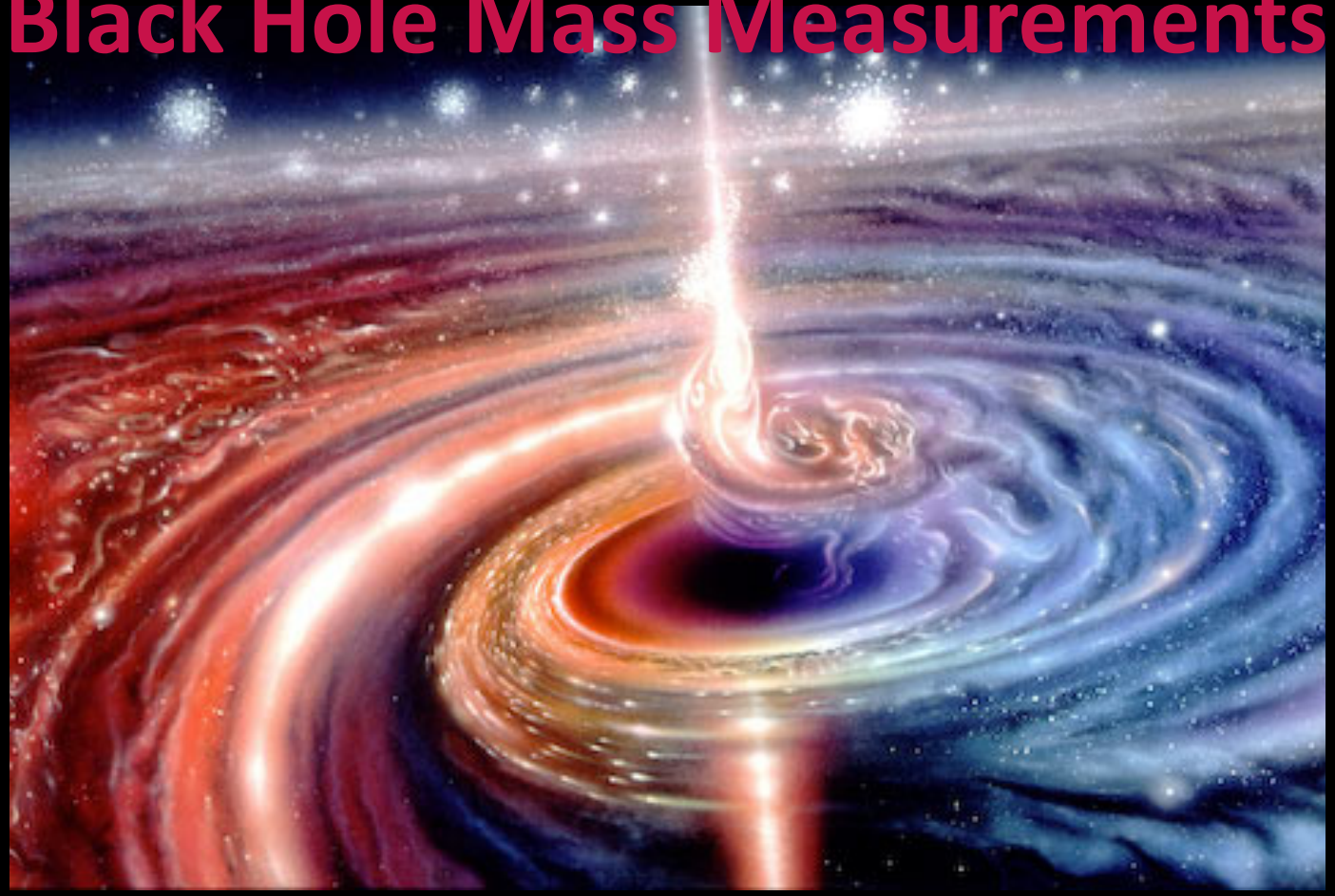
Addressing Systematic Uncertainties in Black Hole Mass Measurements



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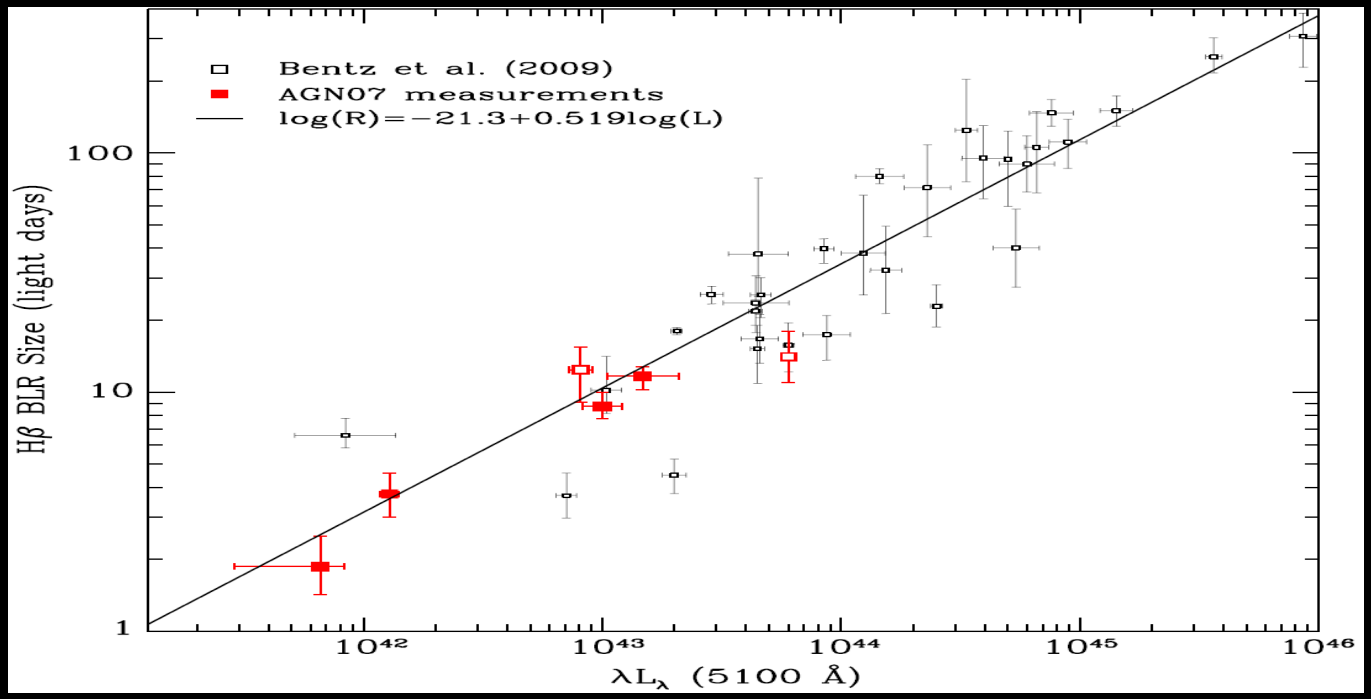
Dark Cosmology Centre

Collaborators: Roberto Assef, Misty Bentz, Matthias Dietrich, Kate Grier, Keith Horne, Chris Kochanek, Smita Mathur, Brad Peterson, Rick Pogge, Marianne Vestergaard

