Multiwaveband Variability of AGN

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Outline

X-ray / UV / Optical variability

- Seyferts
- LINERS

X-Ray / mm / Radio variability

- LINERS
- Seyferts

X-ray / UV / Optical Variability

- What drives UV/optical variability in AGN?
- How is the X-ray band related to UV/optical?
- What do X-ray/UV/optical variations tell us about AGN inner structure?

SEYFERTS
Possible drivers of UV/optical Variability

- **Reprocessing of higher energy photons**
    - which “high” energy? X-ray? Far-UV?
    - reprocessing off what? Disc? BLR?

- **Intrinsic disc variations**

Observational Diagnostics

- Reprocessing - High energies lead uv/optical by short (hour-days) light travel time to reprocessor

- Intrinsic disc variability – High energies 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
Wavelength dependence of lags

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For standard Shakura-Sunyaev DISC, dissipating gravitational potential energy

$$L(R) = \sigma T^4 \propto M_{BH}^{-1} \dot{m}_E R^{-3}$$

(*R* in gravitational radii)

Disc illumination from point source also ~ R^-3

In both cases giving $$Lag \propto Wavelength^{4/3}$$ (eg Cackett et al 2007)

For illumination of a shell-type structure, eg the BLR or torus, Illumination falls off as R^-2 giving

$$Lag \propto Wavelength^{4/2}$$ **i.e.** $$Lag \propto Wavelength^2$$

RXTE + Ground based optical: MKN 79

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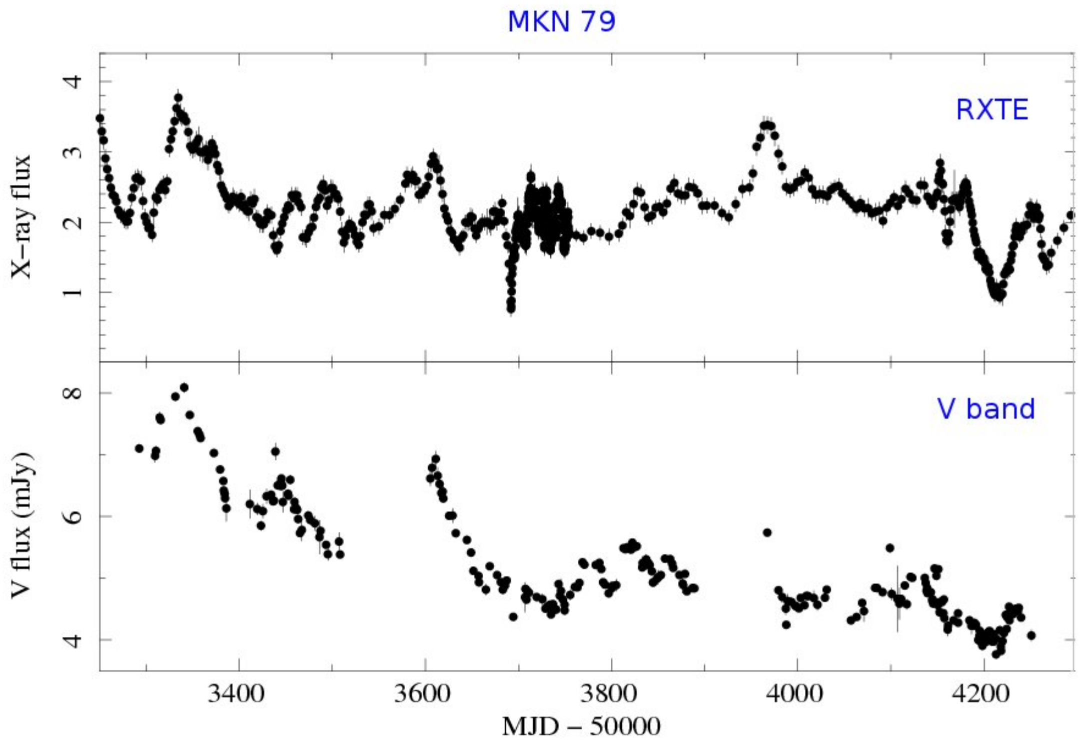
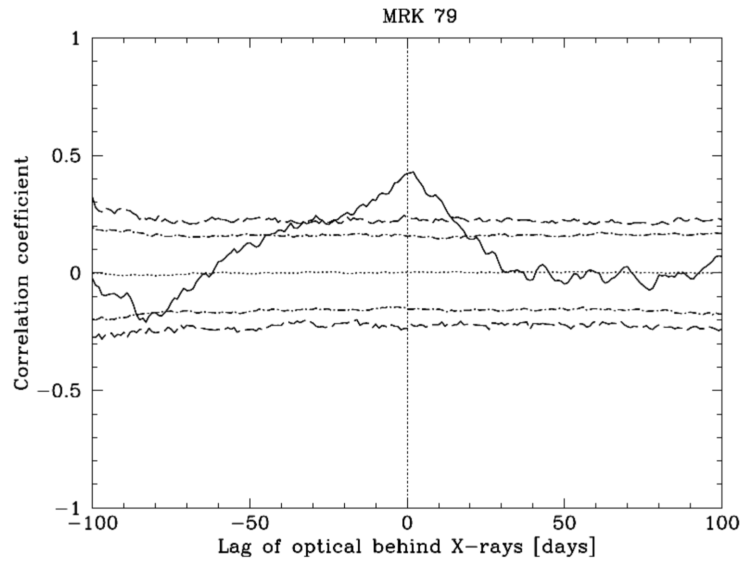


(Breedt et al, 2009, MNRAS)



Long timescales (years)

– uncorrelated behaviour. Intrinsic disc variations in optical?

Short timescales (days-weeks)

- well correlated. Hint that optical lags, but lag not well defined

Correlations

A few comments:

Discrete correlation function is always correct, but not the most sensitive

Interpolation function is more sensitive.

Need simulations to determine confidence levels.

-- Timmer and Konig (1995) method is OK for linear, Gaussian lightcurves
but cannot simulate non-linear lcs, eg TeV or most blazar lcs

-- Use iterative method of Emmanoulopoulos et al 2013
Produces correct power spectral density AND flux distribution

CCFs often asymmetric – possibly multiple components

DCF and ICCF not very accurate at measuring lags. Javelin is better (later)

Swift Monitoring of NGC5548:
(> 500 observations)

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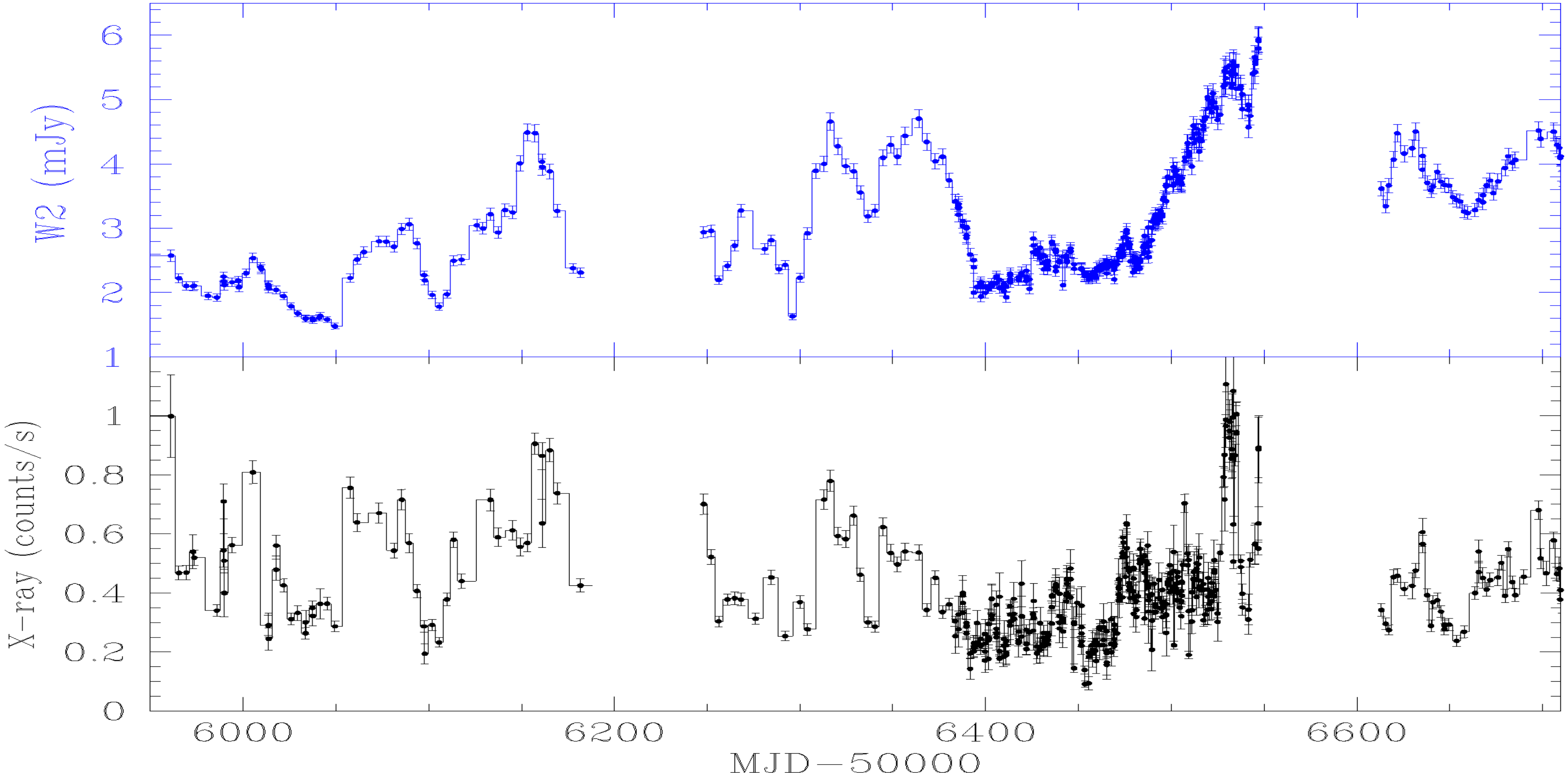
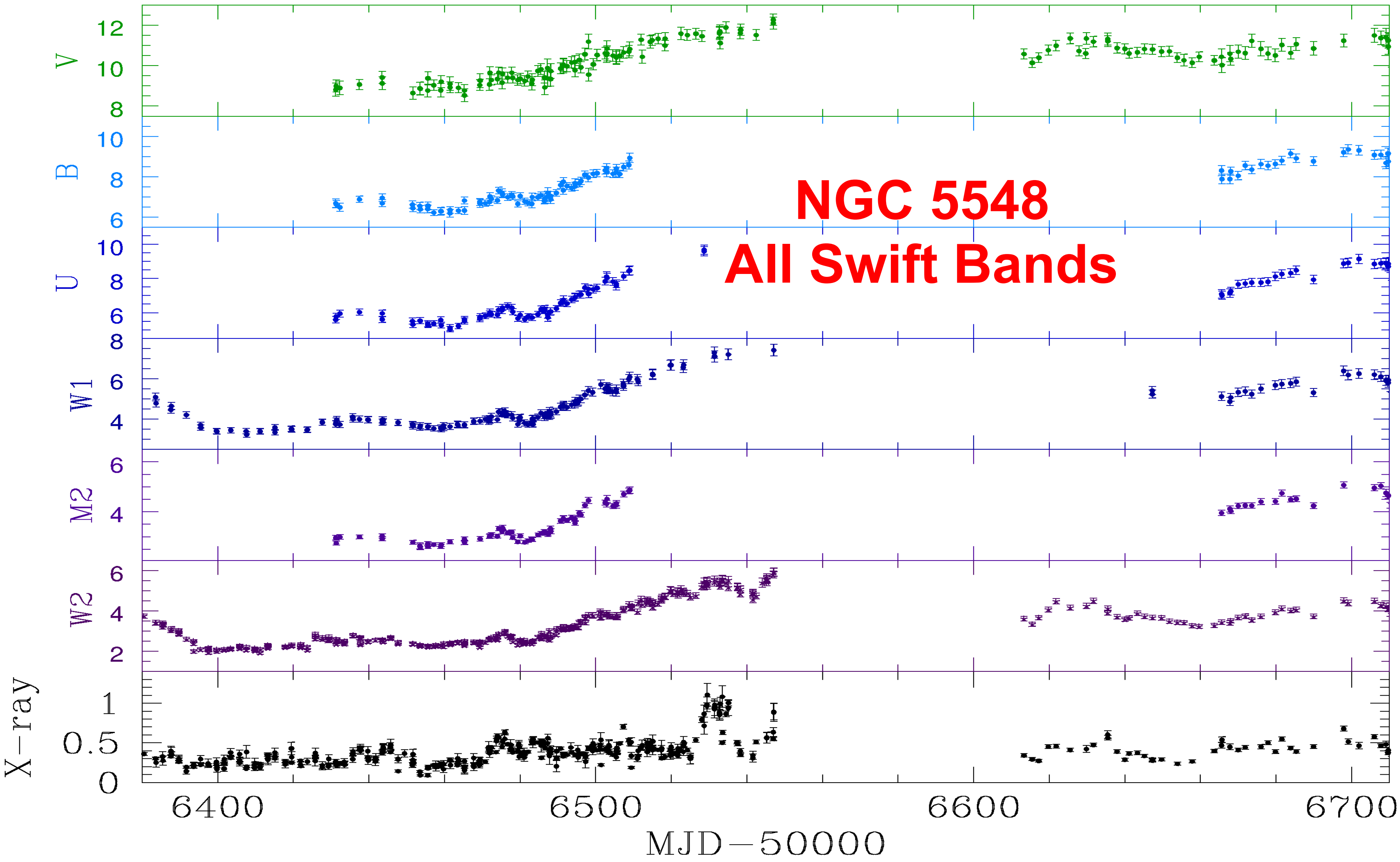


