The Origin of UV-optical Variability in AGN: Probes of Disc Models

Observations of NGC4395 and NGC5548

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X-ray / Optical Variability in AGN

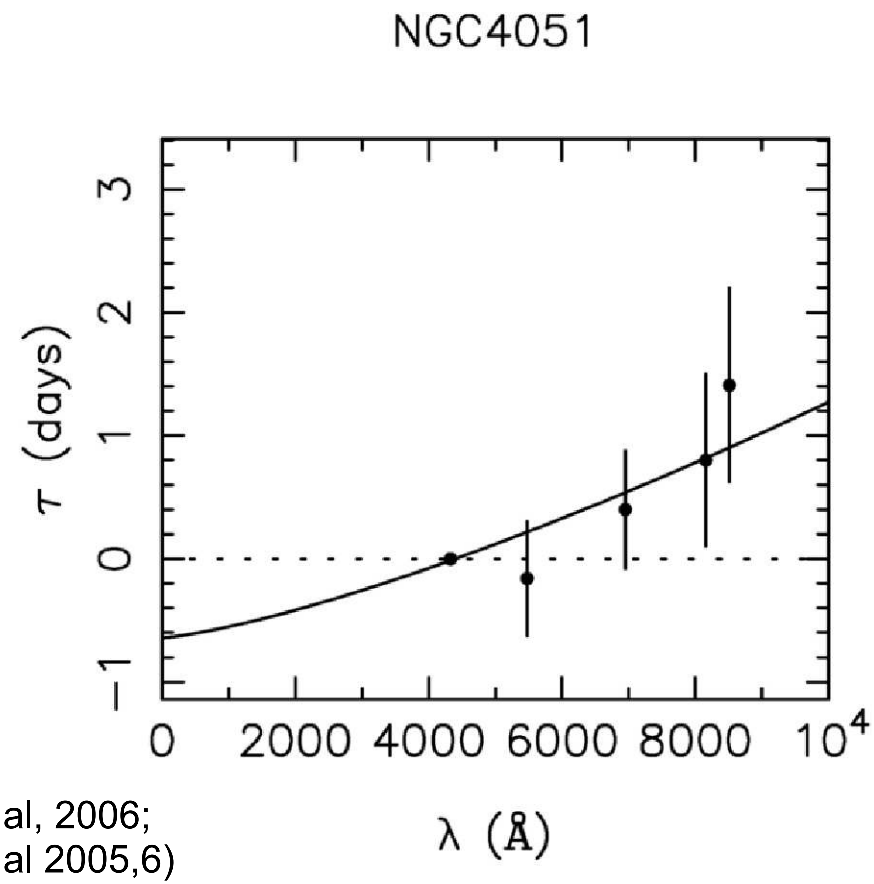
Two main models for optical variability:

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

Reprocessing: Optical interband lags



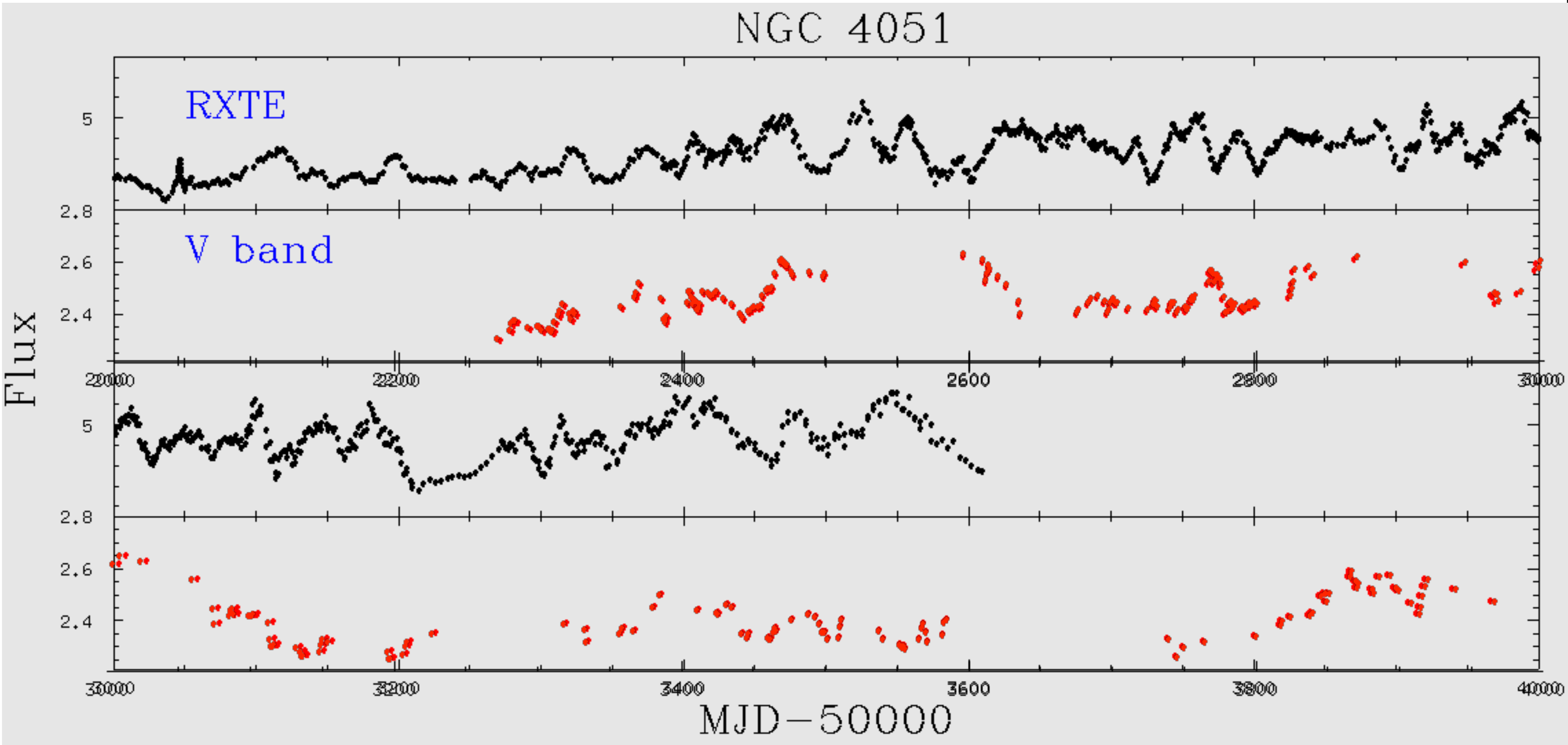
(Cackett et al, 2006;
Sergeev et al 2005,6)

Consistent with reprocessing but no link to X-rays

For reprocessng by Shakura-Sunyaev thin disc expect:

$$Lag \propto Wavelength^{1.33}$$

NGC 4051: Optical – X-ray



NGC 4051

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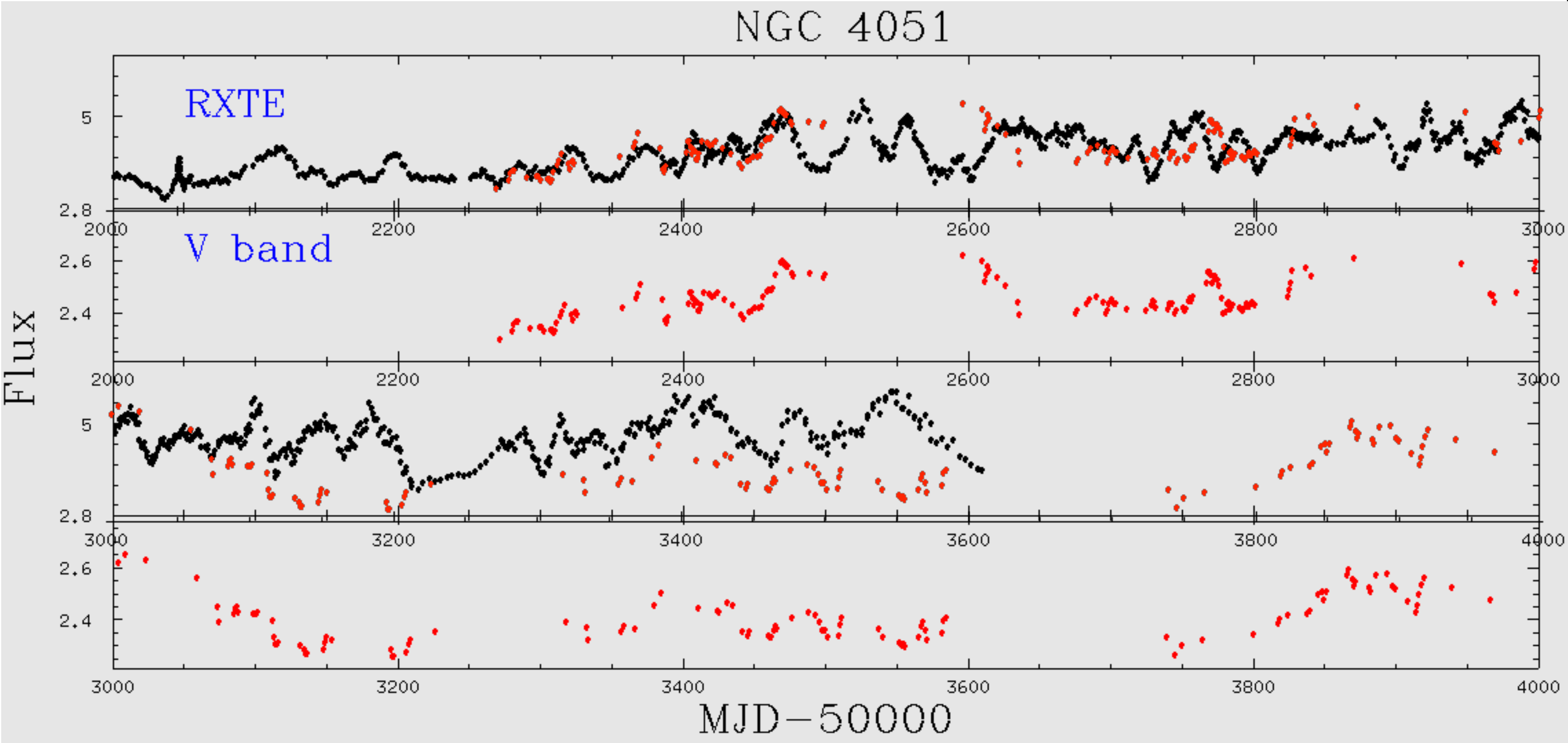

