The Origin of UV-optical Variability in AGN

and the relationship to X-ray Variability

Ian McHardy, Sam Connolly

with Duncan Cameron, Dimitrios Emmanoulopoulos et al

X-ray / Optical Variability in AGN

Two main models for optical variability:
Reprocessed X-rays or intrinsic disc variability
due to inwardly propagating fluctuations

- Reprocessing - X-rays lead uv/optical by short (hour-days) light travel time

- Disc variability – X-rays lag: two possibilities

  – Long lag (months), viscous propagation timescale for perturbations to reach X-ray region from optical in disc

  – Short lag (hour-day), light travel time of UV seed photons to corona

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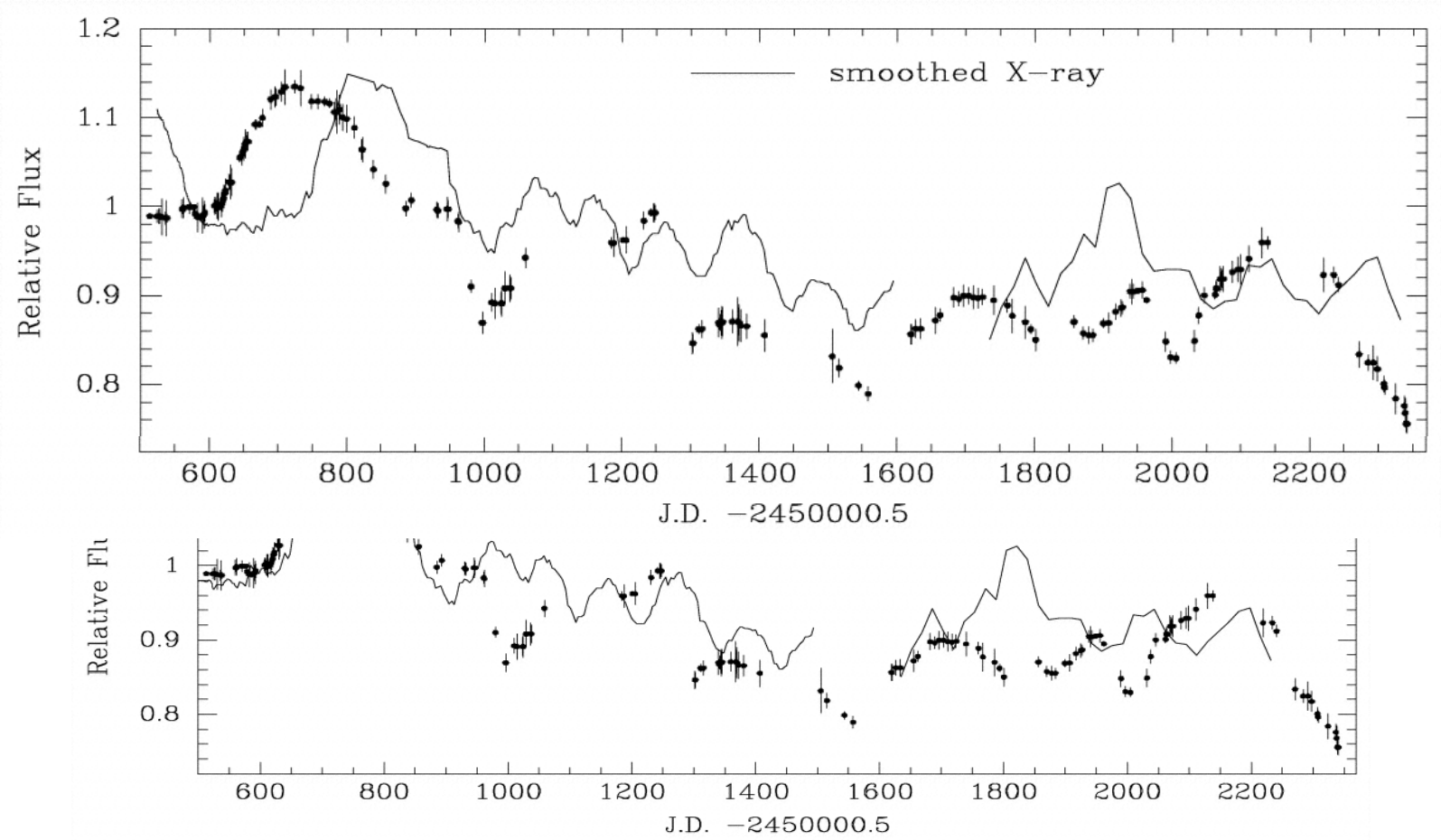
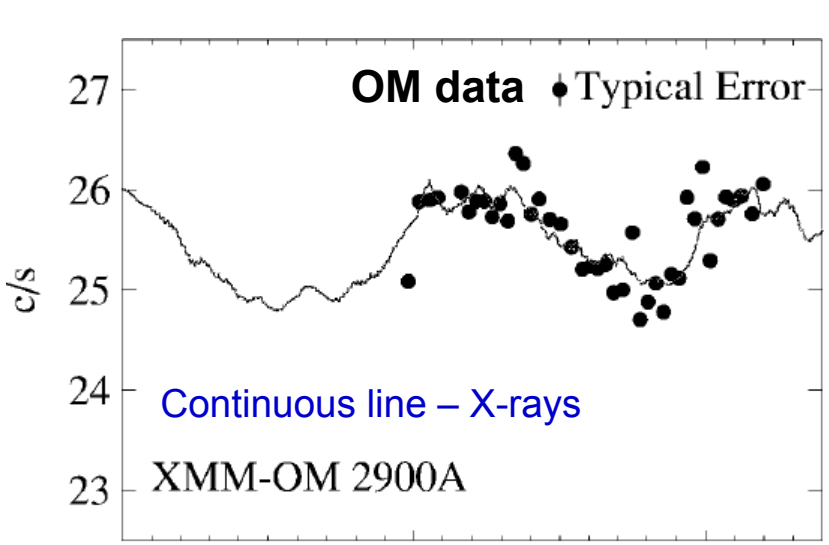
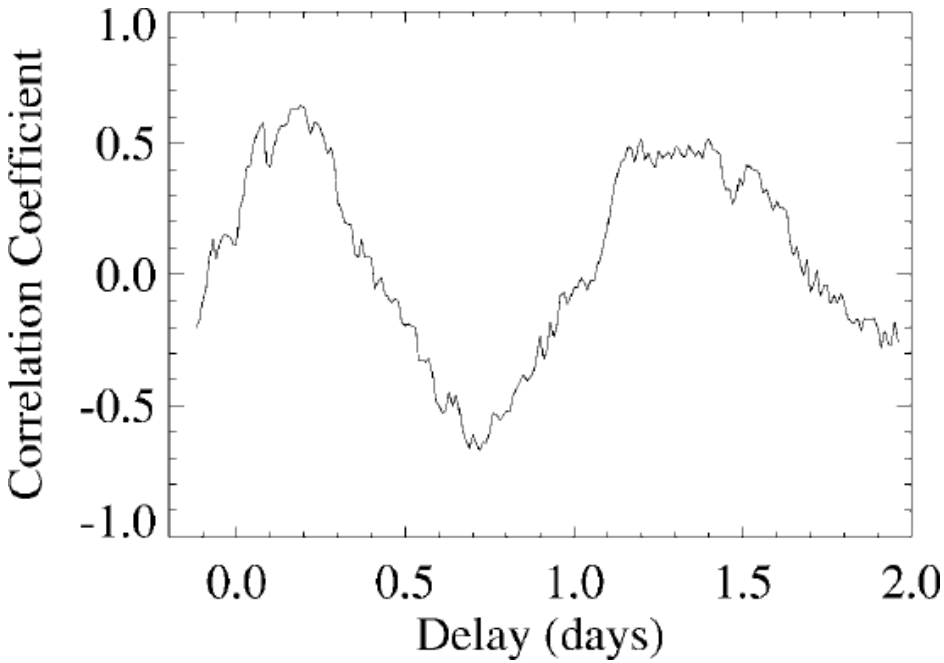
RXTE and Ground-Based Optical



NGC3516, intermediate mass (~2 x 10^7 M_0) Maoz et al 2002

NGC4051 XMM and RXTE X-rays vs. XMM OM UV





UV lightcurve reasonably (85% confidence) described by reflection from broad ring at 0.2 light days.