Single-epoch BH Masses

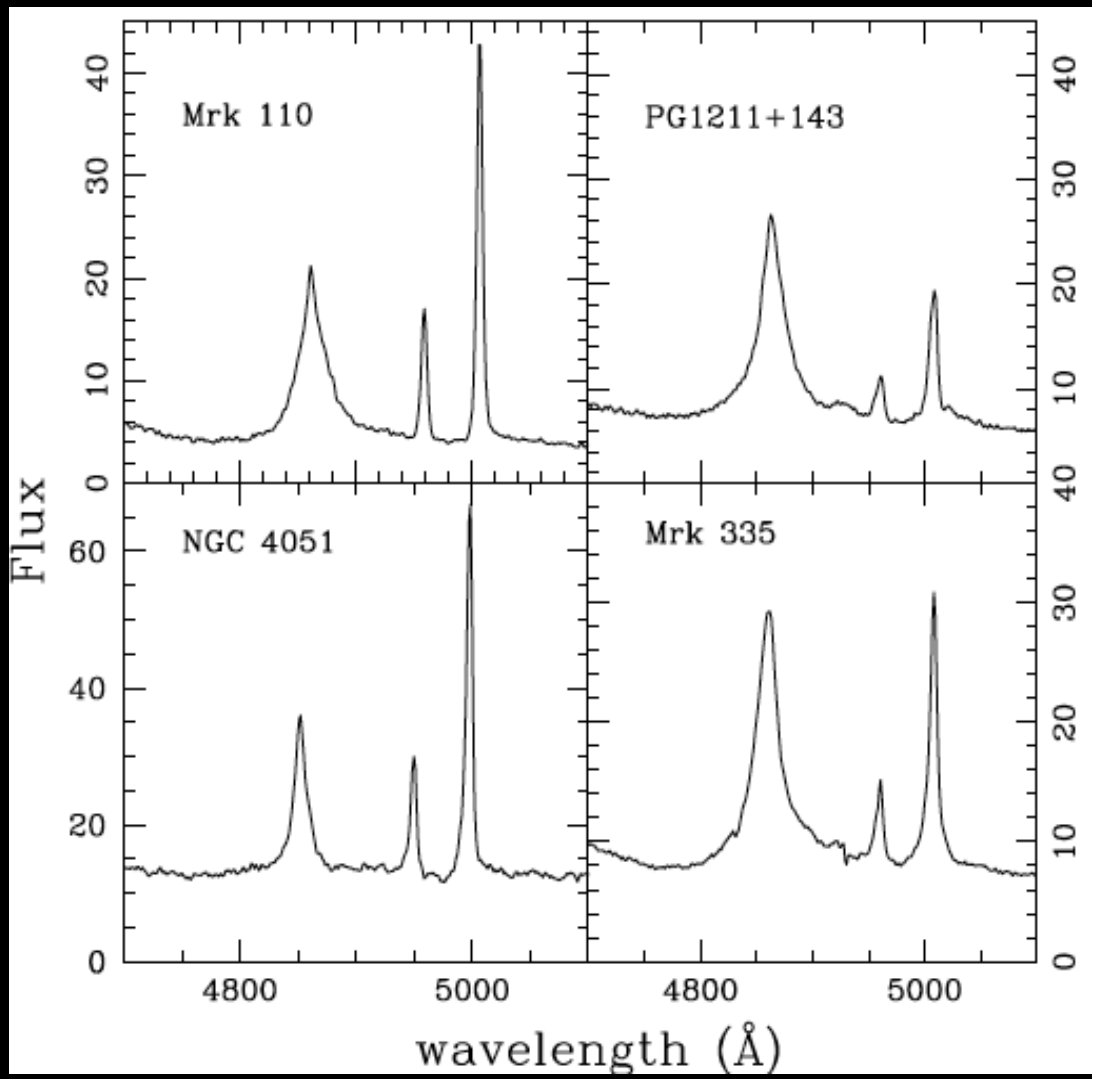


$$M_{BH} = f \frac{RV^2}{G}$$

Powerful method, but beware of systematics!

