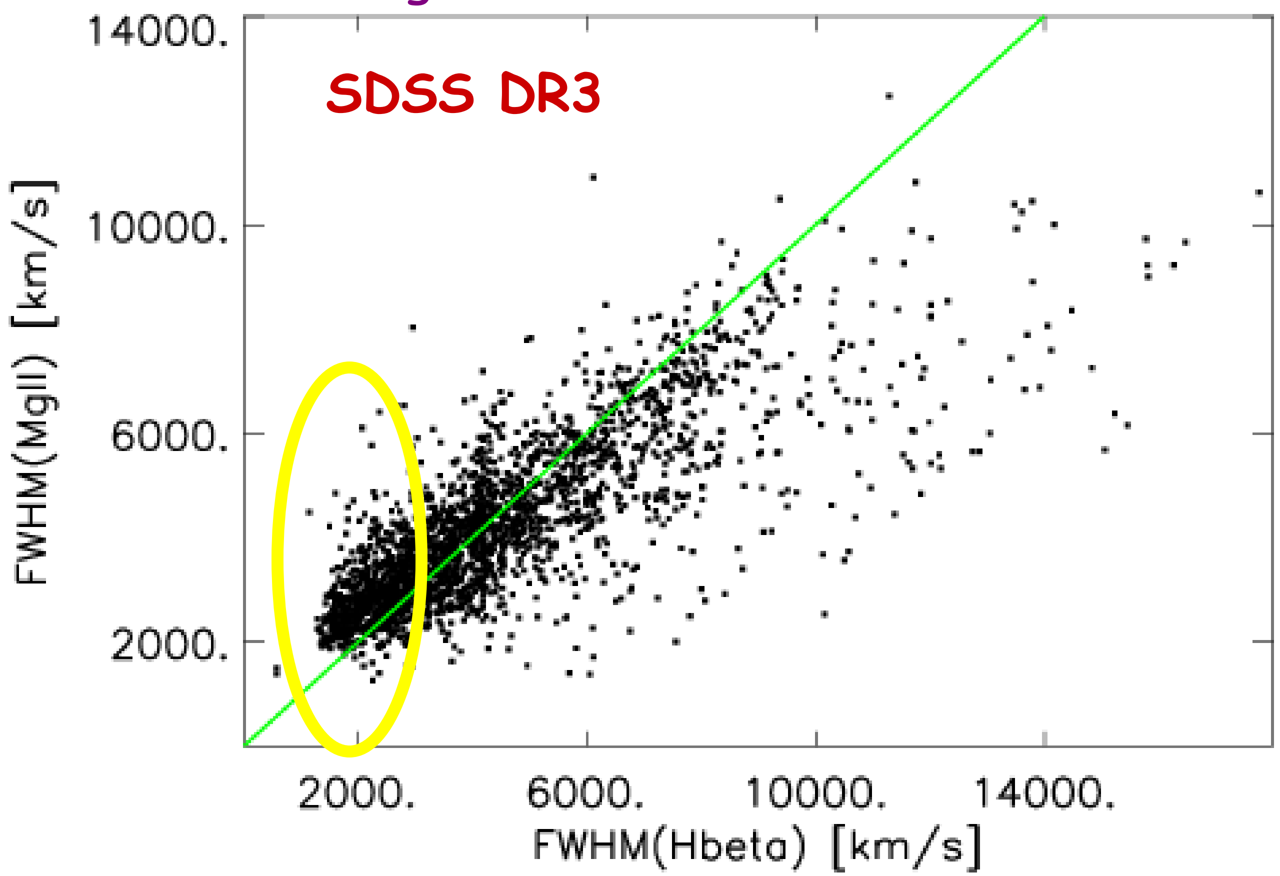
- Hβ and MgII FWHM are not always the same – contrary to common claims



MgII Masses Problematic for NLS1s?

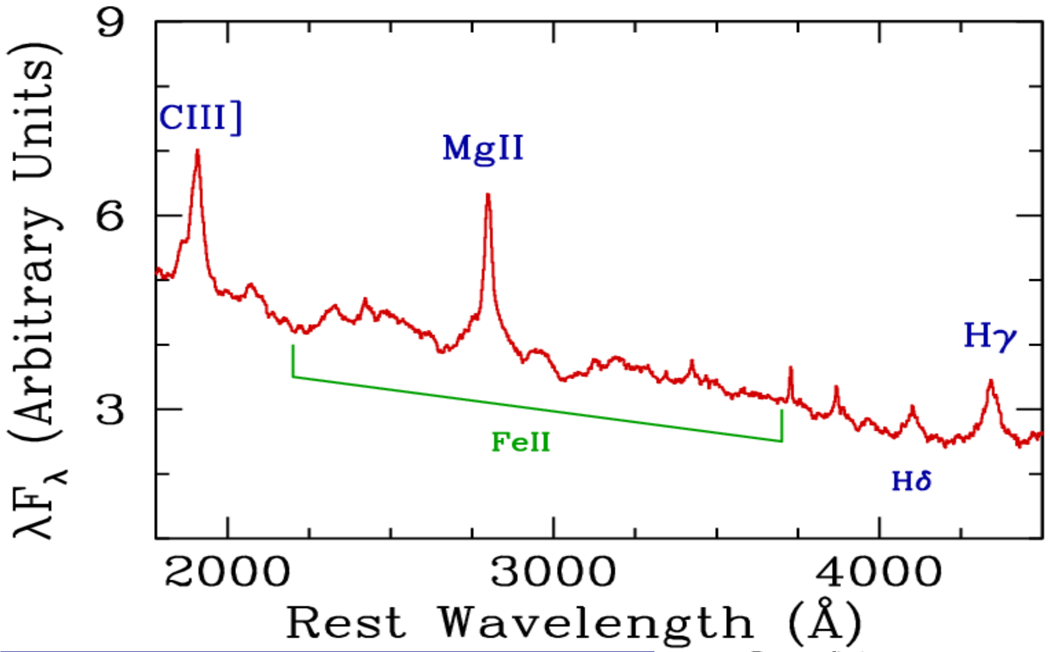
- Hβ and MgII FWHM relation is not 1-to-1 for FWHM<2500 km/s