Mason et al 2002

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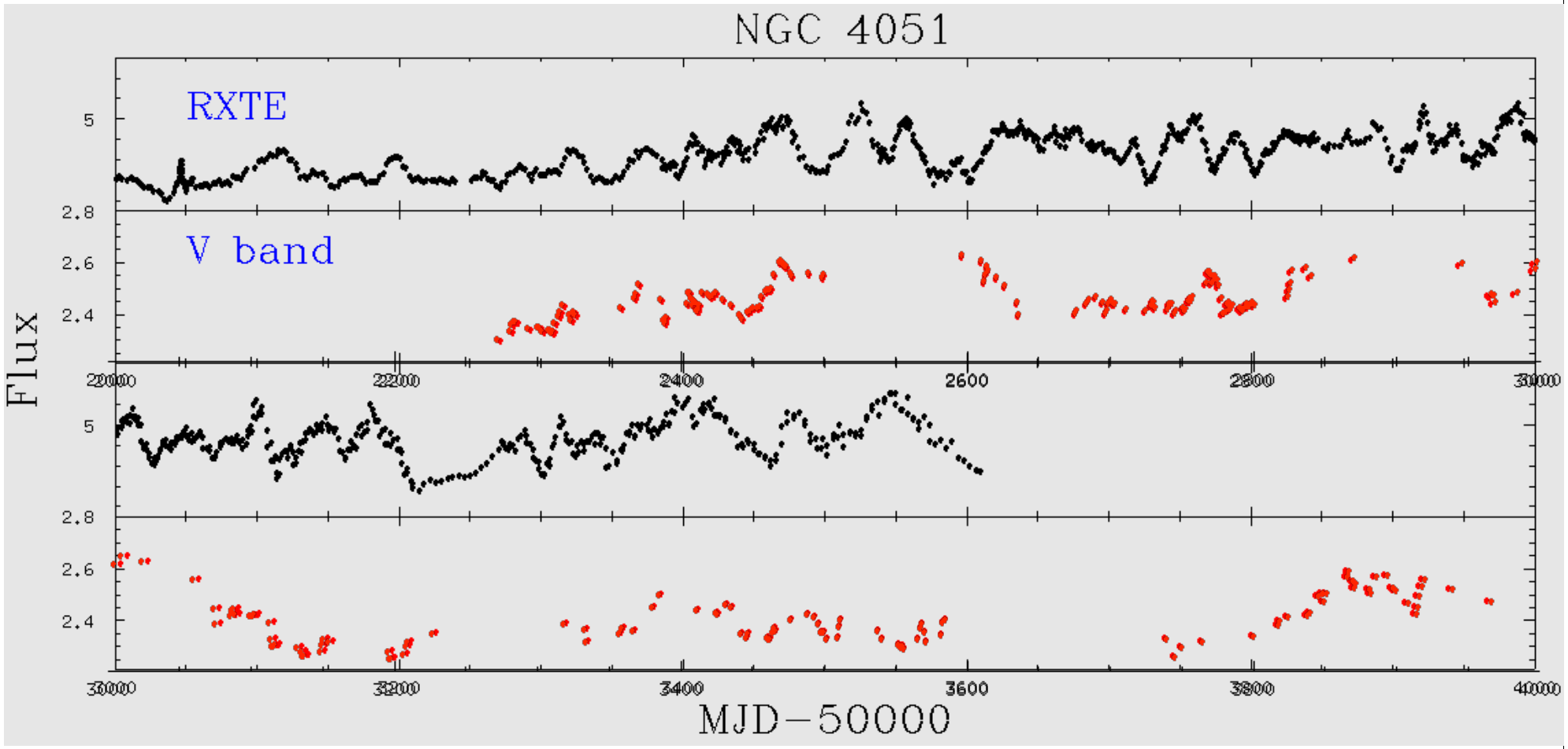
NGC 4051: Optical – X-ray



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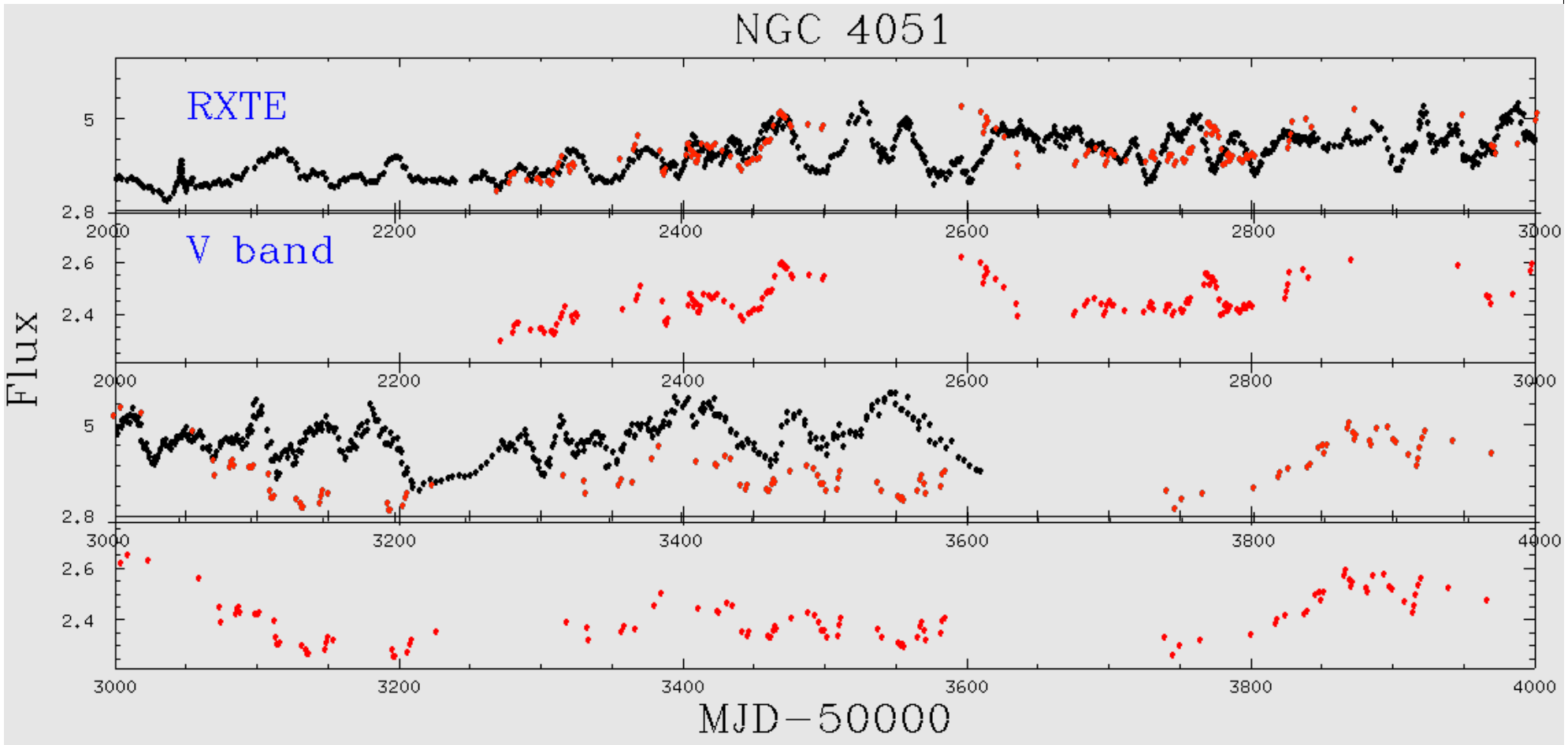
NGC 4051



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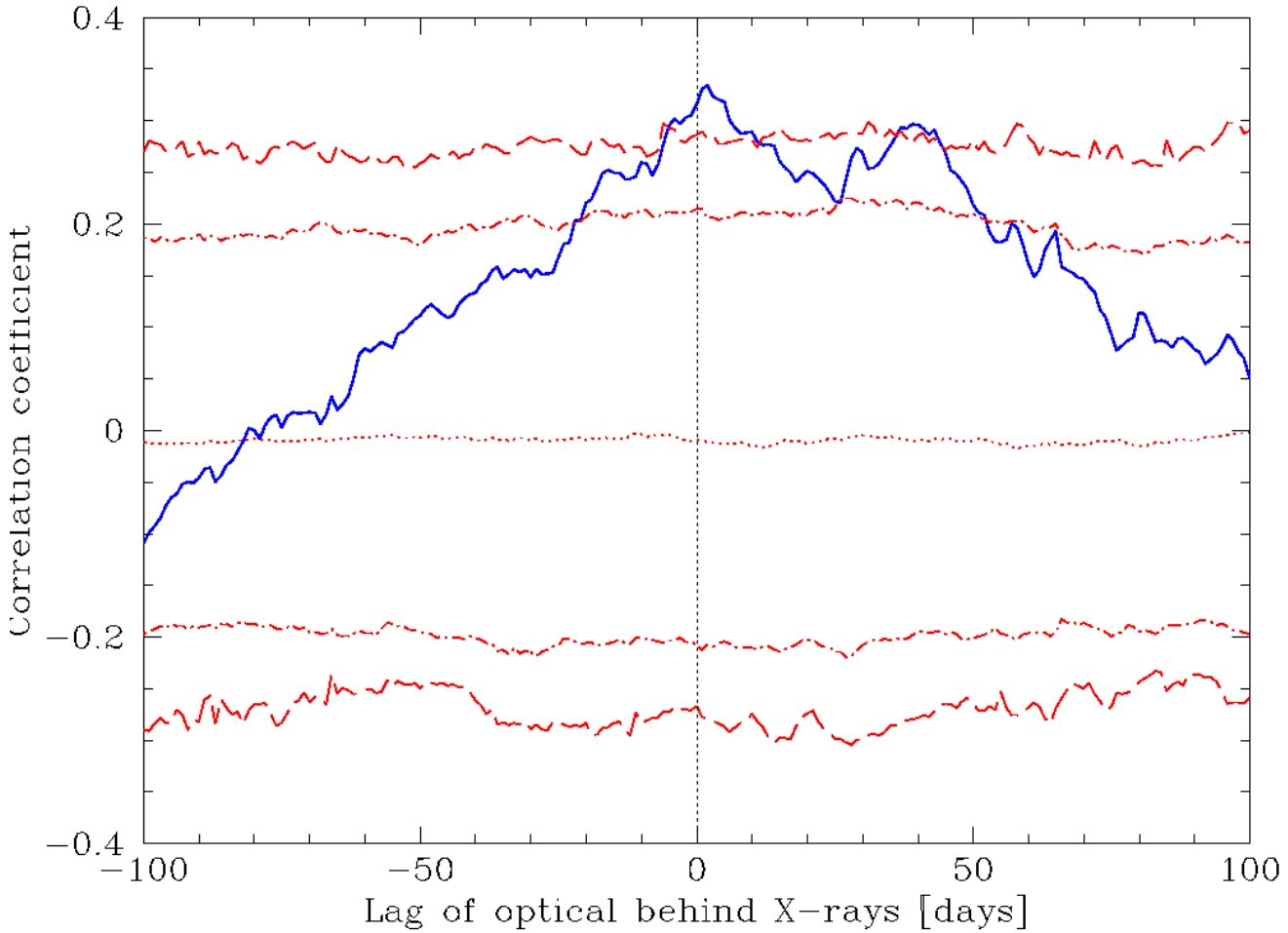
NGC4051