Good correlation, but not perfect, eg large W2 rise after day 6480

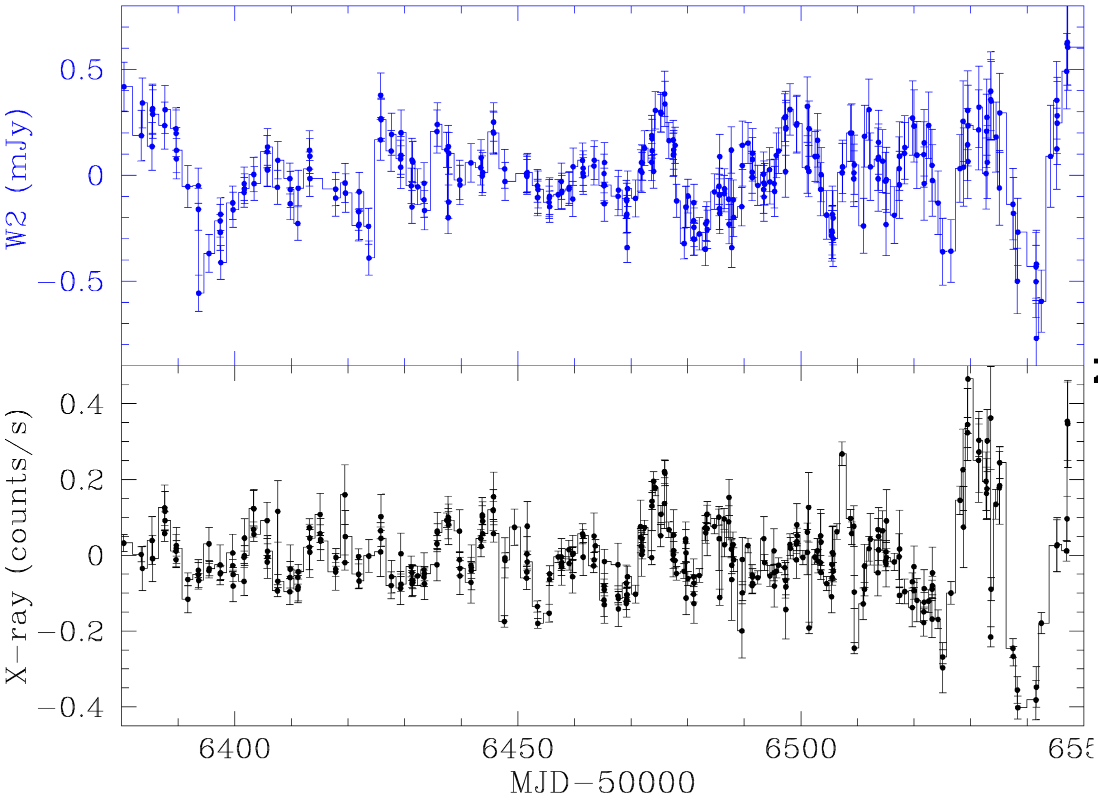
McHardy et al, 2014, MNRAS, 444, 1469



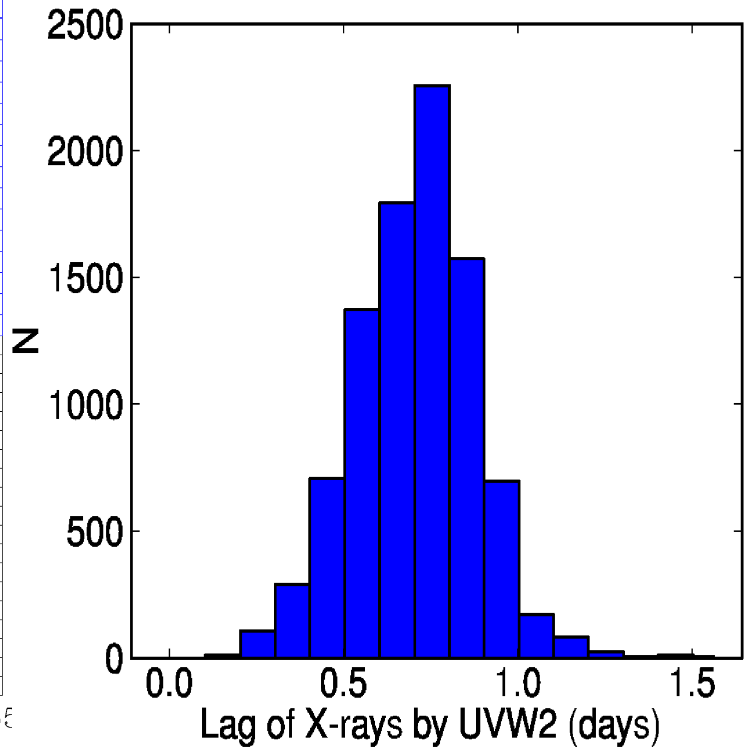
Well correlated long term variability in UV and optical bands, not seen in X-rays

Lag of X-rays by UVW2

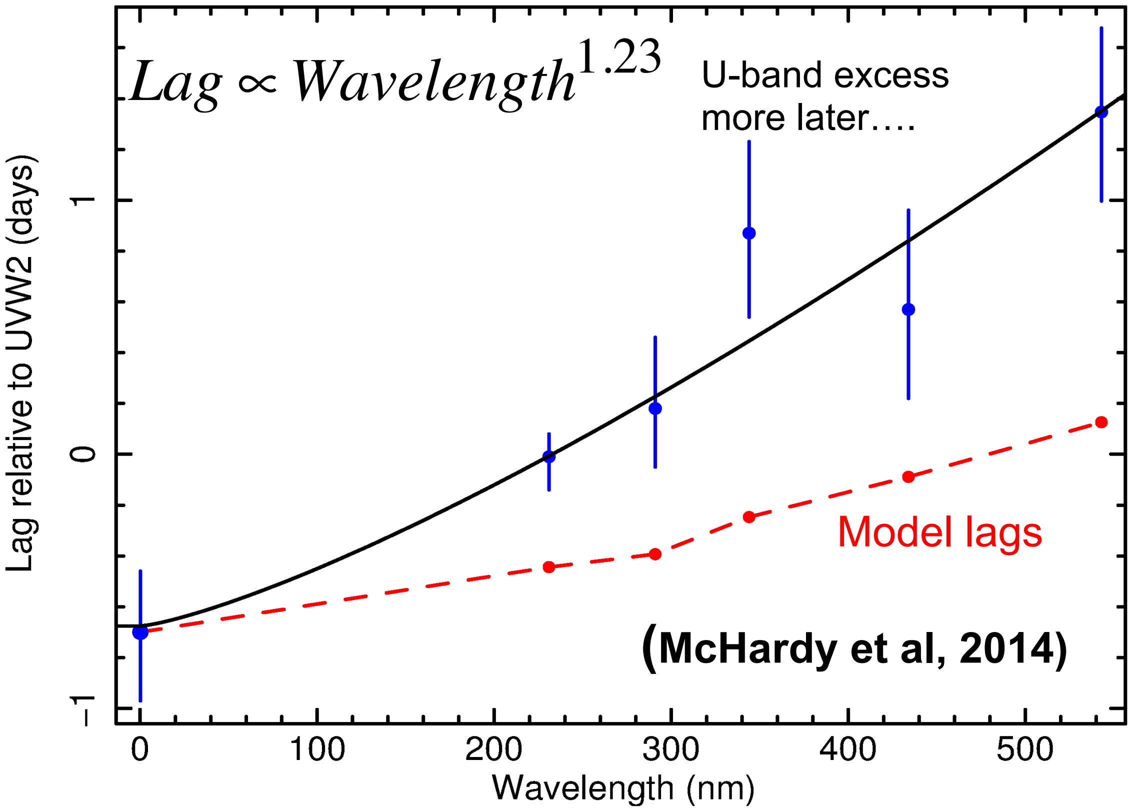
Mean-subtracted lightcurves
Intensively sampled period



Lag distribution
(Javelin – Zu et al 2011)



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 longer than expected for the Mass and $\dot{m}$

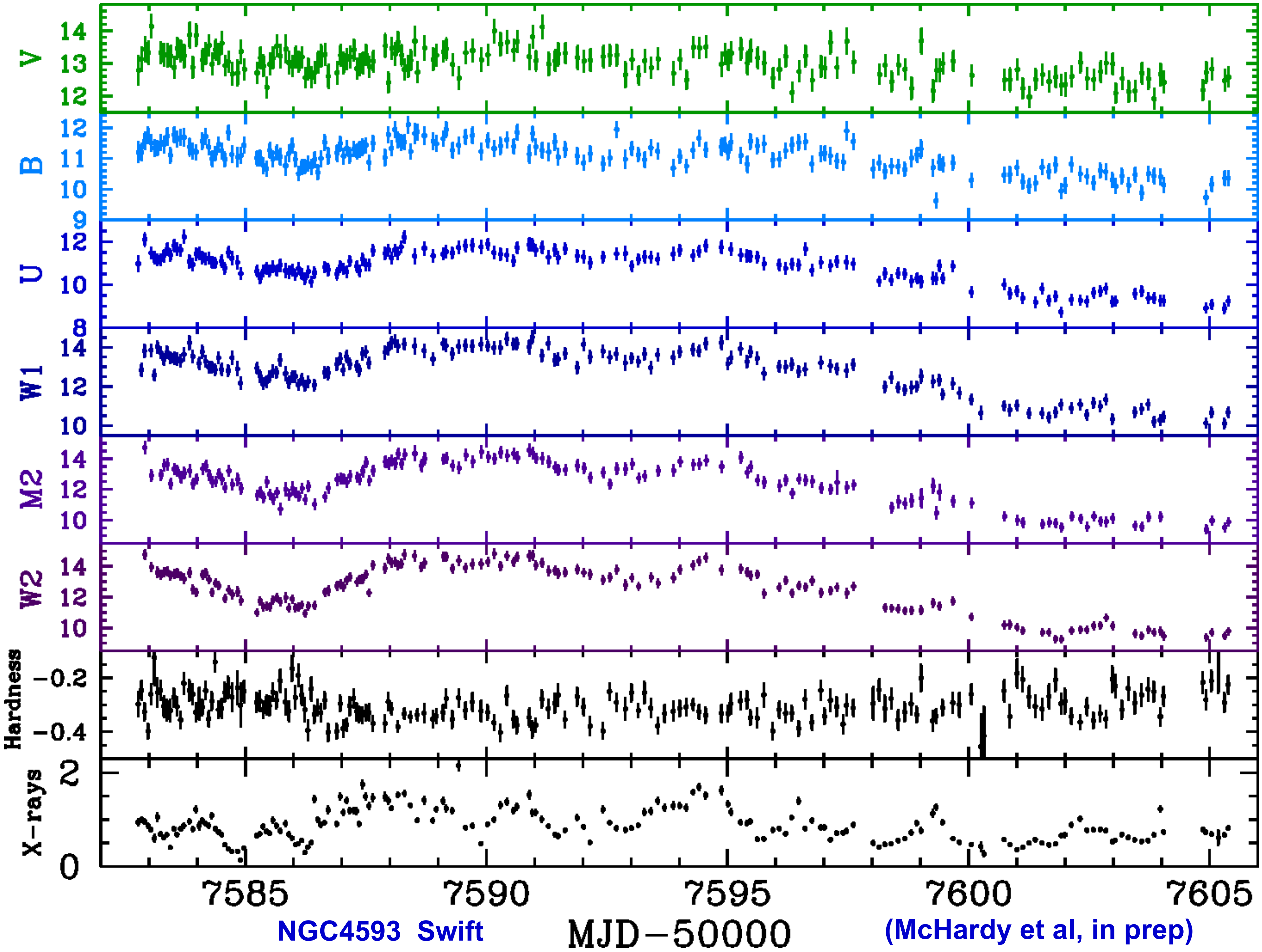
Red line is time for HALF of reprocessed light to arrive.

