Exploratory X-ray Monitoring of High Redshift Radio-Quiet Quasars

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The X-ray Universe 2011, Berlin, June 28, 2011
Outline

1. Were Quasars More X-ray Variable in the Early Universe?
2. *Chandra* Monitoring of Radio-Quiet Quasars at $z\approx 4.2$
3. *Swift* Monitoring of Radio-Quiet Quasars at $z\approx 2$
4. Ongoing and Future Work
1. Were Quasars More X-ray Variable in the Early Universe?

**Motivation (a):**

X-ray spectral properties of quasars have not changed significantly across cosmic time.

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1. Were Quasars More X-ray Variable in the Early Universe?

**Motivation (b):**

Quasars of matched luminosity appear to be more X-ray variable at higher redshift.

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1. Were Quasars More X-ray Variable in the Early Universe?

Motivation (c):

But distant quasars, being more luminous and hence physically larger than nearby quasars/AGN/Seyferts, are supposed to exhibit slower and suppressed variations?!?

Some possible interpretations include evolution of:

- The X-ray variability mechanism
- The X-ray emitting region size
- The accretion rate/mode/efficiency

Testing this requires X-ray variability information about the most distant quasars. What are the amplitudes and timescales of X-ray variations of the most distant quasars?
2. Chandra Monitoring of Radio-Quiet Quasars at $z \approx 4.2$

Systematic X-ray variations of the most distant quasars have not been carried out yet.

Why X-rays?

X-ray variations are typically faster and stronger relative to those in the optical.

X-ray monitoring is more efficient for studying continuum variations in the most distant quasars.
2. Chandra Monitoring of Radio-Quiet Quasars at z ≃ 4.2

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2. Chandra Monitoring of Radio-Quiet Quasars at $z \approx 4.2$

**Target selection**

- RQQs at $z > 4$.
- Have at least two distinct epochs (i.e., continuous exposures).
- Bright enough for economical *Chandra* observations.

**Sample Properties**

<table>
<thead>
<tr>
<th>Quasar</th>
<th>$z$</th>
<th>$M_B$</th>
<th>Galactic $N_H$ (10$^{20}$ cm$^{-2}$)</th>
<th>$\log L_{2-10 \text{ keV}}$ (erg s$^{-1}$)</th>
<th>$\alpha_{ox}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSS 0926+3055</td>
<td>4.19</td>
<td>−30.1</td>
<td>1.89</td>
<td>45.8</td>
<td>−1.76</td>
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<tr>
<td>PSS 1326+0743</td>
<td>4.17</td>
<td>−29.6</td>
<td>2.01</td>
<td>45.7</td>
<td>−1.76</td>
</tr>
<tr>
<td>Q 0000−263</td>
<td>4.10</td>
<td>−29.3</td>
<td>4.08</td>
<td>45.7</td>
<td>−1.70</td>
</tr>
<tr>
<td>BR 0351−1034</td>
<td>4.35</td>
<td>−28.2</td>
<td>1.67</td>
<td>45.4</td>
<td>−1.69</td>
</tr>
</tbody>
</table>

Maximum excess variance: $\sigma_{\text{max}} = \max_{i \in 1, \ldots, N_{\text{obs}}} \sqrt{\left(\frac{(n_i - \bar{n})^2}{\bar{n}^2} - \sigma_i^2\right)}$

Need to break the strong $L$-$z$ dependence inherent in quasar samples.
3. Swift Monitoring of Radio-Quiet Quasars at $z \approx 2$

Sample Properties and Light Curves

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<tr>
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<th>Galactic $N_H$</th>
<th>$\log L_{2-10,\text{keV}}$ (erg s$^{-1}$)</th>
<th>$\alpha_{\text{ox}}$</th>
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<tbody>
<tr>
<td>PG 1247+267</td>
<td>2.04</td>
<td>-29.5</td>
<td>0.90</td>
<td>45.9</td>
<td>-1.75</td>
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<tr>
<td>PG 1634+706</td>
<td>1.33</td>
<td>-30.1</td>
<td>4.48</td>
<td>46.1</td>
<td>-1.68</td>
</tr>
<tr>
<td>HS 1700+6416</td>
<td>2.74</td>
<td>-29.9</td>
<td>2.66</td>
<td>46.2</td>
<td>-1.91</td>
</tr>
</tbody>
</table>

Target selection

- RQQs at $z \sim 2$.
- Luminosities comparable to the Chandra sample.
- Have the most epochs (5-14).
- Bright enough for economical Swift observations.

Fractional variability amplitude

$$F_{\text{var}} = \frac{1}{\langle X \rangle} \sqrt{S^2 - \langle \sigma_{\text{err}}^2 \rangle}$$

Variability amplitudes similar to low-$L$ AGN.

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Extreme X-ray variability of HS 1700+6416

X-ray fluctuations of $\approx 4 \times 10^{12} \, L_\odot$ on timescales of $\approx 1$ day(!)

Implying $\Delta L / \Delta t \approx 2 \times 10^{41} \, \text{erg s}^{-2}$

Taking a radiative efficiency ($\eta$) limit $\eta \approx 4.8 \times 10^{-43} \Delta L / \Delta t$

(e.g., Fabian 79), this gives $\eta \approx 0.1$. 

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3. Swift Monitoring of Radio-Quiet Quasars at $z \approx 2$

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Extreme X-ray variability of HS 1700+6416?

Month-Year

Continuum  HS 1700+6416  $z=2.74$

Lyα

C IV

Kaspi et al. (2007)

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3. Swift Monitoring of Radio-Quiet Quasars at $z \approx 2$

Variability Structure Function

$$SF(\tau) \equiv \sqrt{\left\langle [m(t + \tau) - m(t)]^2 \right\rangle}$$

Denser sampling is required to assess variability timescales.
4. Ongoing and Future Work

- Continue the *Chandra* monitoring and add one epoch per Cycle for the $z=4.2$ sources.
- Continue the *Swift* monitoring to obtain better temporal sampling for the $z=2$ sources.
- Compute variability structure functions and $F_{\text{var}}$ values for the *Chandra* sources.
- Search for correlated X-ray-optical variations ($\alpha_{\text{ox}}$): 1) *Swift* XRT vs. *UVOT*, 2) *Chandra* vs. ground-based photometry and spectroscopy.
- Search for X-ray spectral variations in the brightest *Swift* sources.
- Obtain a *qualitative* assessment of the timescales and magnitudes of the X-ray variability allowing development of a strategy for more ambitious and long-term monitoring programs of distant quasars.