VO09 MgII calibration not valid < 2500 km/s

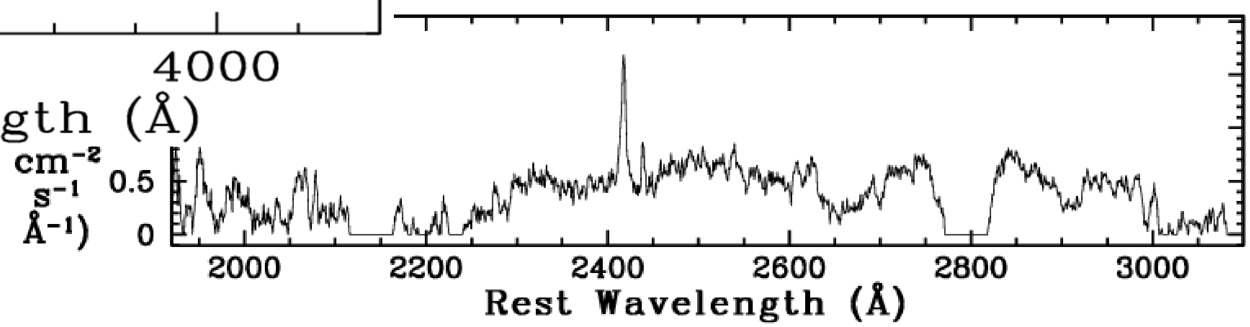


No Broad Emission Line is Perfect!

- Hβ and MgII FWHM are not always the same – contrary to common claims
- MgII is strongly contaminated by strong, broad features of FeII, complicating its measurement



Half the MgII line flux is submerged in FeII emission



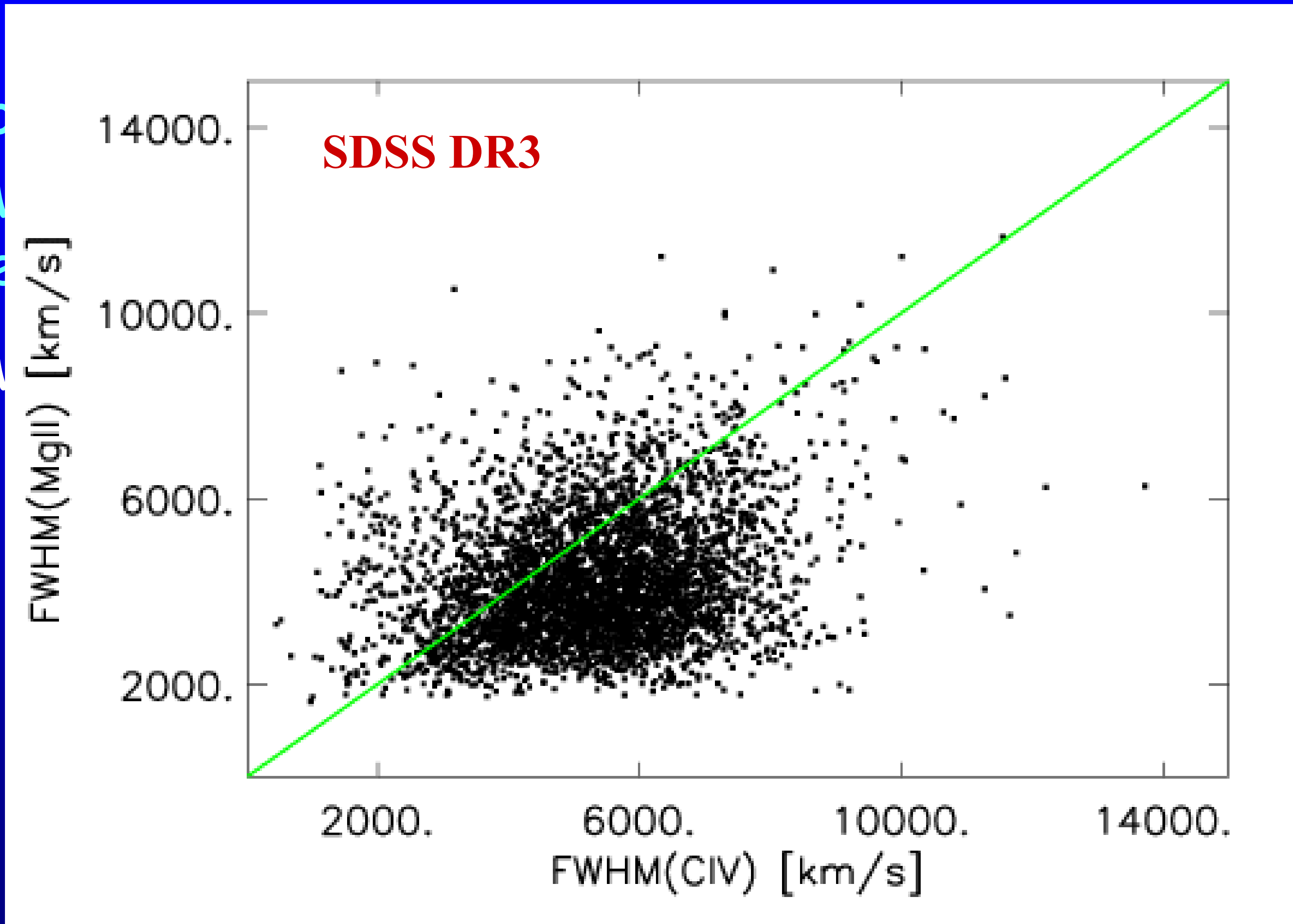
(Vestergaard & Wilkes 2001)

No Broad Emission Line is Perfect!

- Hβ and MgII FWHM are not always the same – contrary to common claims
- MgII is strongly contaminated by strong, broad features of FeII, complicating its measurement
- MgII and CIV FWHM often deviate

No Broad Emission Line is Perfect!