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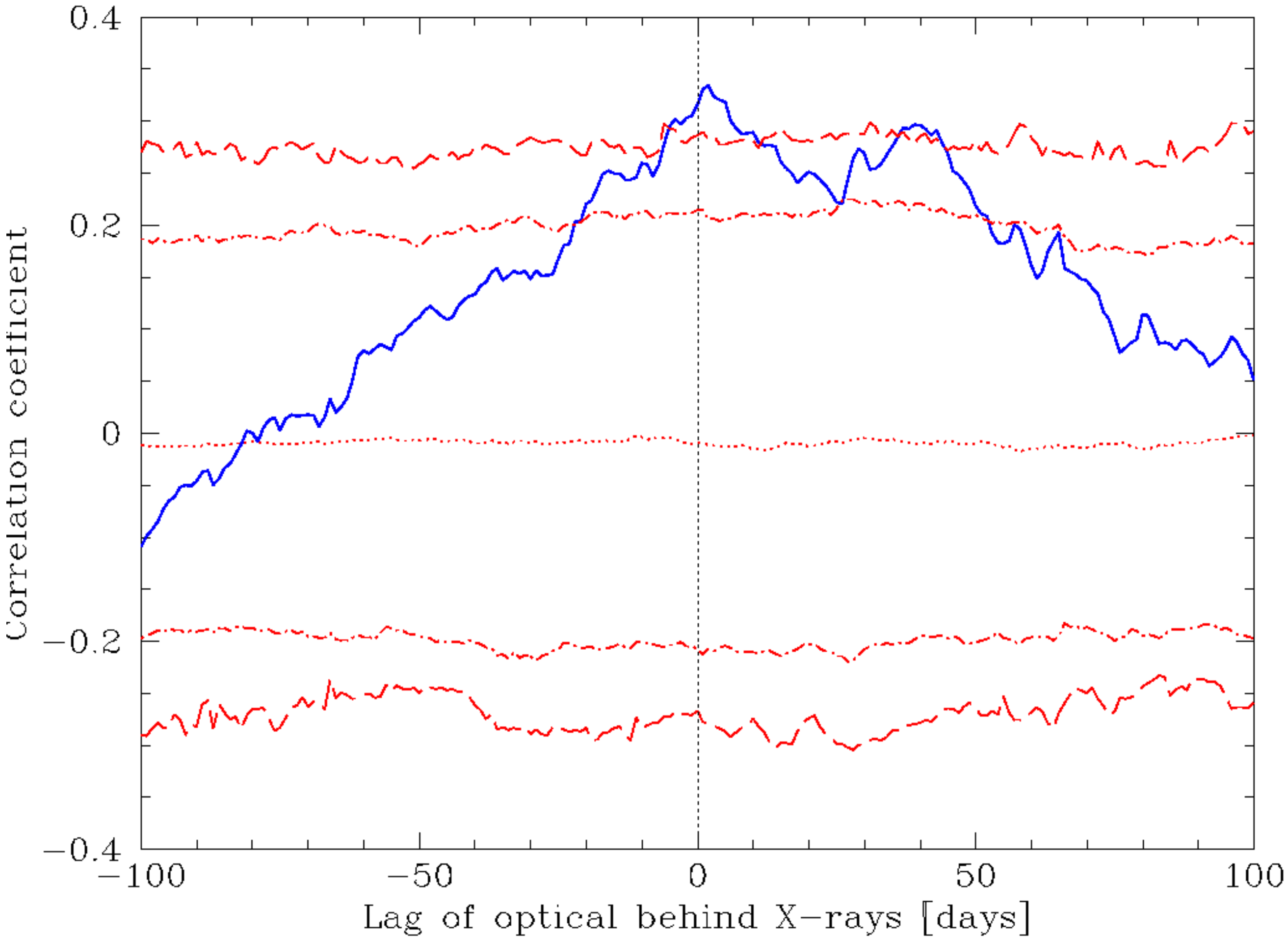
NGC4051



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

Breedt et al 2010

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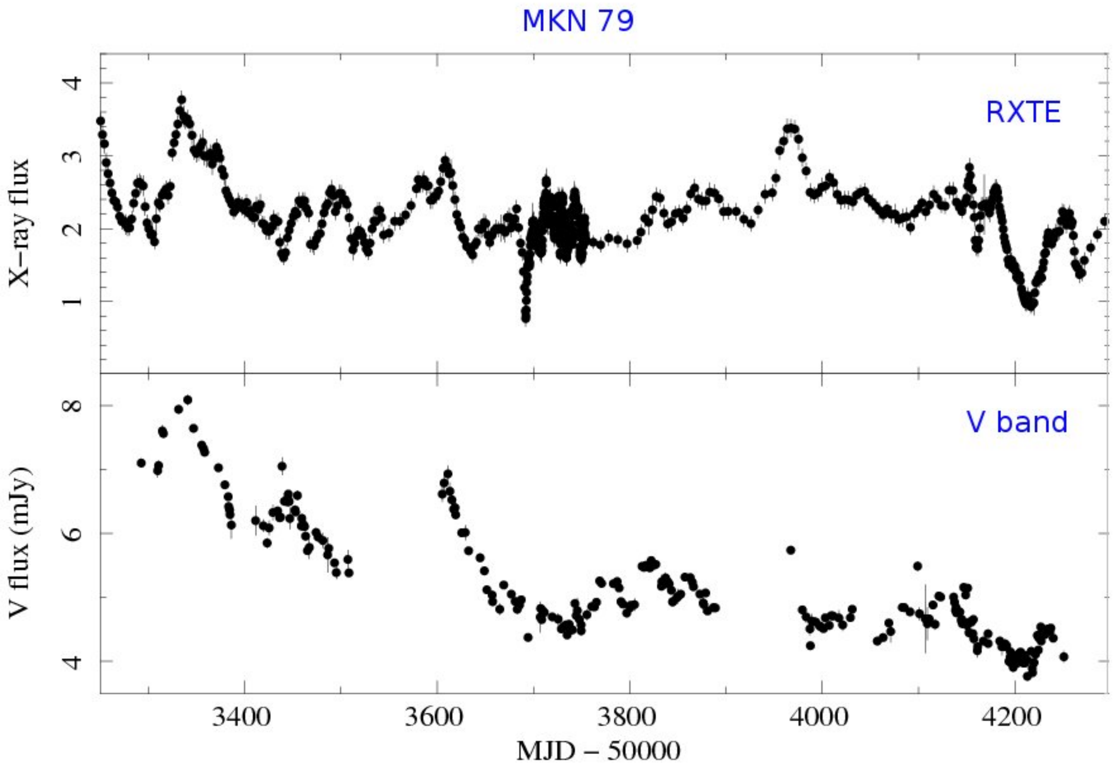
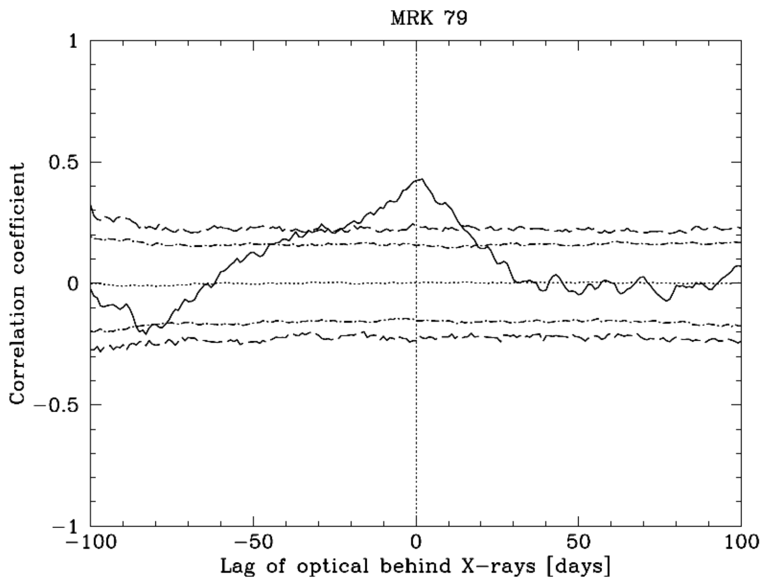
MKN 79



(Breedt et al, 2009, MNRAS)