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)?

Same result in extensive follow up observations (Edelson et al 2015, Fausnaugh et al 2016)


V
B
U
W1
M2
W2
Hardness
X-rays
7585
7590
7595
7600
7605
NGC4593 Swift
MJD−50000
(McHardy et al, in prep)

NGC4593 Lags

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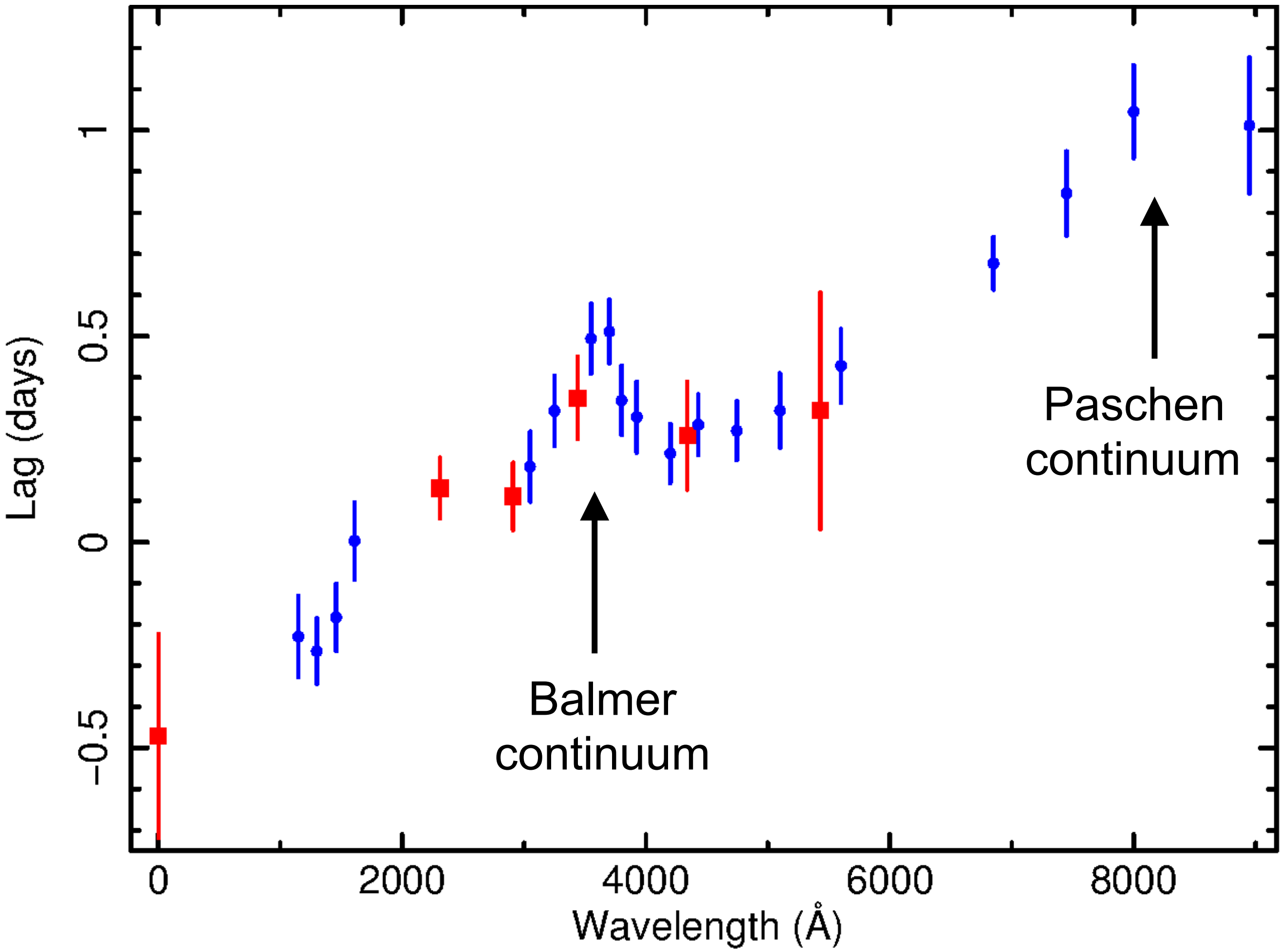


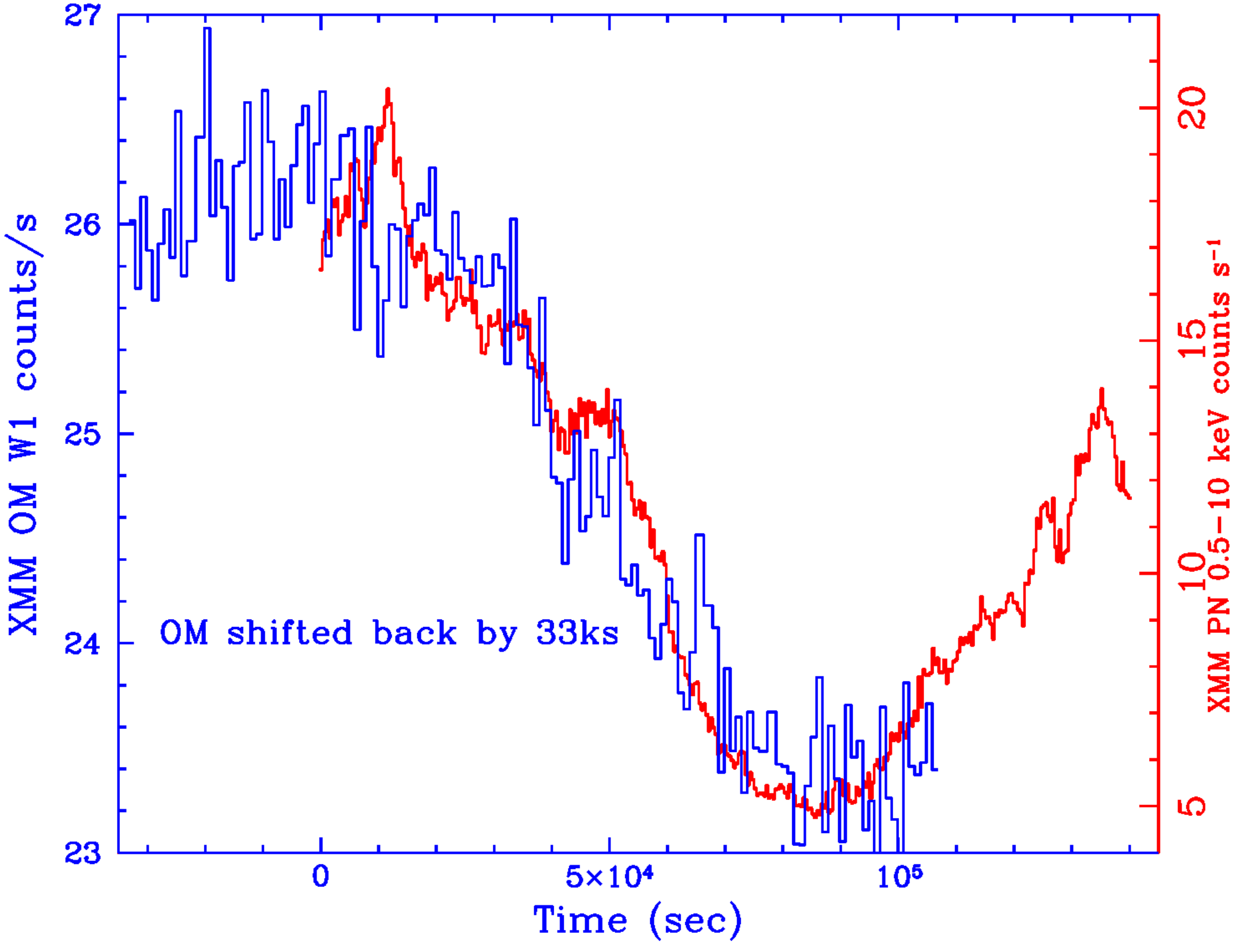
(Lags relative to high quality Swift UVW2)

Swift (McH) and HST (Cackett) combined lags

Balmer emission from BLR very clear (3800A)

Broad line region can contribute ~50% of the lags.

NGC4593 XMM PN-OM lag

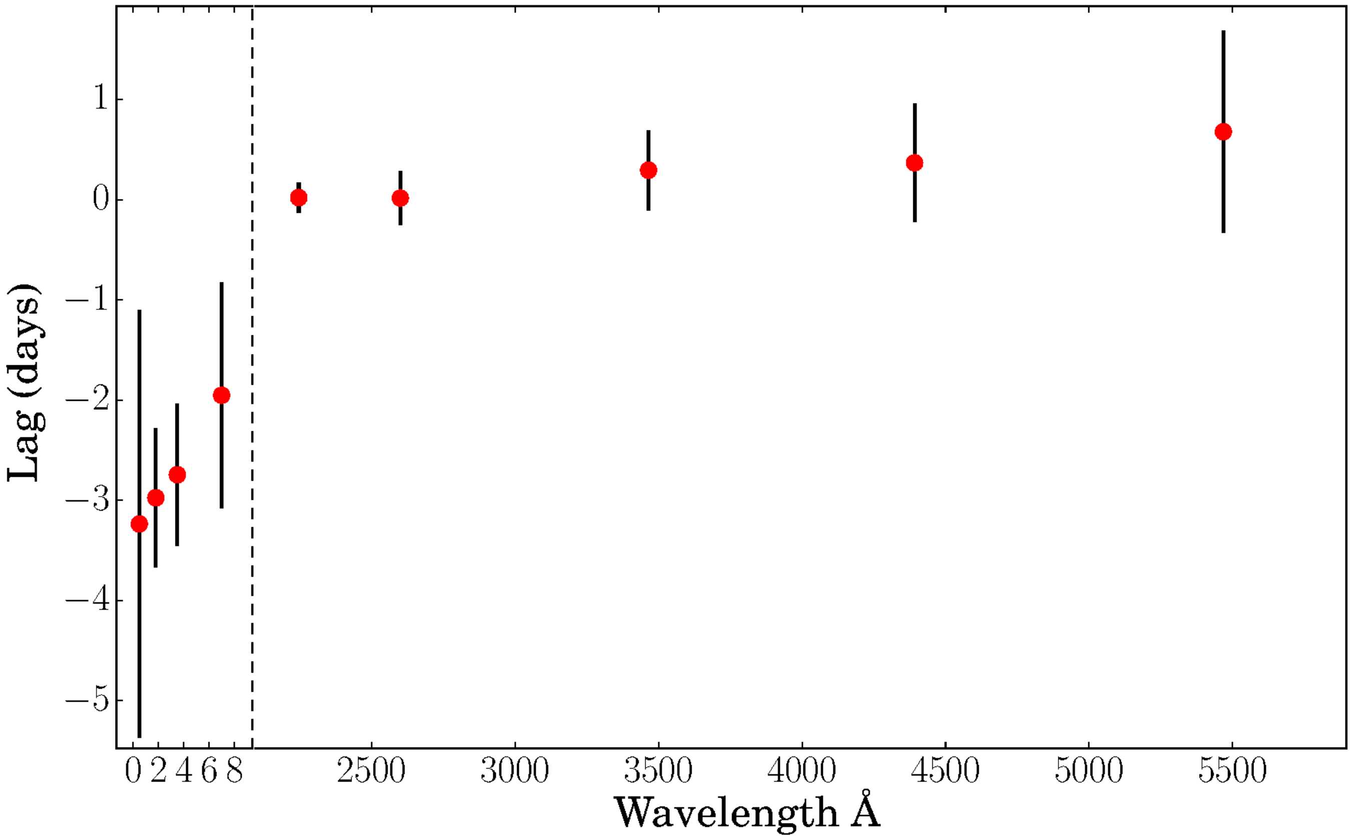


Identical lag measurement to Swift (McH+, in prep).