- H … ntrary
  to
- M
  fe
- M

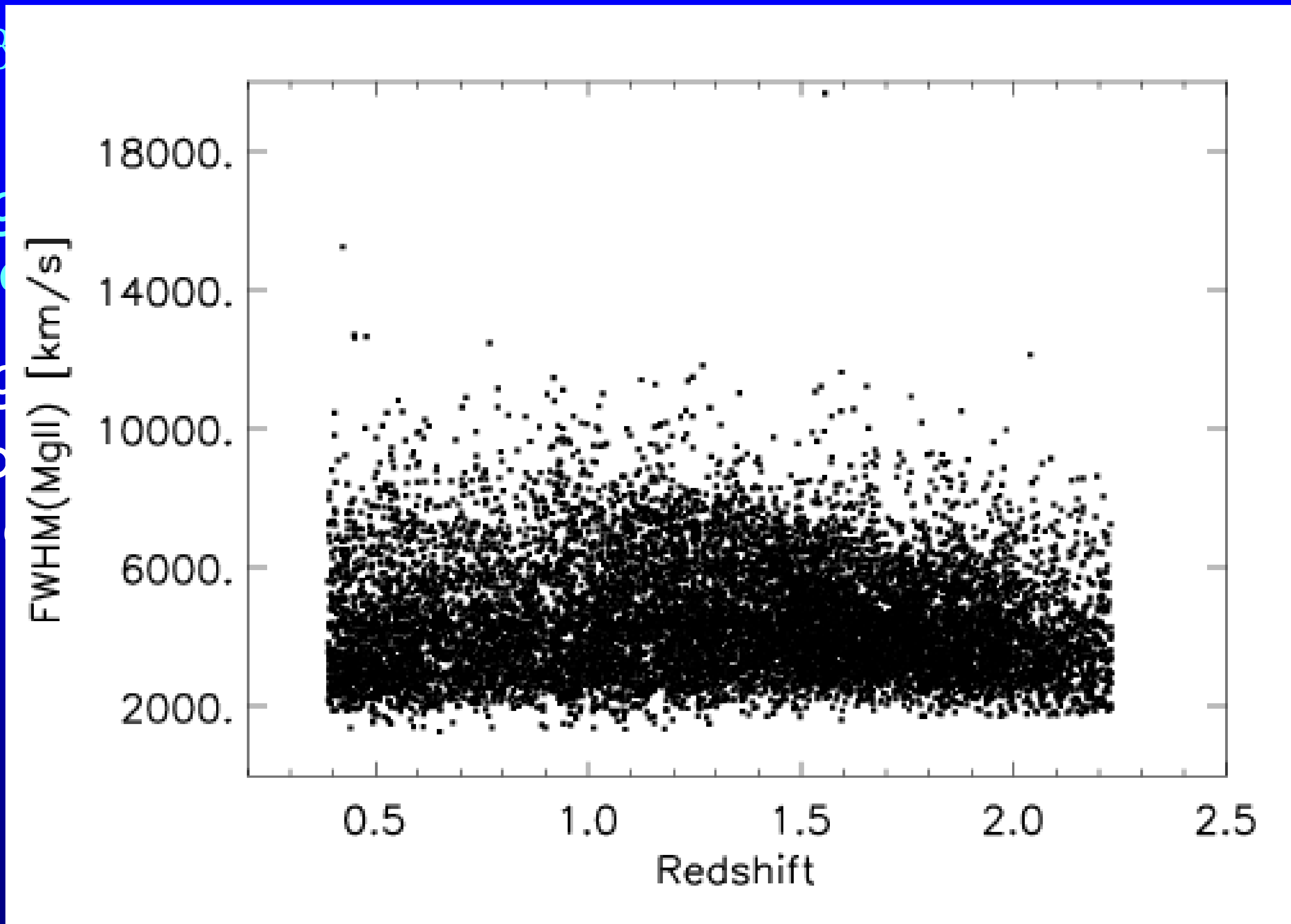


No Broad Emission Line is Perfect!

- Hβ and MgII FWHM are not always the same – contrary to common claims
- MgII is strongly contaminated by strong, broad features of FeII, complicating its measurement
- MgII and CIV FWHM often deviate
- - but cause is unclear: MgII is likely also problematic due to systematic narrowing with *z*

No Broad Emission Line is Perfect!

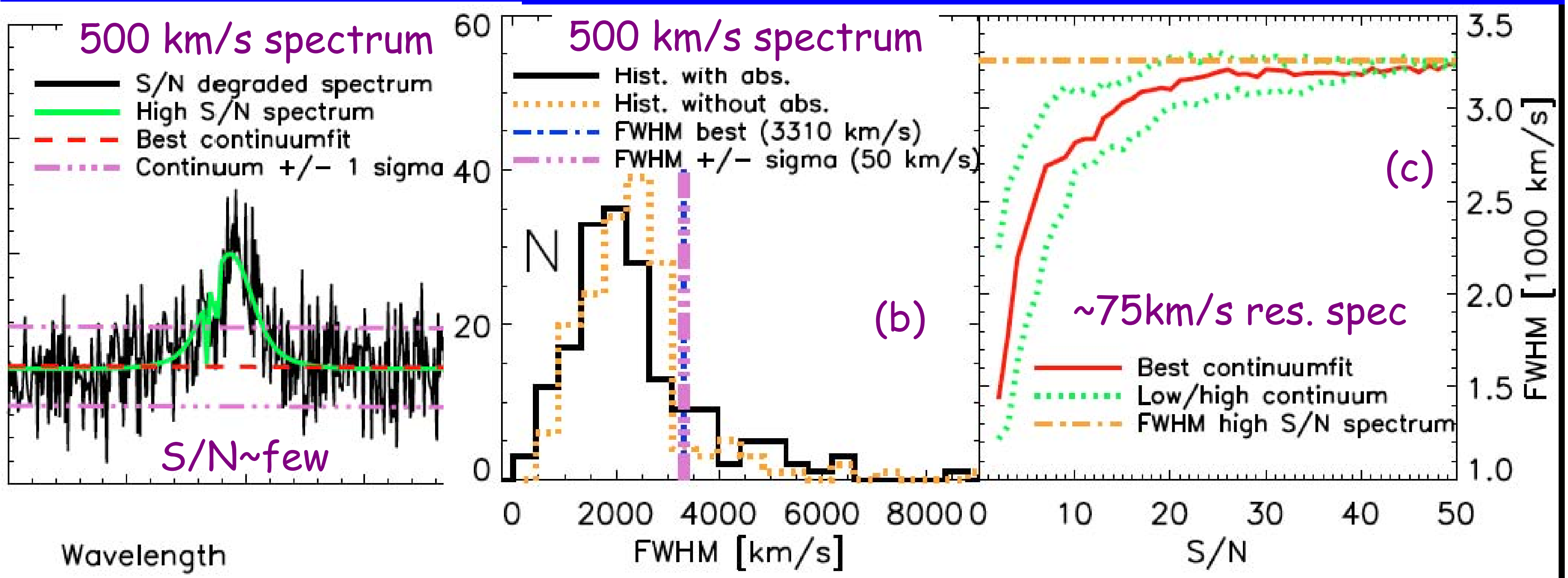
- Hβ ... trary to
- Mg... fe...
- Mg...
- - b... atic du...



