AGN X-ray Variability and relationship to optical and radio galaxy properties

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TYPICAL AGN X-RAY DATA....
Eg NGC4051 RXTE Long Timescale Observations

(McHardy et al 2004)
TIMING STATES

Unfolded' Power Spectral Density (PSD) (McHardy et al., 2004)

• NGC 4051 partly like Cyg X-1 low-hard state, but no second break at low-frequency
• More like high-soft state of Cyg X-1
• High break timescale scales approximately linearly with mass

Cyg X-1 Low-hard state PSD:
Can be described either as powerlaw with two bends, or as sum of ‘Lorentzian’ shaped bumps

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( McHardy et al., 2004)
AGN with narrower lines and higher accretion rates have shorter $T_B$.

$T_B$ associated with inner edge of disc?

Higher accretion rate pushes in disc?

(McHardy et al 2004, MN, 348, 783)

(Note rough lines of linear scaling, not fits, from Cyg X-1 in its `low-hard' and `high-soft' states)
Proper 3D fit to $T_B$, $M$, $\dot{m}_E$

\begin{align*}
\text{i.e} \quad T_B &\sim M^{1.12} \dot{m}_E^{-0.98} \\
\text{(eg, for } M=10^8 \text{ } M_\odot, \text{ } \dot{m} =0.1, T_B = 6 \text{d} )
\end{align*}

Large contours, just to AGN (20) (mostly soft state)

As $\dot{m}_E = \frac{L_{\text{Bol}}}{M}$

we fit to $T_B \sim M^A L_{\text{Bol}}^{-B}$

Smaller contours include soft state binaries, GRS1915+105 and Cyg X-1

Good fit. Additional parameter (eg spin) not needed.

(McHardy et al, 2006; Summons et al in prep)
Optical linewidth correlates with X-ray variance

-but, physically, how?

(Turner et al 1999)

NLS1s are the filled squares
**$T_B$ and Linewidth, V**

(McHardy et al, 2006; Summons et al in prep)

\[ T_B \sim V^{3.8} +/- 0.6 \]

**Simple scaling relationships:**

1. \[ L \sim M \dot{m}_{Edd} \]
2. \[ R_{BLR} \sim L^{0.5} \] (LOC - Kaspi et al 1996) \[ \text{Bentz et al 2006} \]
3. \[ v^2 \sim GM/R_{BLR} \]

Then expect

Linewidth, \[ V^4 \sim \frac{M}{\dot{m}_{Edd}} \]

**Powerful confirmation that** \[ T_B \sim \frac{M}{\dot{m}_E} \]

Strong link between Black Hole timing and larger scale AGN properties

**IMPLICATION:** NLS1 same as other AGN, just have smaller ratios of \[ \frac{M}{\dot{m}_E} \]

Small masses are selection effect as \[ \dot{m}_E \] can’t easily exceed unity
Optical Variability in AGN: Reprocessed X-rays or intrinsic disc variability?

Solid line gives fit of lags between optical bands to reprocessing model

\[ T \propto M_{BH}^{-1/4} \dot{M}^{1/4} R^{-3/4} \]

(Cackett et al, 2006; Sergeev et al 2005,6)
NGC 4051

RXTE

V band

Flux

MJD−50000
NGC 4051

RXTE

V band

Flux

MJD - 500000
Optical lags by 1.5 +/- 0.5 d (above 99% confidence)
Breedt et al 2010

Remove reprocessed model lightcurve.
Still leaves second lag peak at ~40d - Torus??
Infrared – Optical Lags: NGC3783

Green is V-band, for comparison.

J-band similar lightcurve to V-band, but K-band lags.

V and J mostly reprocesing from disc, K includes some torus contribution

Lira et al, submitted also Saganuma et al 2006
MKN 79

Short term correlation but different long term trends

Optical probably a combination of X-ray reprocessing and intrinsic disc variations (inwardly propagating fluctuations)

(Breedt et al, 2009, MNRAS)
X-ray/optical peak correlation coefficient vs. black hole mass

Breedt et al (in preparation)
Correlation looks tighter than with mass, but is statistically very similar.

Temperature correlation explained by solid angle subtended by the optical emitting region at X-ray source.
NGC4395 (~$10^5$ solar mass BH)- Swift
NGC4395 lightcurves

**UVOT**

**XRT**
NGC4395: Shorter timescale (hours- days)
NGC4395: Short timescale CCF

Very small lag < 45min
again indicating reprocessing

(Cameron et al, in prep)
How does NGC4395 fit the M, T correlations?

