QSO variability and black hole mass

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“The nuclear region, host galaxy and environment of AGN”, Huatulco, Mexico, April 18-20, 2007
QSO optical/UV variability

- optical/UV variability observed since (even before) the discovery of qsos
- non-periodic, erratic; $\Delta m \sim$ few tenths of a magnitude: changes in the energy generation mechanism
- holds clues to understanding the AGN mechanism
- temporal variability probes physical scales we cannot resolve
- reverberation mapping: structure of BLR and BH mass (e.g. Peterson et al. 1998; 2004; Kaspi et al. 2000)

What is causing the fluctuations in quasar continua?
QSO optical/UV variability: Models

- short-term (days - weeks)
- long-term (months - decades)
  - relativistic beaming (projection effects in blazars) [Blandford & Rees 1978]
  - flares and optical depth variations in X-ray corona [e.g. Krolik et al 1991; Nandra et al 1991; review by Ulrich et al 1997]
- starburst models (e.g. Terlevich et al 1992; Cid Fernandes et al 1996)
- microlensing (e.g. Hawkins 1993; 2002; Alexander 1995; Yonehara et al 1999)
- accretion disk instabilities (e.g. Kawaguchi et al 1998; Starling et al 1994)
Results from long-term QSO variability surveys


I. variability - time lag

II. variability - luminosity

III. variability - wavelength

QSO variability is an intrinsic property
How does it depend on fundamental AGN parameters?

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Variability survey: QUEST1
QUasar Equatorial Survey Team
(Rengstorf et al 2004a,b)

- 200 deg² surveyed over 26 months
- up to 69 scans of same region
- 200k light curve catalog: SDSS overlap
- contains ~1000 known qsos (Rengstorf et al 2006)

Abazajian et al 2004

- broad emission lines
- z < 0.75 (Hβ @ 4861Å)
- 104 qsos

1m telescope at Llano del Hato Observatory, Venezuela

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SDSS - QUEST sample : temporal sampling

- rest-frame time lag $t / (1+z)$
- deredshifting:
- better light curve coverage
- shorter time span

See also Rengstorf et al 2006
**MBH - variability correlation**

Wold, Brotherton & Shang 2007

Pearson correlation coeffs

<table>
<thead>
<tr>
<th></th>
<th>log MBH</th>
<th>log Lbol</th>
<th>log L/LEdd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max(Δm)</td>
<td>0.285</td>
<td>0.146</td>
<td>-0.189</td>
</tr>
<tr>
<td>Mean(Δm)</td>
<td>0.273</td>
<td>0.137</td>
<td>-0.184</td>
</tr>
<tr>
<td>stddev(Δm)</td>
<td>0.248</td>
<td>0.102</td>
<td>-0.188</td>
</tr>
</tbody>
</table>

P=0.003, σ = 2.9

Selection effects?

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Selection effects

“Primary” correlations for QSOs:
1. variability - luminosity
2. variability - wavelength (redshift)
3. variability - time lag

Sample selection effects:
1. $M_{BH}$ - redshift ($\rho=0.466, \sigma=4.7$)
2. $M_{BH}$ - luminosity ($\rho=0.513, \sigma=5.2$)

- $M_{BH}$ - z + (variability - z):
- Spearman’s partial $\rho=0.203, p=0.35\%$
- $M_{BH}$ - variability at constant $L_{bol}$:
- Spearman’s partial $\rho=0.254, p=0.02\%$

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Residual host galaxy contamination?

Affects low-luminosity qsos:

1) dilutes variability for high host:AGN ratios

2) overestimates BH mass (e.g. Kaspi et al 2000; 2005; Bentz et al 2006)

BUT:
- only a few SDSS spectra show signs of host galaxy light
- МВН - variability correlation present also among high-luminosity qsos
Conclusions

• time scales probed ~6 months up to 2 yrs
  • accretion disk thermal time scales
• more massive black holes have larger variability amplitudes
• not easily explained by selection effects or host galaxy contamination
• no evident correlation with Eddington ratio, Lbol/LEdd
• correlation supports models where the variability is intrinsic to the AGN
• larger samples and/or samples with better temporal sampling needed to confirm the robustness of the correlation
Selection effects

- QUEST samples time scales 1-2 yrs + most variability at 1-2 yrs (Rengstorff et al 2004; 2006)
- $T_{\text{char}}$ depends on BH mass

Some arguments against:

1. variability time scale must be associated with $T_{\text{char}}$ (Collier & Peterson 2001)
2. low-z qsos with lower BH masses contribute most to variability at longer time lags

Collier & Peterson 2001

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BH mass estimation

Virial BH masses estimated from Hβ line widths and 5100 Å continuum luminosity
(Kaspi et al 2000; Vestergaard & Peterson (2006))

Fundamental AGN parameters:
$M_{BH}$, $L_{bol}$, $L_{Edd}$, $L_{bol}/L_{Edd}$

correlate with variability measures