Optical lags by 1.5+/- 0.5 d (above 99% confidence)

Breedt et al 2010

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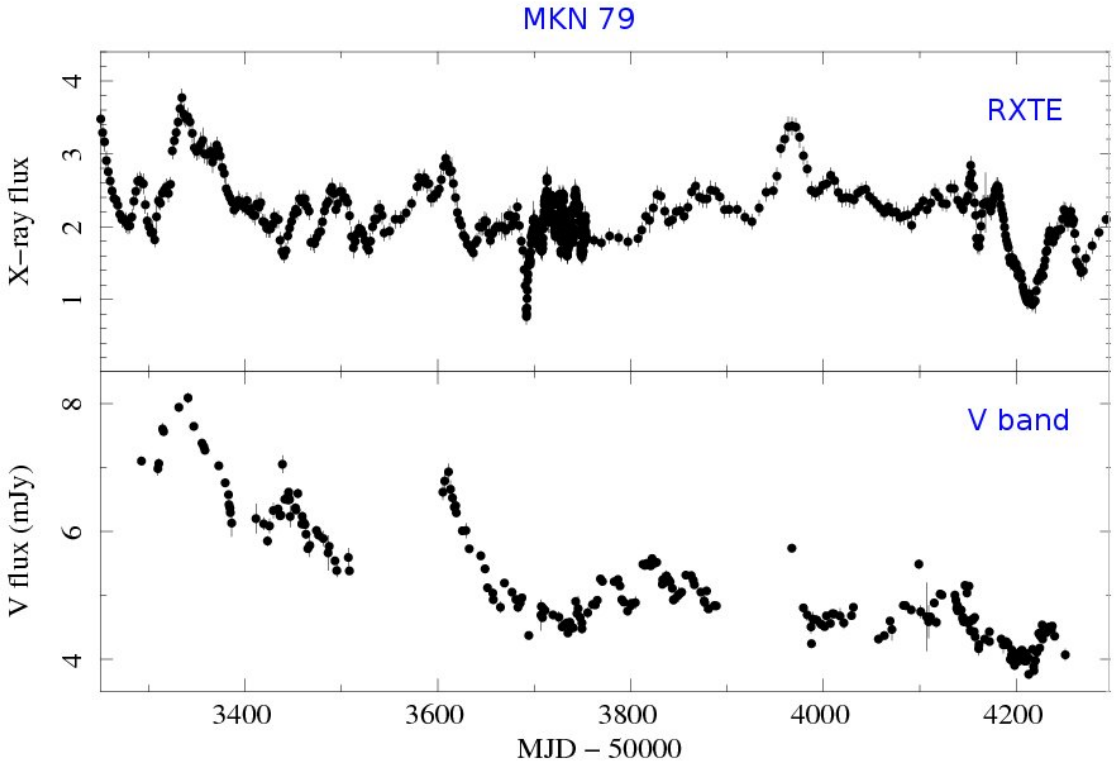
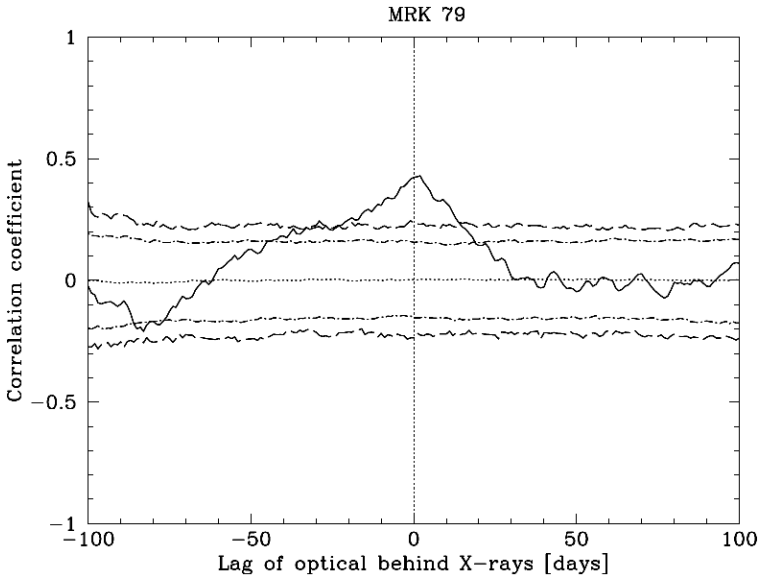
MKN 79



(Breedt et al, 2009, MNRAS)



Long timescales (years)

– uncorrelated behaviour. Intrinsic disc variations in optical?

Short timescales (days-weeks)

- well correlated. Usually a hint of optical lagging by ~day, but large uncertainty

X-ray reprocessing – X-rays lead; Seed photon variations – UV/optical leads

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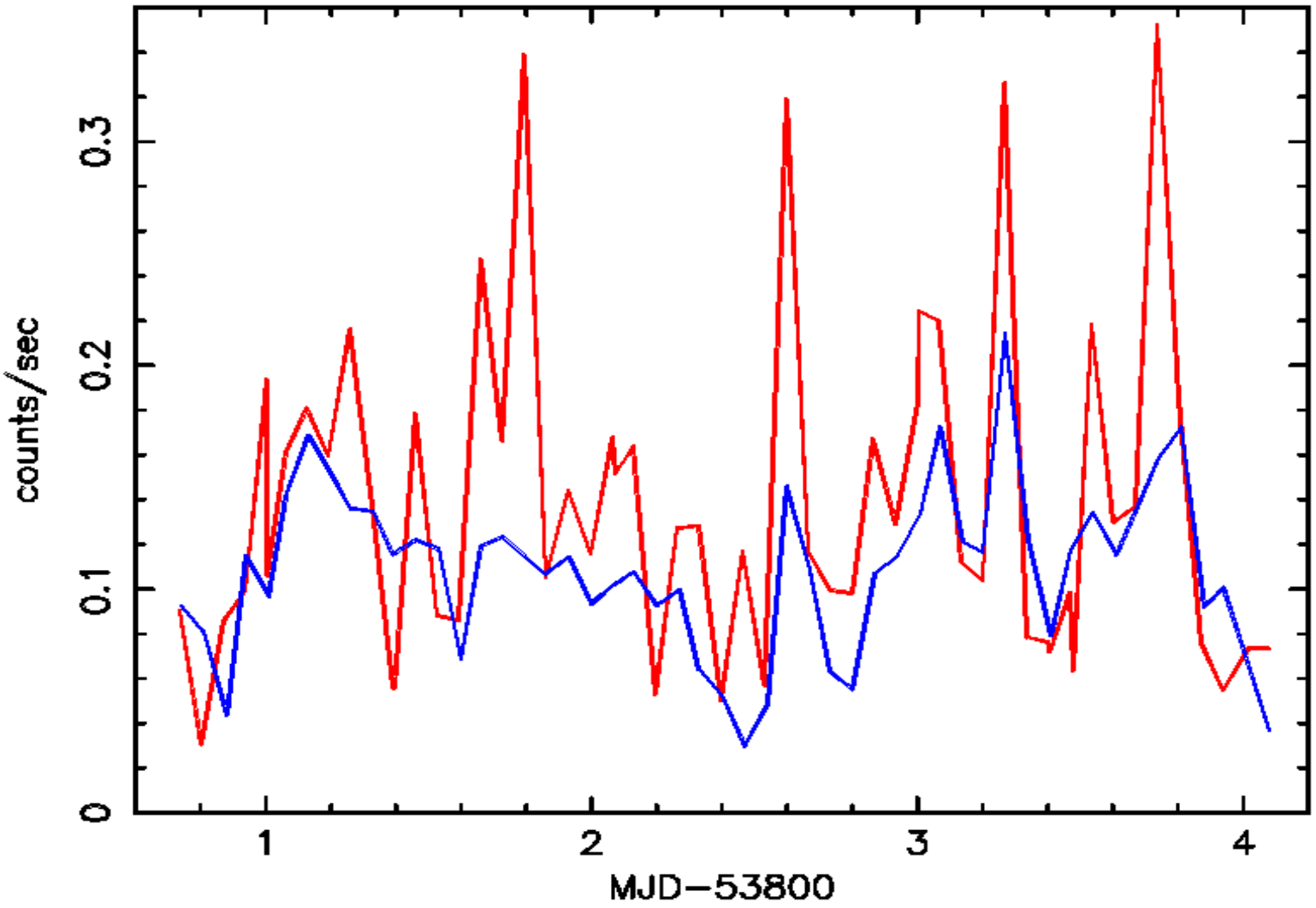
Swift: NGC4395