Long timescales (years)

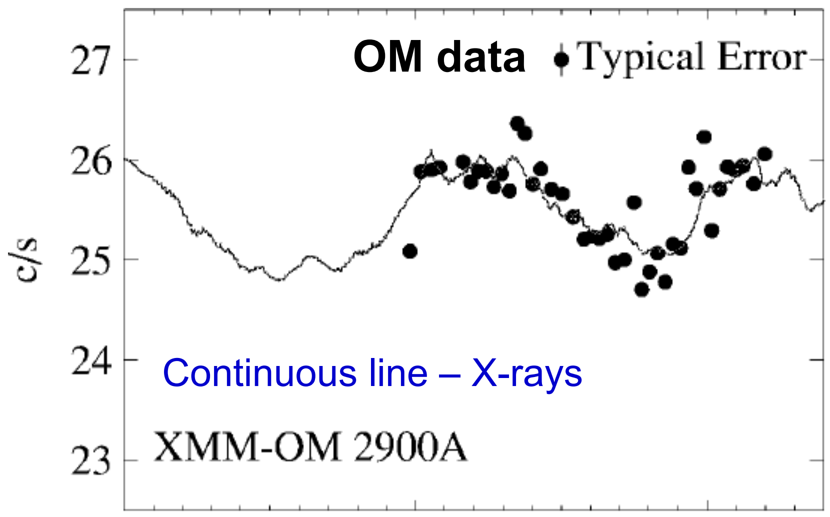
– uncorrelated behaviour. Intrinsic disc variations in optical?

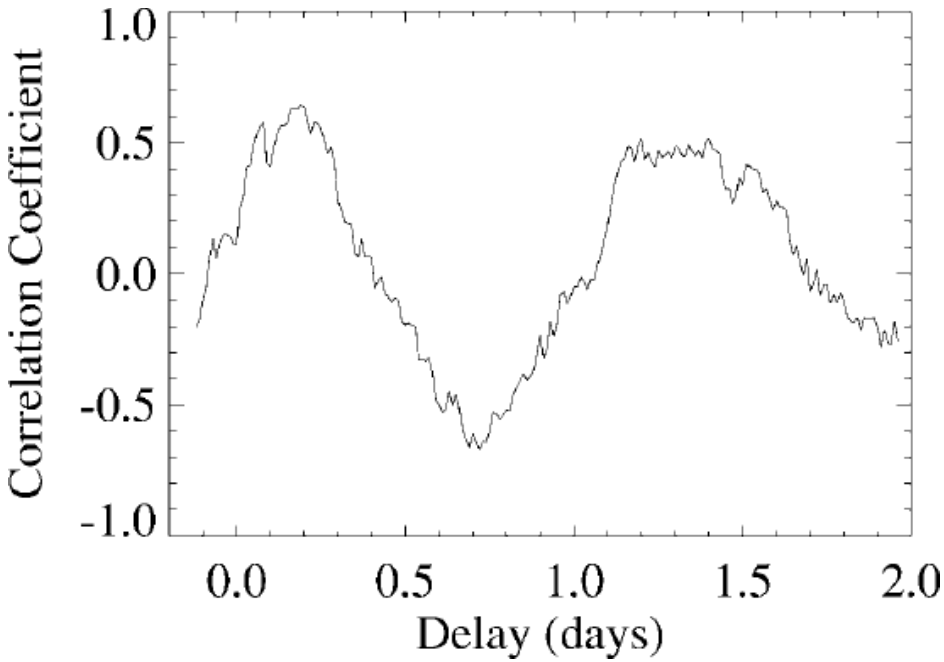
Short timescales (days-weeks)

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

Better Short Timescale Sampling:

NGC4051 XMM and RXTE X-rays vs. XMM OM UVW1





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

Mason et al 2002

See also Alston et al 2013

OM in imaging mode.
~1200 s resolution

Better sampled data: Swift NGC4395

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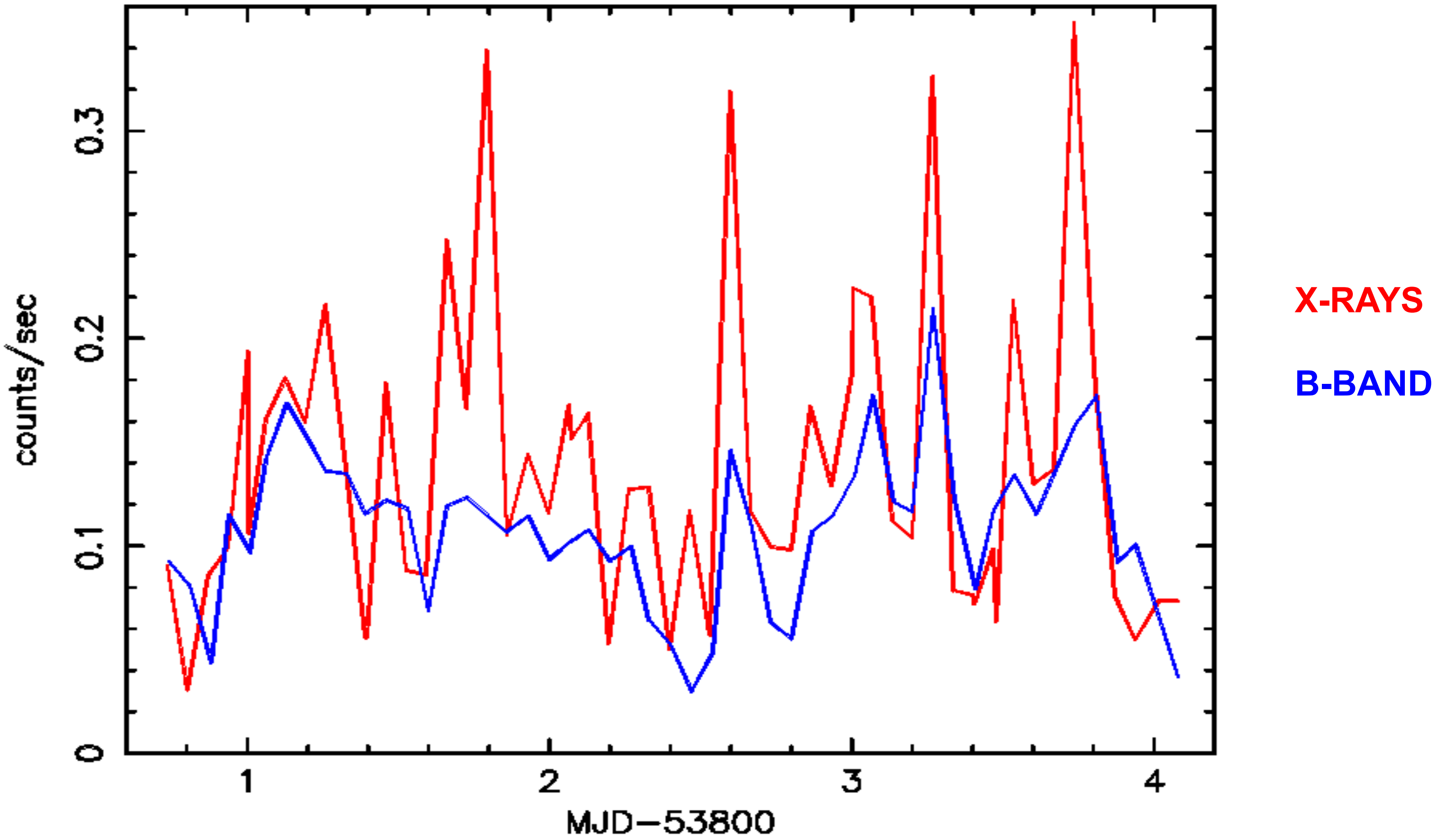