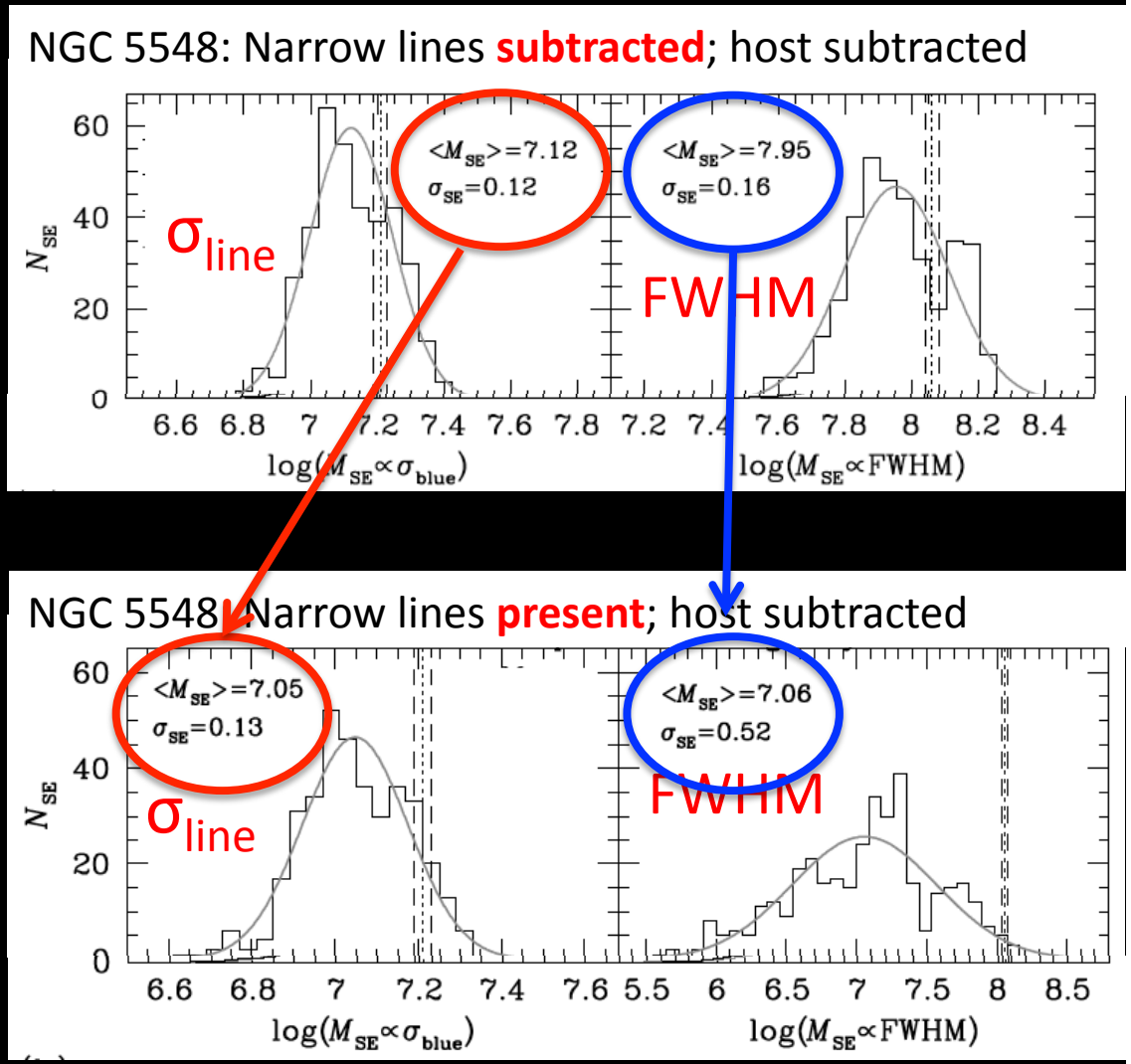
NLS1-sensitive Systematics

- Narrow line contamination



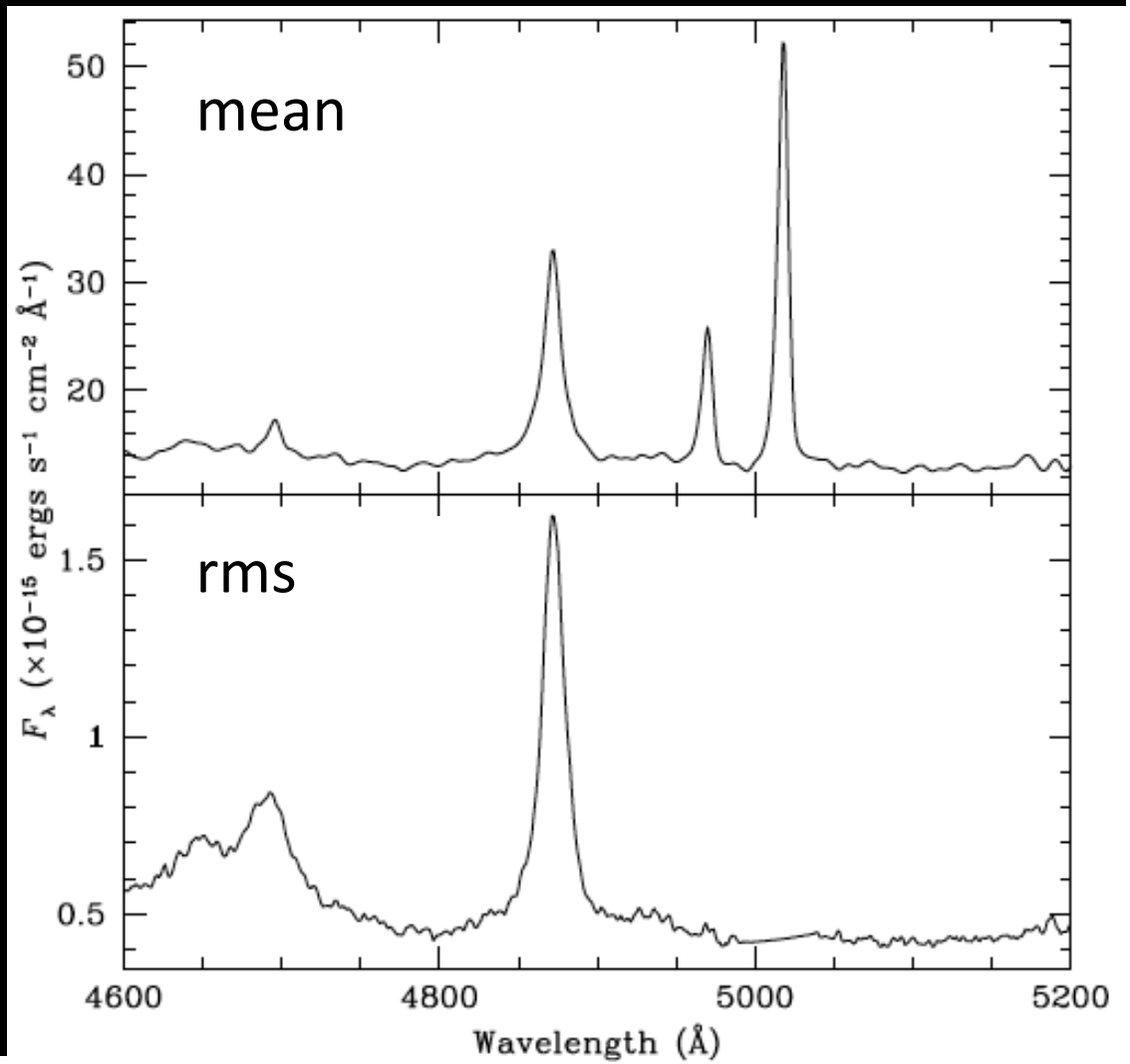
NLS1-sensitive Systematics

- Narrow line contamination
  - Underestimates single-epoch masses!!
  - σ_{line} less susceptible to this than FWHM



NLS1-sensitive Systematics

- Narrow line contamination
  - Underestimates single-epoch masses!!
  - σ_{line} less susceptible to this than FWHM
  - RM widths not susceptible – use rms spectrum



RM Systematic Uncertainties

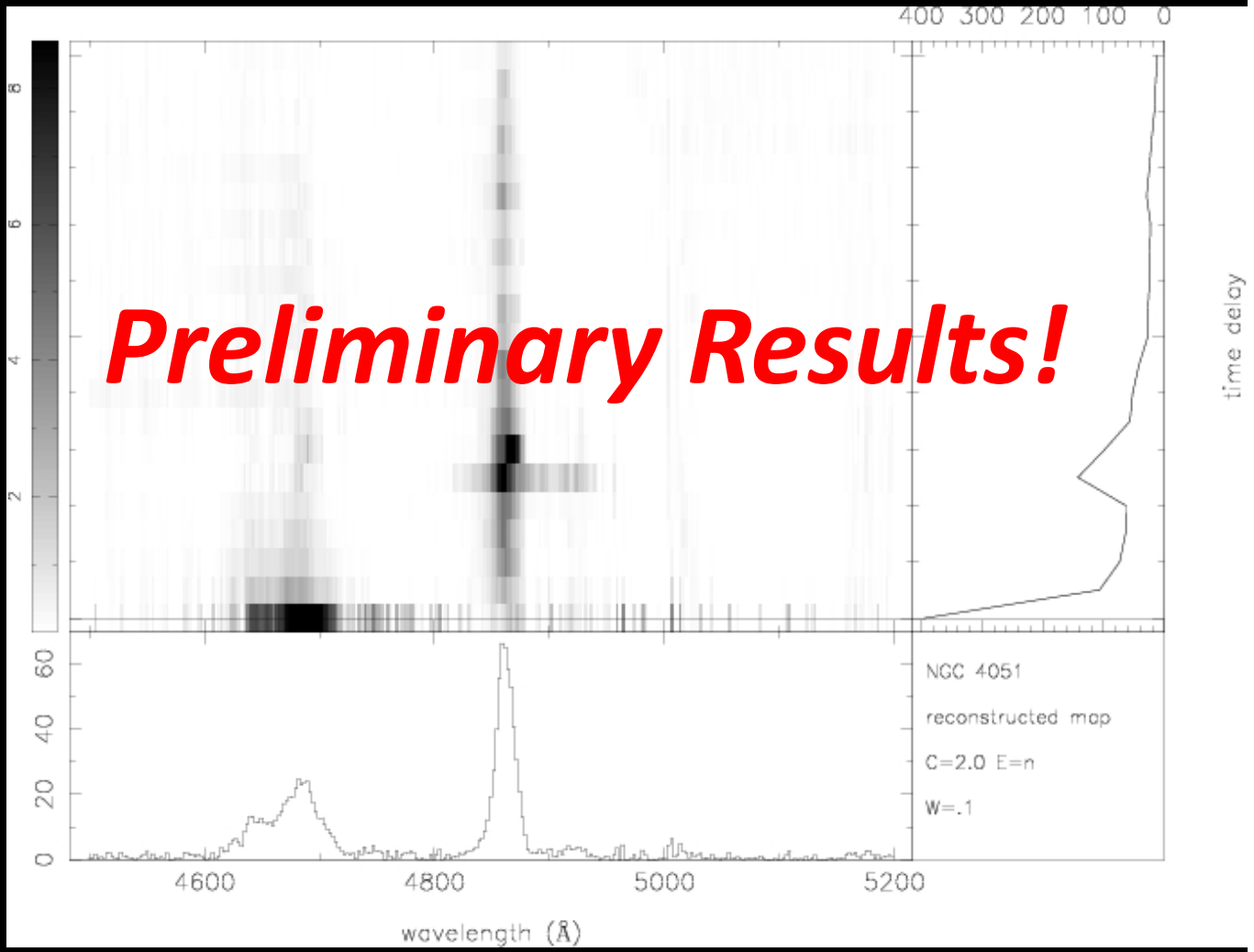
- RM is susceptible to geometric effects in measurement of *V*
- *f* is the largest RM systematic (Woo et al. 2010)

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

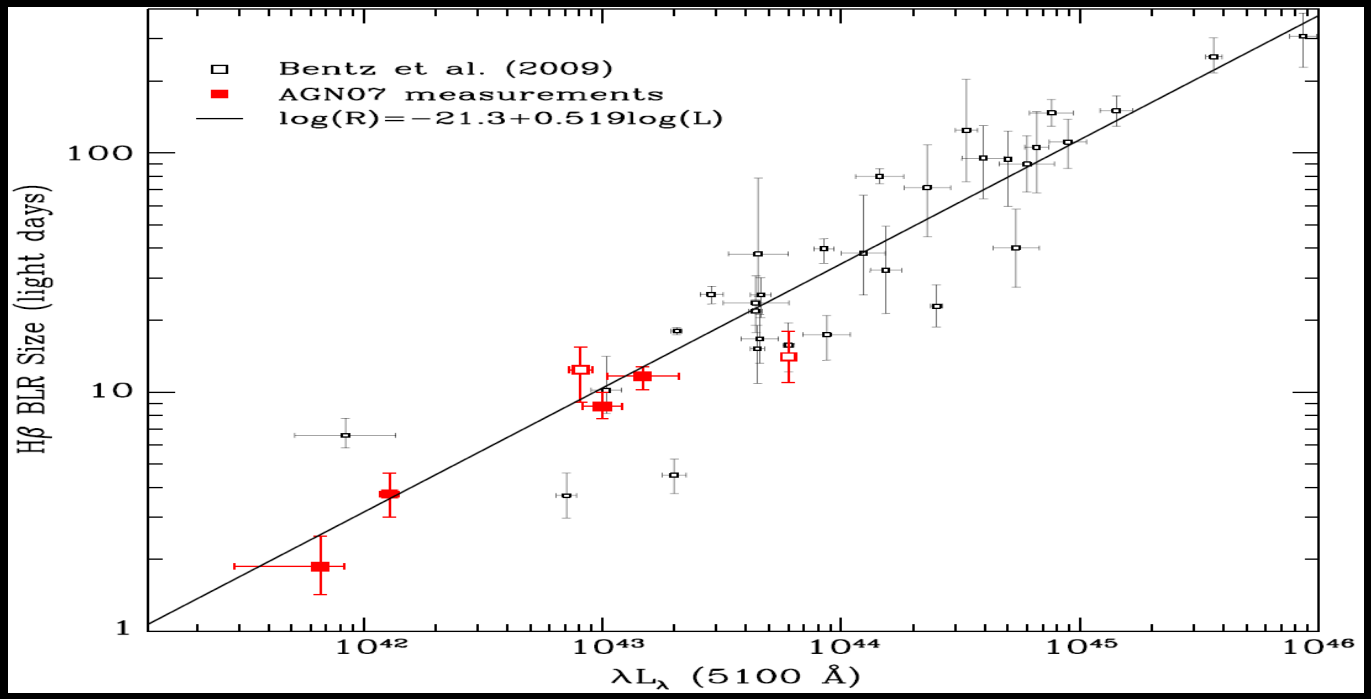
Velocity-Delay Maps are necessary to constrain the BLR geometry and kinematics

Velocity-Delay Maps – NGC 4051

- Largely unresolved
- However:
  - Virialized BLR
  - Face on? (see poster by T. Fischer)
  - HeII winds?



