A multi-wavelength survey of obscured and reddened quasars at the peak of galaxy formation

Rachael Alexandroff
PhD Candidate
Johns Hopkins University

Special Thanks To:
Nadia Zakamska (JHU), Fred Hamann (UCR), Jenny Greene (Princeton), Michael Strauss (Princeton), Nic Ross (St. Andrews), Niel Brandt (Penn State), ...
A multi-wavelength survey of obscured and reddened quasars at the peak of galaxy formation

Rachael Alexandroff
PhD Candidate
Johns Hopkins University

Image credit: David A. Hardy (UK ATC)

Special Thanks To:

Nadia Zakamska (JHU), Fred Hamann (UCR), Jenny Greene (Princeton), Michael Strauss (Princeton), Nic Ross (St. Andrews), Niel Brandt (Penn State), ...
Outline

1. What are the most effective techniques for identifying heavily obscured and Compton-thick AGN?

2. How does obscuration of AGN fit into black hole-galaxy evolutionary model?

3. How applicable is the “unified model” of AGN, and what is the physical nature of the obscuring torus?
1. What are the “most effective” techniques for identifying heavily obscured and Compton-thick AGN?

... In particular early in the universe?
Why make our observations more difficult?

Peak in quasar density & star formation rate 10 billion years ago

Madau & Dickinson 2014
“Traditional” Obscured Quasar Candidates

• selected using optical (SDSS-III) BOSS spectroscopy  
• ~150 candidate obscured quasars from SDSS III, 2 < z < 4 
  • “traditional” narrow emission lines (FWHM < 2000 km/s) 
  • mostly obscured continuum

One of the largest samples of optically-selected obscured quasars in the early universe
“Traditional” Obscured Quasar Candidates

14/16 show broad Hα in NIR spectroscopy

SEDs intermediate between Type 1 & Type 2

0.05 < Av < 2.2

Greene, Alexandroff et al. 2014
Introducing: **Extremely Red Quasars**

- 95 quasars selected using a combination of MIR (WISE) & optical (SDSS-III)
  - $i-w3 > 4.6$ (AB mag)
  - picks out heavily dust-enshrouded objects re-radiating in the MIR
  - we noticed something strange....

Ross et al. 2015
Hamann et al. 2016, submitted
Introducing: **Extremely Red Quasars**

- 95 quasars selected using a combination of MIR (WISE) & optical (SDSS-III)
  - **REW CIV > 100 Å**

- Hypothesis-
  - suppressing quasar continuum but not emission line region? Dusty outflow with patchy obscuration?

---

Ross et al. 2015
Hamann et al. 2016, submitted
2. How does obscuration of AGN fit into black hole-galaxy evolutionary model?

... What evidence do we see for quasar feedback?
Tracing ionized outflows using [OIII] gas

- Ionized outflows can be traced by forbidden emission line [OIII]
- Without IFU observations (pending), rely on kinematics

"Type 2" objects show hints of blueshifted emission

Greene, Alexandroff et al. 2014
Tracing ionized outflows using \([\text{OIII}]\) gas

- Ionized outflows can be traced by forbidden emission line \([\text{OIII}]\)
- Without IFU observations (pending), rely on kinematics

**most extreme ERQs** show \([\text{OIII}]\) FWHM > 3000 km/s

this is too large to be contained by any reasonable galaxy potential

Zakamska et al. 2016
Origin of Radio Emission in Radio-Quiet Quasars

- z < 0.8 observed correlation between line width & radio luminosity

- Could the quasar-driven shocks also accelerate particles and produce the observed radio emission?

- How to differentiate from young/weak radio jets?

Zakamska & Greene 2014
Origin of Radio Emission in Radio-Quiet Quasars

\[ \nu L_\nu [1.4\,\text{GHz}] = 8 \times 10^{40}\,\text{erg s}^{-1} \]

median stack of 81 extremely red quasars at \(z \sim 2.5\) from FIRST

mean stack of 11 obscured quasars at \(z \sim 2.5\) at 6.0GHz from the VLA

Possible Evolutionary Link?

Merging galaxies

Obscured quasar

Unobscured quasar

Type 2

ERQ

Katen Teramura, IfA, University of Hawaii
The Evolution of Hidden Monsters?

Merging galaxies

Unobscured quasar

Obscured quasar

Katen Teramura, IfA, University of Hawaii

Type 2

ERQ

Correlation Between Black Hole Mass and Bulge Mass

Mass of central bulge

Increasing

flux density, $10^{-19}$ erg/sec/cm$^2$/Å

rest wavelength, Å
3. How applicable is the “Unified Model” of AGN?
Spectropolarimetry can reveal scattering geometry

- quasar light may be scattered into our line of sight from dust or free electrons
- the light becomes linearly polarized in the process
- traditional obscured quasars have optical polarization of a few %
Warning: Results still preliminary. Proceed with caution.
Spectropolarimetry of high redshift obscured and reddened quasars

• Our most spectacular detection appears to show very high levels of polarization
  • high values put tension on dust scattering as possible source of polarization
  • lower levels in emission line implies extended emission region
• Polarization fraction and angle varies over the emission line
  • may help understand outflow geometry
• Stay tuned!
Conclusions

1. A combination of optical & MIR selection reveals “abnormal” obscured quasars that may nevertheless shed some light on important open questions

2. ERQs especially display tantalizing evidence of quasar feedback that is likely driving SMBH-galaxy co-evolution

3. Spectropolarimetry will allow us to probe the Unified Model
Origin of Radio Emission in Radio-Quiet Quasars

- Distinguish between compact jets and quasar winds?
- At $z \sim 0.5$ we demonstrate that combination of radio luminosity, morphology and spectral index can help
  - steep spectrum, unresolved radio core and radio lobes imply
    - compact jets with episodes on scales of $\sim 10^7$ years
    - synchrotron emission from quasar winds

“Teacup AGN”
Harrison et al. 2015
$z = 0.085$

Alexandroff et al, arXiv:1603.07325
$z = 0.13$

$\alpha = -0.65$