X-ray and Multiwaveband Variability of AGN

-with suggestions for Astrosat

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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) Accretion rate perturbations in the disc propagate inwards at viscous speed (Lyubarskii 1997). Modulate outer part of disc (red) first, then blue/UV, eventually hit X-ray emitting corona.

  – 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

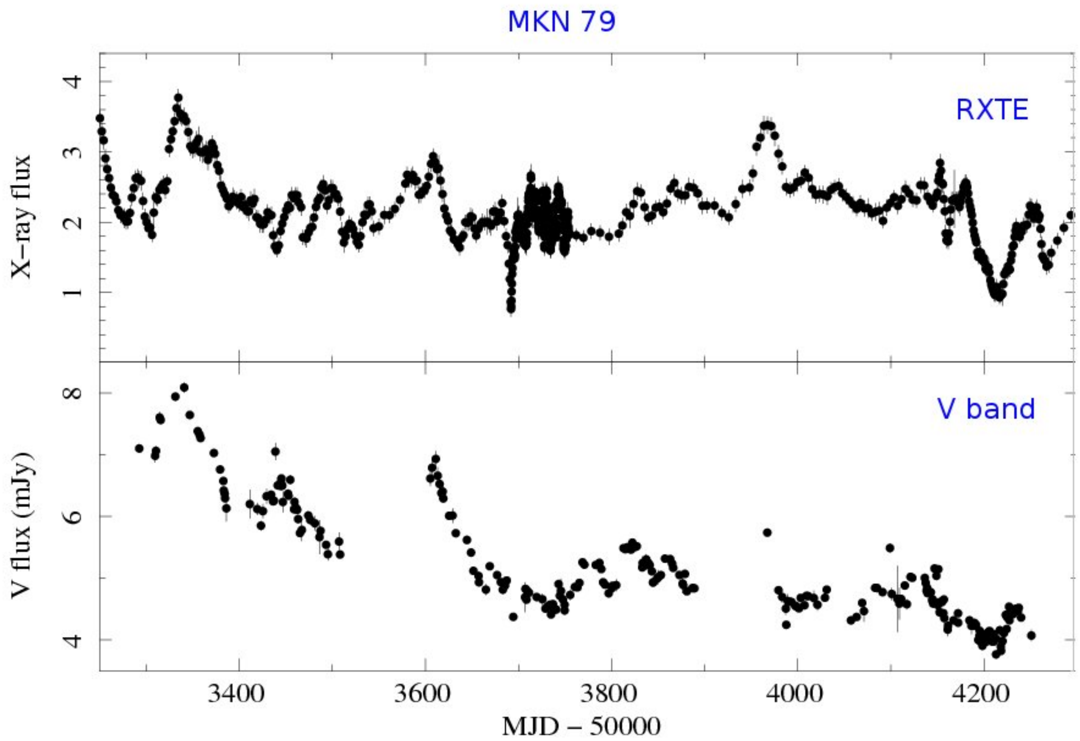
$$L(R) = \sigma T^4 \propto M_{BH}{}^{-1} \dot{m}_E R^{-3}$$

(R in gravitational radii)

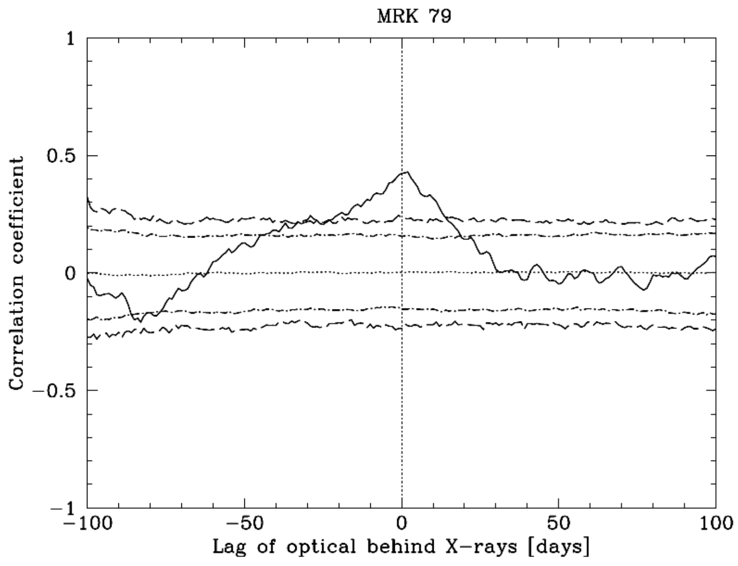
Disc illumination from point source also ~ R^{-3}