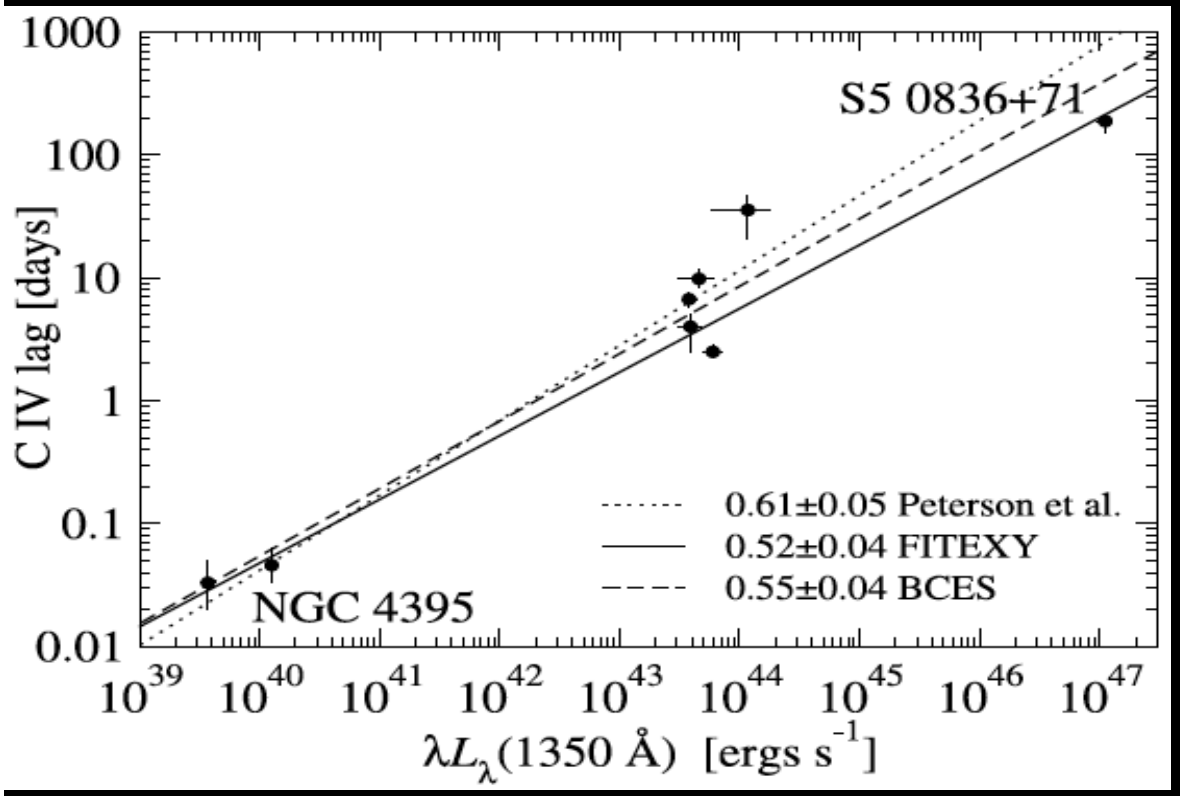
Single-epoch BH Masses



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

Hβ is great locally, but if you want to go to high redshift…

Single-epoch BH Masses



- Kaspi et al. 2007
- Slope is consistent with Hβ – GREAT!
- But calibrated by few points

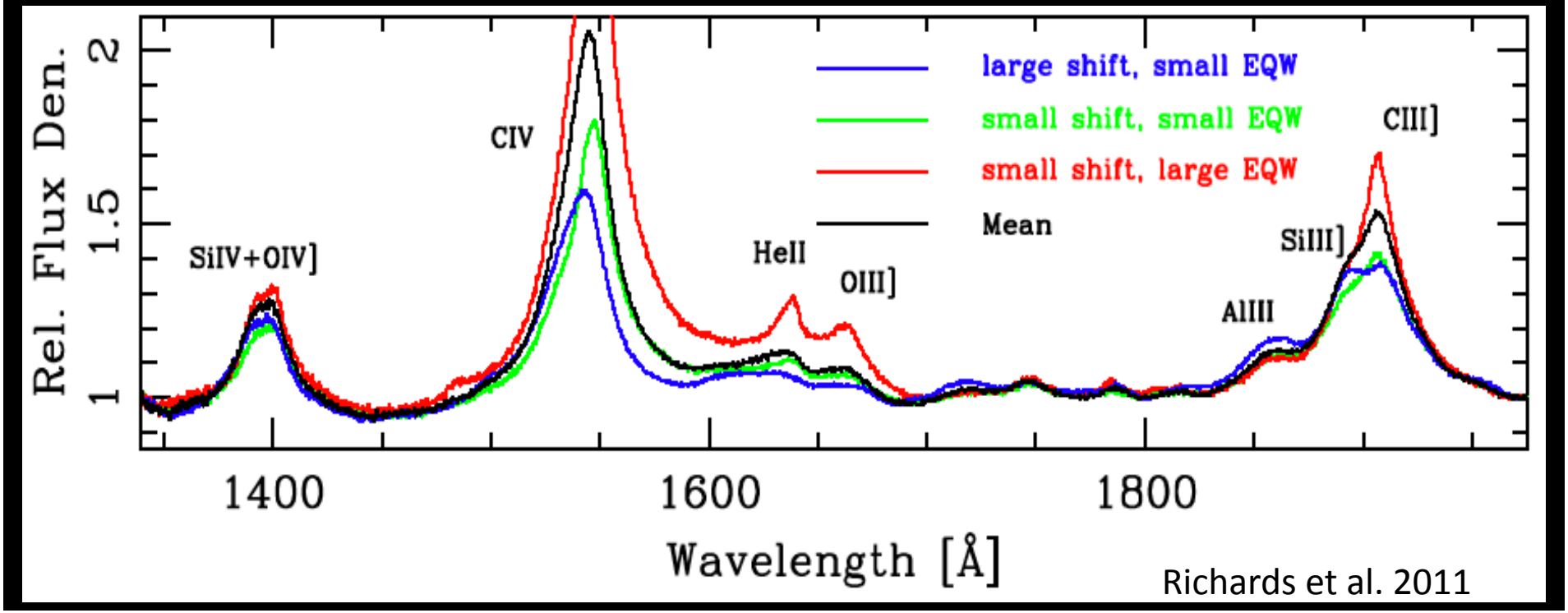
CIV single-epoch black hole masses anchored to Hβ

$$\log M_{\rm BH}({\rm C\ IV}) = \log\left\{\left[\frac{\rm FWHM(C\ IV)}{1000\ {\rm km\ s^{-1}}}\right]^2\left[\frac{\lambda L_\lambda(1350\ \text{Å})}{10^{44}\ {\rm ergs\ s^{-1}}}\right]^{0.53}\right\} + (6.66 \pm 0.01). \quad (7)$$

Vestergaard & Peterson 2006

Are CIV BH Masses Reliable?

