Mapping the Inner Parsec of Quasars

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WHY YOU SHOULD CARE ABOUT QUASARS

DO YOU CARE ABOUT GALAXY EVOLUTION?

ARE YOU CURIOUS HOW SUPERMASSIVE BLACK HOLES GROW?

WHAT?!
BLACK HOLES = AWESOME

QUASARS HAPPEN TO ALL MASSIVE GALAXIES

BLACK HOLES GROW AS QUASARS

(thanks to xkcd.com)
Every massive galaxy hosts a supermassive black hole

100,000 light years

(Gueltekin+ 2009)
Goals of the High-z MSE Quasar Program

Measure black holes masses for ~2500 quasars up to z~3.

→ properly calibrate single epoch $M_{BH}$ measurements for all quasars

Numbers to date: ~60
(to be improved, see Shen talk)

Map the inner parsec of 100s of quasars.

→ powerfully constrain accretion physics

Numbers to date: handful

Obtain extremely high S/N spectra of ~5000 quasars across the rest-frame optical-UV.

→ enable unprecedented studies of host galaxy properties, intervening absorption-lines, detailed emission line structure...

Numbers to date: <100

BONUS: High-z Hubble diagram for cosmology
Reverberation Mapping: Variability & Photoionization $\rightarrow$ Distance

Continuum and emission line flux vary stochastically over time


Short timescale variability gives access to small spatial scales
Reverberation Mapping: Variability & Photoionization $\rightarrow$ Distance

Continuum and emission line flux vary stochastically over time


Line variations track continuum variations with a time delay
Reverberation Mapping

\[ c \times \text{delay} = R_{\text{line}} \]

Animation credit: K. D. Denney
Distance & Velocity → Black Hole Mass

Broad line region gas velocities are dominated by the black hole’s gravitational potential.

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

Scale Factor  Doppler Line Width
Time Delay

Approaching side
Velocity-Resolved Reverberation Mapping

NO MORE AVERAGING!

Time to Observer:

\[ \Delta t_1 < \Delta t_3 < \Delta t_2 < \Delta t_4 \]

Animation credit: K. D. Denney
Multi-Line 2D Velocity-Delay Maps

\[ \tau = \frac{R}{c} \left(1 + \sin i \cos \theta \right) \quad V = \sqrt{\frac{GM}{R}} \sin i \sin \theta \]
Applying RM: Single-Epoch BH Masses

The empirical $R_{\text{line}}-L_{\text{cont}}$ (radius-luminosity) relationship provides an opportunity to use $L_{\text{cont}}$ as a proxy for the broad line region radius.

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Single-epoch (SE) mass:

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


ALL SE masses calibrated to H$\beta$. 

(AGN Luminosity (5100A) vs. H$\beta$ BLR Radius (light days))
Emission Lines Used for SE Masses

Composite from the Large Bright Quasar Survey (Francis et al. 1991)

ALL SE masses calibrated to Hβ.
Large Samples of $M_{BH}$

- Currently, **ALL** single epoch masses tied to Hβ
- MSE reverberation mapping program will be able to calibrate independent relationships for *every* major broad emission line used.
Wavelength coverage at $z=2$

Composite from the Large Bright Quasar Survey (Francis et al. 1991)
Broad Lines Accessible to MSE

CIV and Hβ: $\lambda_{\text{max}}$ to 1.8 $\mu$m

$\lambda_{\text{max}}$ to 1.3 $\mu$m
Wavelength coverage at $z=2$

Composite from the Large Bright Quasar Survey (Francis et al. 1991)
Specs for the High-z MSE Quasar Program

5000 quasars:

\[ \rightarrow 7 \text{ fields, } \sim 700 \text{ quasars per } 1.5 \text{ deg}^2 \text{ field} \]

Repeat observations:

\[ \rightarrow 100 \text{ epochs; cadence from days to months over } \sim 5 \text{ yrs} \]

Sensitivity (1 hr exposure):

\[ \rightarrow S/N \sim 30 \text{ (10) } i=21.8 \text{ (23.25) } @ \text{ CIV for } z=2 \]

Accurate spectrophotometry:

\[ \rightarrow 3-4\% \text{ (relative) accuracy across the bandpass} \]
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