NGC4395 does not agree with pure mass scaling but is consistent with disc temperature scaling.
Swift X-ray/Optical Correlations for NLS1s 1H0707 and IRAS13224

..nothing much, in agreement with the temperature correlation

(Cameron, with McH, Fabian, Uttley..)
Radio/X-Ray Variability

1. Liners - NGC7213 + M81

2. Seyfert – NGC4051
NGC7213 – X-RAY/RADIO

\[ S \sim \nu^{+\alpha}\]  

(Bell et al., 2010)
8 GHz lags X-rays by \( \sim24 \) days
M81 X-ray and 15GHz lightcurves

Swift 0.5-10 keV
M81 X-ray and 15GHz Cross-correlation

Interpolated CCF

AMI 15GHz

OVRO 15GHz

Lag of 15GHz flux behind X-rays (days)
X-ray and 15GHz lightcurves of M81

Advanced by 60d
M81 X-ray and 15GHz

From Falcke et al 2004
cf Merloni et al 2003

Mass-scaling assuming X-rays and radio are jet-dominated (ie sync.)
Radio variability from Seyferts, i.e. high accretion rate, Soft State, AGN

NGC5548 – Wrobel 2000 - no parallel X-ray observations

(c) VLA 1210 mas at 1989.253±50d

(d) VLA 1210 mas at 1993.241±50d

Flux density, $S_{\nu}$ (mJy)

8.4 GHz

4.9 GHz

UT Epoch (years)
NGC4051

- Looks just like a classical radio galaxy – except much smaller and of much lower luminosity.

- Component separation is ~50 light years

(See also Girolletti and Panessa 2009)
NGC4051 – Global VBLI
NGC4051 VLA A and B array 8GHz observations

Jones et al, submitted

Peak flux ~0.5mJy in A-array
NGC4051 VLA A array observations
NGC4051  VLA B array observations
NGC4051 Radio vs. X-ray – A array

Interpolated **unsmoothed X-rays** (ergs/cm²/sec x 10⁻¹¹)

Interpolated **smoothed X-rays** (ergs/cm²/sec x 10⁻¹¹)

**Weak correlation?**
NGC4051 Radio vs. X-ray – B array

Positive correlation gone..
NGC4051  Radio vs. X-ray - all arrays

No strong evidence for large amplitude radio variability
NGC4051 on radio `fundamental plane’ for jet-dominated sources


Here plotting just hard state objects from Koerding et al

Slightly radio quiet
NGC4051 as a coronal radio source?

From Fig.6 of Laor and Behar 2008

\[ \frac{L_R}{L_x} \sim 10^{-5} \]

Maybe a combination of fast inner jets and slower, more diffuse, outflow, or corona
CONCLUSIONS

Direct link between X-ray timing properties and host galaxy linewidth.

Short timescale optical variability in Seyferts dominated by reprocessing of X-rays. Strength of O/X correlation depends on disc temperature.

Probable contribution to optical variability on longer timescales from intrinsic disc variability.

Good correlation between X-ray and radio in liners ($\sim 10^{-4}$ Eddington) Strong support for jet-dominated model for radio and X-rays

In higher accretion rate Seyferts, radio variations seen in NGC5548 but not (strongly) in NGC4051. However radio jets are seen. Radio is maybe a mixture of jet and coronal emission.
NGC4051

\[ \log(L_e) \text{ (ergs s}^{-1}) \]

\[ 0.63 \log(L_x) + 0.64 \log(M) \]

\[ \log(L_x) \text{ (erg s}^{-1}) \]
Next slide shows what you get left with if you remove Elme’s reprocessed model NGC4051 lightcurve from the observed optical lightcurve. I didn’t show it but it gives some idea of the intrinsic disc variations.
Proper 3D fit to $T_b$, $M$, $\dot{m}_E$

(McHardy et al, 2006)

First, just to AGN  (10)
(mostly soft state)

As $\dot{m}_E = L_{\text{Bol}} / M$

we fit to $T_B \sim M^A L_{\text{Bol}}^{-B}$

Add soft state binaries, GRS1915+105 and Cyg X-1

So the Binary data is entirely consistent with the AGN data

Good fit. Additional parameter (eg spin) not needed.
Projection of the Variability Plane