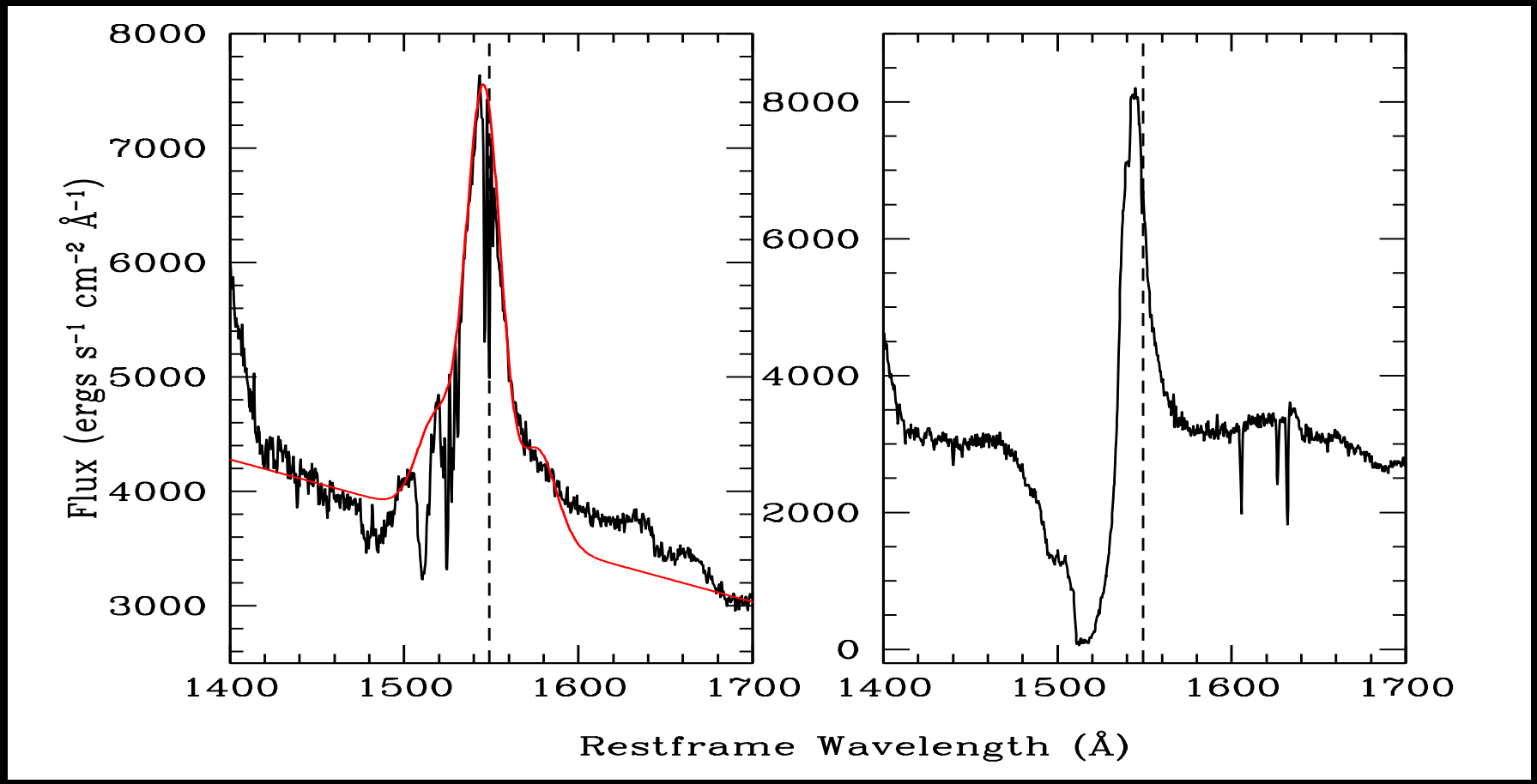
- CIV Suffers from:
  - Baldwin Effect
  - Blueshifted line center
  - Line blending



Richards et al. 2011

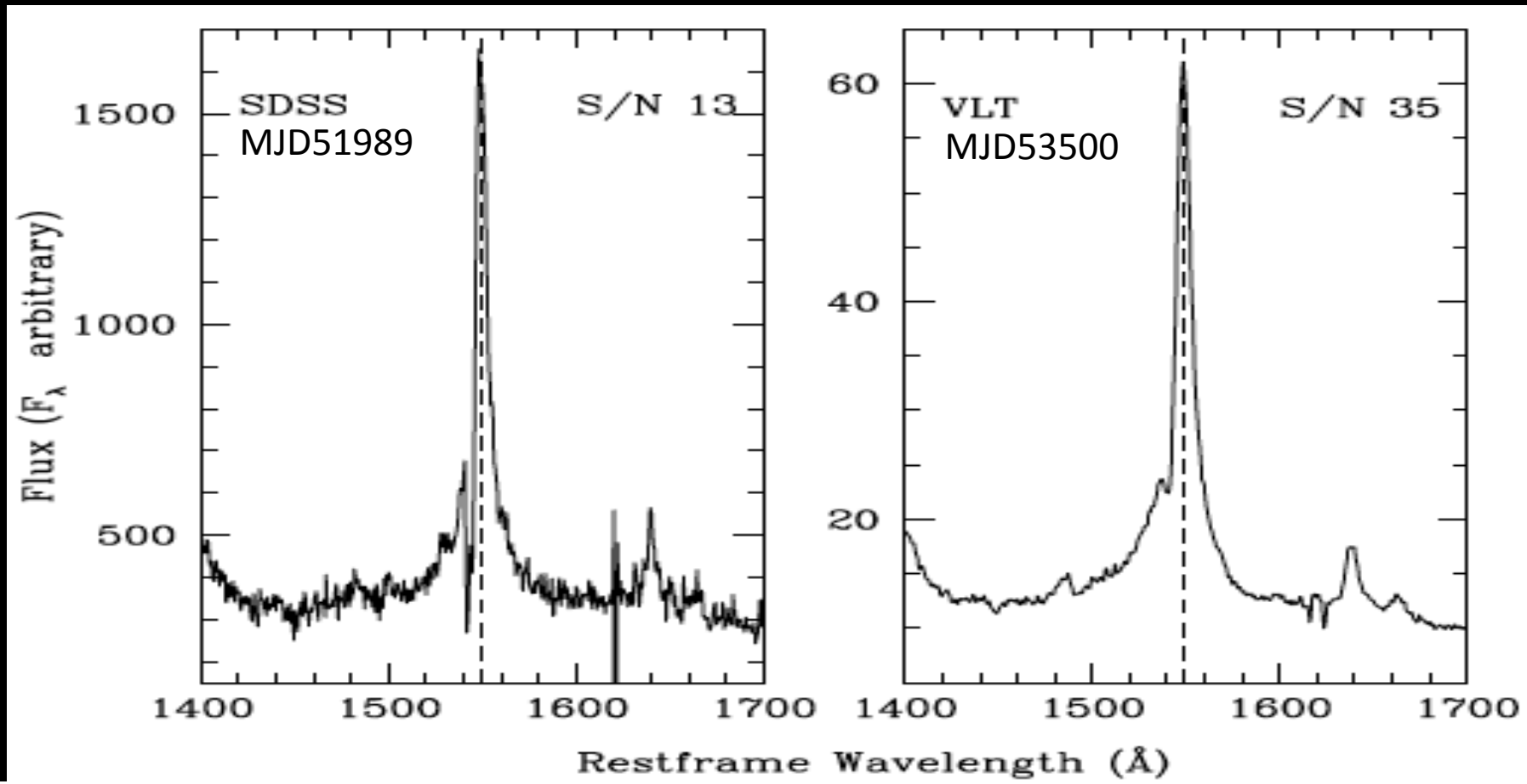
Are CIV BH Masses Reliable?