No Broad Emission Line is Perfect!

- Hβ and MgII FWHM are not always the same – contrary to common claims
- MgII is strongly contaminated by strong, broad features of FeII, complicating its measurement
- MgII and CIV FWHM often deviate
- - but cause is unclear: MgII is likely also problematic due to systematic narrowing with *z*
- Better understanding of profile differences needed
- Investigations of systematic biases needed to improve and enhance black hole mass estimates (ongoing!)

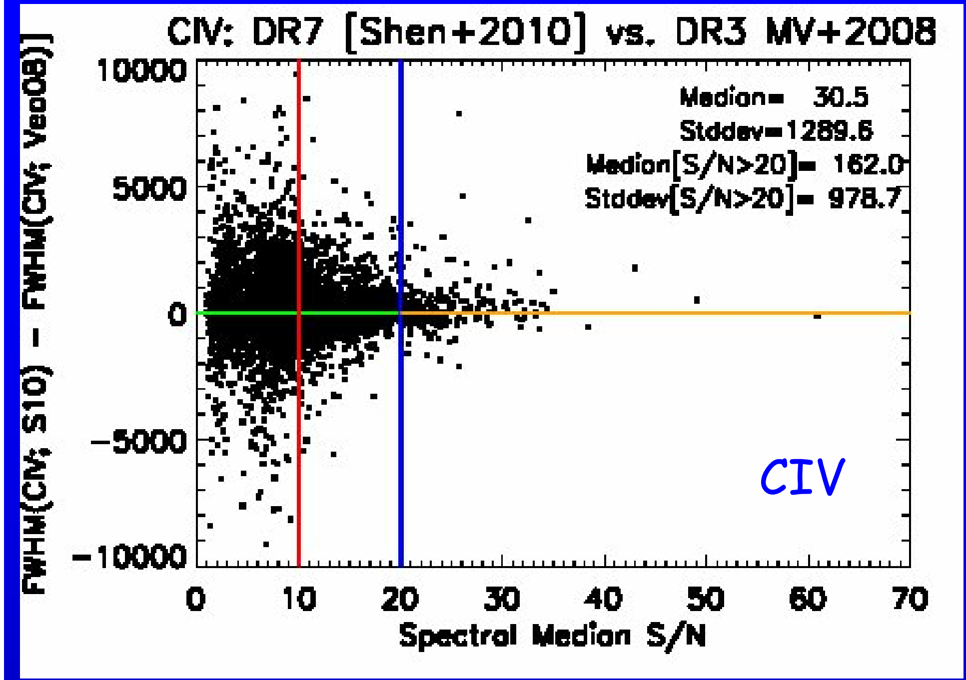