Only one UV/optical band but easy to make.

See also XMM PN-OM lags on NGC4395, McHardy et al, 2016.

NGC4151 Swift Lags



(Edelson et al, 2016, submitted)

UV-optical lags as in other AGN, but X-ray lags energy dependent.

Absorption and re-emission?

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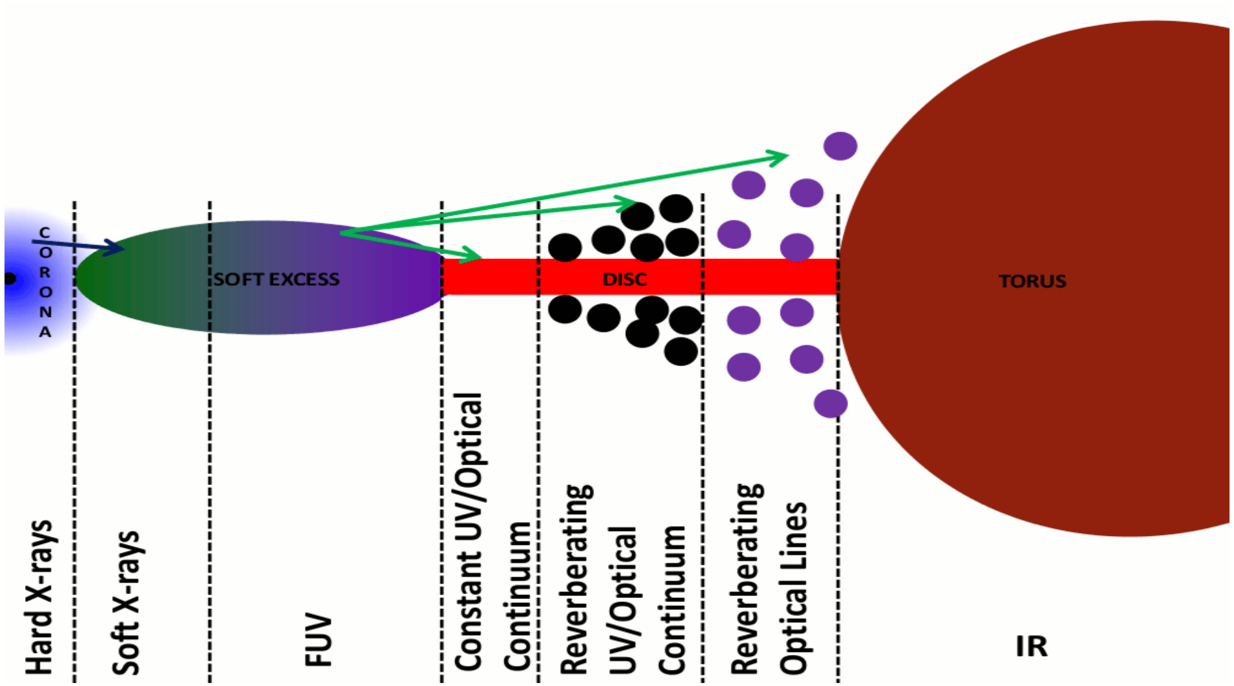
Possible geometry



Gardner +Done 2016

X-rays hit inner part of disc which re-radiates far-UV onto outer part, producing near-UV and optical.

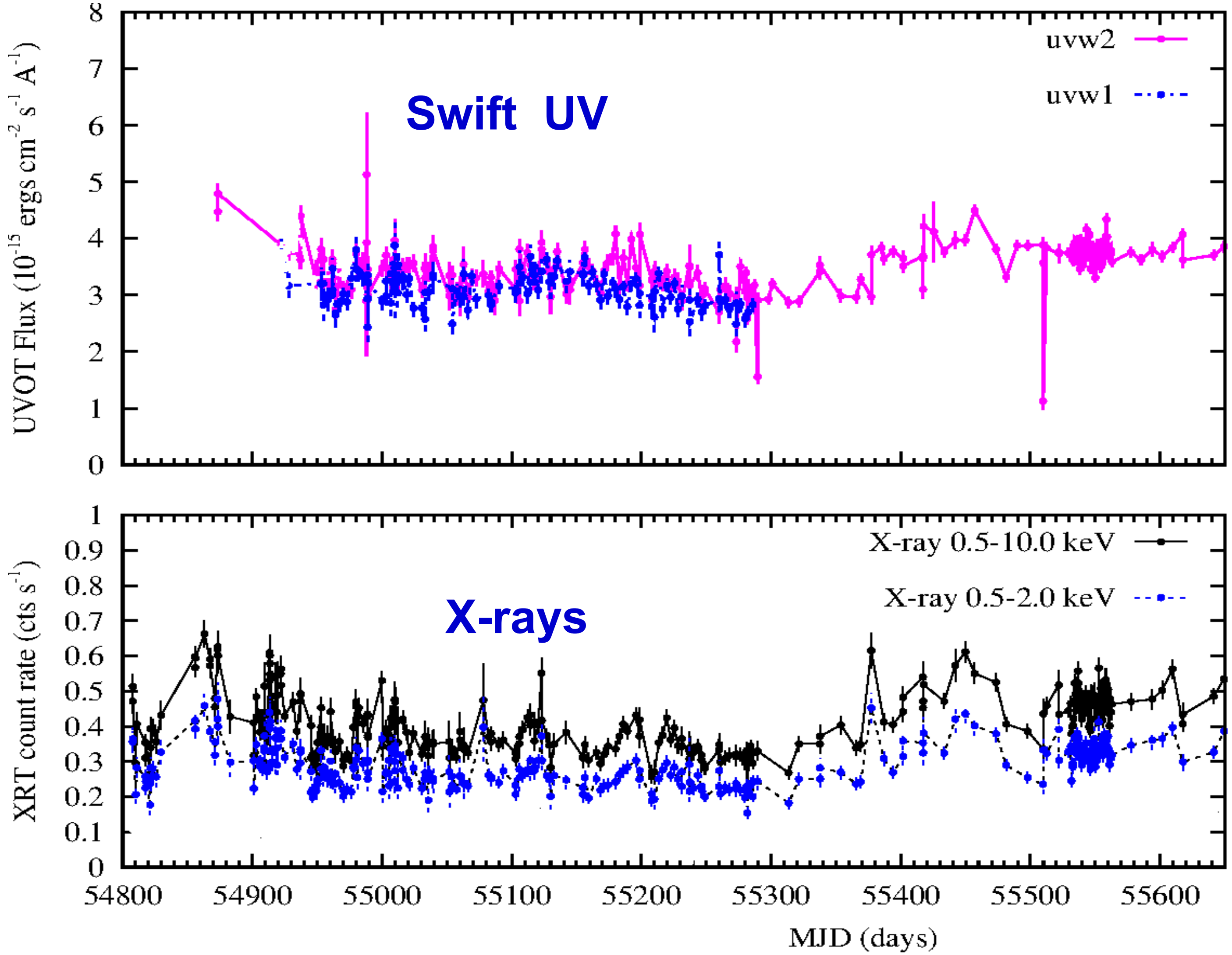
X-ray / UV Variability of LINER – M81

Very low accretion rate - no disc

If X-rays lag UV: UV could be seed photons for X-rays (SSC)

If UV lags X-rays: UV could be synchrotron from jet, downstream from X-ray corona

X-ray / UV Variability of M81



Cameron
2014
Phd Thesis
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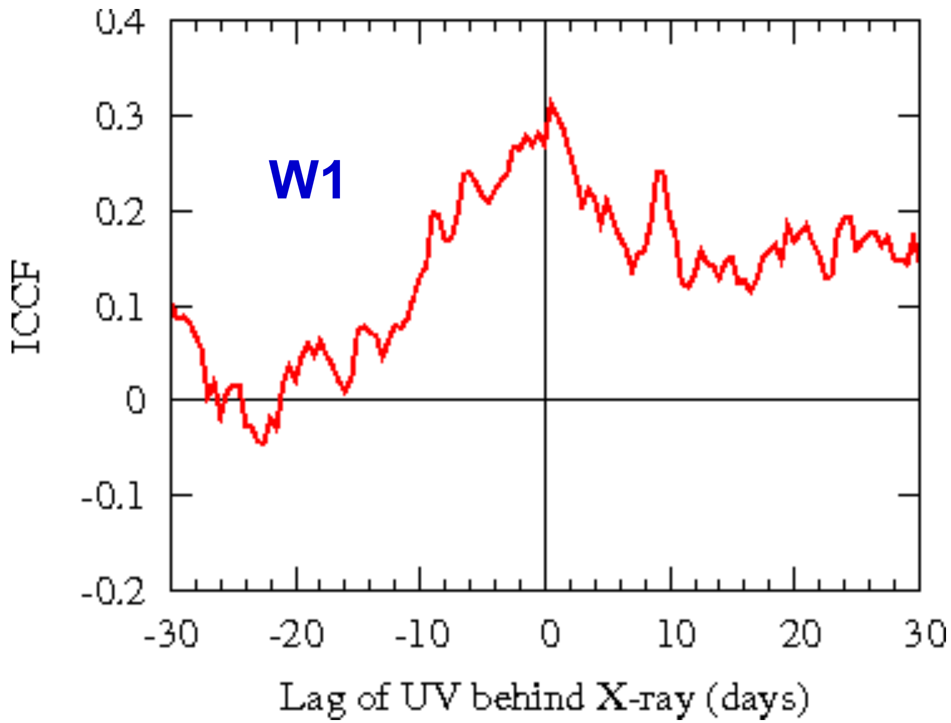
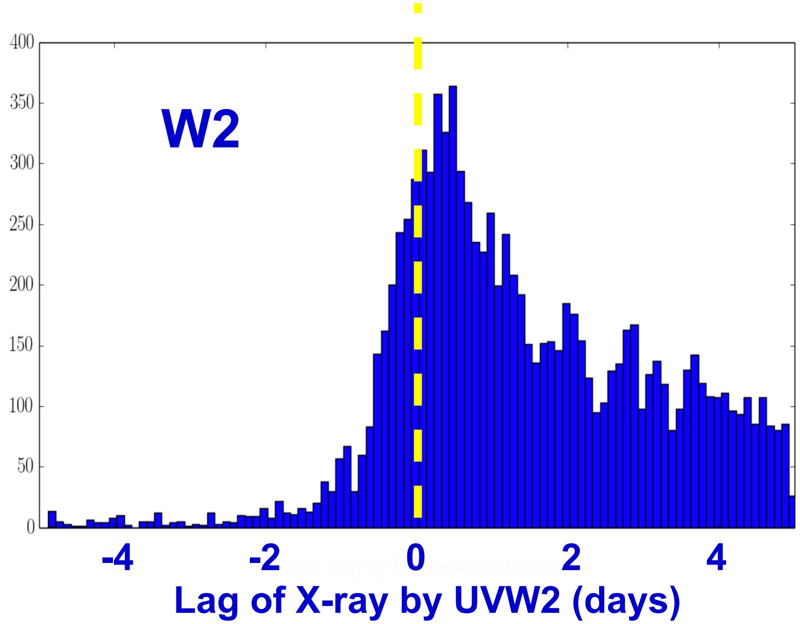
X-ray / UV Variability of M81





Javelin result
from Harvey-Taylor
Southampton UG

Weak correlations, small UV lag

**-> UV are probably synchrotron from jet, downstream from X-rays,
Probably from the pre-acceleration region, close to BH**