- CIV Suffers from:
  - Absorption



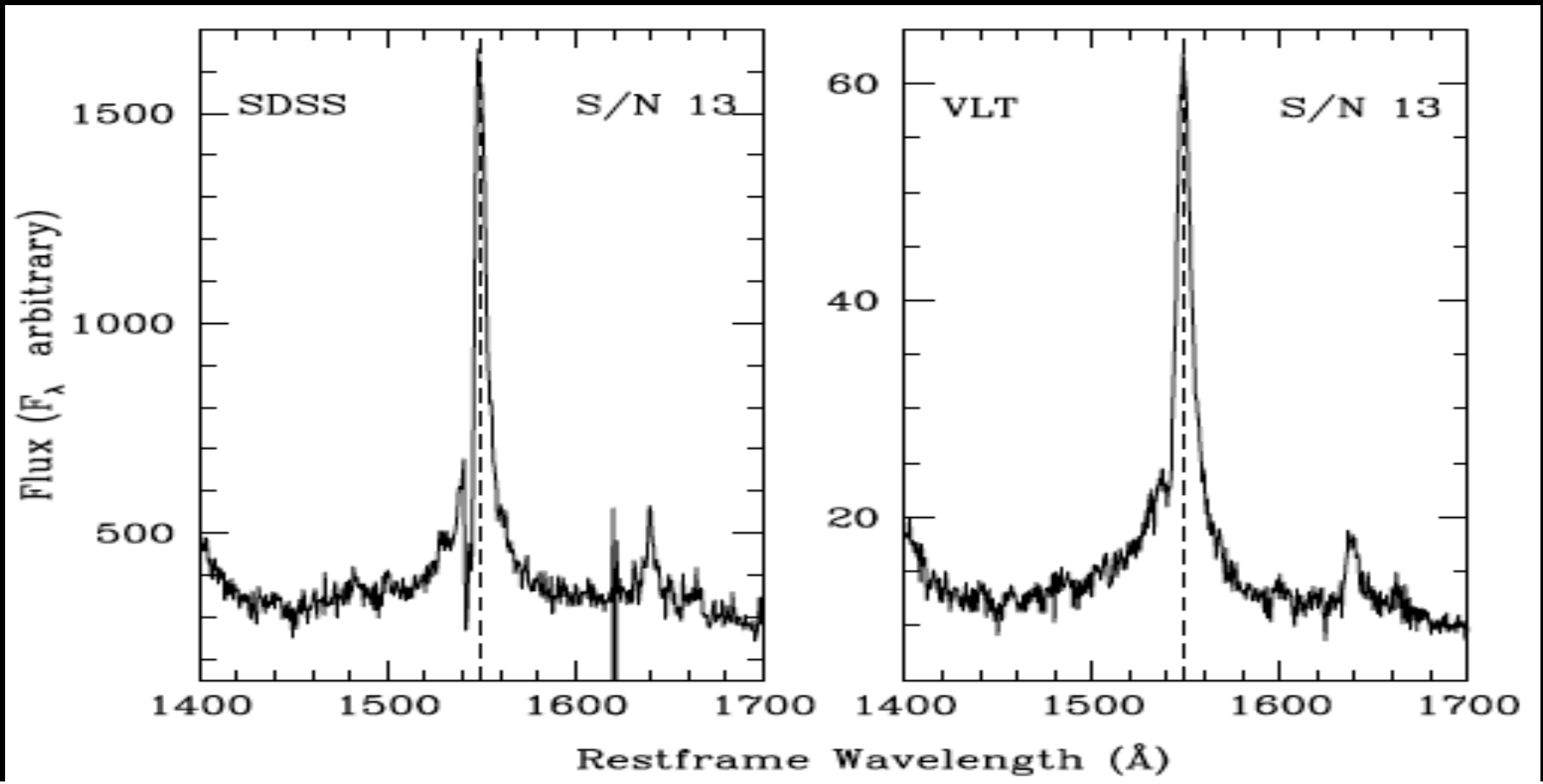
Are CIV BH Masses Reliable?

- CIV Suffers from:
  - Variable Absorption (SDSS 1138: ~4 years apart)



Are CIV BH Masses Reliable?

- The Importance of Data Quality:
  - S/N considerations



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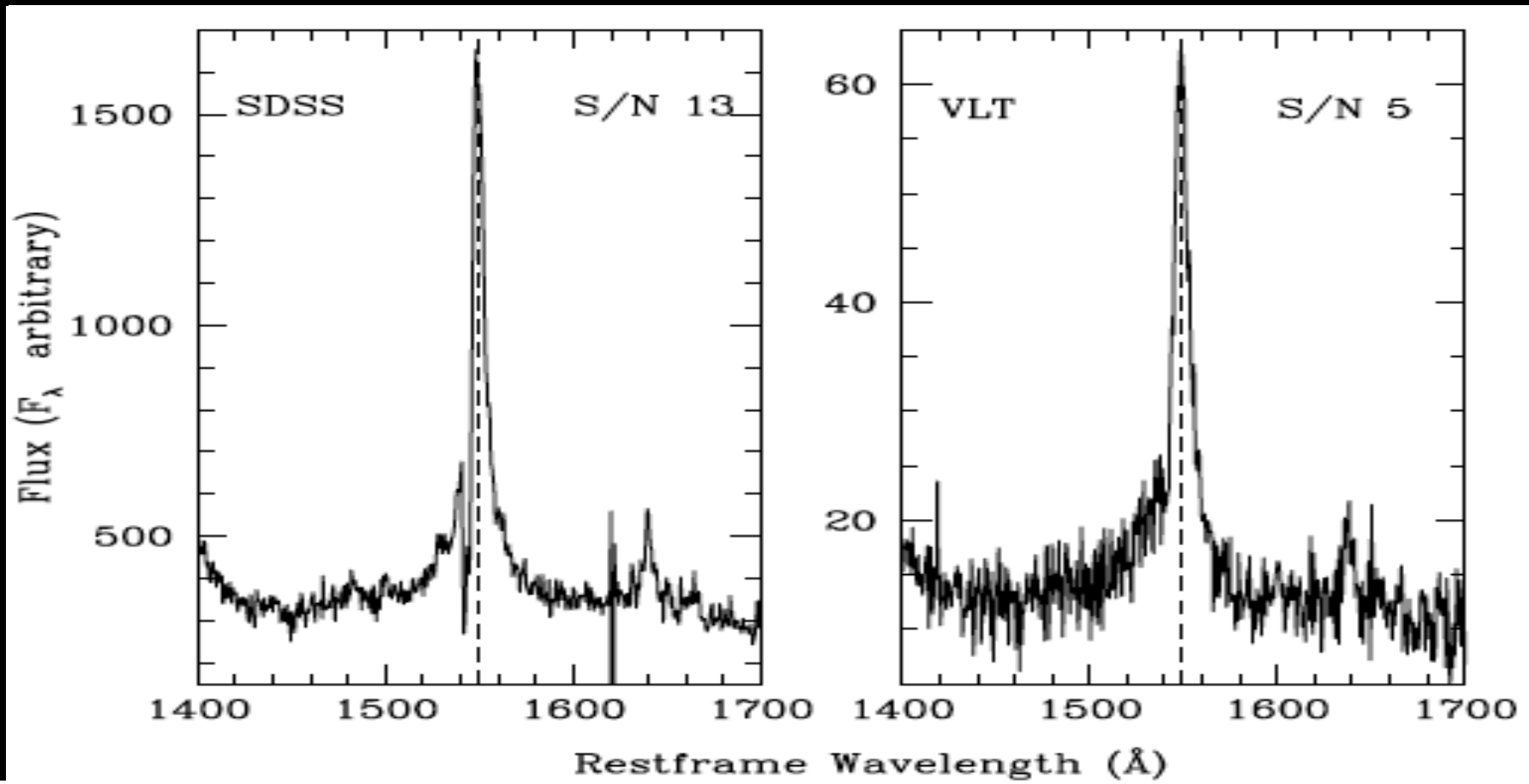
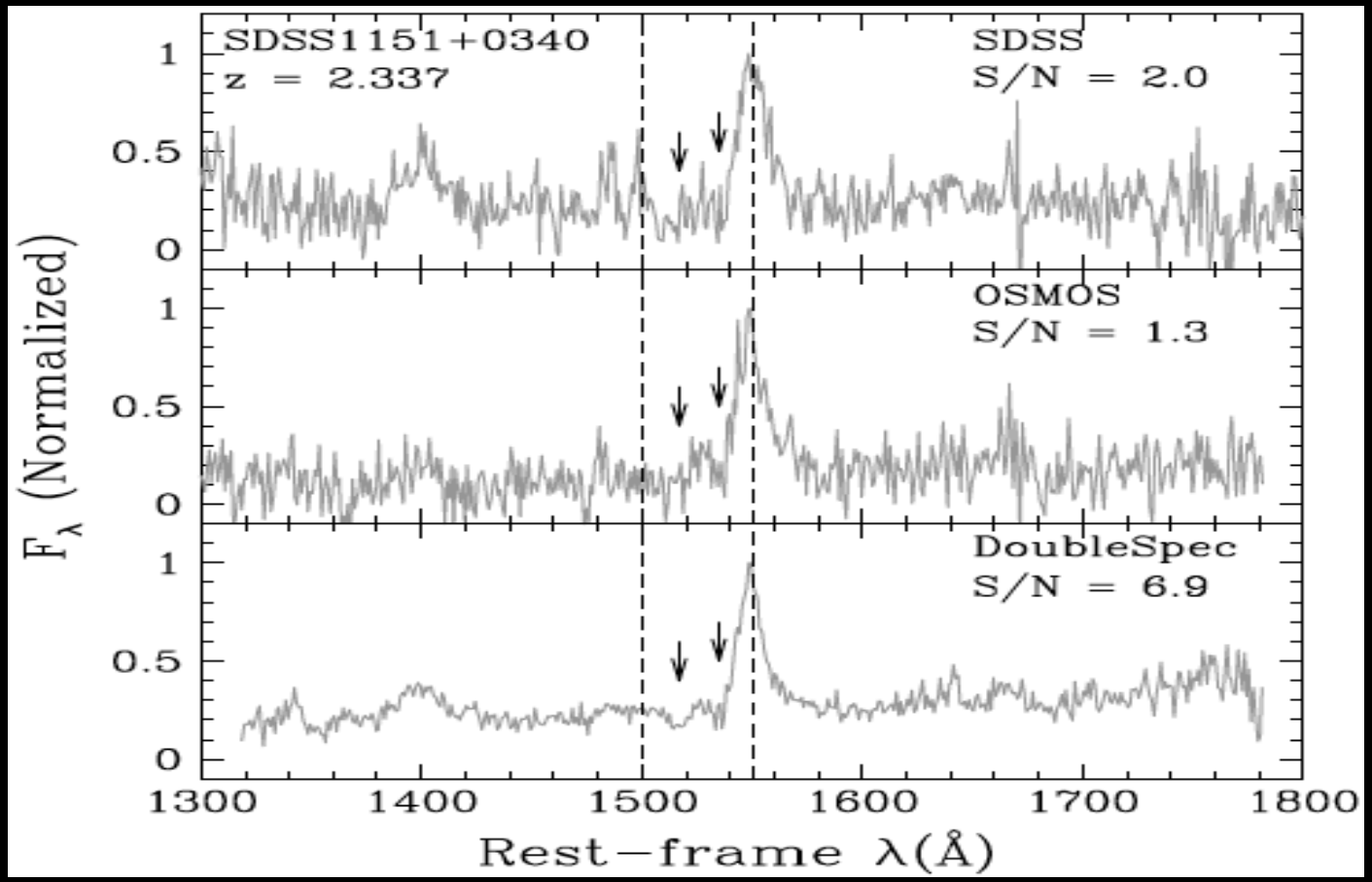