Cameron et al 2012, MN, 422, 902

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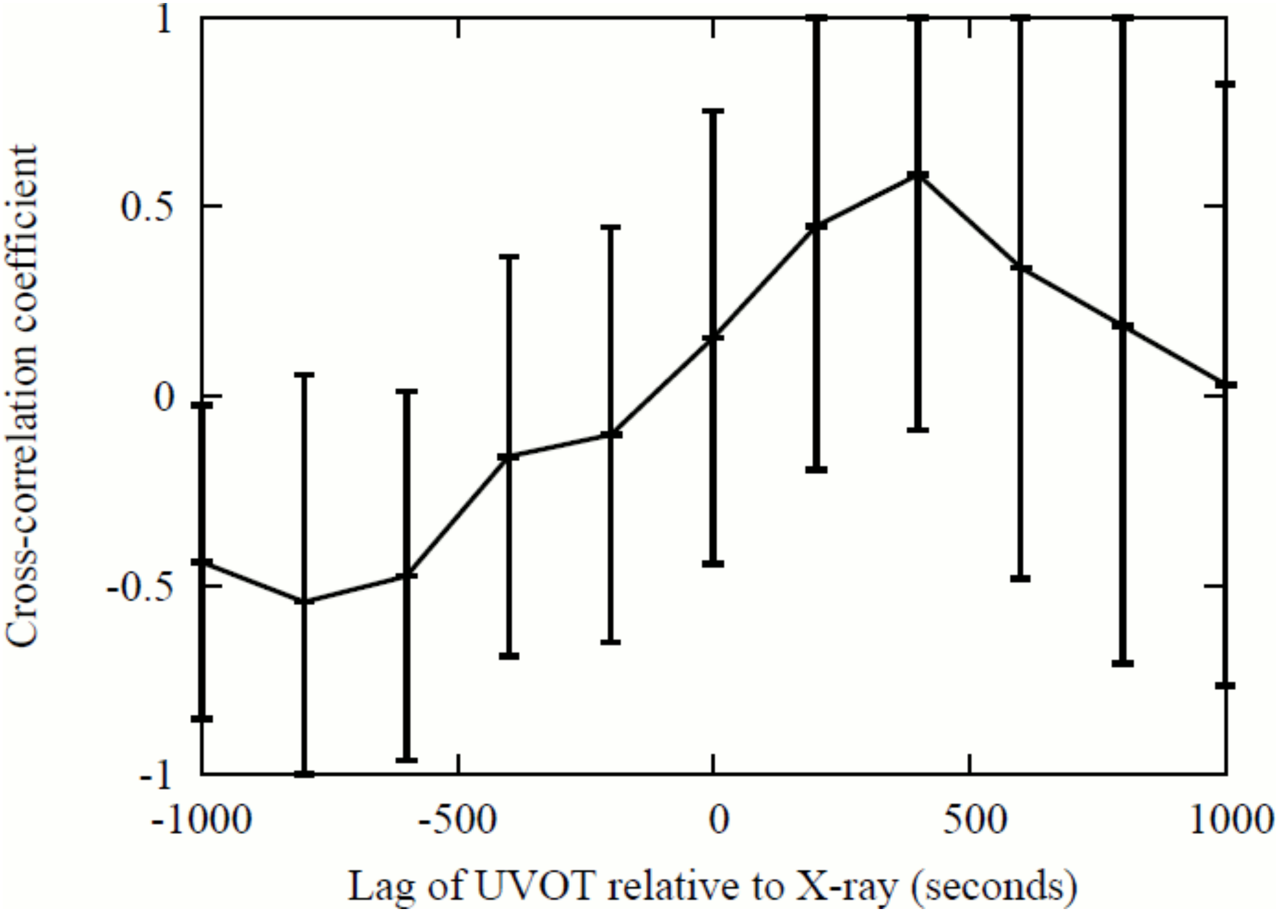
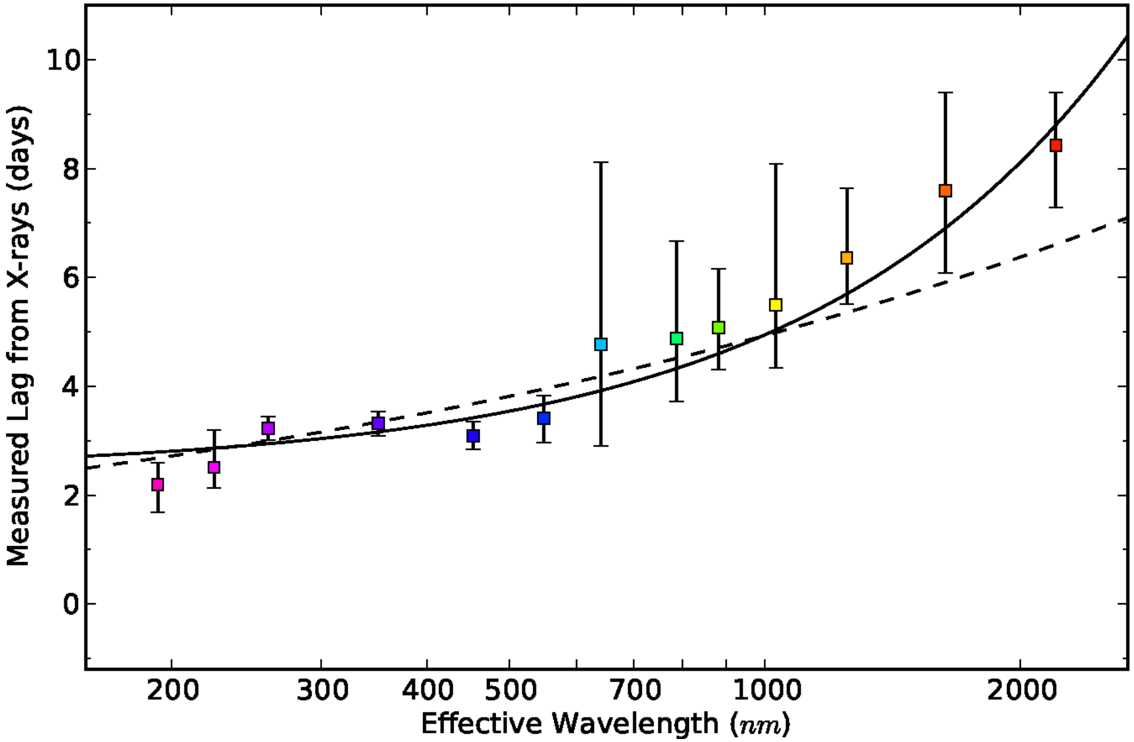
NGC4395: Very Short timescale CCF



Looking within individual Swift visits (TOO – 12ksec)

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

NGC2617 – Swift + Ground



Shappee et al, 2014

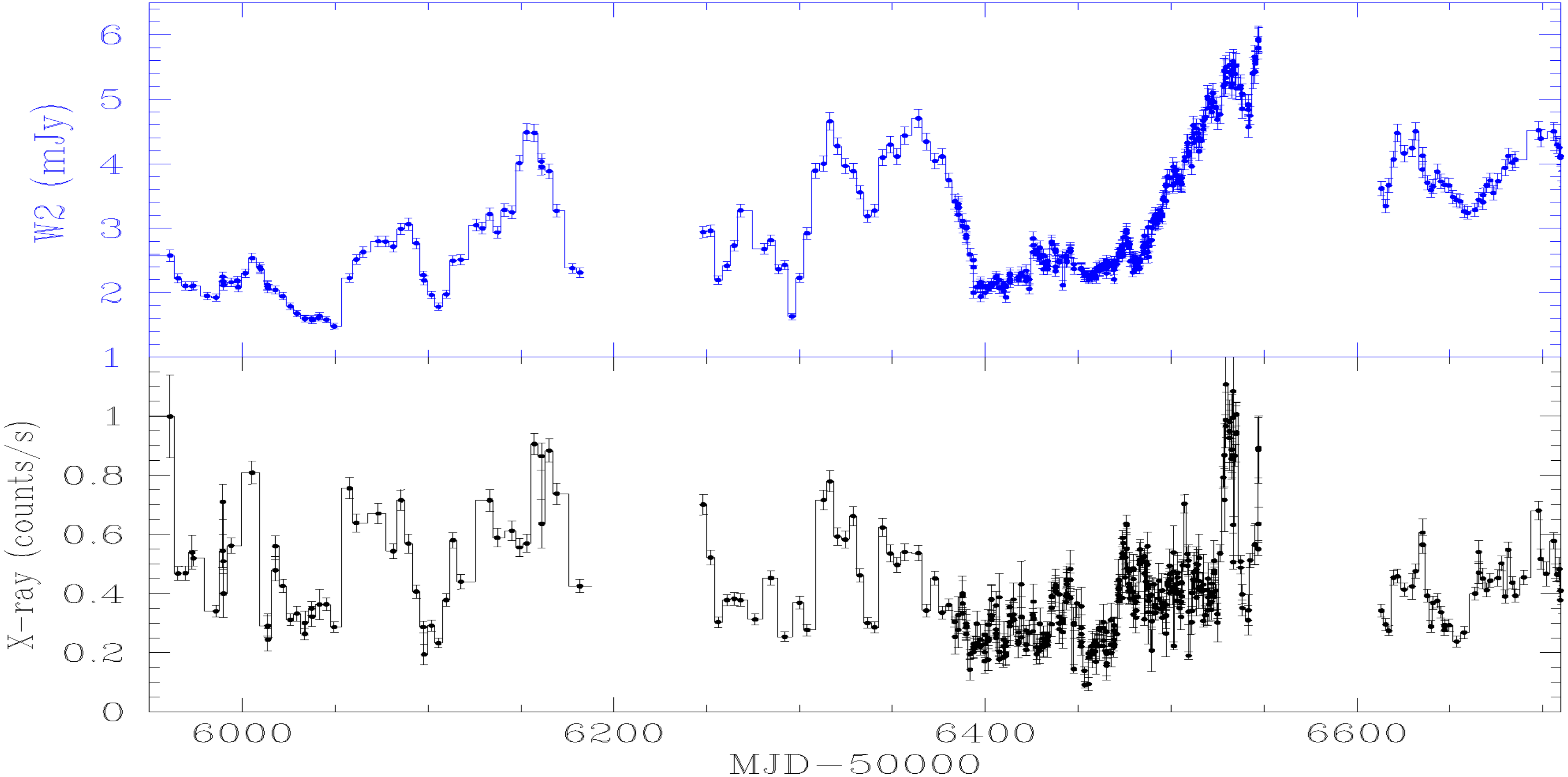
~60 observations per band

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: First Campaign: (> 500 observations)