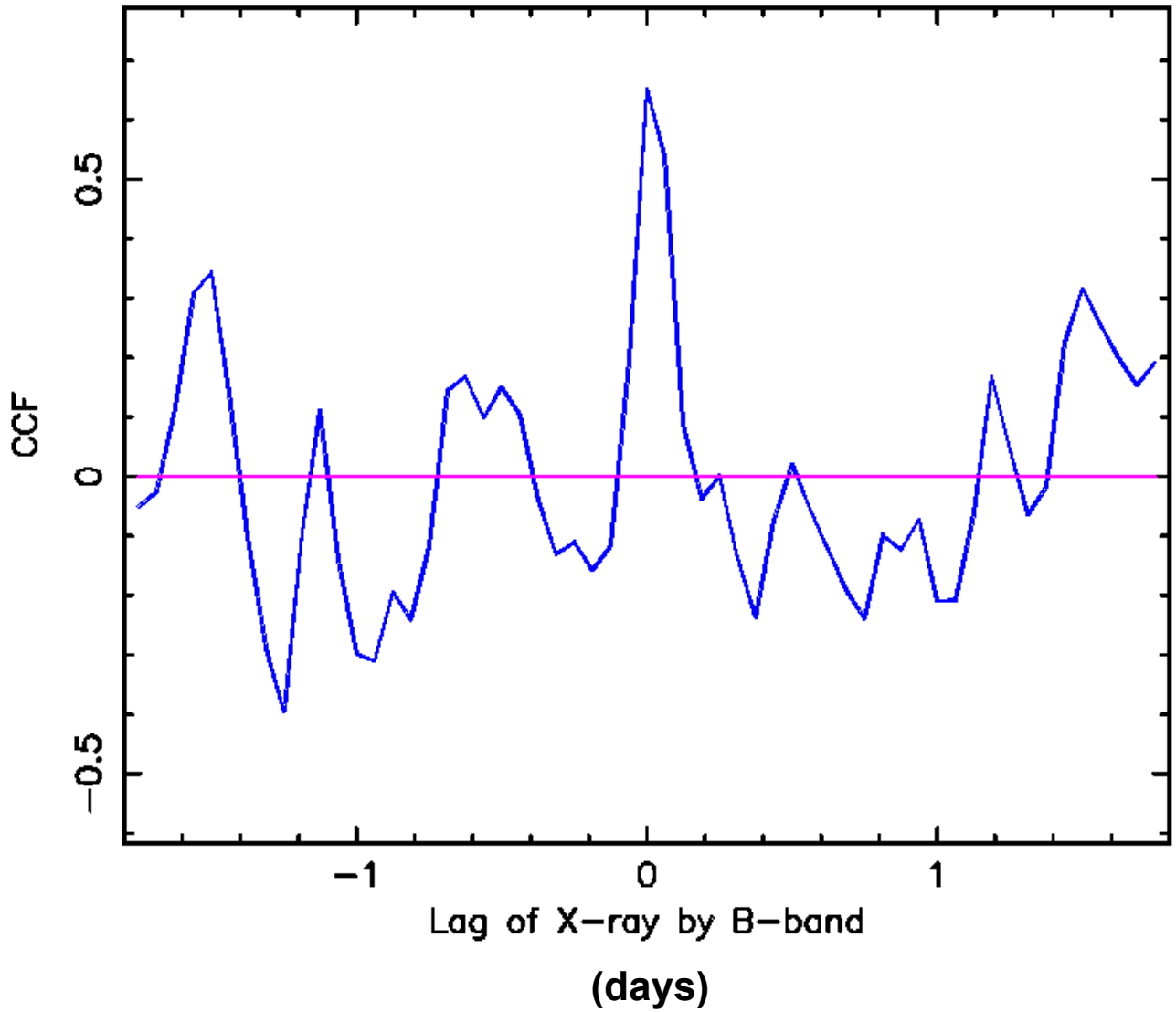


X-RAYS

B-BAND

Cameron et al 2012, MN, 422, 902

NGC4395: Short timescale CCF



Very small B-band lag
< 45min

suggesting reprocessing, but not confirming

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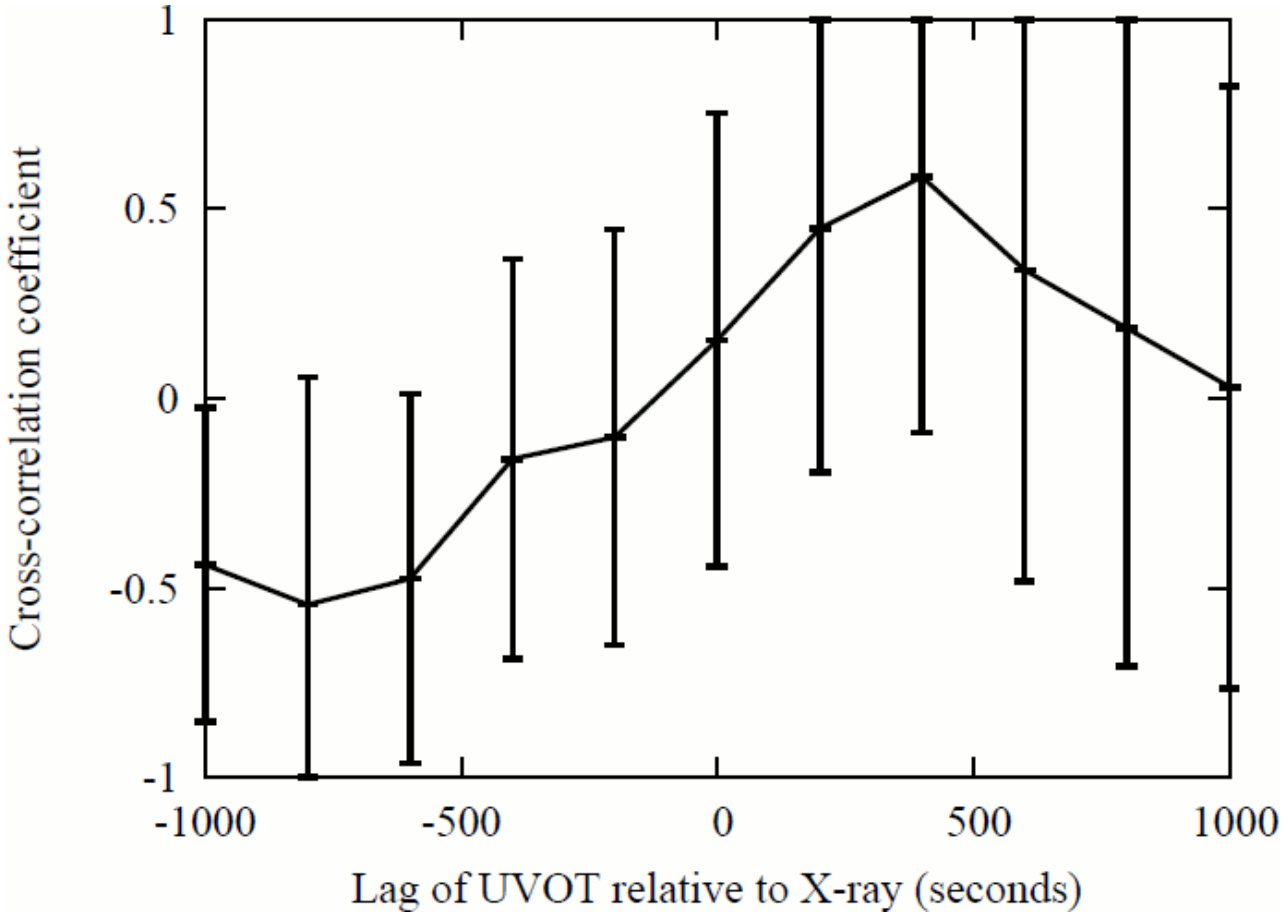
NGC4395: Very Short timescale CCF



Looking within individual Swift visits (TOO – 12ksec)

