THE FREQUENCY OF INTRINSIC X-RAY WEAKNESS AMONG BAL QUASARS

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Outline

• Introduction to AGN X-rays

• Intrinsically X-ray Weak Broad Absorption Line Quasars

• Summary and Future Work
AGN X-rays

From immediate vicinity of black hole. Accretion-disk corona is empirically *robust*, even if poorly understood.

Compton reflection or Fe Kα emission

Solar Coronal Loops Seen in EUV with TRACE

Tr’Ehnl & Brandt (2017)
AGN X-ray Spectral Components

Photon index: $\Gamma \sim 2$

- Soft X-ray excess
- Power law
- Iron K line
- High-energy cutoff
- Compton reflection "hump"

$$\alpha_{OX} = 0.3838 \log \left( \frac{I_{2\text{ keV}}}{I_{2500\text{ Å}}} \right)$$

- Disk
- Corona
- $2500 \text{ Å (5 eV)}$
- $2 \text{ keV}$
$\alpha_{\text{ox}}$ and X-ray Weak AGNs

Elvis & Fabbiano (1984)
Robustness of Quasar X-ray Emission

For type 1 quasars, which are optically selected luminous AGNs, significant X-ray emission appears universal (excluding broad absorption line quasars; see below).
Central to the X-ray Survey Industry

Brandt & Alexander (2015)
An X-ray Weak Outlier: PHL 1811

Has an X-ray weak spectral energy distribution (SED).

No apparent X-ray absorption (soft spectral shape). No UV BALs or mini-BALs. X-ray variability.

Appears intrinsically X-ray weak!
Extreme Objects Are Interesting and Probably Valuable

Let’s find more of these …

- To constrain their frequency
- To probe their nature
Identifying Intrinsically X-ray Weak AGNs

- X-ray weak (relative to the $\alpha_{\text{ox}} - L$ relation)
- X-ray weakness not entirely accounted for by absorption
Absorption vs. Intrinsic X-ray Weakness

• Spectral fitting of <8 keV X-rays not sufficient to recover the intrinsic X-ray absorption, e.g., Compton-thick + reflection could produce a soft spectrum.

• Must use hard X-rays: soft spectrum rules out Compton-thick absorption.

• *NuSTAR* observations or go to high-z.
Broad Absorption Lines (BALs)

Radiatively Driven Accretion-Disk Wind with WindVelocities of ~ 1000-30000 km s$^{-1}$

Commonly see blueshifted transitions of, e.g., C IV, Si IV, Mg II, Al III.

Brandt et al. (2000)

Non-BAL quasars
Role of X-ray Shielding

Quasar X-ray emission can be problematic for launching winds.

Proposed “shielding gas” is central to BAL wind driving - prevents wind over-ionization.

Such shielding gas is commonly observed in X-ray absorption with $N_H \sim 10^{21-10^{23}}$ cm$^{-2}$.

Usually excluded from the search for intrinsically X-ray weak AGNs.

Schematic Model of Equatorial BAL Outflow

e.g., Murray et al. (1995); Proga et al. (2000)
A Couple Candidates Suggested By *NuSTAR*

- 3-24 keV hard X-rays
- X-ray weak by factors of ~10
- Soft photon index $\Gamma \sim 1.8$ indicated via *stacking analysis*
- No individual candidates

Luo et al. (2013, 2014)
Intrinsically X-ray Weak BAL Quasar Population Constrained by Chandra

Chandra Stacking Results for $z \sim 1.5$-3 LBQS BAL Quasars from the Gallagher et al. (2006) Sample

- At high redshifts, Chandra nearly samples the NuSTAR band.
- Outside the shaded regions: X-ray weak.
- Close to the slanted line: soft spectral shape.
- Candidates suggested via stacking analysis.
### New Chandra Observations

<table>
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<tr>
<th>Object Name (LBQS B)</th>
<th>Redshift</th>
<th>$B_J$</th>
<th>Observation Star Date</th>
<th>Observation ID</th>
<th>New Obs. Exposure (ks)</th>
<th>Combined Exposure (ks)</th>
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<td>2.35</td>
<td>18.68</td>
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<td>1203+1530</td>
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<td>8.60</td>
<td>13.69</td>
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</table>

- Targeting the 7 hard-band undetected HiBAL quasars.
• Among the most luminous quasars in the optical/UV.