Are CIV BH Masses Reliable?

- The Importance of Data Quality:
  - Unrecognized absorption leads to biased CIV widths

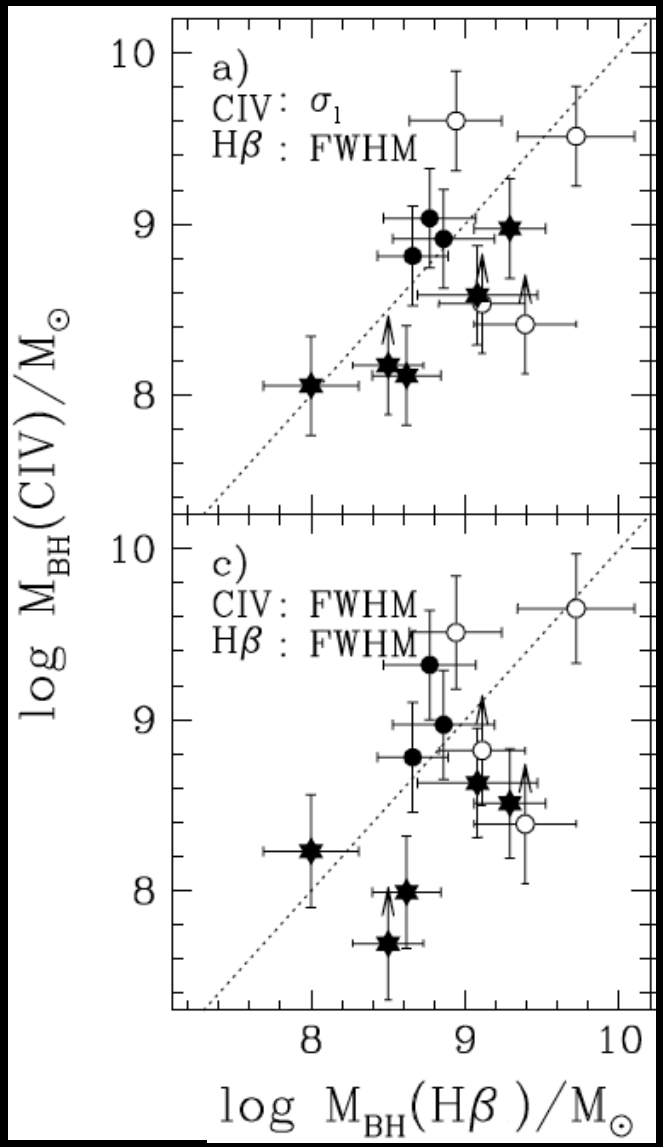


Used by Netzer et al. 2007

Attempts at MDM (middle) and Palomar (bottom) by Assef, Denney+ to re-observe and look for absorption.

CIV vs Hβ BH Masses

- With high S/N and careful, homogeneous data handling, CIV and Hβ masses consistent (Assef, Denney+ arXiv:1009:1145)
- Solid = reliable CIV and Hβ
  open = unreliable Hβ
  (Greene+ 2010, ApJ 709, 937)



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- Solid = reliable CIV and Hβ
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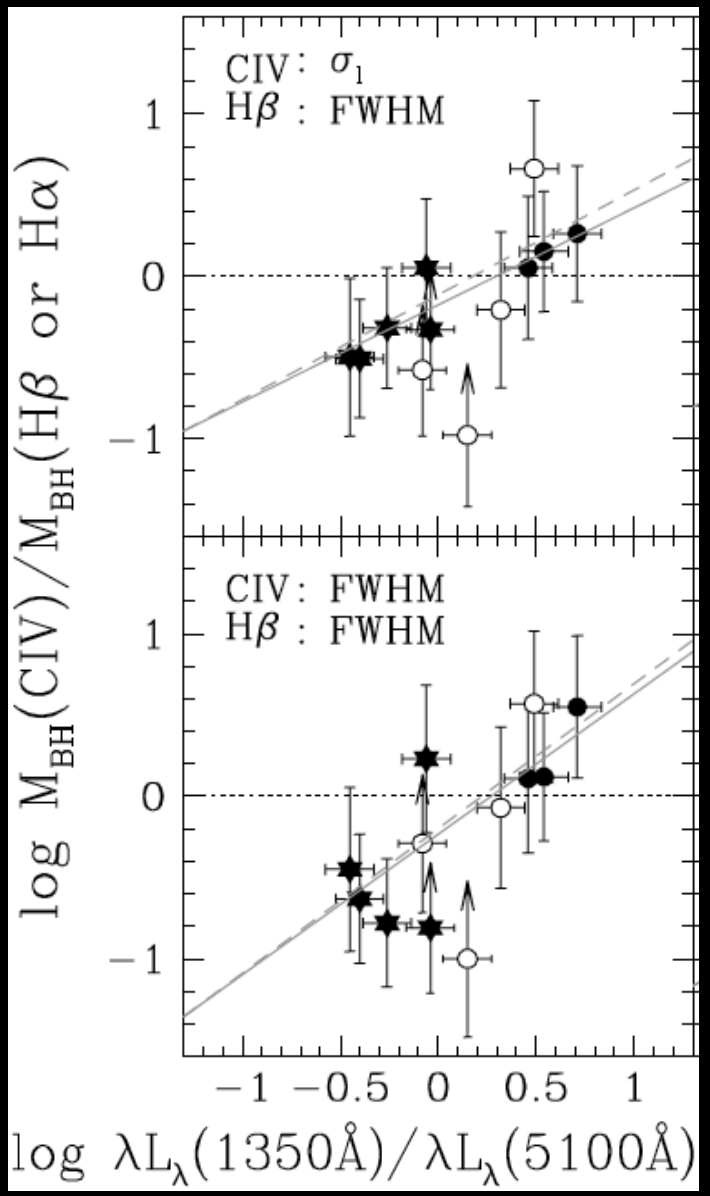
- Mass residuals strongly correlated with Luminosity ratio, i.e., color term
  - Slope 0.6 – 0.9 depending on line width characterization