Hint that uvw2 lags X-rays by ~400s but large uncertainty

Evidence for X-ray Reprocessing: Optical and X-ray PSDs

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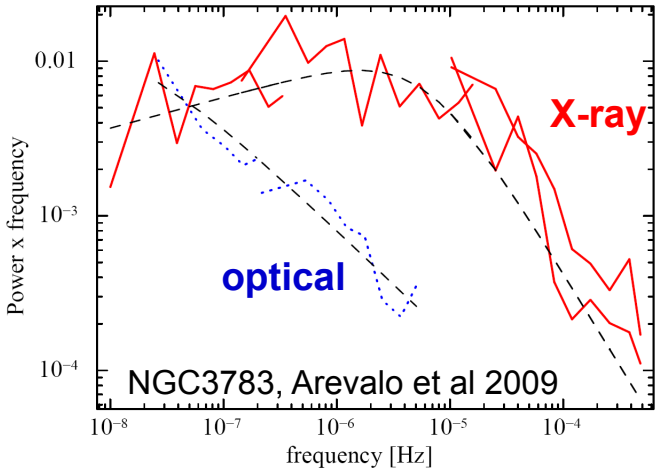
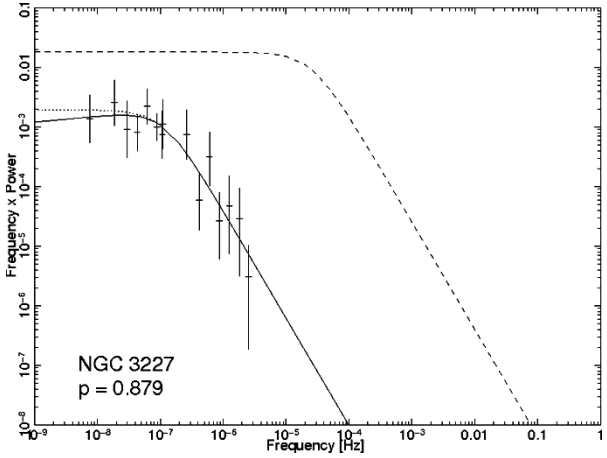
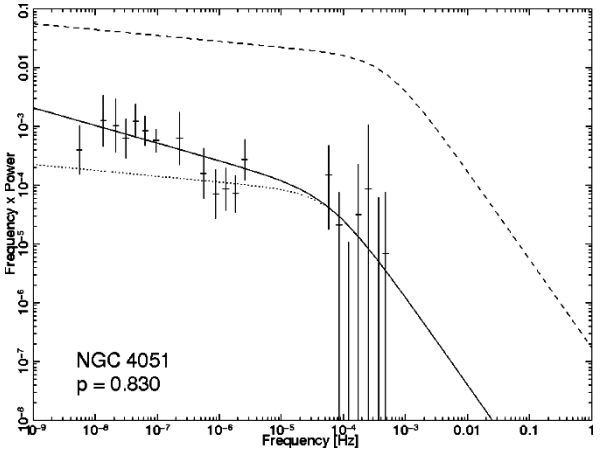
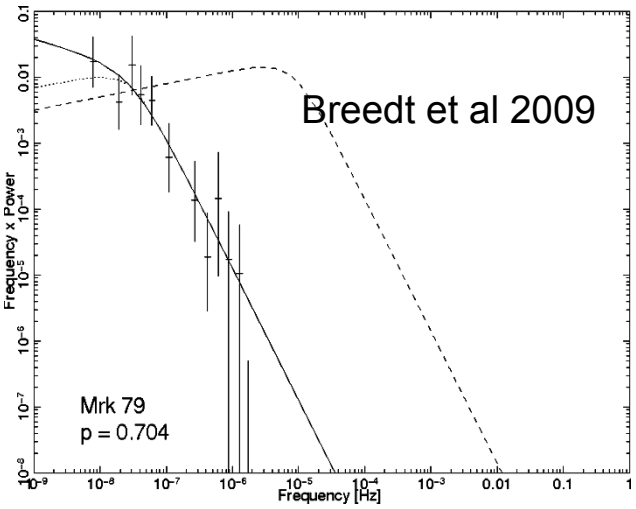


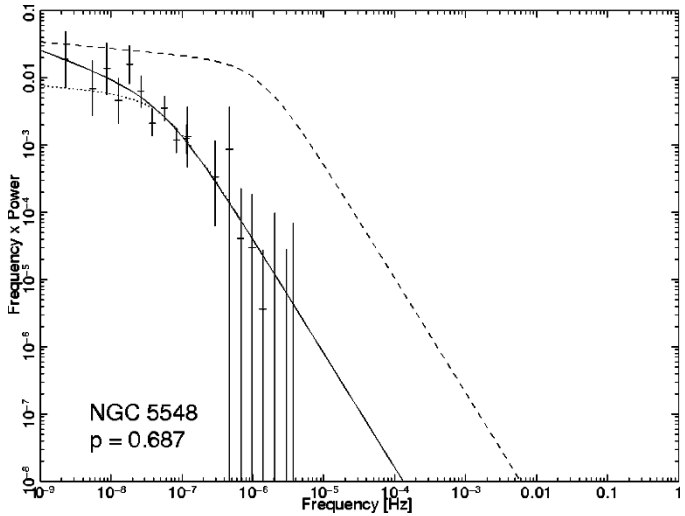




Breedt 2010 thesis



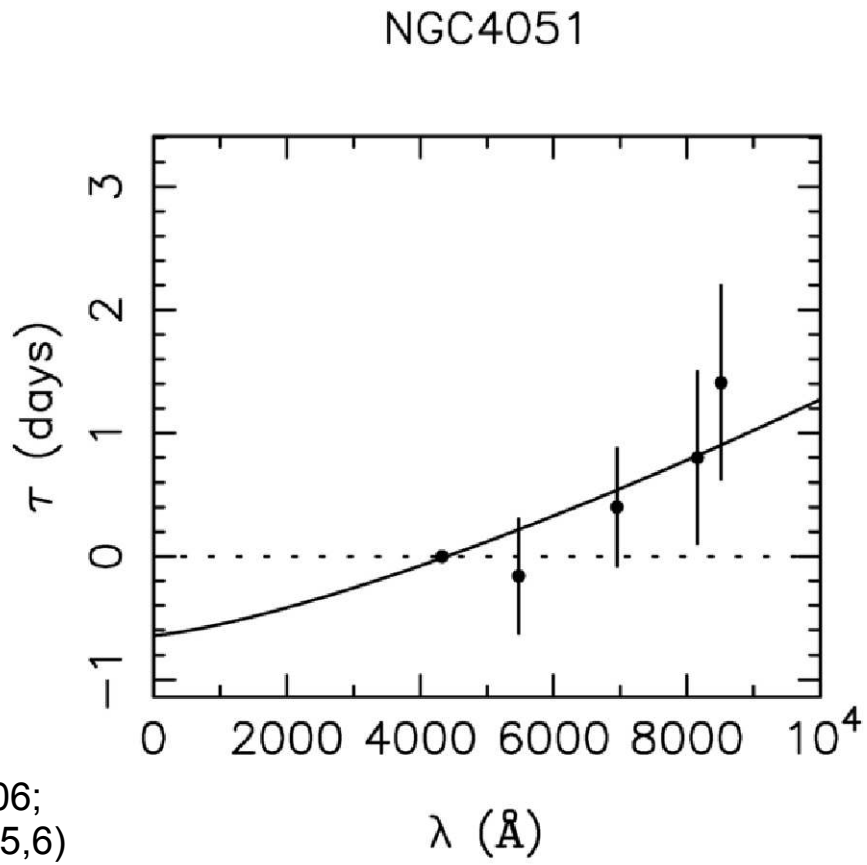
Errorbars - Optical data.
Dashed line – X-rays



See also Kelly et al 2010

Optical – less high frequency power: smoothed by reprocessing from large area.

Reprocessing: Optical interband lags



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

Solid line gives fit of lags to reprocessing model

For X-ray reprocessing, we expect: $T \propto M_{BH}^{-1/4} \dot{m}^{1/4} R^{-3/4}$

Therefore $Lag \propto Wavelength^{1.33}$

($\frac{\dot{m}}{R}$ in Eddington units and in gravitational radii)