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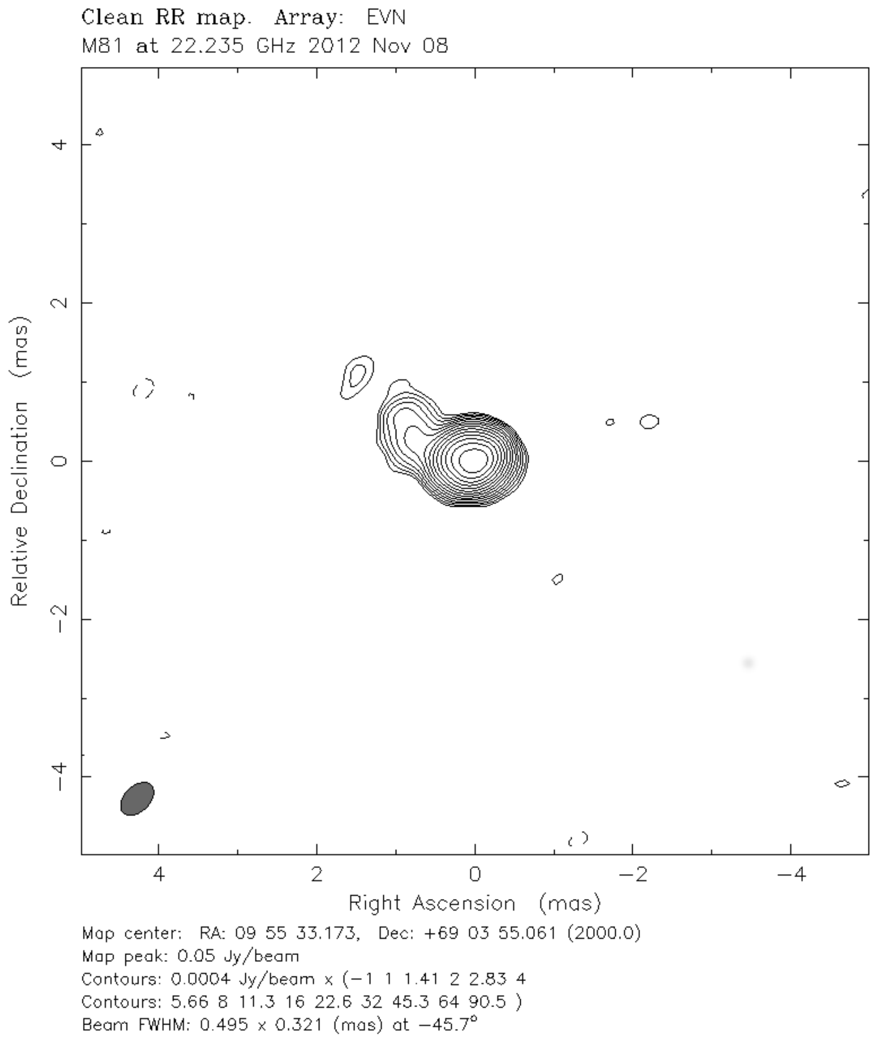
X-Ray / mm / Radio Relationship in LINERS

Do the perturbations which drive the X-rays carry on into the jet?

Are liners the equivalent of `hard state' X-ray binaries?

Are liners anything like blazars?