• More representative of the typically studied BAL quasar population than those low-luminosity and low-redshift objects amenable to observations with *NuSTAR*.

• A well-defined BAL quasar sample with systematic X-ray investigations.
Six Are Now Hard-Band Detected

- Four are hard X-ray weak ($\Delta \alpha_{ox} > -0.3$)
Two Candidates For Being Intrinsically X-ray Weak

- LBQS 1203+1530 and LBQS 1442-0011.
- Best candidates besides PHL 1811.

Liu et al. (submitted)
<table>
<thead>
<tr>
<th>Object Name</th>
<th>Net Counts</th>
<th>Band</th>
<th>$\Gamma_{\text{eff}}$</th>
<th>Flux ($10^{-14}$ erg cm$^{-2}$ s$^{-1}$)</th>
<th>log $L_X$ (erg s$^{-1}$)</th>
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<td>(LBQS B)</td>
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<td>2-8 keV</td>
<td>Ratio</td>
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<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
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<td>0021 − 0213</td>
<td>$6.0^{+3.7}_{-2.5}$</td>
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<td>0.85$^{+1.57}_{-0.44}$</td>
<td>1.1$^{+0.6}_{-0.4}$</td>
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<td>1203 + 1530</td>
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<td>$4.0^{+3.3}_{-2.0}$</td>
<td>$6.6^{+4.0}_{-2.7}$</td>
<td>1.63$^{+2.73}_{-0.71}$</td>
<td>0.4$^{+0.3}_{-0.8}$</td>
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<td>1442 − 0011</td>
<td>$5.1^{+3.5}_{-2.2}$</td>
<td>$2.0^{+2.9}_{-1.4}$</td>
<td>0.39$^{+1.00}_{-0.16}$</td>
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<td>1443 + 0141</td>
<td>$24.9^{+6.2}_{-5.1}$</td>
<td>$10.7^{+4.7}_{-3.4}$</td>
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<table>
<thead>
<tr>
<th>Object Name (LBQS B)</th>
<th>Count Rate (0.5-2 keV)</th>
<th>$f_{2,\text{keV,soft}}$</th>
<th>$f_{2,\text{keV,hard}}$</th>
<th>$f_{2500 ,\text{Å}}$</th>
<th>log $L_{2500 ,\text{Å}}$</th>
<th>$\alpha_{\text{OX,soft}}$</th>
<th>$\alpha_{\text{OX,hard}}$</th>
<th>$\Delta \alpha_{\text{OX,soft}} (\sigma)$</th>
<th>$\Delta \alpha_{\text{OX,hard}} (\sigma)$</th>
<th>$f_{\text{weak}}$</th>
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<td>(2)</td>
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<td>0021 − 0213</td>
<td>$0.16^{+0.10}_{-0.07}$</td>
<td>0.34</td>
<td>1.78</td>
<td>2.34</td>
<td>31.46</td>
<td>$-2.24^{+0.10}_{-0.07}$</td>
<td>$-1.96^{+0.12}_{-0.08}$</td>
<td>$-0.57(3.90)$</td>
<td>$-0.29(2.00)$</td>
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<td>1203 + 1530</td>
<td>$0.38^{+0.14}_{-0.11}$</td>
<td>0.90</td>
<td>0.71</td>
<td>1.68</td>
<td>31.05</td>
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<td>$-0.41(2.79)$</td>
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<td>1212 + 1445</td>
<td>$0.26^{+0.21}_{-0.13}$</td>
<td>0.31</td>
<td>2.28</td>
<td>4.46</td>
<td>31.47</td>
<td>$-2.36^{+0.08}_{-0.08}$</td>
<td>$-2.03^{+0.12}_{-0.08}$</td>
<td>$-0.69(4.73)$</td>
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<td>1235 + 1453</td>
<td>$0.22^{+0.11}_{-0.09}$</td>
<td>0.19</td>
<td>3.54</td>
<td>1.48</td>
<td>31.38</td>
<td>$-2.26^{+0.08}_{-0.08}$</td>
<td>$-1.77^{+0.12}_{-0.08}$</td>
<td>$-0.60(4.13)$</td>
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<tr>
<td>1442 − 0011</td>
<td>$0.34^{+0.24}_{-0.15}$</td>
<td>0.86</td>
<td>1.13</td>
<td>3.45</td>
<td>31.60</td>
<td>$-2.15^{+0.08}_{-0.08}$</td>
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<td>1443 + 0141</td>
<td>$1.55^{+0.32}_{-0.24}$</td>
<td>3.50</td>
<td>6.12</td>
<td>2.28</td>
<td>31.50</td>
<td>$-1.85^{+0.04}_{-0.04}$</td>
<td>$-1.75^{+0.07}_{-0.07}$</td>
<td>$-0.17(1.16)$</td>
<td>$-0.08(0.53)$</td>
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<tr>
<td>2201 − 1834</td>
<td>&lt; 0.29</td>
<td>&lt; 0.37</td>
<td>&lt; 2.29</td>
<td>9.40</td>
<td>31.88</td>
<td>&lt; 2.46</td>
<td>&lt; 2.15</td>
<td>&lt; 0.73(4.99)</td>
<td>&lt; 0.42(2.91)</td>
<td>&gt; 12.78</td>
</tr>
</tbody>
</table>
Typical SEDs
Frequency Constraints