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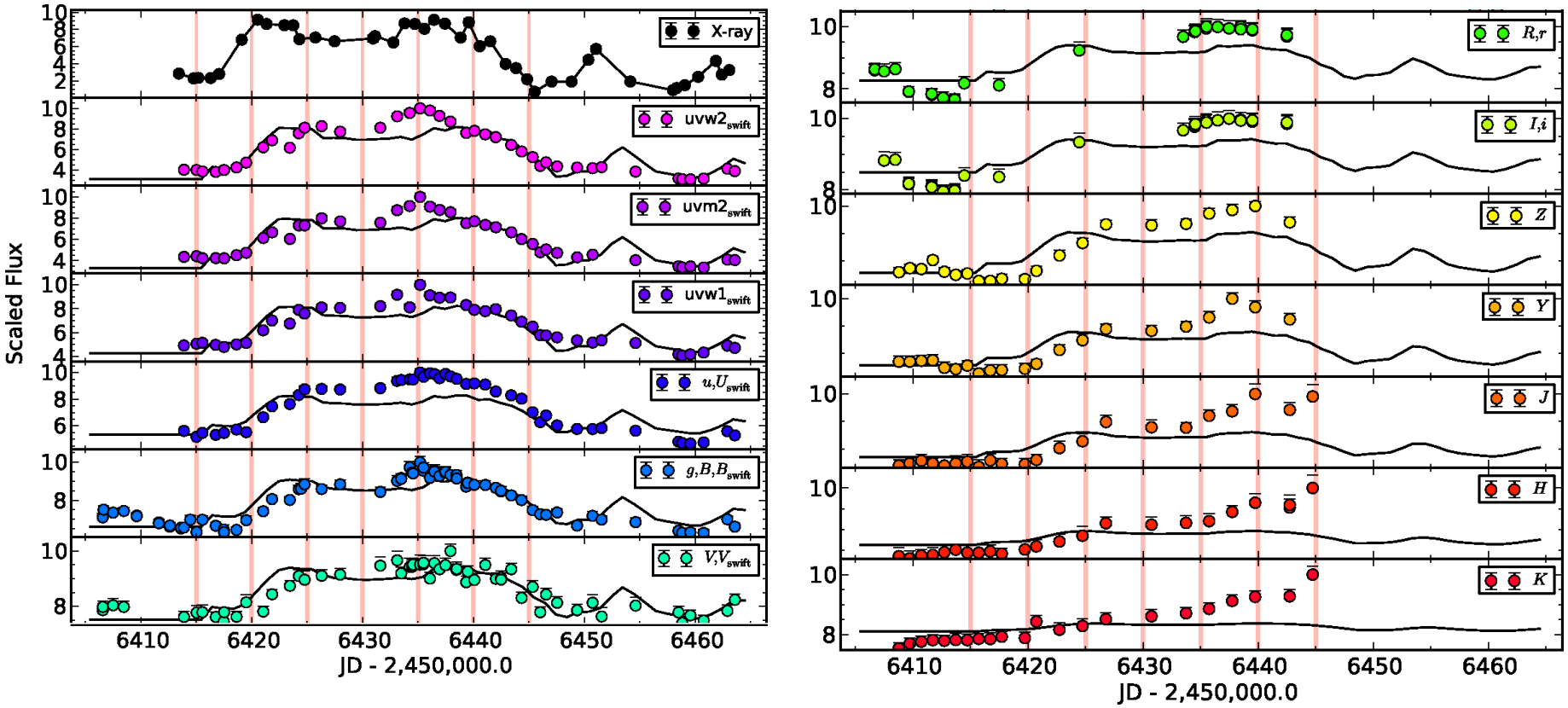
NGC 2617 - Swift

Swift Observations

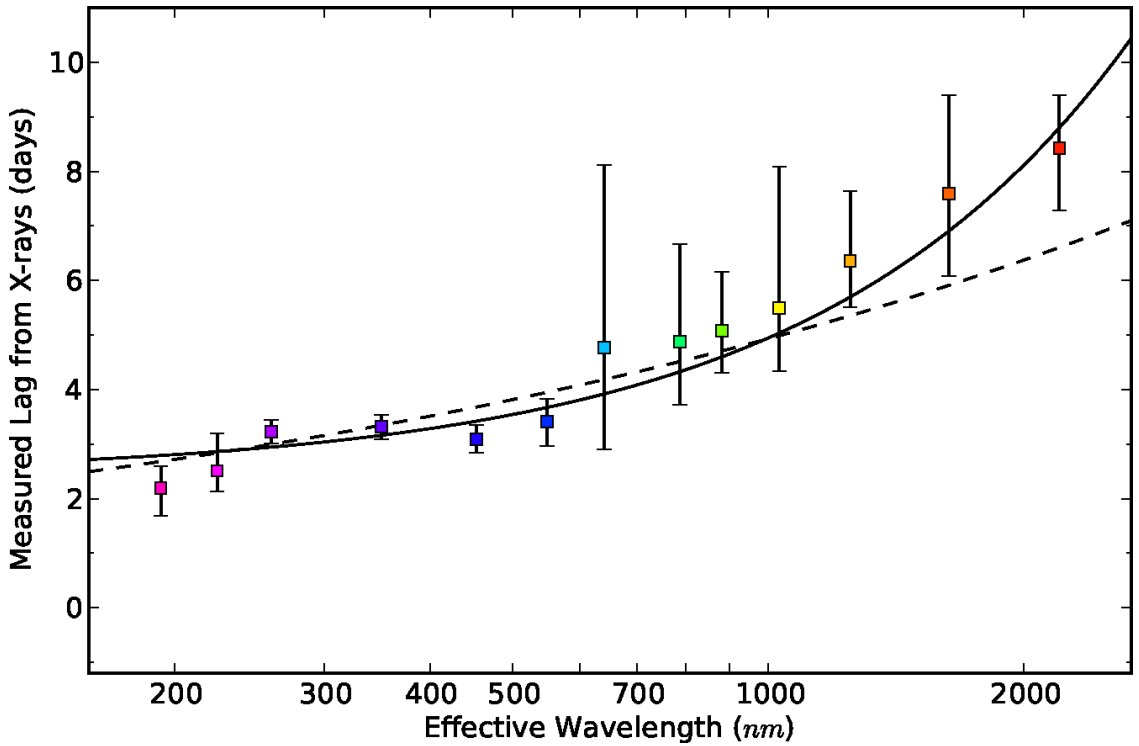
Ground Based Observations



From Shappee et al, 2014, ApJ, 788, 43

Solid lines are expected response from simple reprocessing disc

NGC2617 Lag Fits

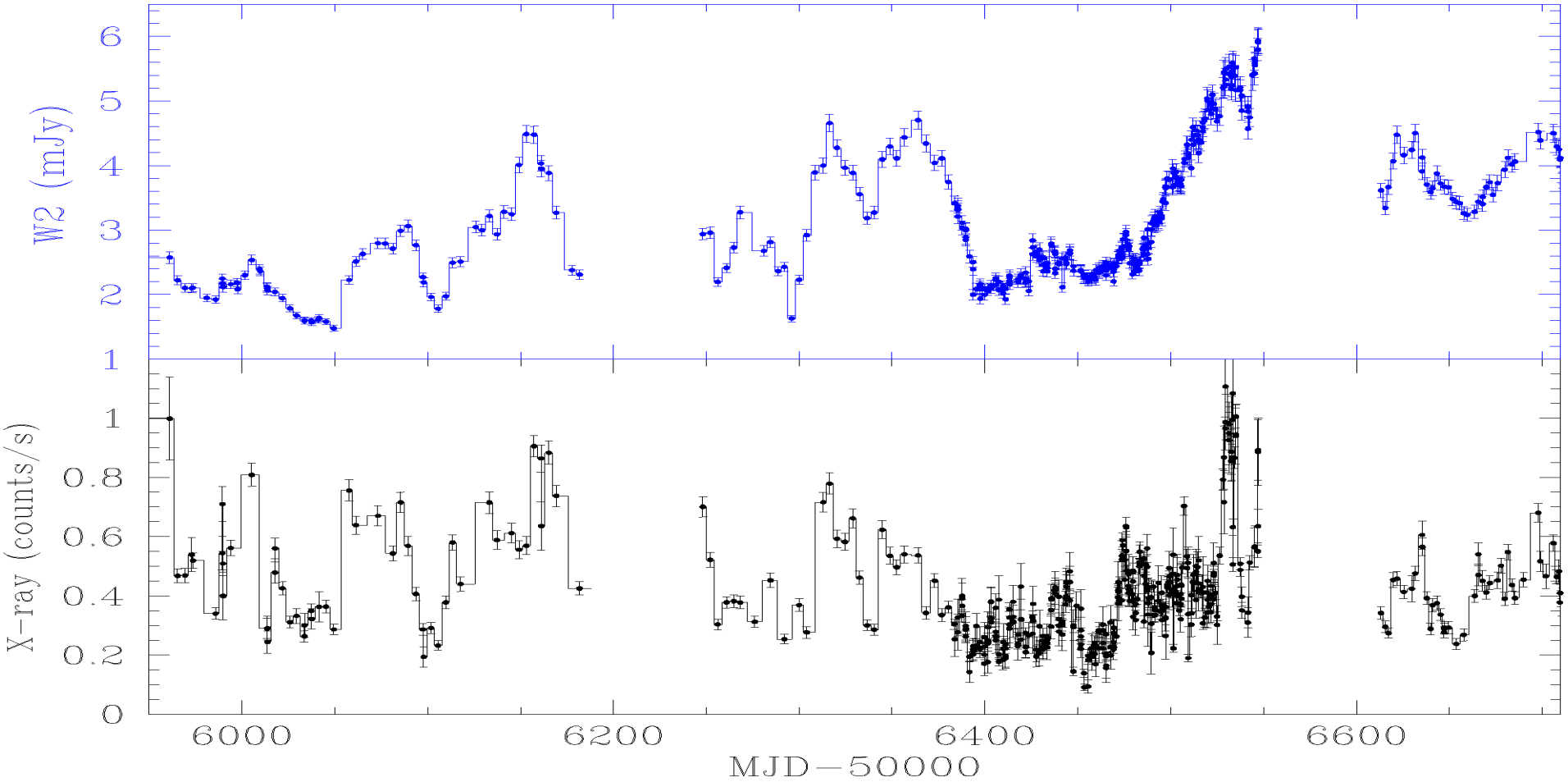


For $\text{lag} \sim \text{wavelength}^{\beta}$

Dashed line goes through X-ray point but $\beta = 0.37$, inconsistent with reprocessing