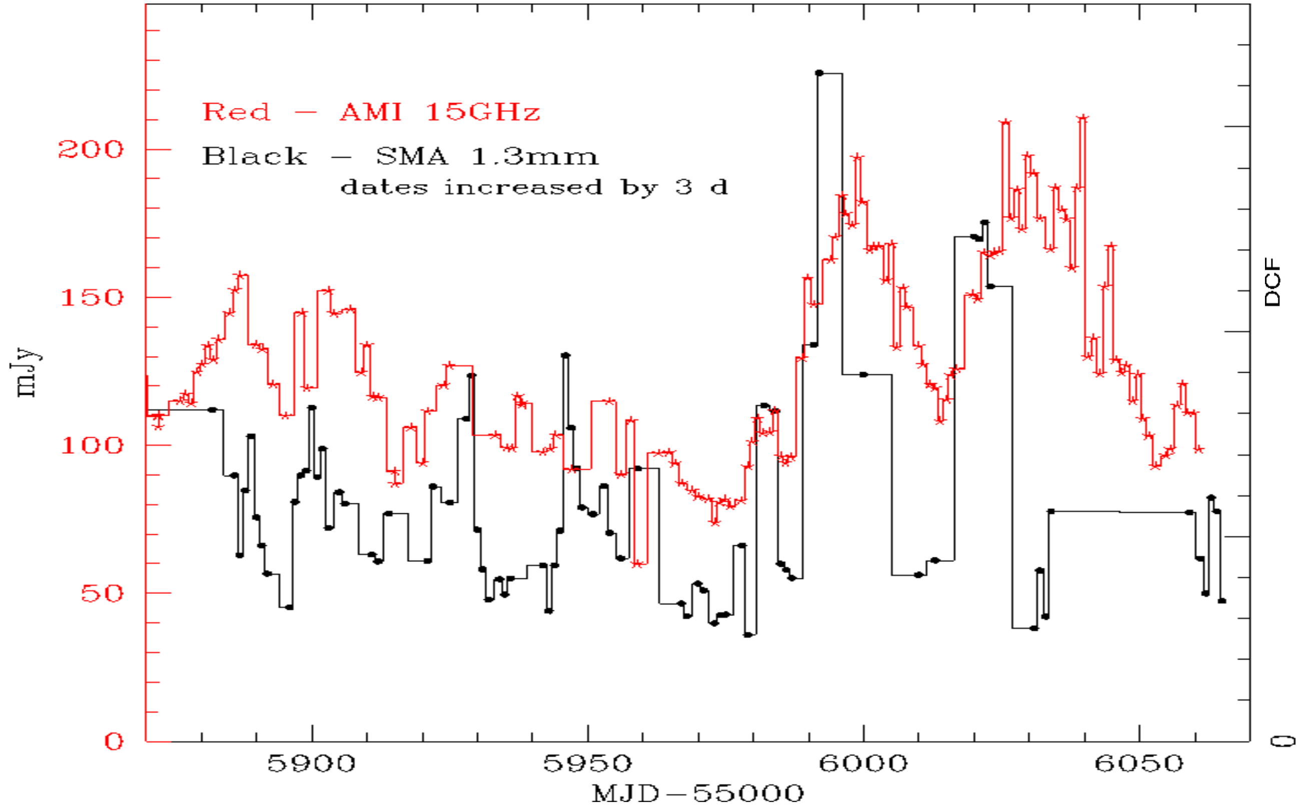
M81 sub-mas structure

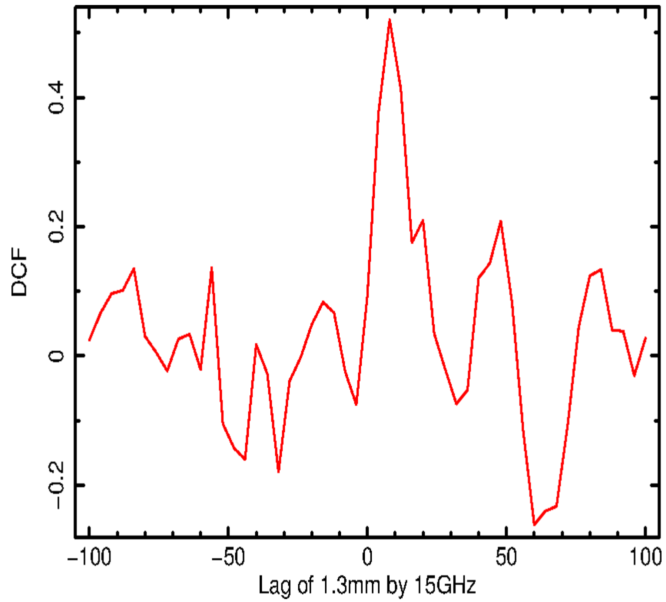


Sub-mas bending jet similar to blazars

Here from Ros, McH et al;
See also Marti-Vidal et al 2011

M81 radio-mm variability: strong correlation



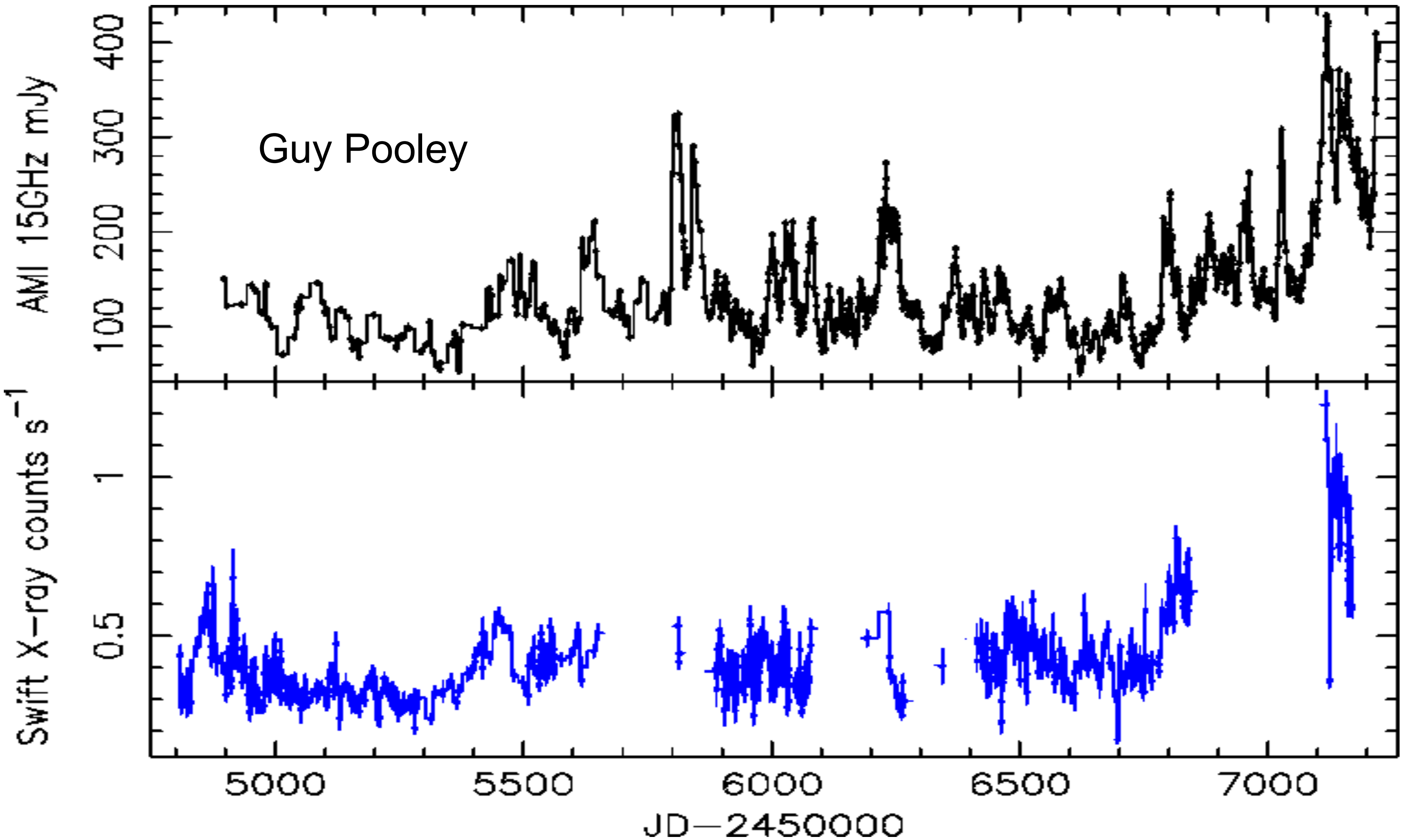


Radio lags mm by ~3 days

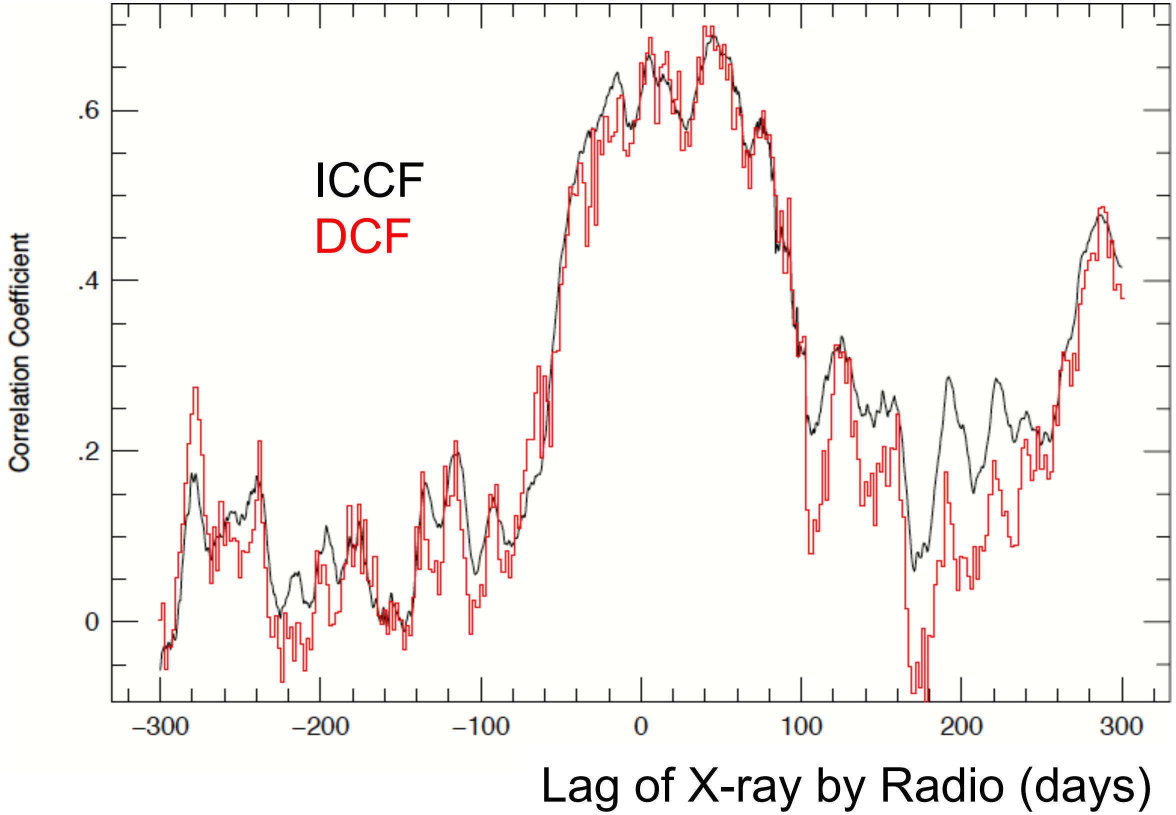
Radio-mm flux densities similar – flat spectrum

Consistent with standard synchrotron jet

M81 Swift X-ray and AMI 15 GHz Radio



M81 X-ray / Radio ICCF / DCF



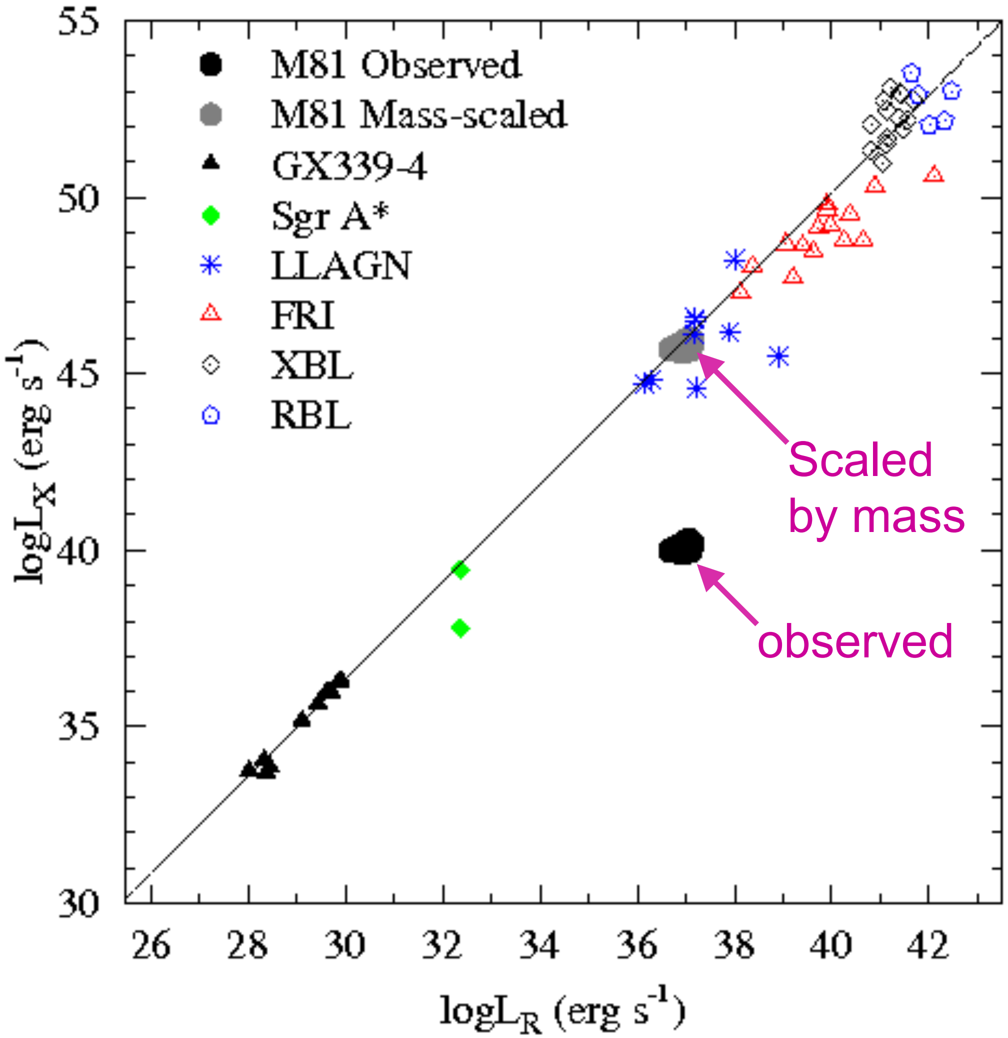
Good overall correlation.

(Not enough data to produce reliable X-ray / mm correlation.)

Centroid of lag, using Peterson FR/RSS simulation method 21 +/- 3d
Peak of lag 44 +/- 3d

(c.f weaker correlation, but similar lag, in NGC7213 – Bell et al 2011)

M81 X-ray and Radio



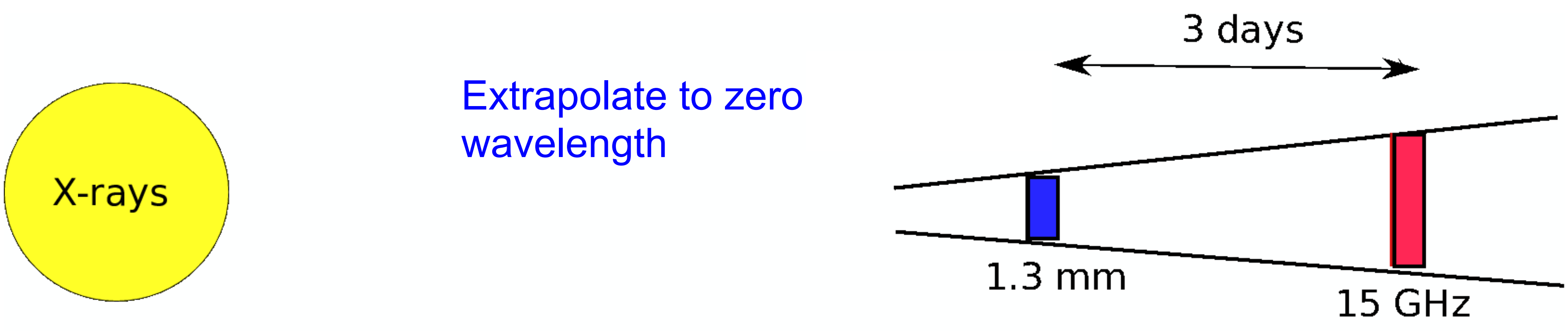
When scaled for mass, M81 data fits on **Fundamental Plane** of mass, Lx and L_R for jet dominated sources very well

So M81 is like a hard state binary

Merloni et al 2003,
Falcke et al 2004,
Koerding et al 2006

M81 – Geometry from lags

Extrapolate to zero wavelength

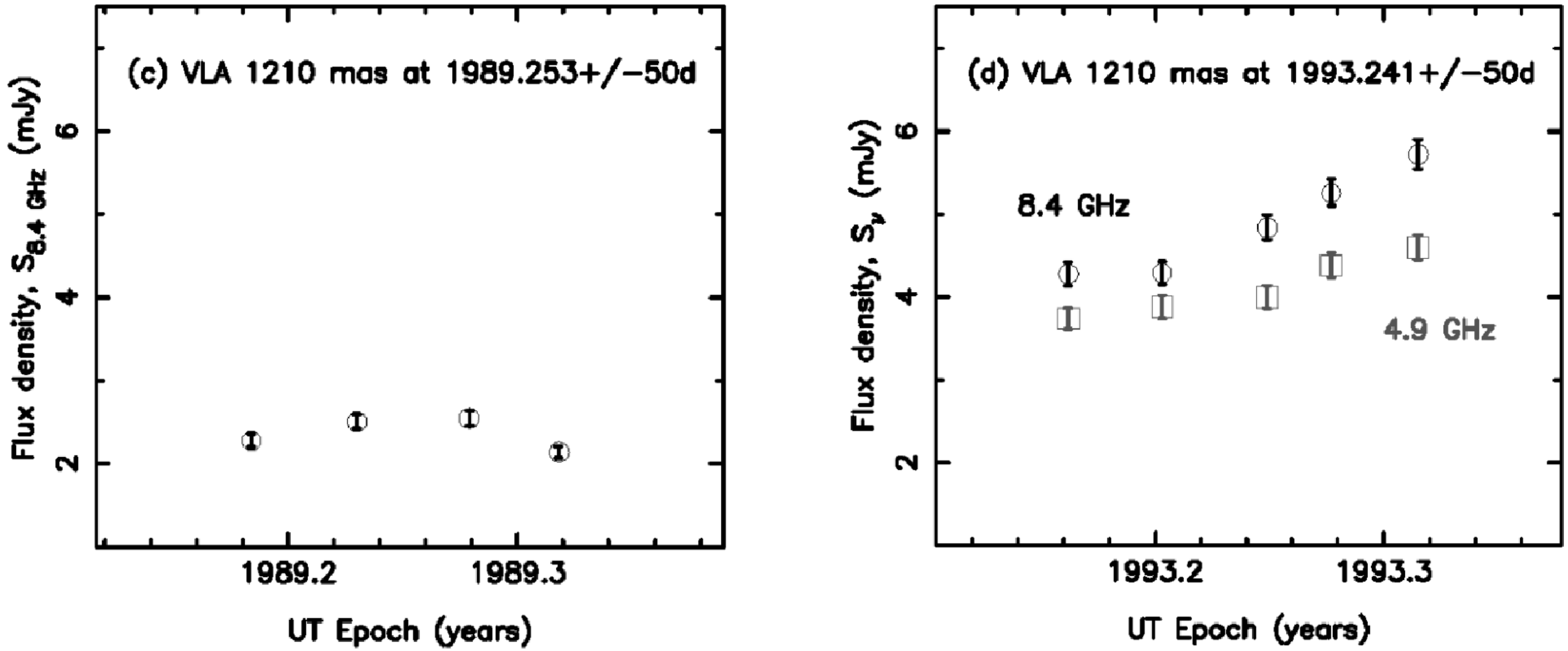


Base of synchrotron jet (acceleration zone) may be ~3000 Rg from BH

Consistent(ish) with 0.1s lag of X-ray by optical in binary GX339-4 (Gandhi+ 11)

X-ray / Radio Variability of 'Radio Quiet' Seyferts

Radio variability from Seyferts, ie high accretion rate AGN



NGC5548 – Wrobel 2000 - radio variability over months but no X-ray observations

Seyferts **were** thought to be the equivalent of soft state X-ray binaries.