Simulations: Narrow lines & low-S/N

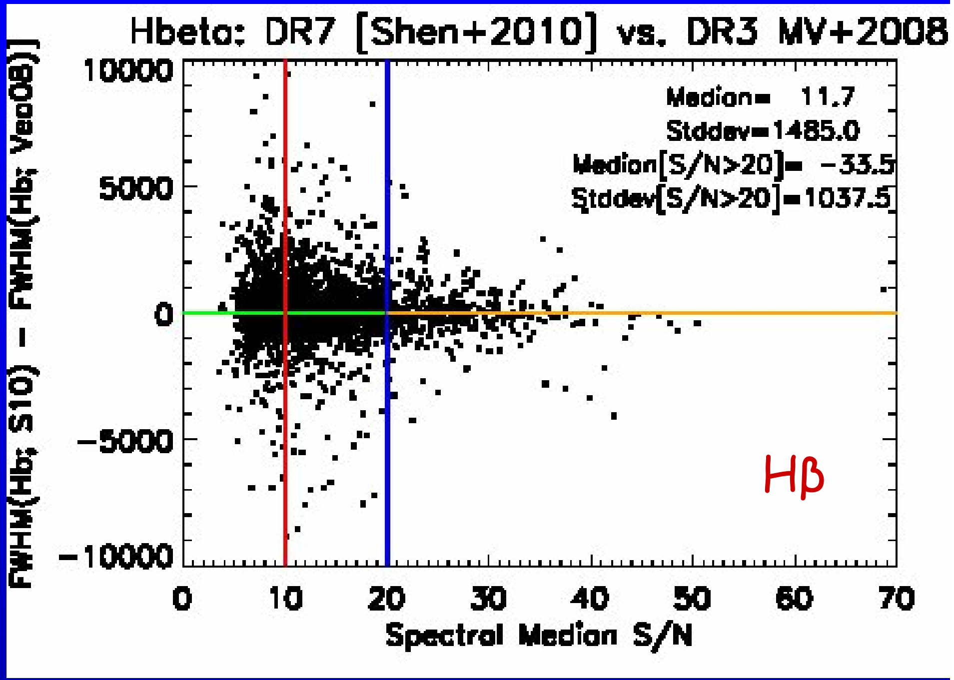


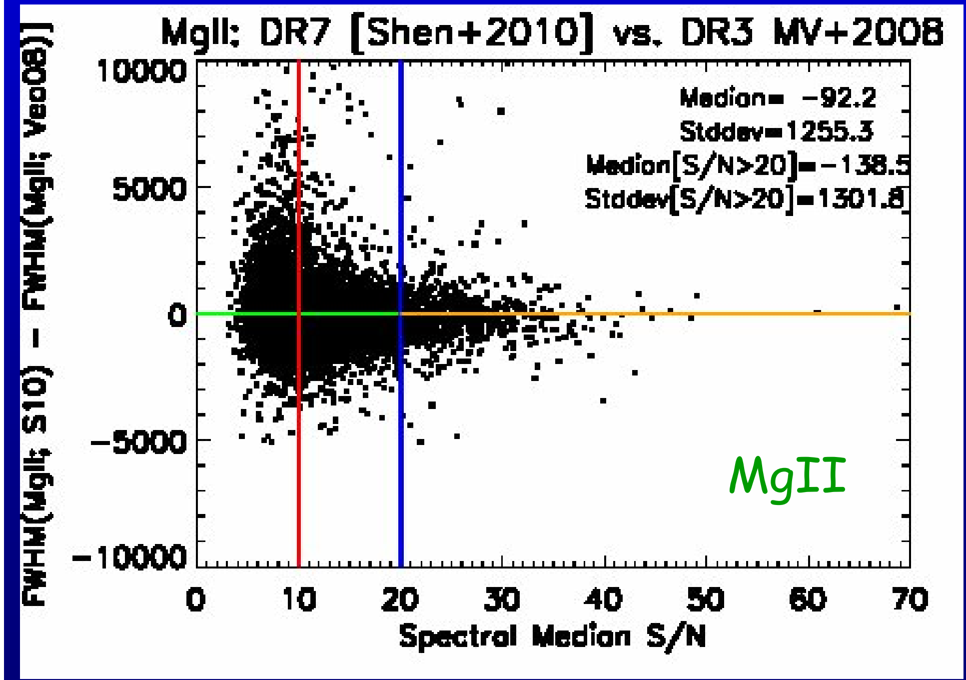
- Low-S/N underestimates FWHM (fig b)
- Undetected absorption worsens issue
- S/N > 20-25 needed to limit measurement error (fig c)

(J.J.Jensen, Work in progress)

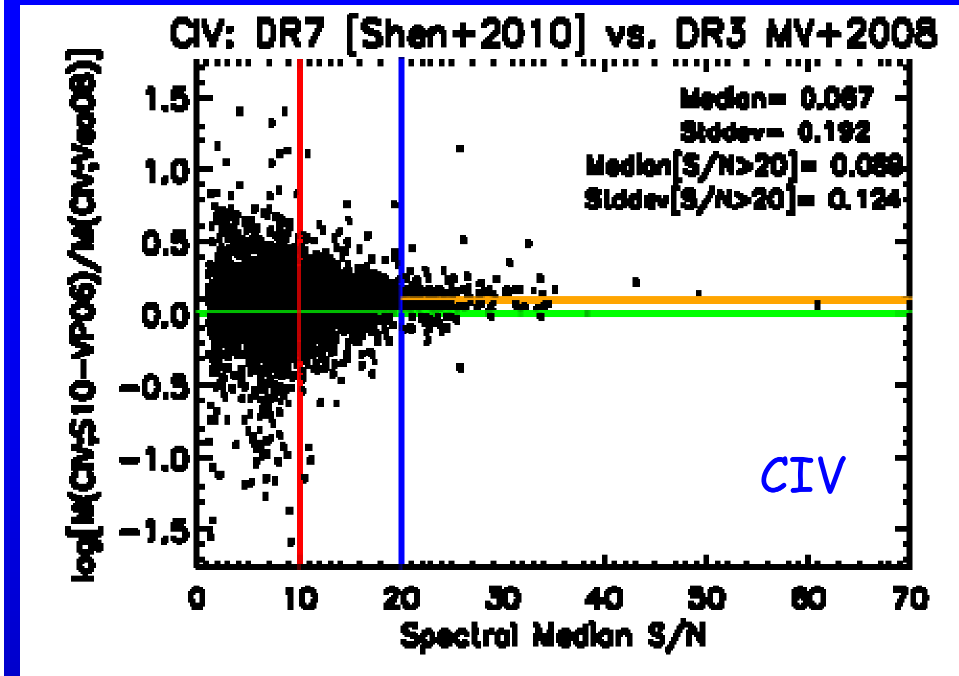
S/N Matters!

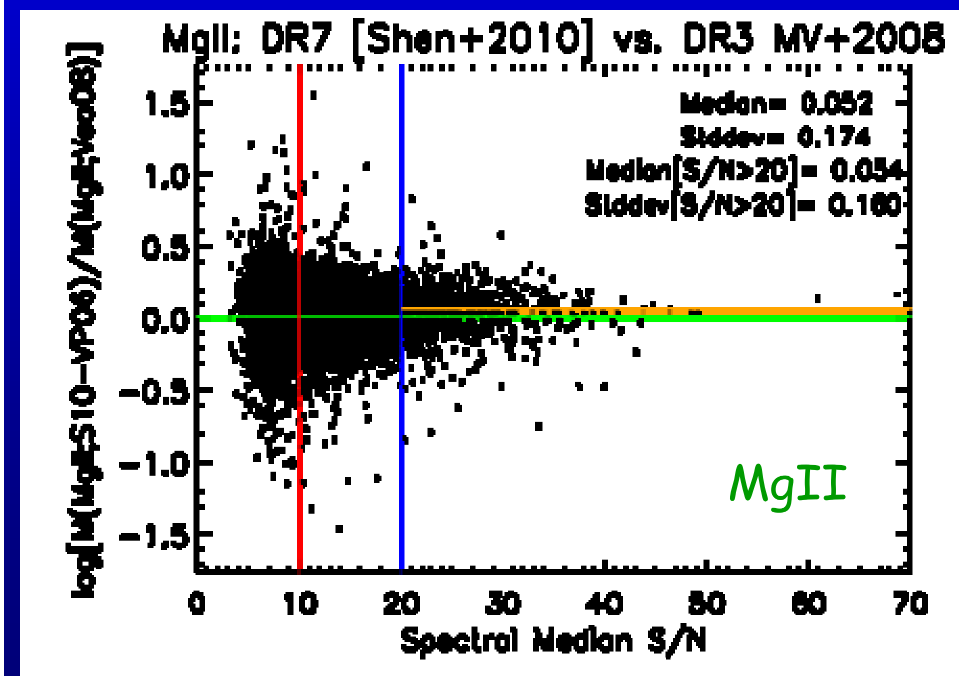

CIV: DR7 [Shen+2010] vs. DR3 MV+2008
FWHM(CIV; S10) − FWHM(CIV; Ves08)]
Median= 30.5
Stddev=1289.6
Median[S/N>20]= 162.0
Stddev[S/N>20]= 978.7
CIV
Spectral Median S/N