Solid line has $\beta = 1.18$ but is offset from X-ray point by 2.4d

Swift Monitoring of NGC5548:



Good correlation, but not perfect, eg large W2 rise after day 6480

McHardy et al, 2014, MNRAS, 444, 1469

Over 500 observations.
Largest Swift AGN Monitoring Program

X-ray / W2 Correlations

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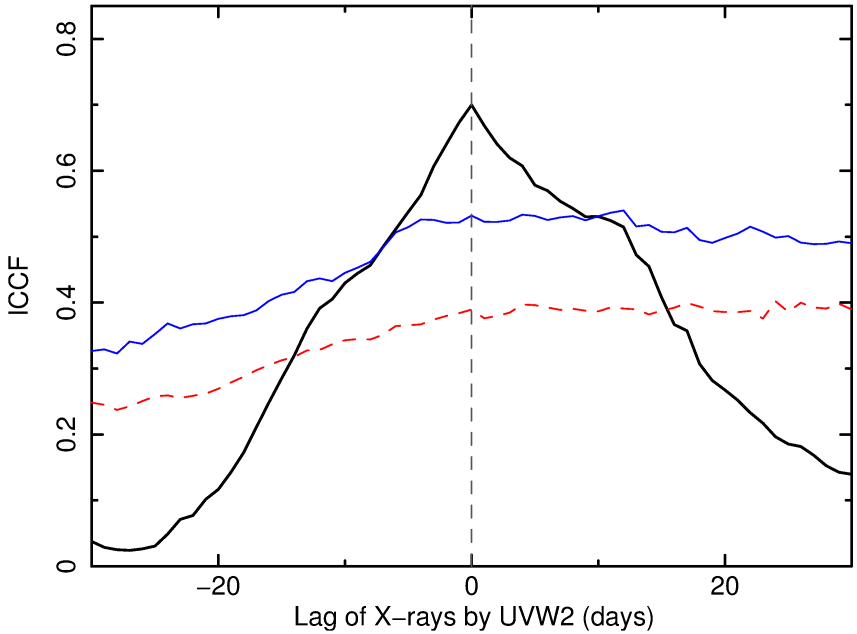
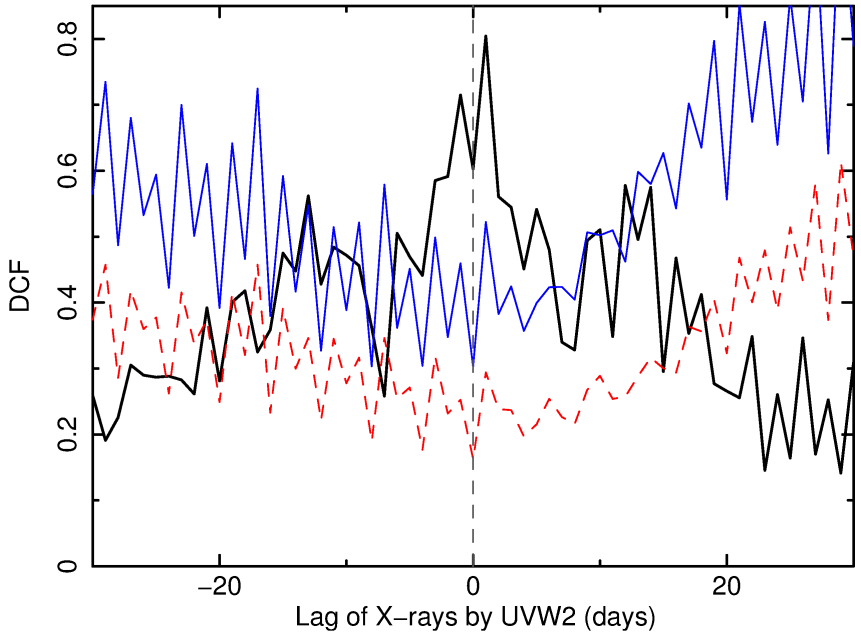
All of the data





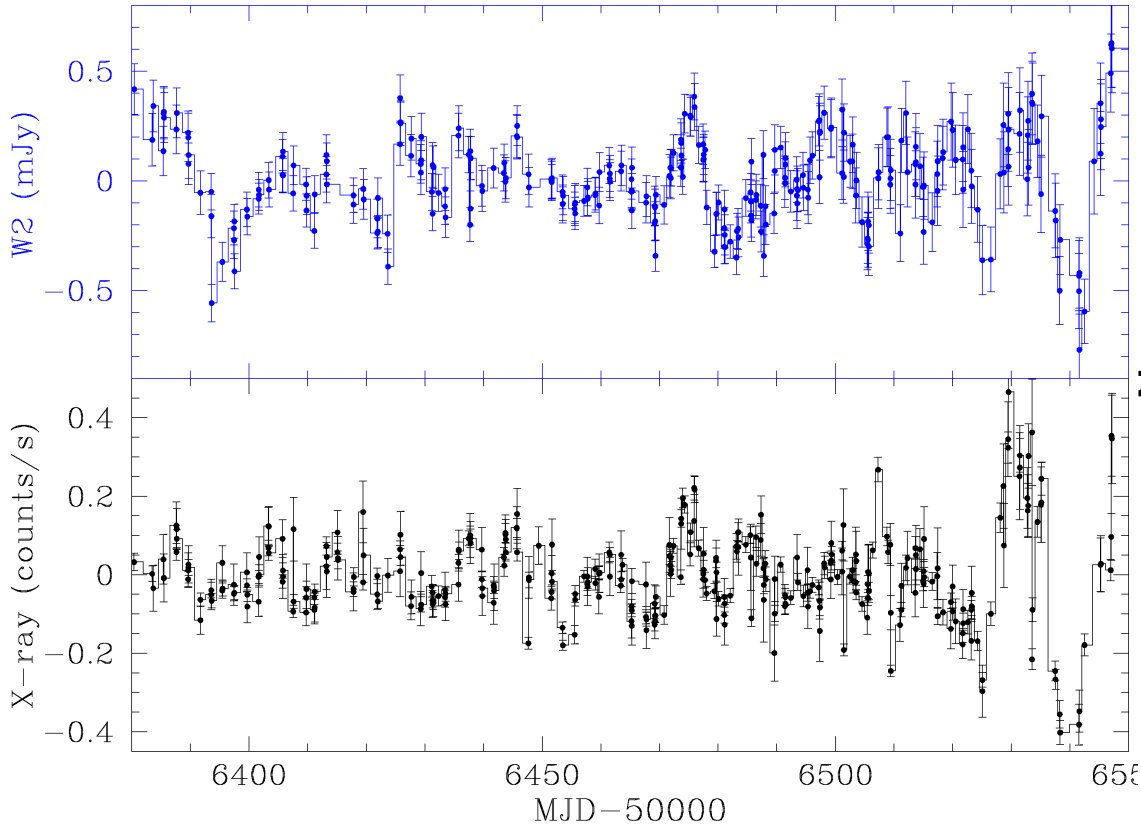
ICCF

DCF

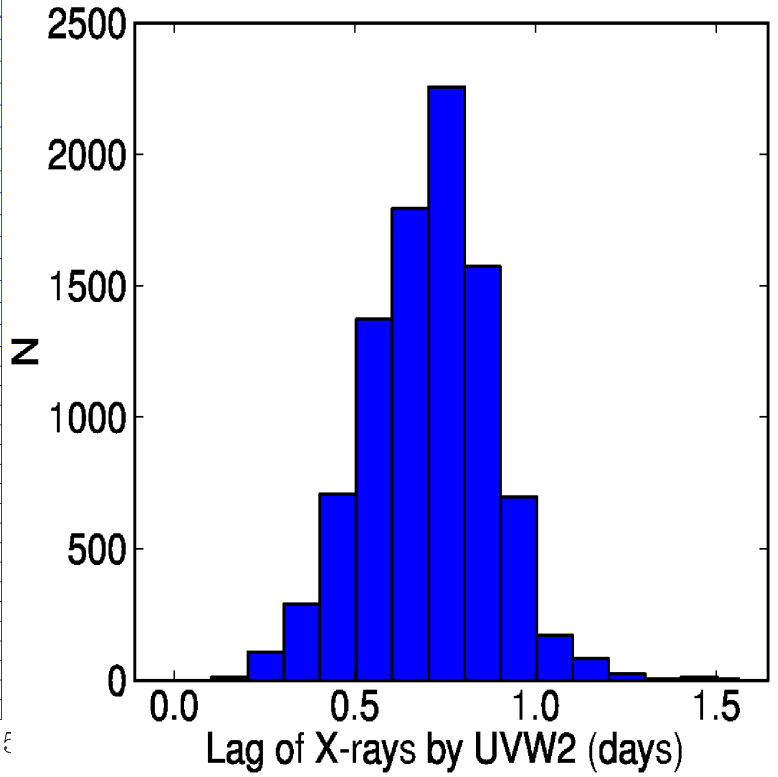
Lag close to 0 day, but hard to be certain. Possibly W2 lags slightly.