Red circles – fitted AGN
Open circle – LLAGN NGC4395
Green squares are AGN with poorly determined $T_b$, not included in the fit.
Blue crosses – Cyg X-1
Magenta star – GRS1915+105
Outlying (red dot) AGN is NGC5506; mass is only from width of OIII lines

$\log T_{\text{observed}} \text{ (days)}$

$\log T_{\text{predicted}} \text{ (days)} \; i.e \sim M^{1.12} \; m_E^{-0.98}$

Useful for mass determination for IMBHs and obscured AGN

Hard state binaries are consistent (without fitting), with an offset (Koerding et al 2007)
Projection of the Variability Plane

Red circles – fitted AGN
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Blue crosses – Cyg X-1 and GRS1915+105

Outlying (red dot) AGN is NGC5506; mass is only from width of OIII lines

Useful for mass determination for IMBHs and obscured AGN

Hard state binaries are consistent (without fitting), with an offset

$$\log T_{\text{predicted}} \text{ (days)} \quad \text{i.e.} \quad M^{1.12} \quad m_E^{-0.98}$$
**\( T_B \) and Linewidth, \( V \)**

(McHardy et al, 2006)

**Tight relationship**

\[ T_B \sim V^{4.2} +/- 0.6 \]

Simple scaling relationships:

1. \( L \sim \dot{m}_{\text{Edd}} \)
2. \( R_{\text{BLR}} \sim L^{0.5} \) (LOC - Kaspi et al 1996)
   Bentz et al 2006
3. \( v^2 \sim G M / R_{\text{BLR}} \)

Then expect

Linewidth, \( V^4 \sim \frac{M}{\dot{m}_E} \frac{1}{\dot{m}_{\text{Edd}}} \)

**Powerful confirmation that** \( T_B \sim M / \dot{m}_E \)

New strong link between Black Hole timing and larger scale AGN properties

**IMPLICATION:** NLS1 same as other AGN, just have smaller ratios of \( M / \dot{m}_E \)

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NGC3516, intermediate mass ($\sim 2 \times 10^7 \, M_\odot$) Maoz et al 2002
Simulated Optical Lightcurves
Propagating fluctuations plus X-ray reprocessing

(from Arevalo et al 2008; also Arevalo and Uttley 2006)
**Optical and X-ray PSDs**

NGC3783, Arevalo et al 2009

Breedt et al submitted

**Errorbars - Optical data. Dashed line – X-rays**

Mrk 79
p = 0.704

NGC 3227
p = 0.879

NGC 4051
p = 0.830

NGC 5548
p = 0.687
Simulated optical and X-ray PSDs

Simulated reprocessed optical PSD shows same slopes as the input X-ray PSD, but the bend is about 2.5 decades lower in frequency.

No intrinsic disc variability is included.

Some observed optical PSDs exceed the X-ray PSDs at low frequencies, which requires additional intrinsic disc variability.
NGC4051: Residual lightcurve
M81 X-ray and 15GHz Cross-correlation

Interpolated CCF vs. Lag of 15GHz flux behind X-rays (days)

AMI 15GHz
OVRO 15GHz
M81 X-ray and 15GHz

- M81 Observed
- M81 Mass-scaled
- GX339-4
- Sgr A*
- LLAGN
- FRI
- XBL
- RBL

\[ \log L_X \text{ (erg s}^{-1}\text{)} \]

\[ \log L_R \text{ (erg s}^{-1}\text{)} \]

\[ 0.5-10\text{keV flux (}10^{-11}\text{ erg cm}^{-2}\text{ s}^{-1}\text{)} \]
M81 X-ray and 235GHz

235GHz by Mark Gurwell
Based on ~60d lag at 15GHz, lag of ~3d expected in standard, constant velocity, jet model (Blandford and Konigl 1979) at 235GHz
M81 X-ray vs. 235GHz

\[ F_R \sim F_X^{0.7} \]
NGC4051 radio spectra

![Graph showing NGC4051 radio spectra](image)
NGC4051 X-ray Spectra and radio
NGC4051

8.4GHz flux density (mJy) vs. Interpolated $T$ and Interpolated Smoothed $T$.
Conclusions

Reprocessing of X-ray emission from the accretion disc is an important source of optical variability in all AGN.

Reprocessed component depends mainly on disc temperature, ie solid angle subtended by X-ray source.

But reprocessing isn’t the only source of optical variability.

Intrinsic fluctuations in the disc are probably also important, and reprocessing from the torus might play a small part.