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

RXTE + Ground based optical: MKN 79



(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

Swift Monitoring of NGC5548:
(> 500 observations)

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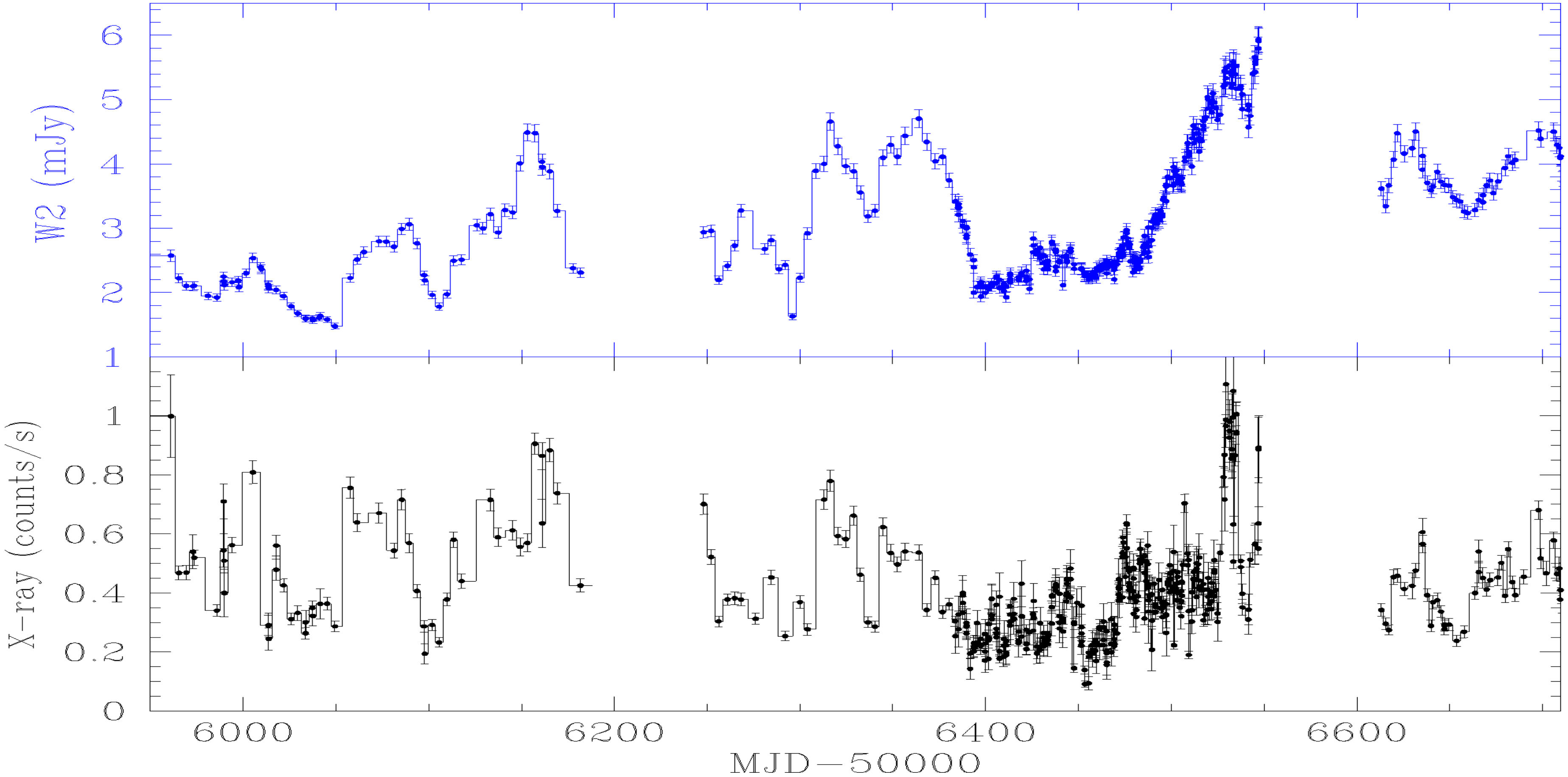
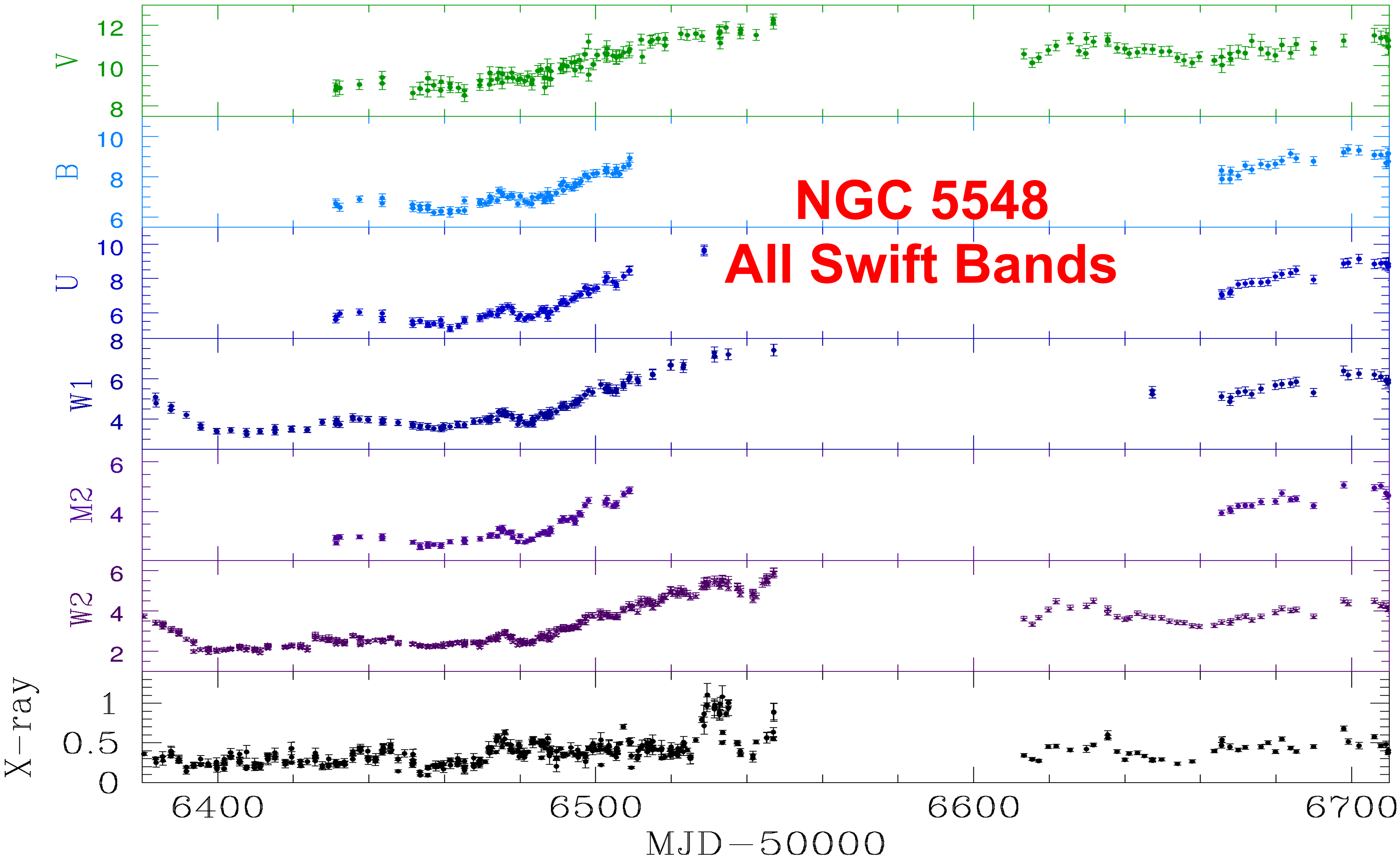