Lag of X-rays by UVW2

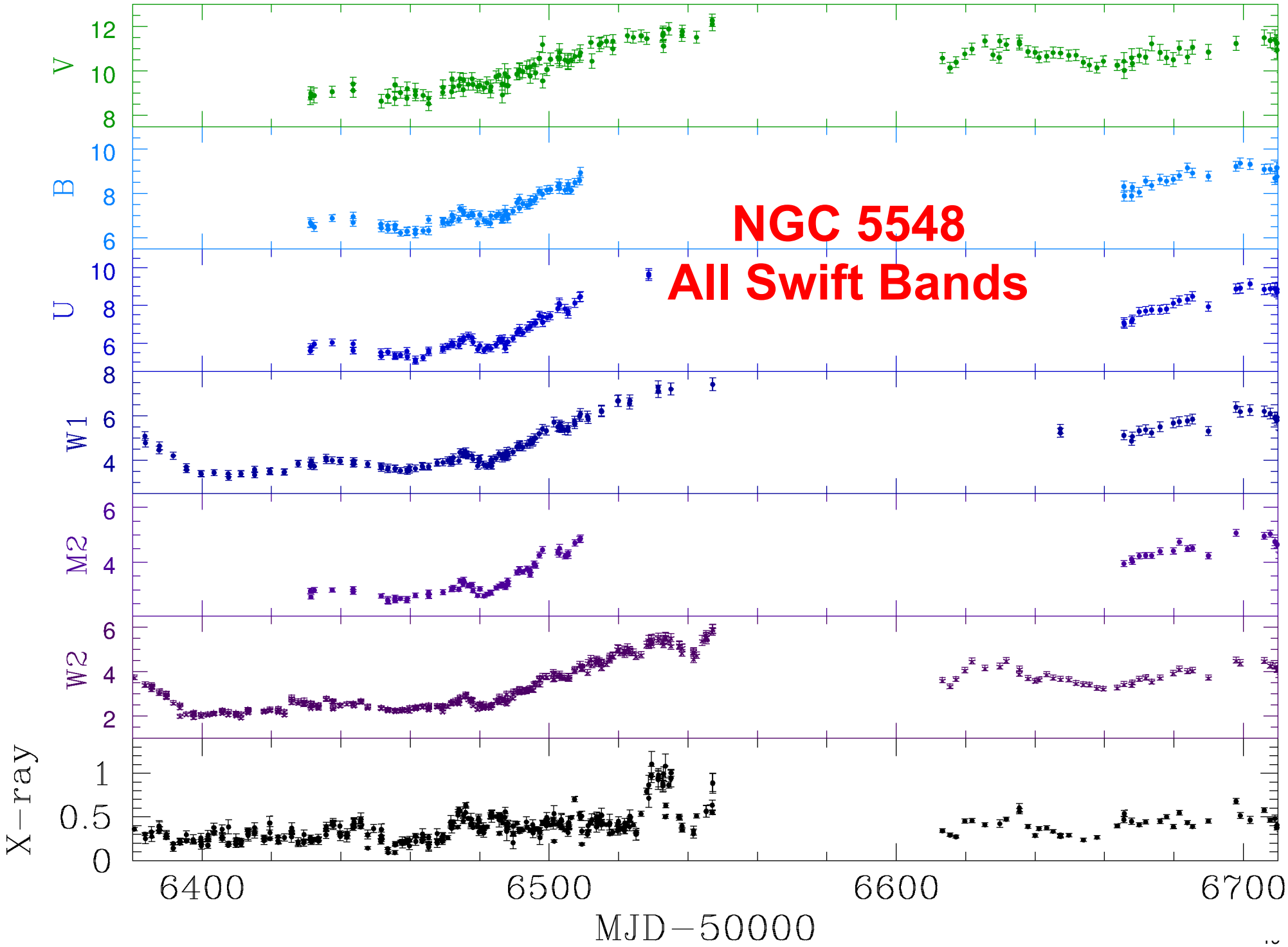
Mean-subtracted lightcurves
Intensively sampled period



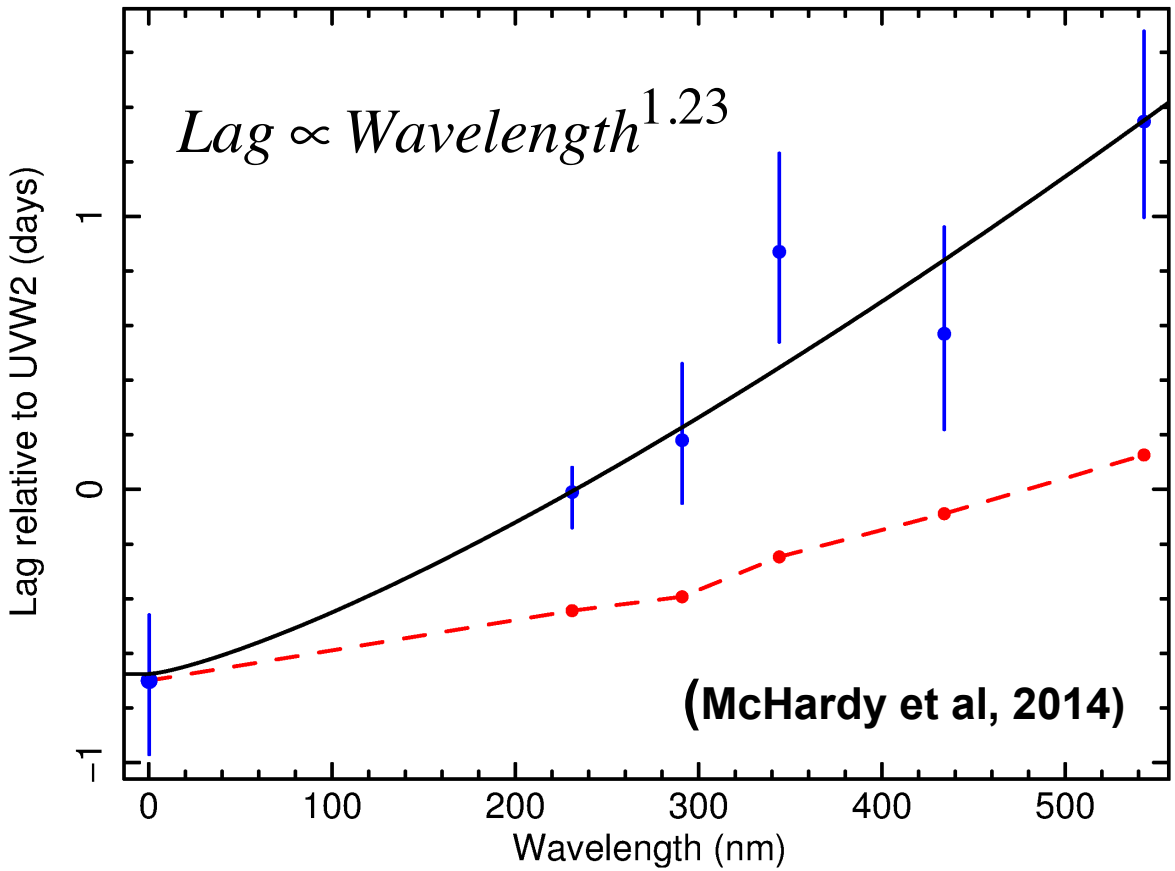
Lag distribution
(Javelin – Zu et al 2011)



Complex long timescale variations, which are different in different bands, can distort short timescale lags (eg Welsh1999) so are removed.


NGC 5548
All Swift Bands
V
B
U
W1
M2
W2
X−ray
MJD−50000
6400
6500
6600
6700

Lags as function of wavelength



Expect 4/3 power for Shakura-Sunyaev disc. So good agreement.

Fit goes through X-ray point

BUT … observed lags are much longer than expected for the Mass and $\dot{m}$

Red line is time for HALF of reprocessed light to arrive.

Microlensing obs (eg Morgan et al 2010) also require larger disc than SS model

Hotter than expected disc (eg higher $\dot{m}$, higher Lx)?

Or inhomogeneous disc (Dexter and Agol 2011)?

Why don't UV/optical disc variations drive X-ray variations?

Solid angle:

Optical/UV variations from larger radii are seen by distant observer but few are seen by central X-ray source

However ~half of the X-ray photons should hit the disc

Photon Conservation:

Compton scattering within X-ray emitting corona conserves photons. However an X-ray photon heating the disc could lead to emission of many more optical/uv photons, dominating variations in intrinsic thermally produced photons.

CONCLUSIONS

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Long timescale (years) UV-optical variability in AGN is probably intrinsic disc variation driven by inwardly propagating accretion rate fluctuations.

Short timescale UV-optical variability in AGN is X-ray reprocessing

But the accretion disc is factors of a few bigger than predicted.
Similar large sizes deduced from microlensing observations.

Inhomogeneous disc?

A combination of solid angle and photon conservations considerations could explain why we don't see uv/optical seed photon variations leading X-ray variations on short timescales.