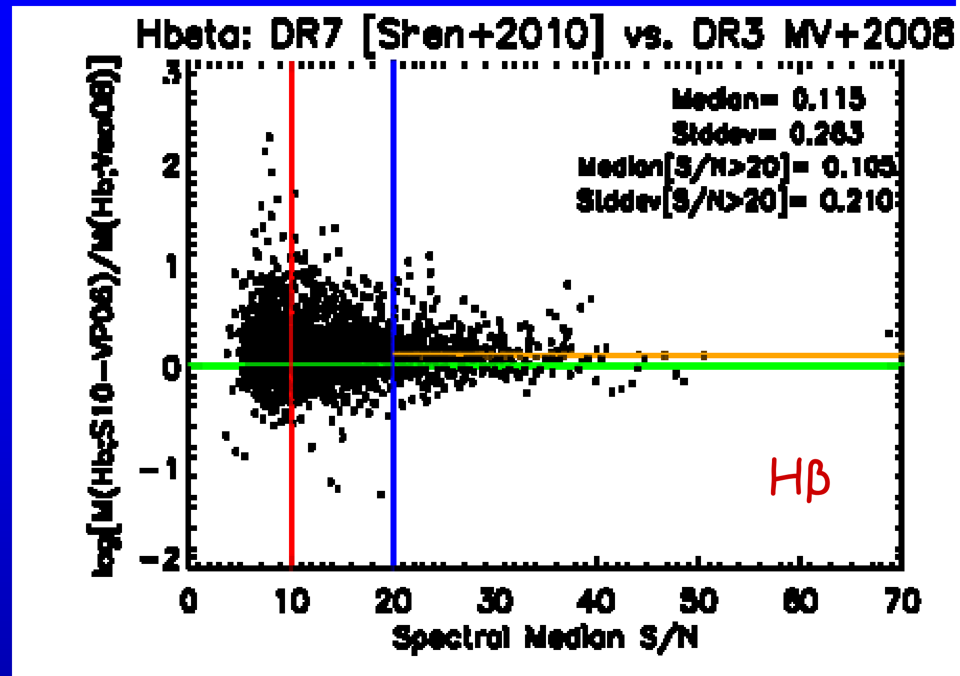

Hbeta: DR7 [Shen+2010] vs. DR3 MV+2008
FWHM(Hb; S10) − FWHM(Hb; Ves08)]
Median= 11.7
Stddev=1485.0
Median[S/N>20]= −33.5
Stddev[S/N>20]=1037.5
Hβ
Spectral Median S/N


MgII: DR7 [Shen+2010] vs. DR3 MV+2008
FWHM(MgII; S10) − FWHM(MgII; Ves08)]
Median= −92.2
Stddev=1255.3
Median[S/N>20]=−138.5
Stddev[S/N>20]=1301.8
MgII
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(CIV;S10−VP06)/M(CIV;Vest08)]
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(MgII;S10−VP06)/M(MgII;Vest08)]
Spectral Median S/N

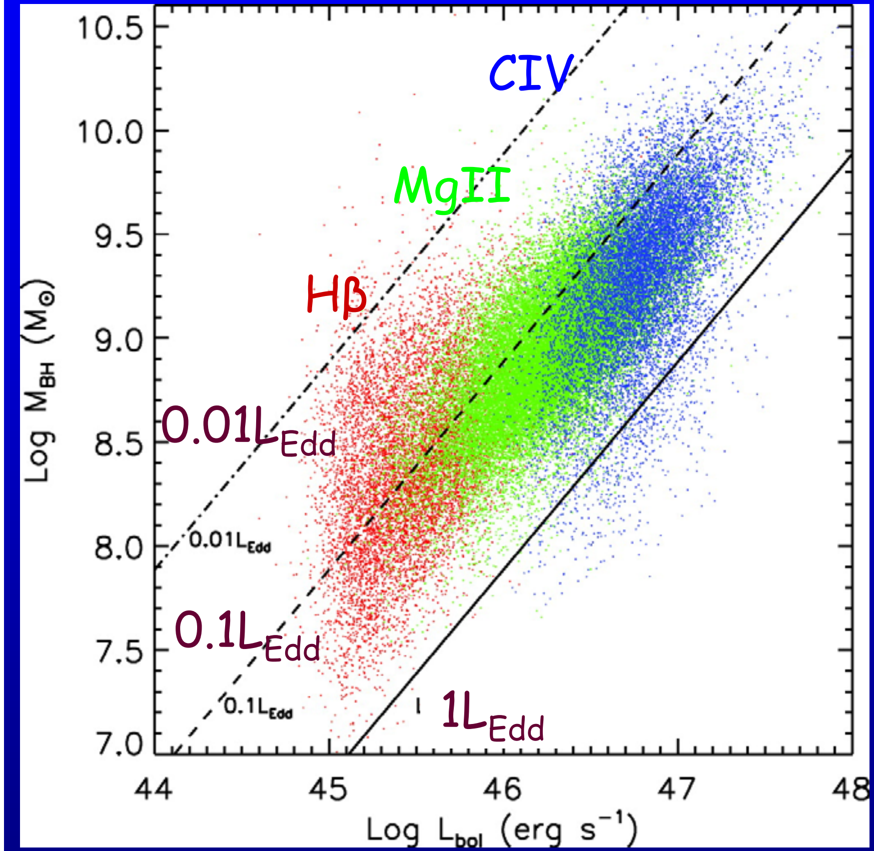

Hbeta: DR7 [Shen+2010] vs. DR3 MV+2008
Median= 0.115
Stddev= 0.263
Median[S/N>20]= 0.105
Stddev[S/N>20]= 0.210
Hβ
log[M(Hb;S10−VP06)/M(Hb;Vest08)]
Spectral Median S/N

Main Points to Take Away

- Single-epoch mass estimates: accurate to within a factor of 3.5 – 4. Can be improved!
- Matters how you measure the spectra
- Caution 1: Use only good data. Beware of absorption and low S/N!!!
- Caution 2: Multiple emission lines yield better mass estimates
- Important to study: Measurement uncertainties & biases, radiation pressure, (MgII) calibration issues for NLS1s?
- Recall: mass estimates work – issues relate to accuracy and precision!