No detectable radio emission from soft state binaries – Russel et al 2010

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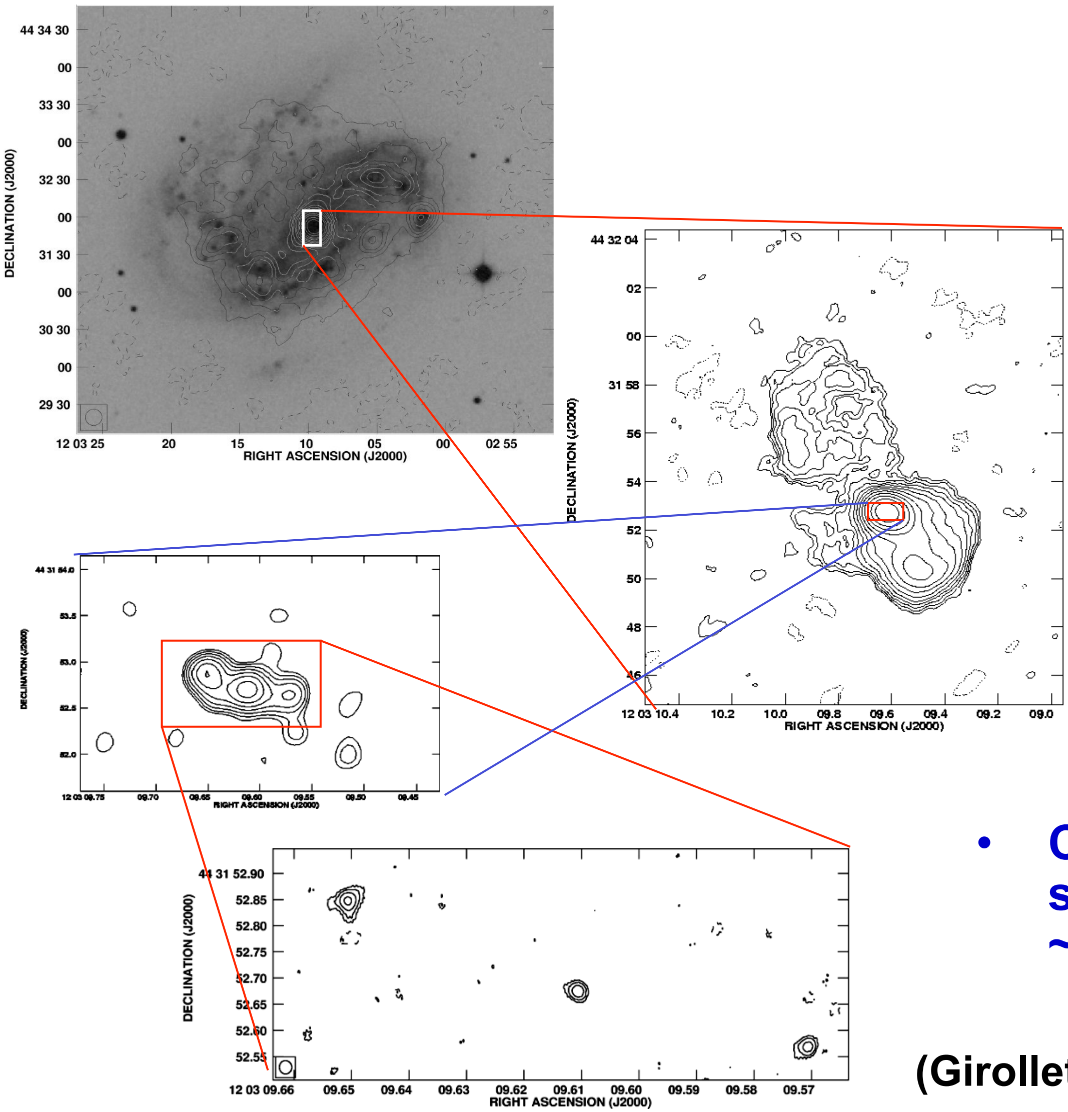
NGC4051 - Seyfert



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

(Jones et al, 2011)

- **Component separation is ~50 light years**

(Girolleti and Panessa 2009)

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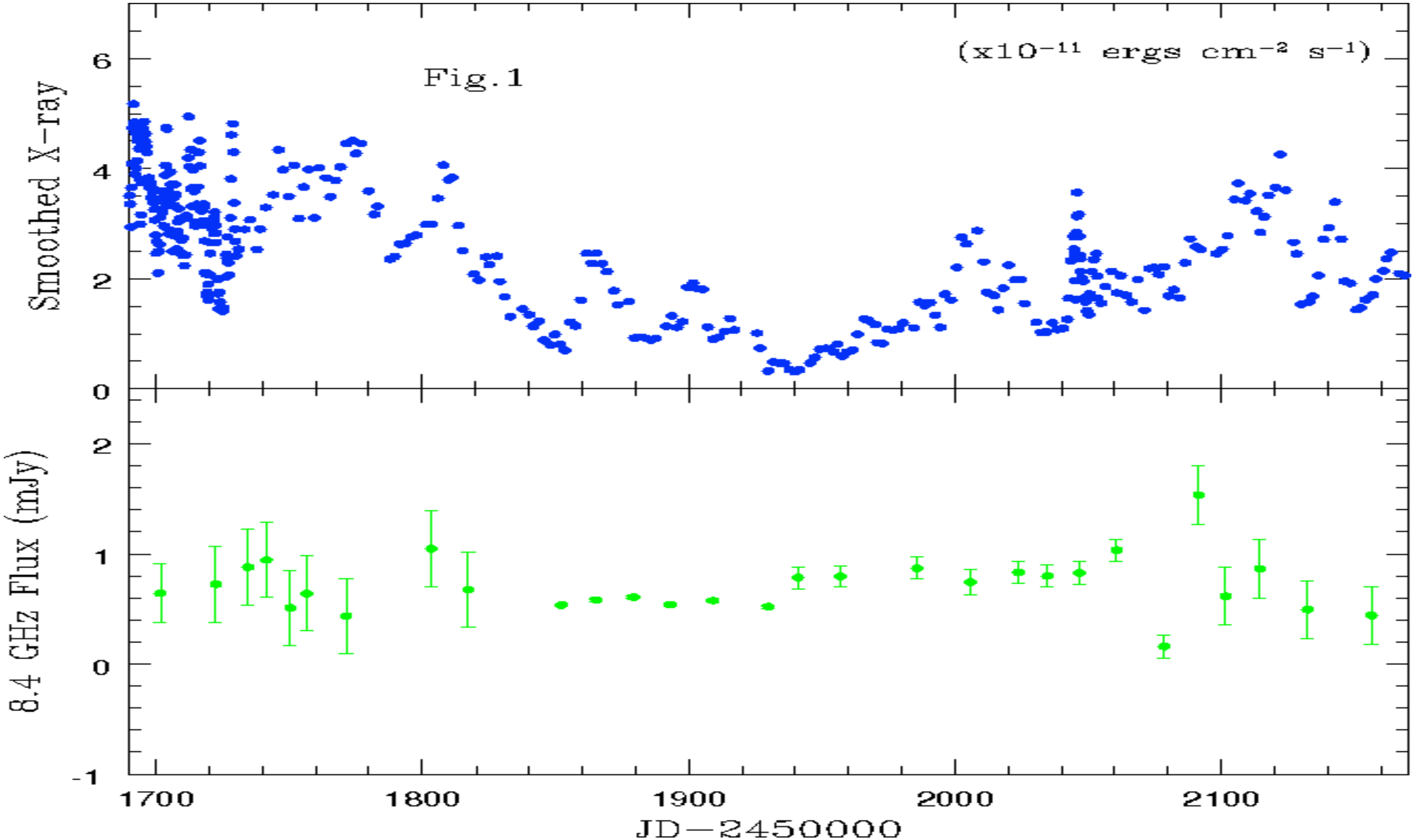
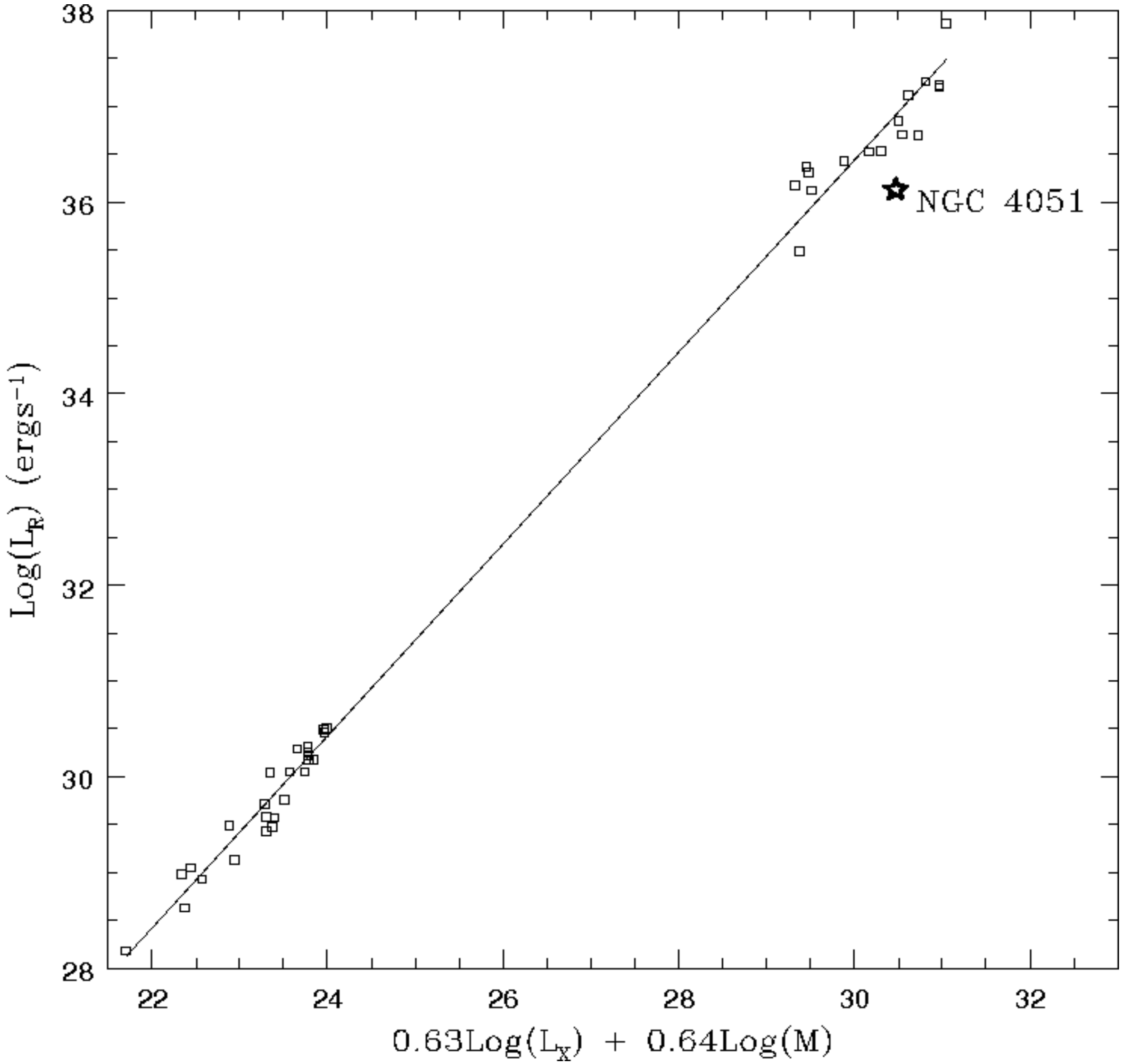
NGC4051 Radio vs. X-ray - VLA all arrays



No strong evidence for large amplitude radio variability (Jones et al, 2011, 2016)

- but NGC4051 is very faint in radio

NGC4051 on radio `fundamental plane' for jet-dominated sources



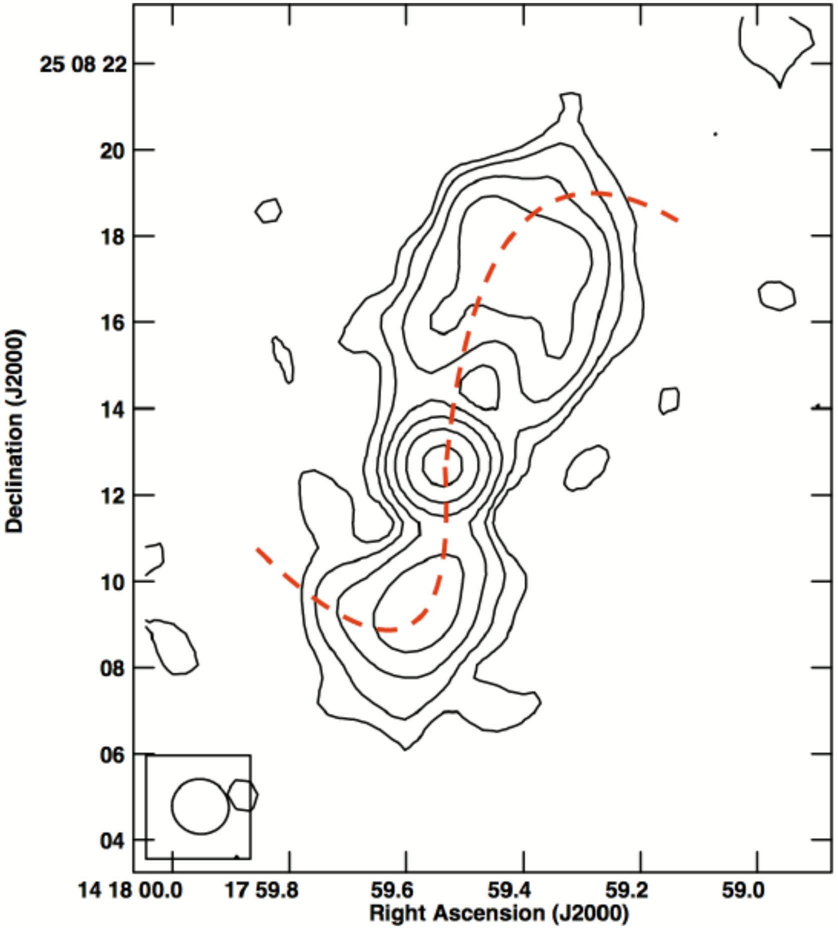
(Merloni et al 2003, Falcke et al 2004, **Koerding et al 2006**)