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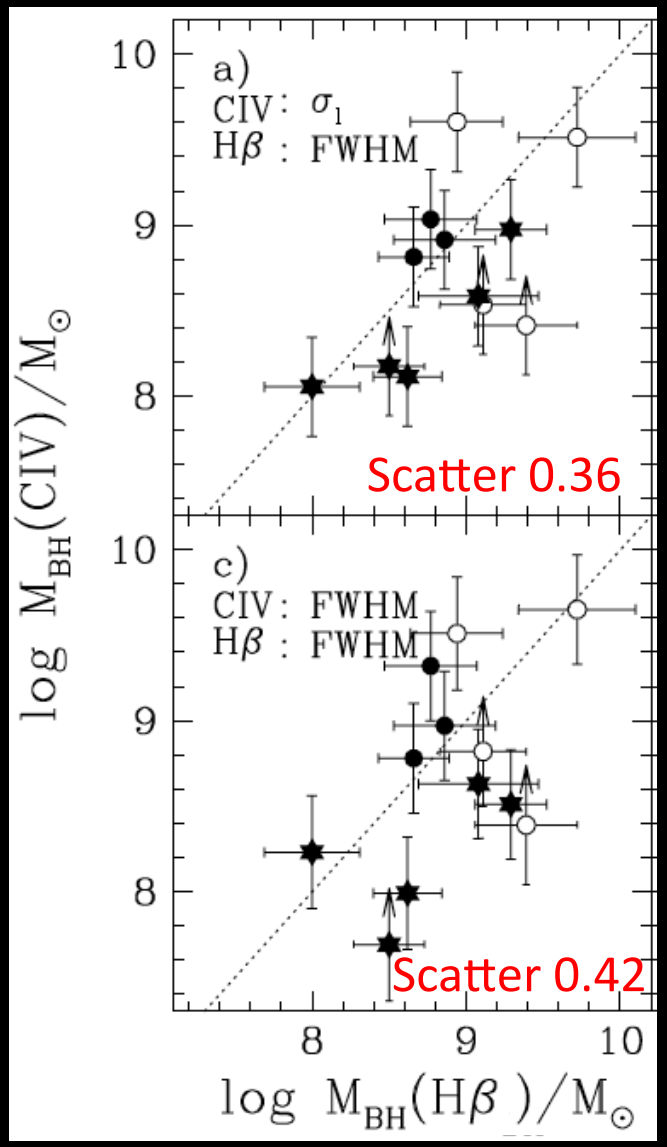
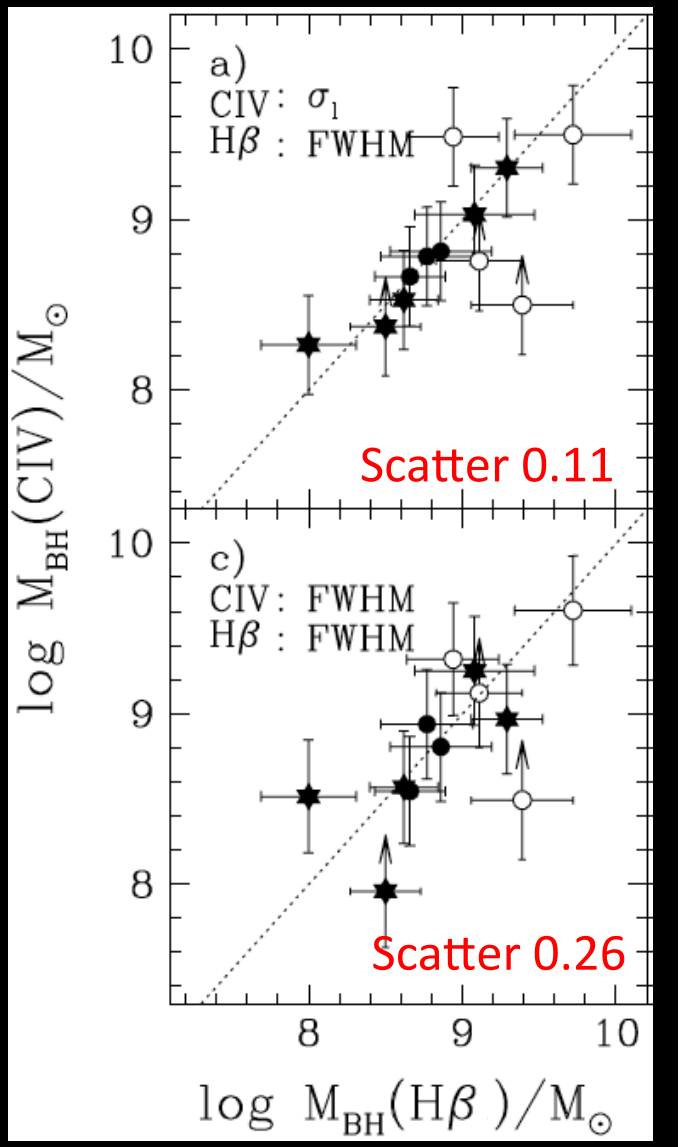


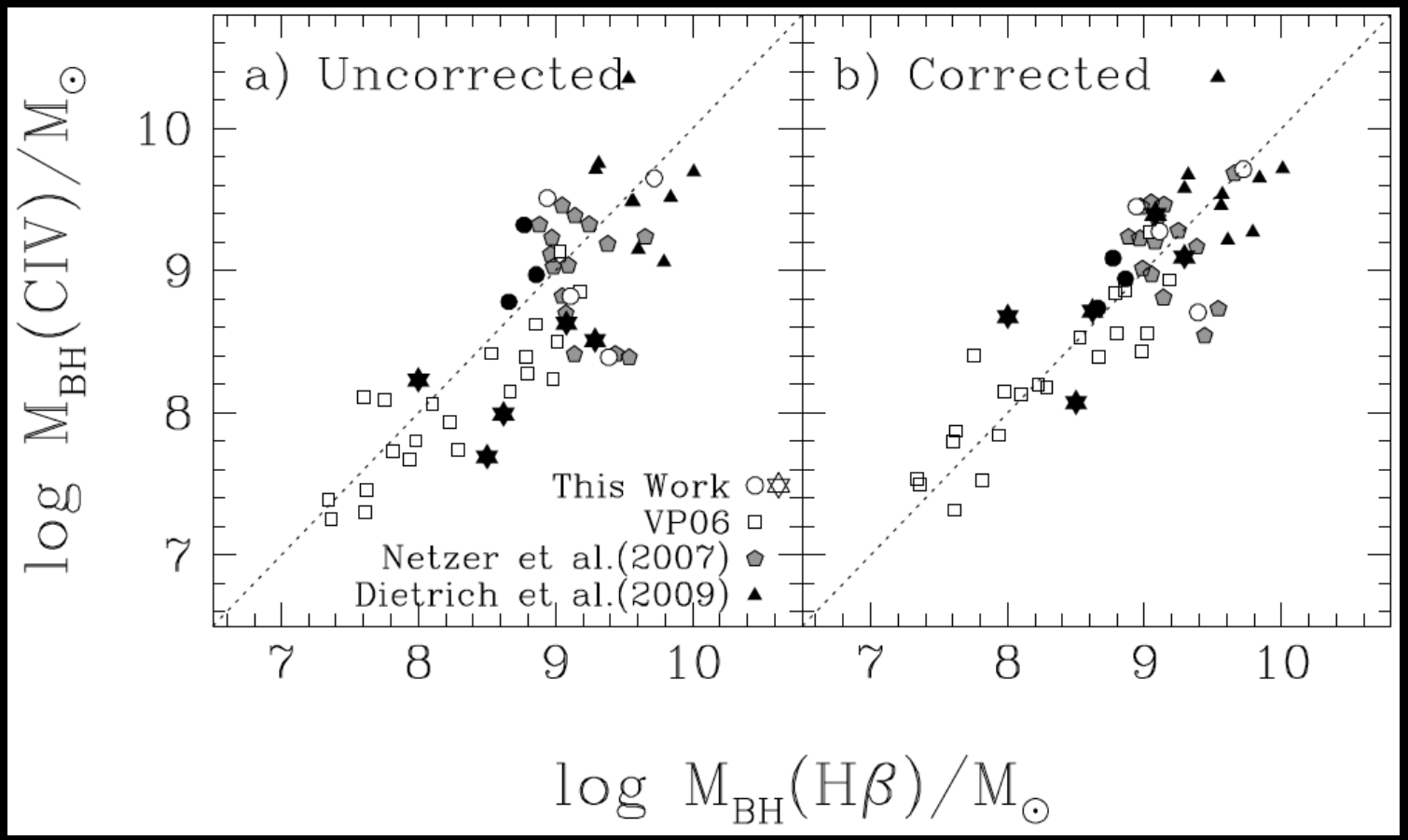
Before

After



CIV vs Hβ BH Masses

- Even correcting masses in heterogeneous literature sample reduces scatter



Summary

- RM calibrates scaling relations for making single-epoch mass estimates
  - Must be careful about data quality and analysis to mitigate introduction of systematic uncertainties
- RM results not as susceptible to these systematics, but faces other challenges, e.g., f
- At high redshift CIV masses are consistent with Hβ with high quality data after making an AGN continuum color correction