SDSS DR5

$L/L_{Edd} \sim 0.25$

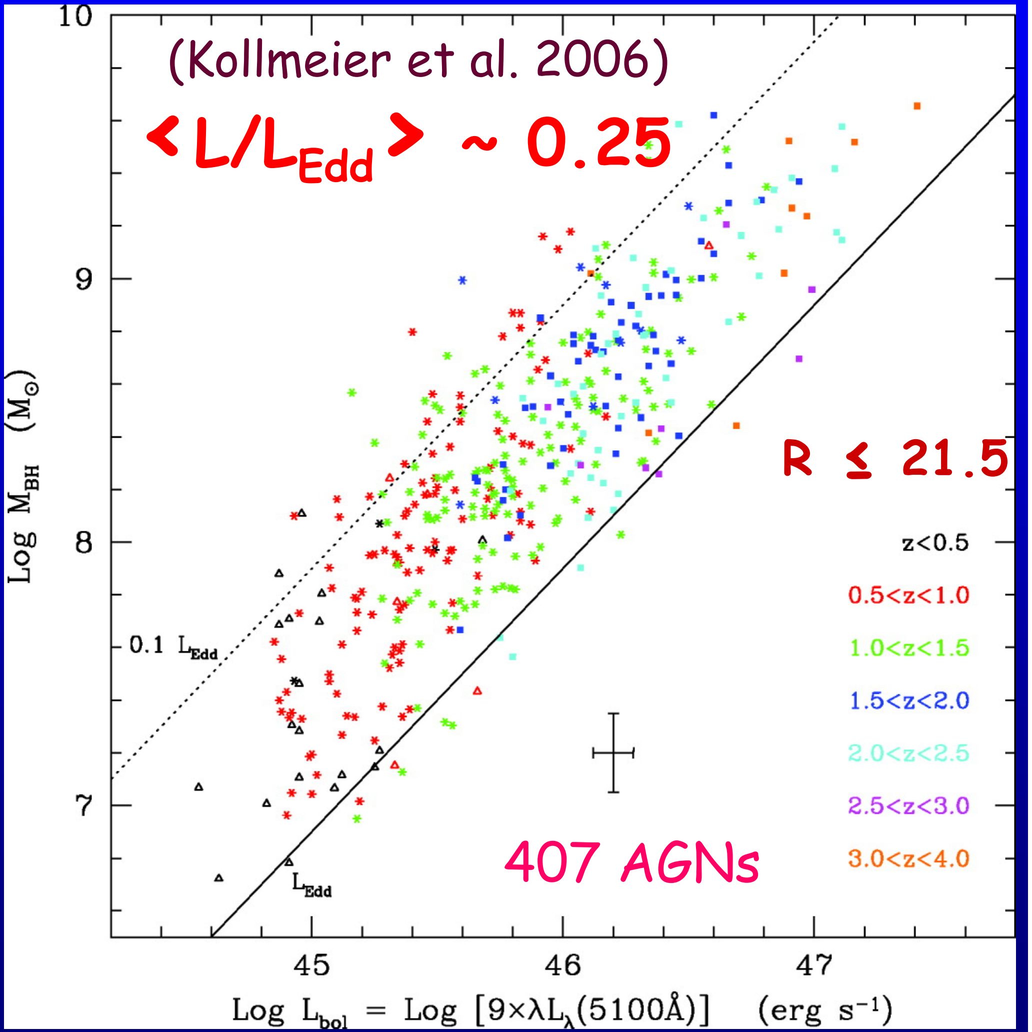


57,000 quasars

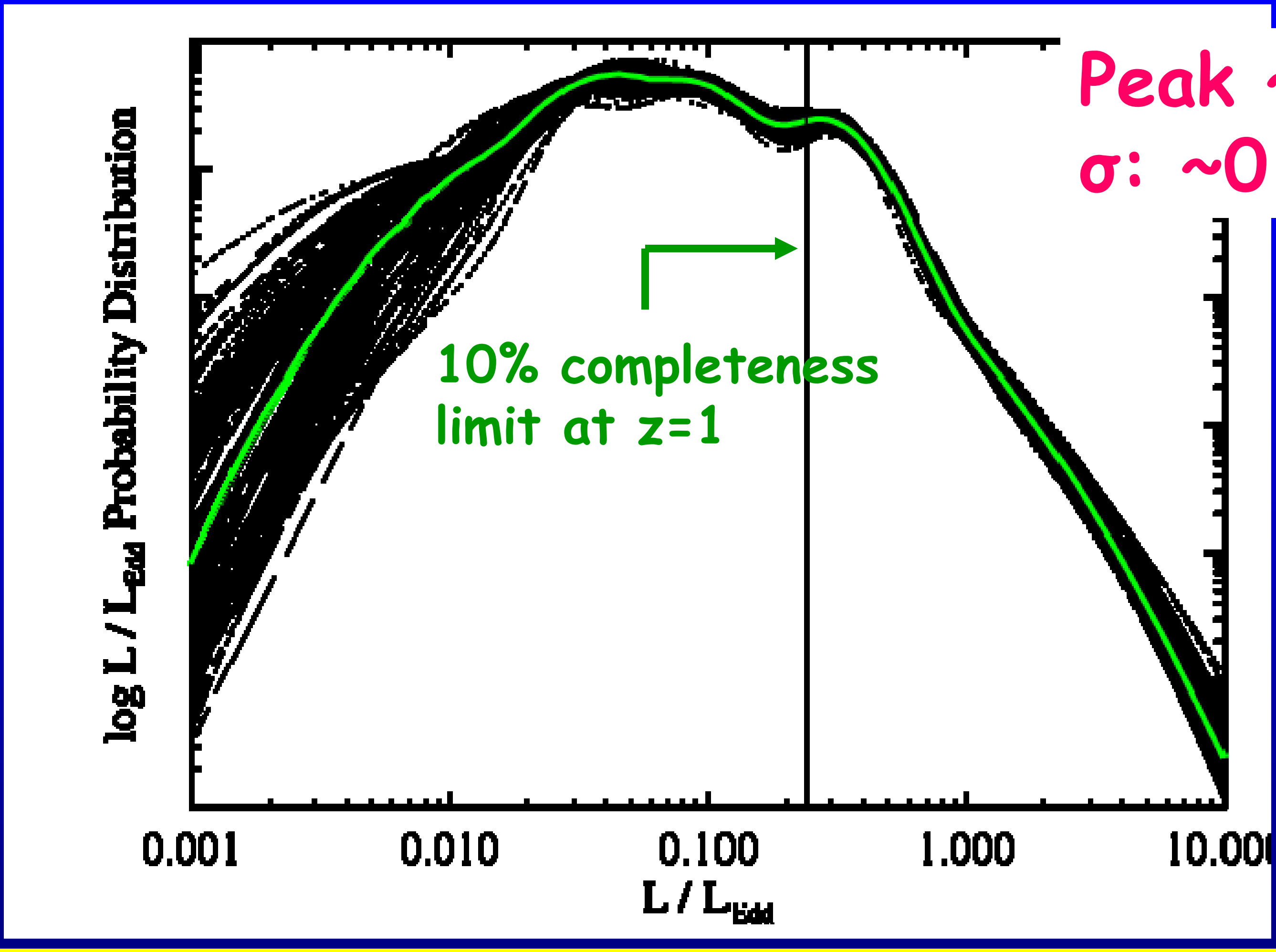
(Shen et al. 2008)