Good correlation, but not perfect, eg large W2 rise after day 6480

McHardy et al, 2014, MNRAS, 444, 1469



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

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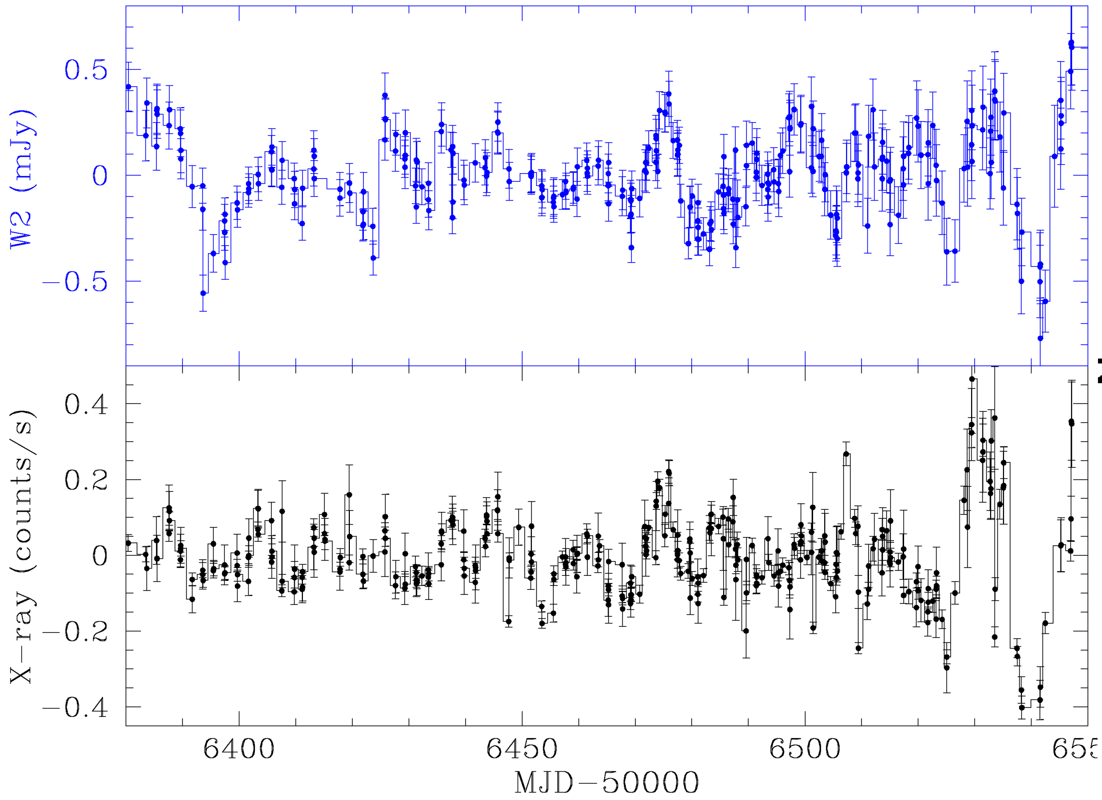
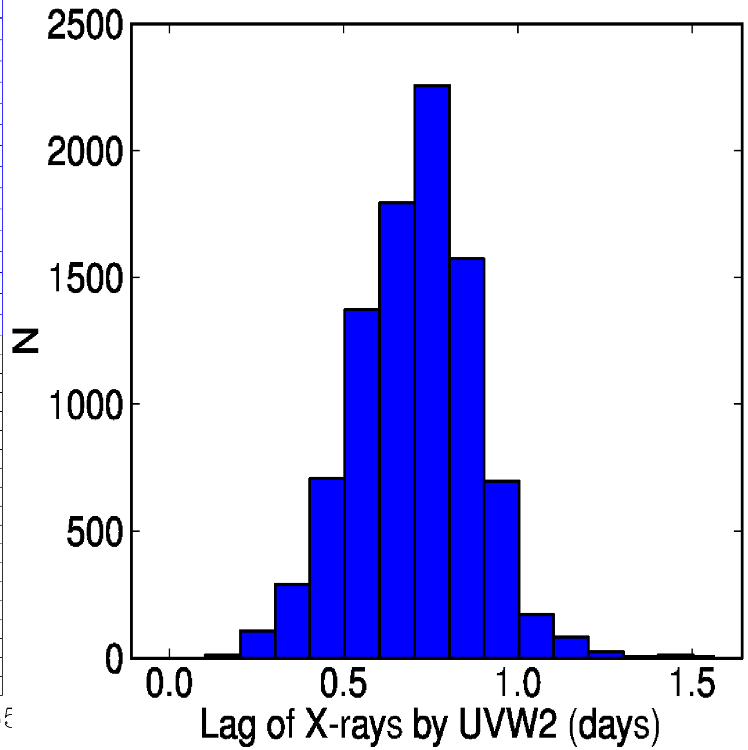
Lag of X-rays by UVW2