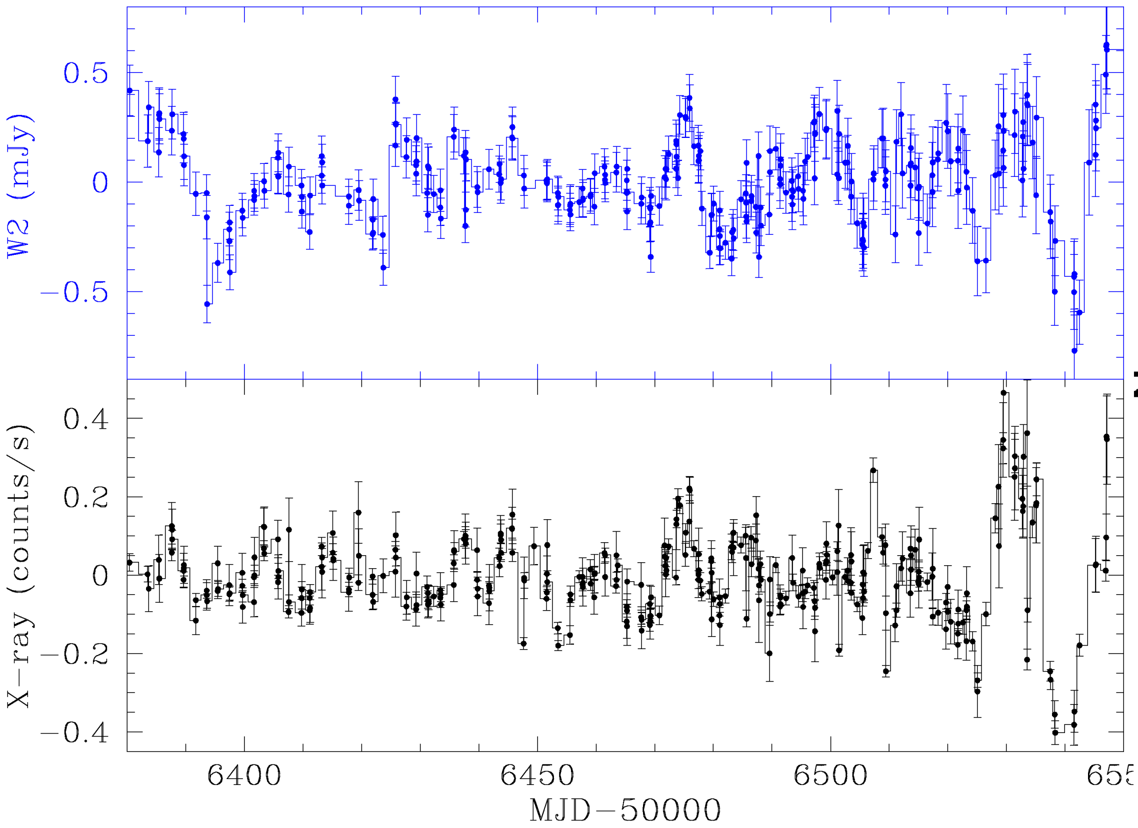
Good correlation, but not perfect, eg large W2 rise after day 6480

First campaign: McHardy et al, 2014, MNRAS, 444, 1469

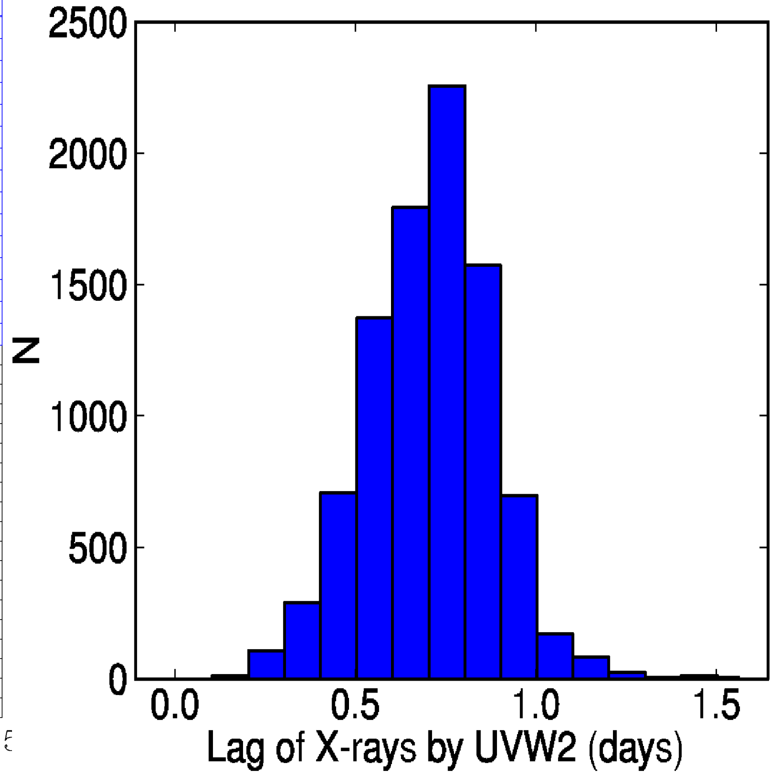
Second campaign: Edelson et al 2015, arXiv150105951E

Lag of X-rays by UVW2

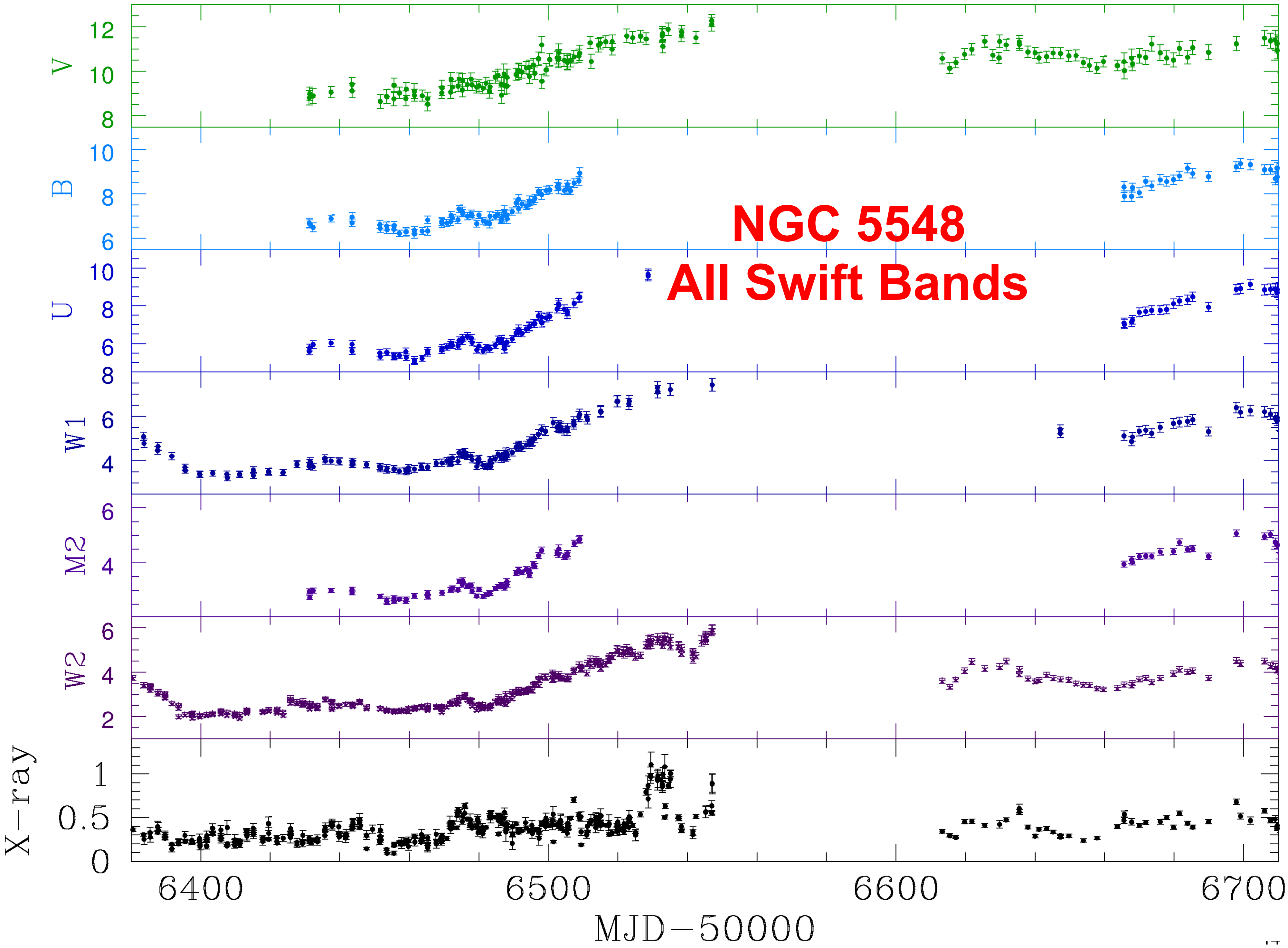
Mean-subtracted lightcurves
Intensively sampled period



Lag distribution
(Javelin – Zu et al 2011,13)