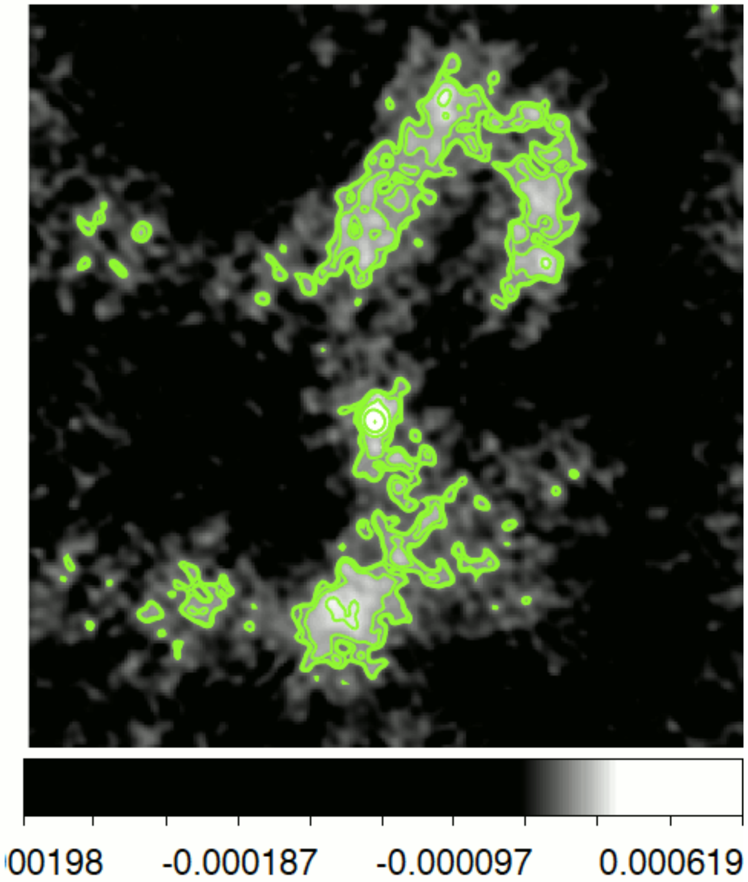
NGC4051 is ~1 decade radio quiet

Jet orientation?

Coronal source?
(Neupert effect, X-ray is integral of radio; too faint to search in 4051)

NGC5548 1.4 GHz

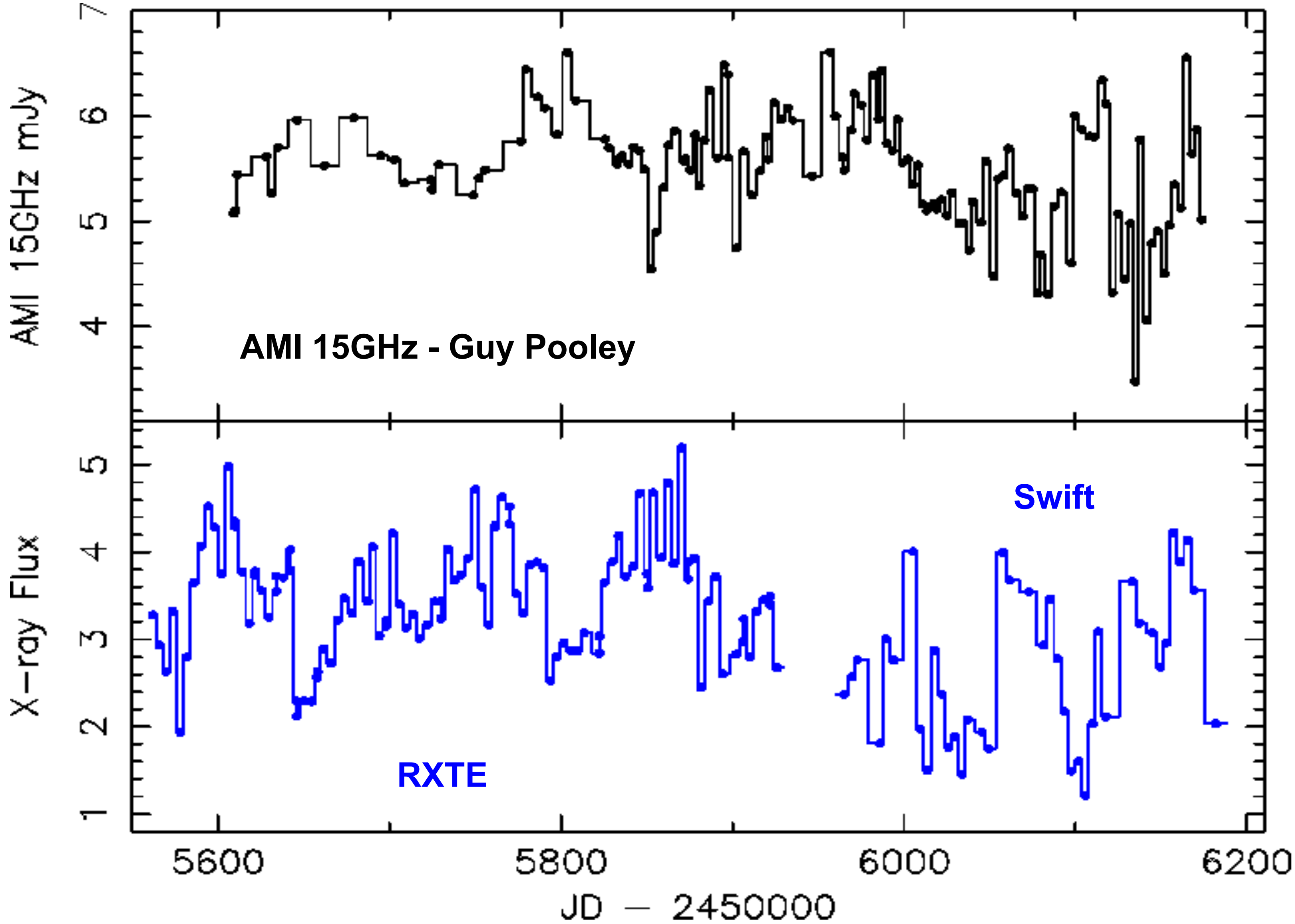




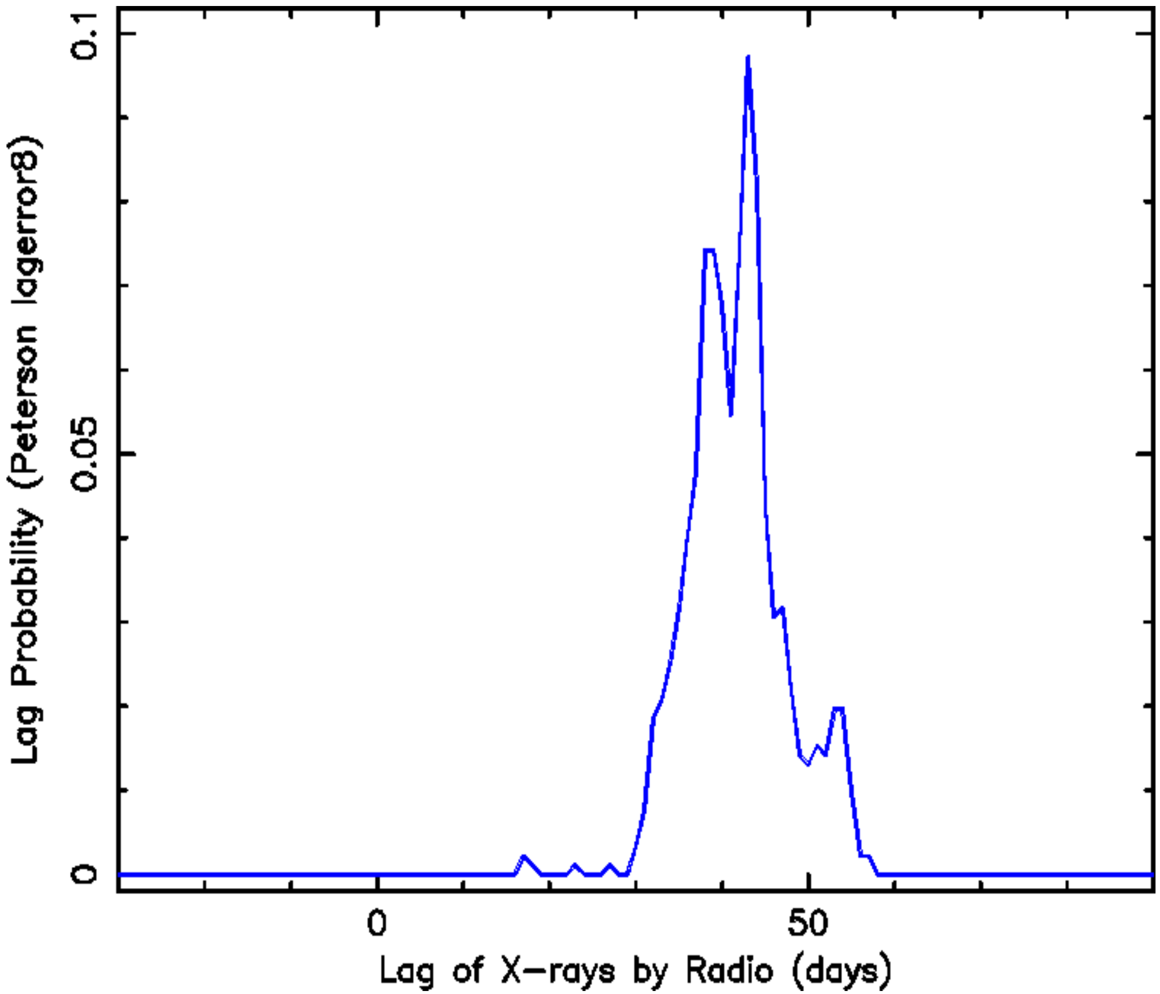
VLA **eMERLIN**

(Possible confusion if face on and both sides of jet are detectable)

NGC5548 X-ray / Radio Variability



NGC5548: X-ray / Radio Lag



Radio lags X-ray by 42 +/- 17d

Similar to M81

Normal Seyferts probably not the analogues of 'soft state' Galactic X-ray binaries.

More like high accretion rate 'hard state' binaries.

(NLS1s are soft-state Analogues)

CONCLUSIONS

Seyfert UV/optical variability

- Short timescale near UV/optical variability is produced by reprocessing from both disc and BLR.
- Both direct X-rays, or X-rays downgraded to far-UV on the inner edge of the disc are, in different AGN, plausible sources of illumination.

The UV/optical lags are at least x3 longer than predicted by Shakura-Sunyaev disc model, but consistent with microlensing observations. Some of the excess is due to longer lags from the BLR. Clumpyness would also make the disc appear larger.

UV in LINER M81 correlates weakly with the X-rays with very short lag (<1d). **Radio in both LINER M81 and Seyfert NGC5584,** correlates with X-rays and lags by 20- 40 days. In M81, mm leads radio by ~3d.

X-rays are probably from corona around black hole. Perturbations from the disc which affect the X-rays propagate down the jet and affect mm/radio, but jet has a non-linear response. Base (acceleration region) of jet is displaced from BH with mm/radio downstream. UV emission may be upstream, from pre-acceleration region near BH.