Mean-subtracted lightcurves
Intensively sampled period

Lag distribution
(Javelin – Zu et al 2011)





Lags as function of wavelength

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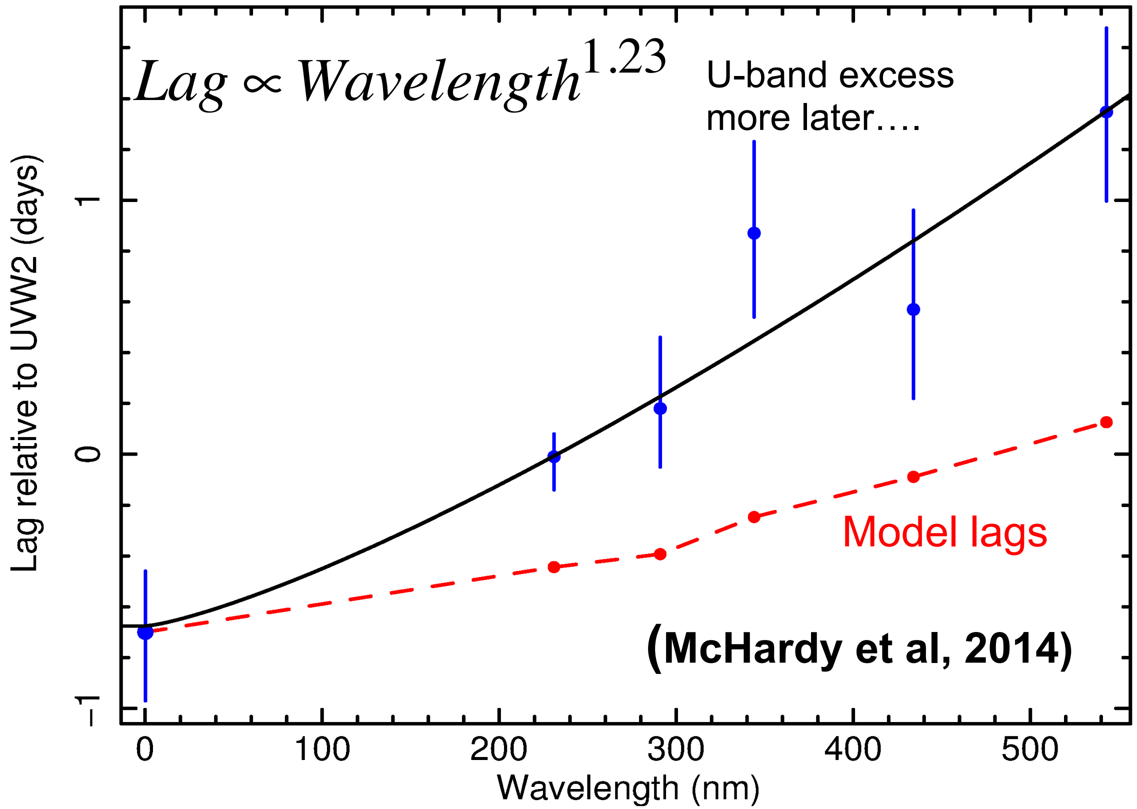


Expect 4/3 power for Shakura-Sunyaev disc. So good agreement.