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

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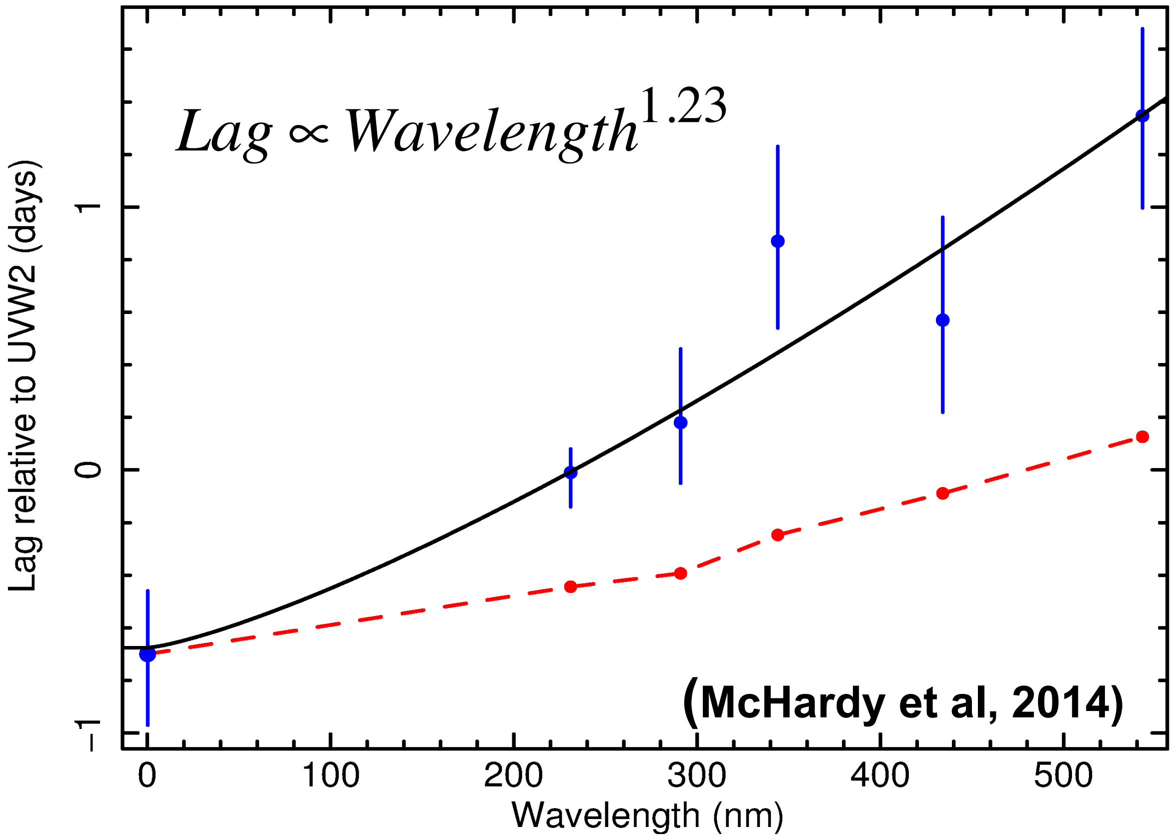

Expect 4/3 power for Shakura-Sunyaev disc. So good agreement.

Fit goes through X-ray point

BUT … observed lags are 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)?

Inhomogeneous disc (Dexter and Agol 2011)?

Time associated with the reprocessing mechanism?

XMM and ground based lags for NGC4395

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Mass 3.6e5, x100 lower than NGC5548, and x10 lower mdot
Needs <100s time resolution

OM used in very fast (sub-second) readout mode using UVW1
- Thanks to Jan-Uwe Ness for helpful advice

First successful use of this mode – as far as we know – for AGN lag measurement

Ground based g-band monitoring around globe.

To appear in Connolly et al..

XMM and ground based monitoring of NGC4395

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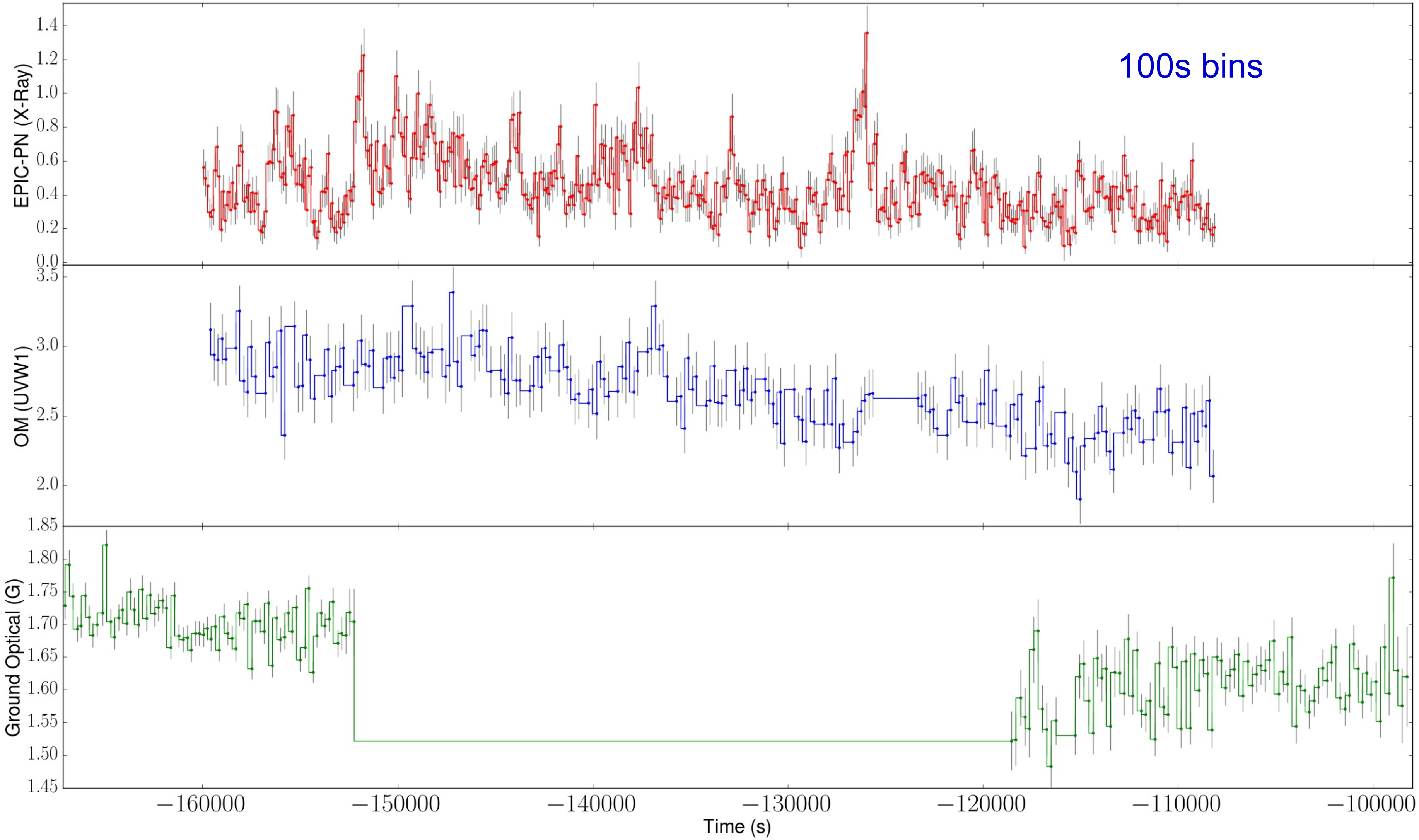

