Probing AGN accretion history through X-ray variability

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Variability properties of AGNs

High frequency break seems to scale with BH mass and accretion rate

(Uttley & McHardy 2005, Markowitz & Uttley 2005, McHardy 2006)

\[ t_B \propto \frac{M_{BH}^\alpha}{L_{bol}^\beta} \]
Variability in poor statistics data

AGN variability is anti-correlated with $L_X$ (Barr & Mushotzky 1986, Lawrence & Papadakis 1993, Nandra et al. 1997)

$\sigma^2_{NXV} = \frac{1}{N\bar{x}^2} \sum_{i=1}^{N} [(x_i - \bar{x})^2 - \sigma^2_{\text{err},i}]$

Can use ‘excess-variance’ to estimate mass (e.g. O’Neill et al., Gierlinski et al. 2007) but should take biases into account!
Variability in poor statistics data

AGN variability is anti-correlated with $L_X$ (Barr & Mushotzky 1986, Lawrence & Papadakis 1993, Nandra et al. 1997)

$$\sigma_{NVX}^2 = \frac{1}{N \bar{x}^2} \sum_{i=1}^{N} [(x_i - \bar{x})^2 - \sigma_{err,i}^2],$$

Does the normalization depend on accretion rate as well?

Best sampled on long timescales!

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Increased variability at high z?
(Almaini et al. 2000; Paolillo et al. 2004)

The evolution of the $L_X$-var. relation could be produced by increase of the accretion rates or a decrease of the X-ray emitting region with look-back time.

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Null result for the XMM Lockmann Hole bright sample 
(Mateos 2007)

- Variability on time scales from months to 2 years, of the 123 brightest objects detected with XMM-Newton in the Lockman Hole field.

- No dependence on redshift, X-ray luminosity or AGN type.

But....if complex dependence on redshift, luminosity and variability we need to take all of them into account simultaneously!
Increased variability in the Lockman Hole?
(Papadakis et al. 2008)

Fitting a more physically motivated model yields:

\[ v_{bf} = 0.029 \eta m_{\text{Edd}} (M_{\text{BH}}/10M_\odot) \]

\[ L_{\text{bol}} = 1.3 \eta m_{\text{Edd}} 10^{39} (M_{\text{BH}}/M_\odot) \text{ erg/s} \]

(N.B. assumes constant PSD amplitude)

- Fitting the Lx-\(\sigma^2\) anticorrelation requires higher accretion at high redshift.

- Variability-LX relation can be used in principle to probe both accretion rate and BH mass
Null result for the Chandra-SDSS sample: (Gibson & Brandt 2012)

• 264 SDSS spectroscopic quasars in the Chandra archive (z<5) and with rest-frame timescales $<\Delta t_{\text{sys}} \approx 2000$ days,

• Significant (>3σ) variation in $\approx 30\%$ of the quasars overall ($\approx 70\%$ for sources with >1000 counts per epoch).

No evidence that quasars are more variable at higher redshifts (z > 2)
XMM and Swift serendipitous samples
(Vagnetti, Turriziani & Trevese, 2011; Vagnetti et al. 2016)

- No evidence of a break in the SF
- Anti-correlation of the variability with X-ray luminosity
- No average increase of X-ray variability with redshift.

**Increasing luminosity**
Constraining the relevant parameters: the CAIXA sample
(Ponti et al. 2011)

XMM-Newton sample of 161 radio quiet, X-ray un-obscured AGN studied on time scales less than a day. Mostly local (z<0.3) AGNs.

Tight (~ 0.7 dex) correlation between σ² and M_BH, but variable PSD amplitude
Accretion dependence challenged by XMM studies


Possible scenarios:

- Break timescale depends only on BH mass

- Break timescale depends on BH mass and accretion rate.

**Conclusion:** Weak or no dependence on accretion rate.
Constraining the relevant parameters: COSMOS field (Lanzuisi et al. 2014)

Dependence on mass, but no dependence on accretion!
7Ms CDFS dataset
(Luo et al. 2016)
7Ms CDFS lightcurves
(Paolillo et al. 2017, submitted)
Lx-variability correlation

High-z AGN do follow the Lx-variability relation but ....
AGNs at different redshift sample different timescales, so need to correct or model this effect!
7Ms CDFS lightcurves

- The 7Ms data allow to sample AGN variability on different timescales, from a few days up to 17 yrs.

- A proxy to a proper PSD analysis
What PSD for high-z AGNs?

- A single flat (\(\sigma_{\text{NXV}} = \nu^{-1}\)) power-law PSD only fits long timescales.

- Steeper PSD slopes (\(\sigma_{\text{NXV}} = \nu^{-1.5}\)) provide poor fits to some timescales.

- A bending power-law seems the best fit for high-z AGNs, reproducing both the high frequency cutoff and the redshift dependence.

\[
\text{PSD}(\nu) = A\nu^{-1} \left(1 + \frac{\nu}{\nu_b}\right)^{-1}
\]
Constraining the model: fit results

Model 1:
- bending frequency depends only on BH mass as $\nu_b \propto M^{-1}$ (Gonzales-Martin & Vaughan, 2012)
- fixed PSD normalization (Papadakis et al. 2004, 2008)

Model is rejected at >99% c.l. for any $\lambda_{\text{Edd}} > 0.03$
Constraining the model: fit results

**Model 2:**

- Bending frequency depends on BH mass and acc. rate through $v_b \propto L/M^2$
  (McHardy et al. 2006)

- Fixed PSD normalization
  (Papadakis et al. 2004, 2008)

Model is acceptable at ~1% c.l.
Constraining the model: fit results

Model 3:
- bending frequency depends only on BH mass as $\nu_b \propto M^{-1}$ (Gonzales-Martin & Vaughan, 2012)
- PSD normalization depends on $\lambda_{\text{Edd}}$ (Ponti et al. 2011)

Model is rejected at $>99\%$ c.l.
Constraining the model: fit results

Model 4:
- Bending frequency depends on BH mass and acc. rate through $v_b \propto L/M^2$ (McHardy et al. 2006)
- PSD normalization depends on $\lambda_{Edd}$ (Ponti et al. 2011)

Model is acceptable at $\sim 10\%$ c.l.
Accretion history results

- A constant $\lambda_{\text{Edd}} \leq 0.1$ is consistent with the data, although some models indicate a possible increase of $\lambda_{\text{Edd}}(z)$ increasing with redshift.

- The low redshift data are consistent with variability of local AGNs (Zhang et al. results).
Calibrated variability correlations can provide cosmological constraints. But what about other parameters (e.g. accretion rates)?
Conclusions

- Multi-epoch surveys offer the opportunity to investigate the timing properties of distant AGN populations.
- Luminosity-variability anticorrelation verified over large redshift range.
- High-z AGNs share similar PSD of local AGNs.
- Variability dependence on both mass and accretion is favored.
- With correct statistical approach and accounting for biases we can constrain the best physical model.
- Variability allows to constrain the average accretion rate over cosmic time.

Wide-field multi-epoch surveys may allow constrain the evolution of the AGN population.

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