Addressing Systematic Uncertainties in Black Hole Mass Measurements

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Single-epoch BH Masses

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

Powerful method, but beware of systematics!
NLS1-sensitive Systematics

- Narrow line contamination
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  - Underestimates single-epoch masses!!
  - $\sigma_{\text{line}}$ less susceptible to this than FWHM
NLS1-sensitive Systematics

- Narrow line contamination
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  - $\sigma_{\text{line}}$ 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)
  – Hell winds?

Preliminary Results!
Single-epoch BH Masses

\[ M_{BH} = \frac{fRV^2}{G} \]

H\(\beta\) 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

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

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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- 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)
CIV vs Hβ BH Masses

- With high S/N and careful, homogeneous data handling, CIV and Hβ masses consistent (Assef, Denney+ arXiv:1009:1145)
- Mass residuals strongly correlated with Luminosity ratio, i.e., color term
  - Slope 0.6 – 0.9 depending on line width characterization
CIV vs Hβ BH Masses

Before

After

Scatter 0.36

Scatter 0.42

Scatter 0.11

Scatter 0.26
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 H$\beta$ with high quality data after making an AGN continuum color correction