AGES Survey

L/L_{Edd} dispersion ~ 0.3dex



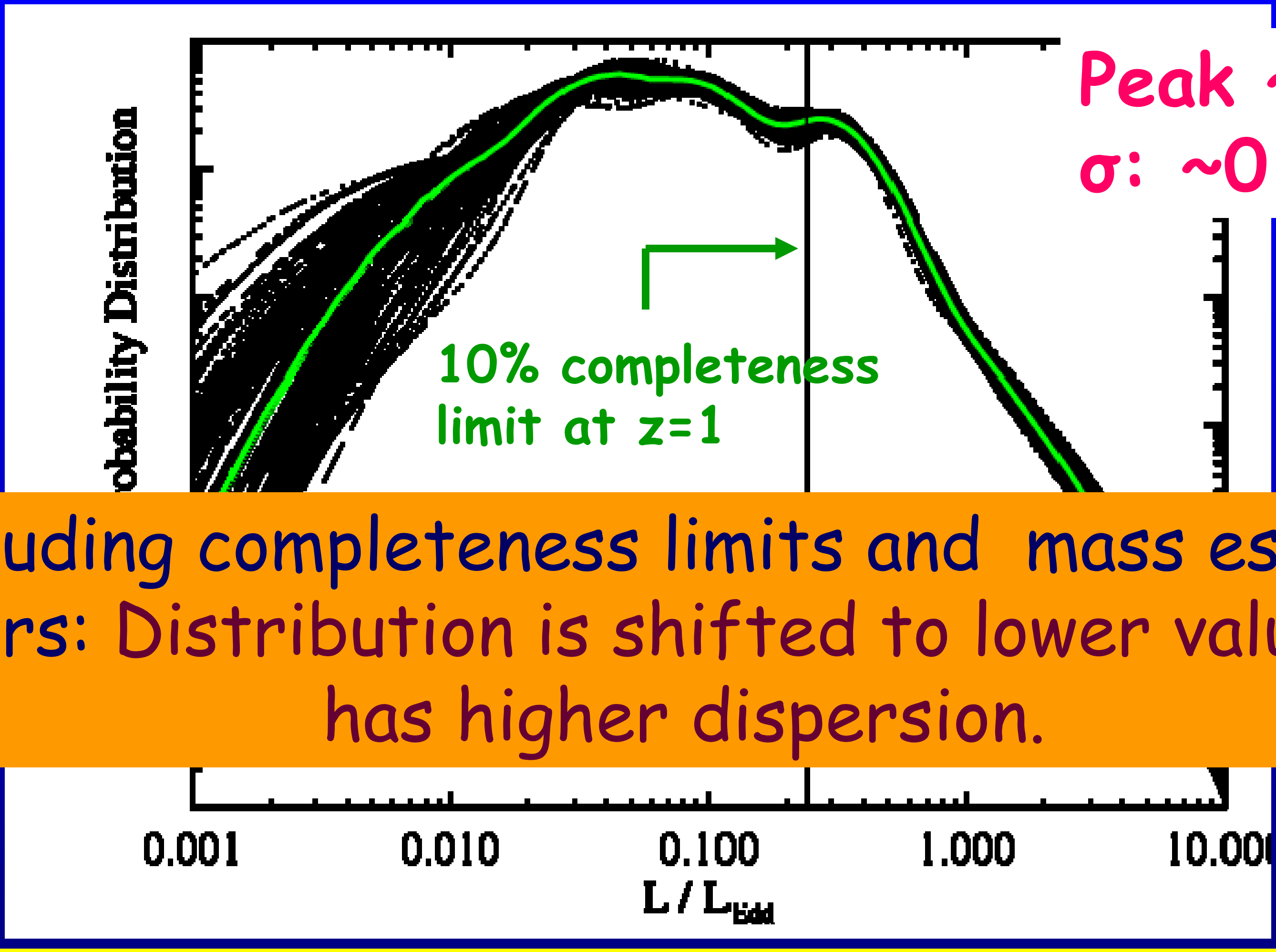
Bayes Stats of DR3 Quasar Luminosity Function sample: Eddington Ratio Distribution



Peak ~0.05
σ: ~0.4 dex

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

Bayes Stats of DR3 Quasar Luminosity Function sample: Eddington Ratio Distribution



Peak ~0.05
σ: ~0.4 dex

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]

Main Points to Take Away

- Single-epoch mass estimates: accurate to within a factor of 3.5 – 4. Can be improved!
- Matters how you measure the spectra
- Caution 1: Use only good data. Beware of absorption and low S/N!!!
- Caution 2: Multiple emission lines yield better mass estimates
- Important to study: Measurement uncertainties & biases, radiation pressure, calibration issues for NLS1s (and for MgII?)
- Recall: mass estimates work – issues relate to accuracy and precision!