28-29 December 2014

XMM and ground based monitoring of NGC4395

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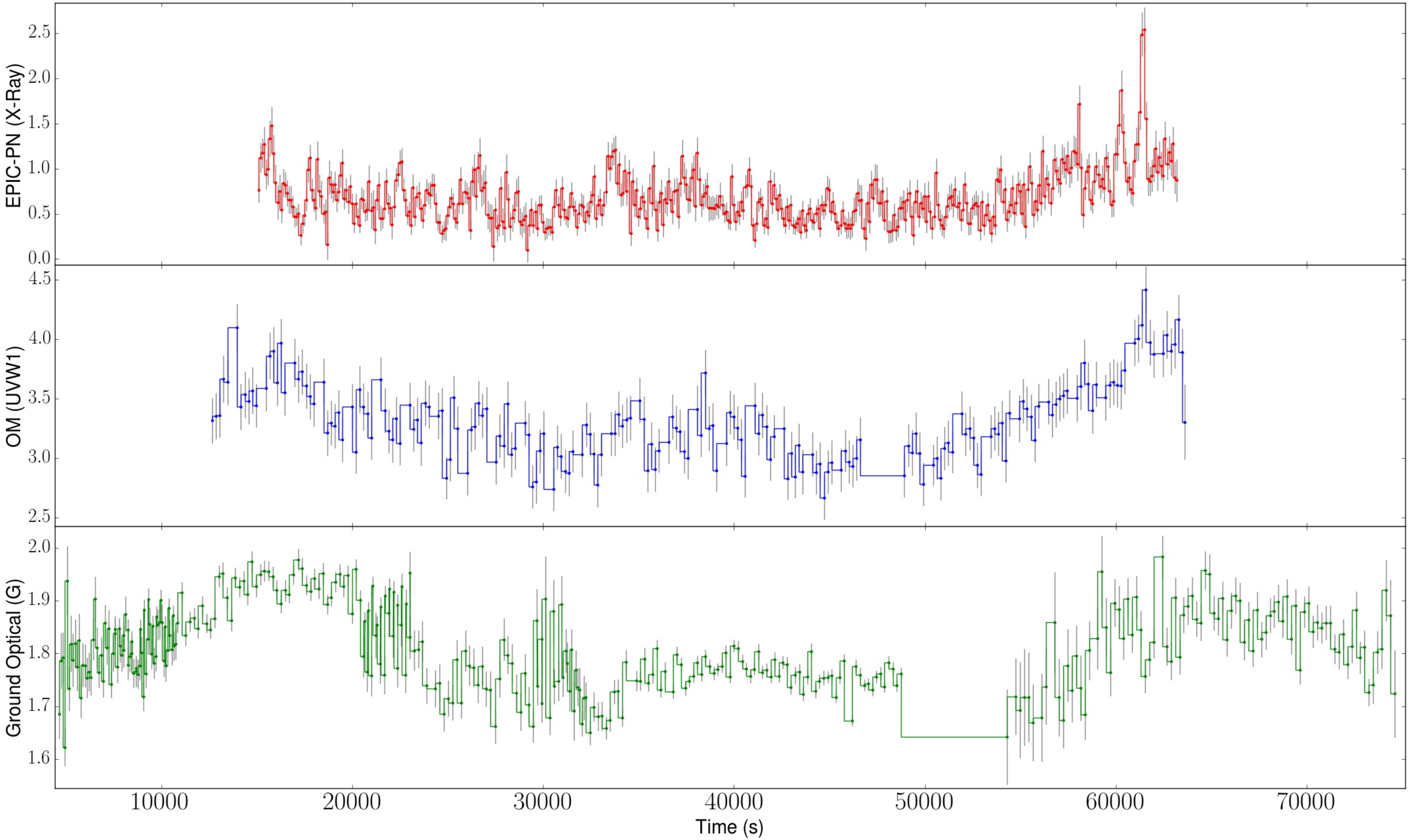
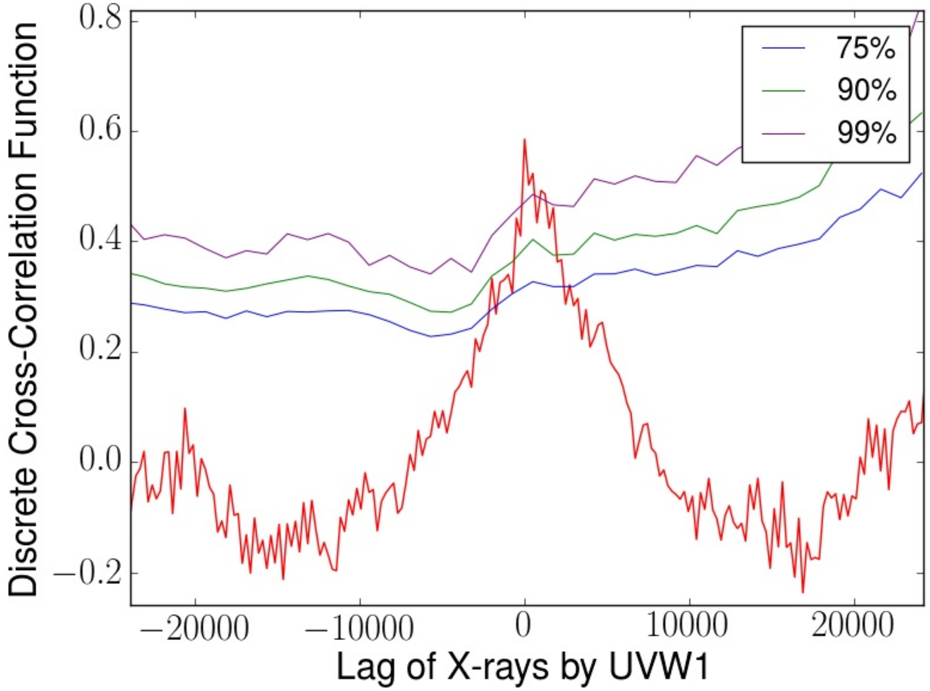
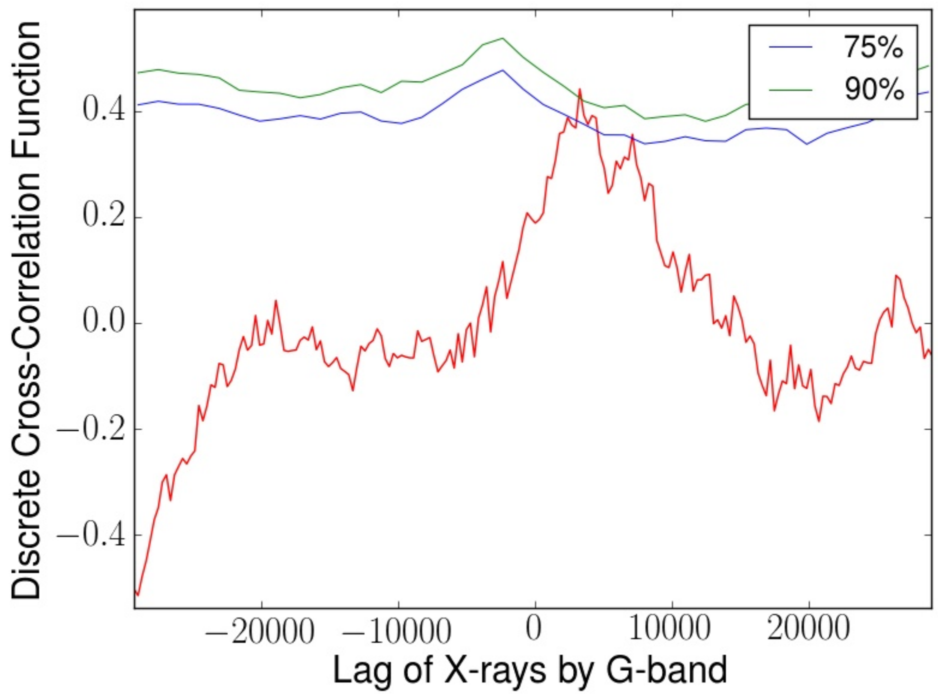


30-31 December 2014

NGC4395 - DCFs





X-rays vs UVW1

X-rays vs g-band

(Using Emmanouloupolos et al 2013 improved lightcurve simulation method for simulations)

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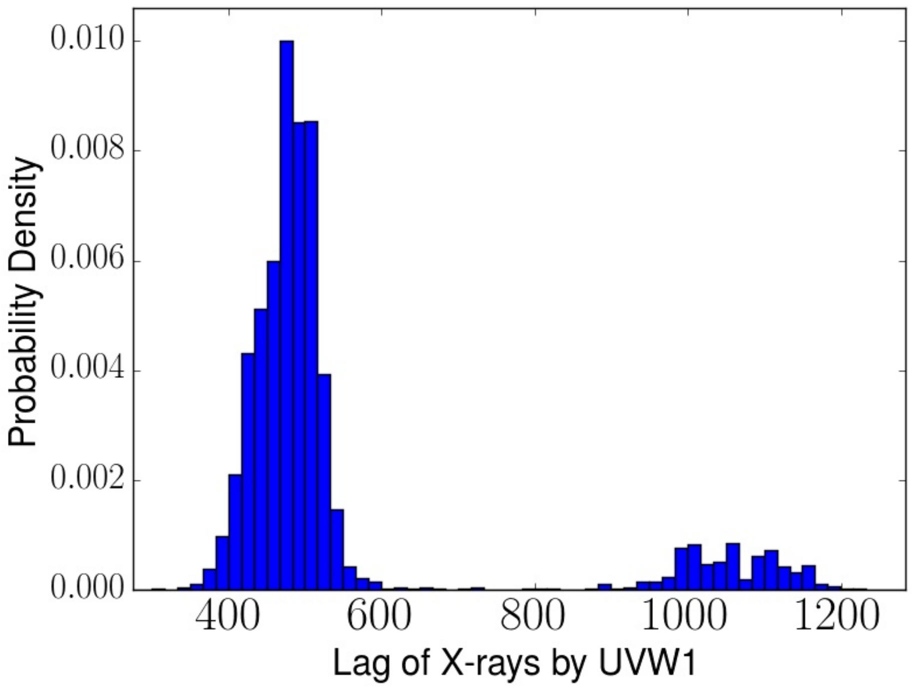
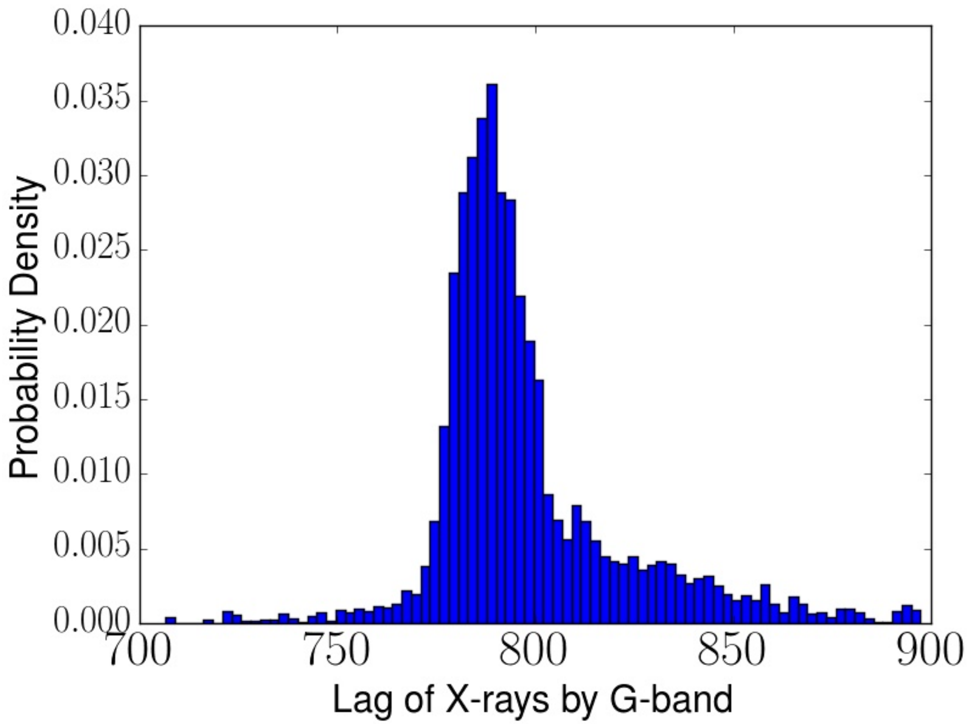
NGC4395 – Javelin lags