• 7-10% among HiBAL quasars.

• LoBAL quasars are X-ray weaker in the hard band. Probably a higher fraction among these. Up to ~23% among BAL quasar.

• Fraction of intrinsically X-ray weak objects among BAL quasars is considerably larger than the <2% fraction among non-BAL quasars.
Relevance to Wind Launching

No luminous X-rays - no shielding gas required!

Perhaps intrinsically X-ray weak quasars preferentially launch strong winds with large covering factors, thereby preferentially appearing with BALs.
Wind Properties

BALnicity Index

Maximum velocity
Physics Not Clear for *Intrinsic X-ray Weakness*

**Supercritical Accretion?**

- Tidal torques from the binary open a gap in the circumbinary gas.
- Miss the inner, highest temperature disk region that produces the X-rays (e.g., Milosavljevic & Phinney 2005; Takamitsu & Kristen 2010).

**SMBH Binaries?**

- Coronal Quenching? (e.g., see discussion in Leighly et al. 2007)

Trapping of the radiation from the innermost parts of disk/corona

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- Radiative flux
- Gas flow
- Trapping Region
- BH

**Ohsuga & Mineshige (2007)**

Kocsis et al. (2012)
An Alternative Scenario

• A very compact Compton-thick absorber along the line of sight.

• No transmitted component \((N_H > 1 \times 10^{25})\).

• No Compton scattering (Compton hump) due to the compactness.

• Spectrum dominated by a scattered component from a large-scale highly ionized reflector. A couple percent of the intrinsic one.

• Unlikely.
Affecting X-ray Surveys?

- <23% among BAL quasars.
- <2% among non-BAL quasars.
- Thus <5% among the luminous type 1 AGN population.
- No significant effect on X-ray surveys for the census of these AGNs.
Summary

- Two candidates for intrinsically X-ray weak BAL quasars discovered (LBQS 1203+1530 and LBQS 1442-0011. Best ones besides PHL 1811.

- A 7-10% fraction among HiBAL quasars.
Future Work

• The two objects are only weakly detected in the hard band ($\sim 2.3 \sigma$ detections), with substantial uncertainties on $\Gamma$ and X-ray weakness. Deeper Chandra or XMM-Newton observations required.

• Deeper observations on the LoBAL quasars to find more such extreme quasars.