Javelin - Zu et al 2011,13





UVW1 lags X-rays by
473 (+47, -98) **s**

g-band lags X-rays by
788 (+44, -54) **s**

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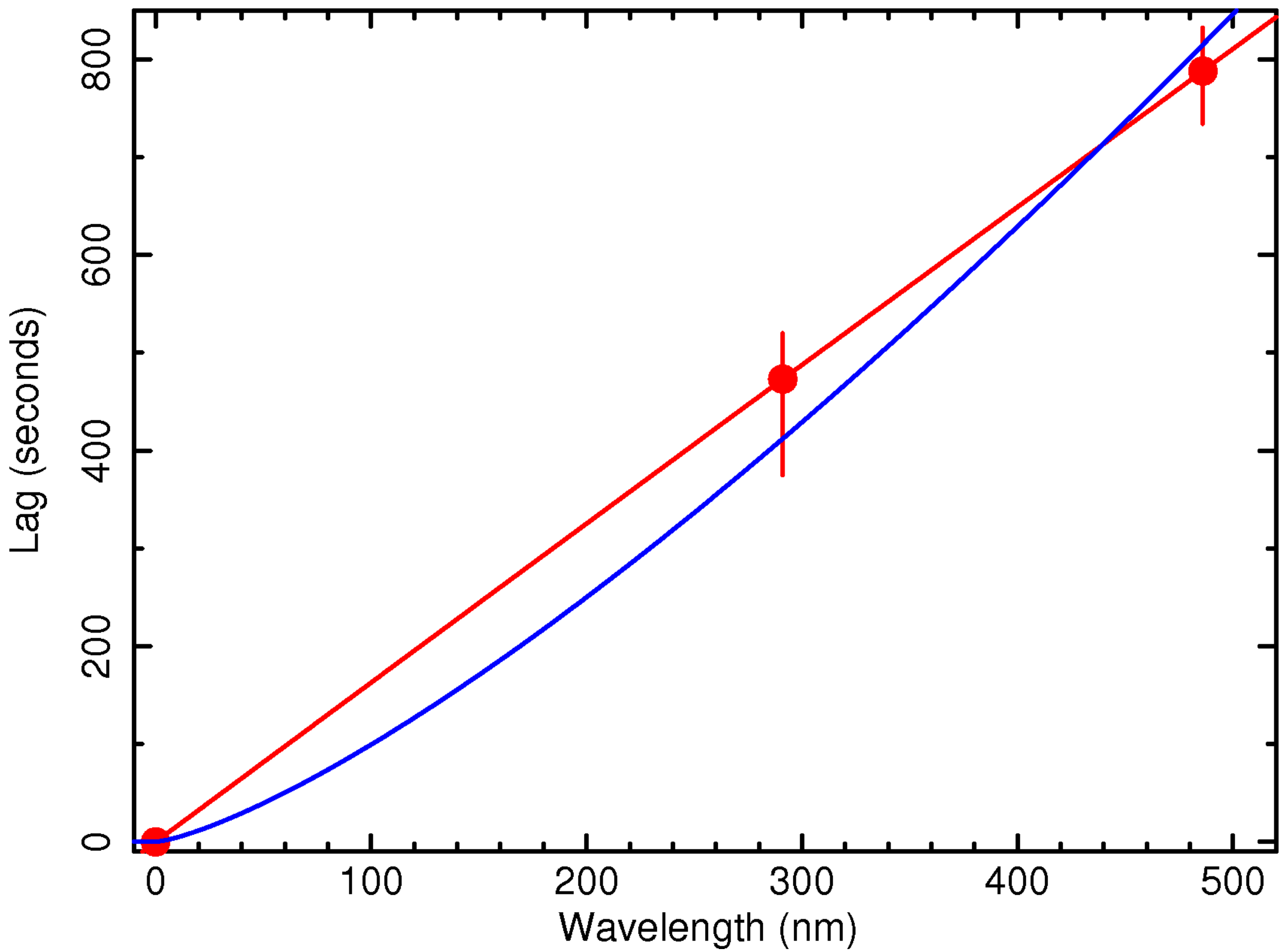
NGC4395 – Lags vs Wavelength



Simple linear fit (red) is best fit (forced through zero)**.**
However powerlaw of index 4/3 (blue) is also acceptable

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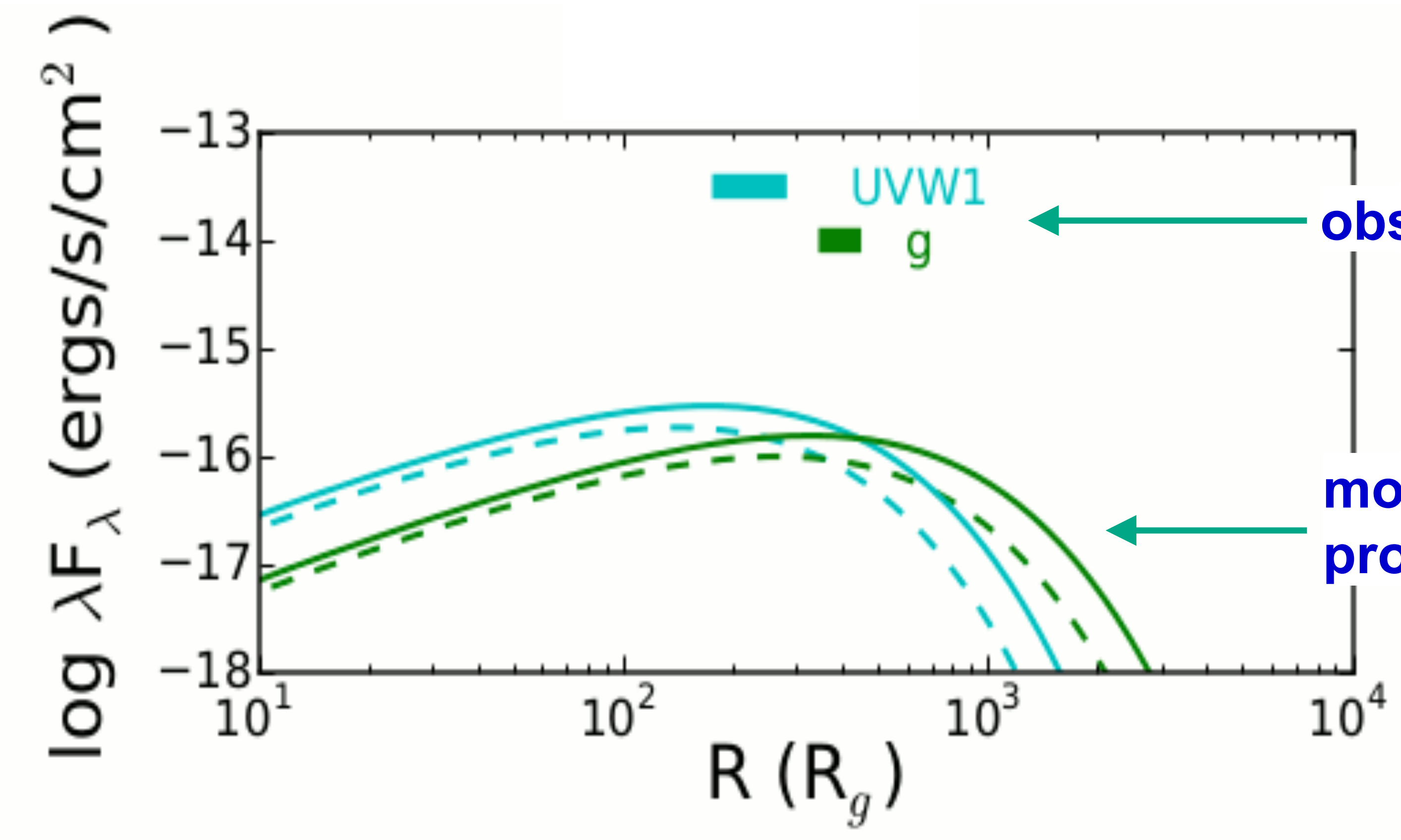
NGC4395 - Models



Solid lines – total disc energy release in band, including X-ray contribution
Dashed lines – gravitational energy release

Observed lags correspond to peak emission radii (models from P. Lira)

CONCLUSIONS

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

For NGC5548 observed lags are longer than expected for standard SS thin disc; for much lower mass, and lower mdot NGC4395, SS thin disc may be acceptable.

Larger than expected disc sizes also deduced from microlensing observations - inhomogeneous disc?

To test disc models properly, need lag observations of larger sample of AGN.