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.

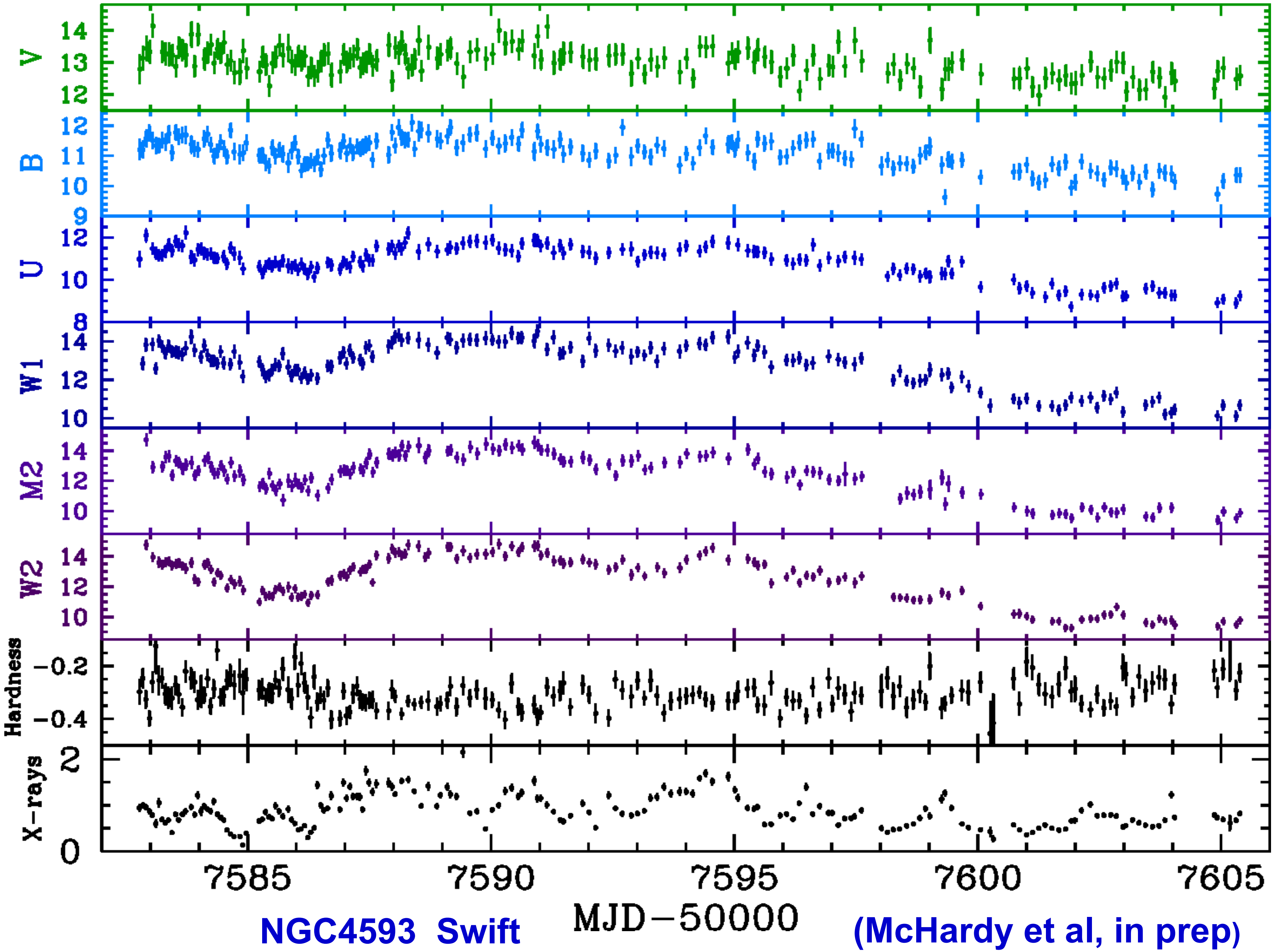
Microlensing obs (eg Morgan et al 2010) also require larger disc than SS model

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

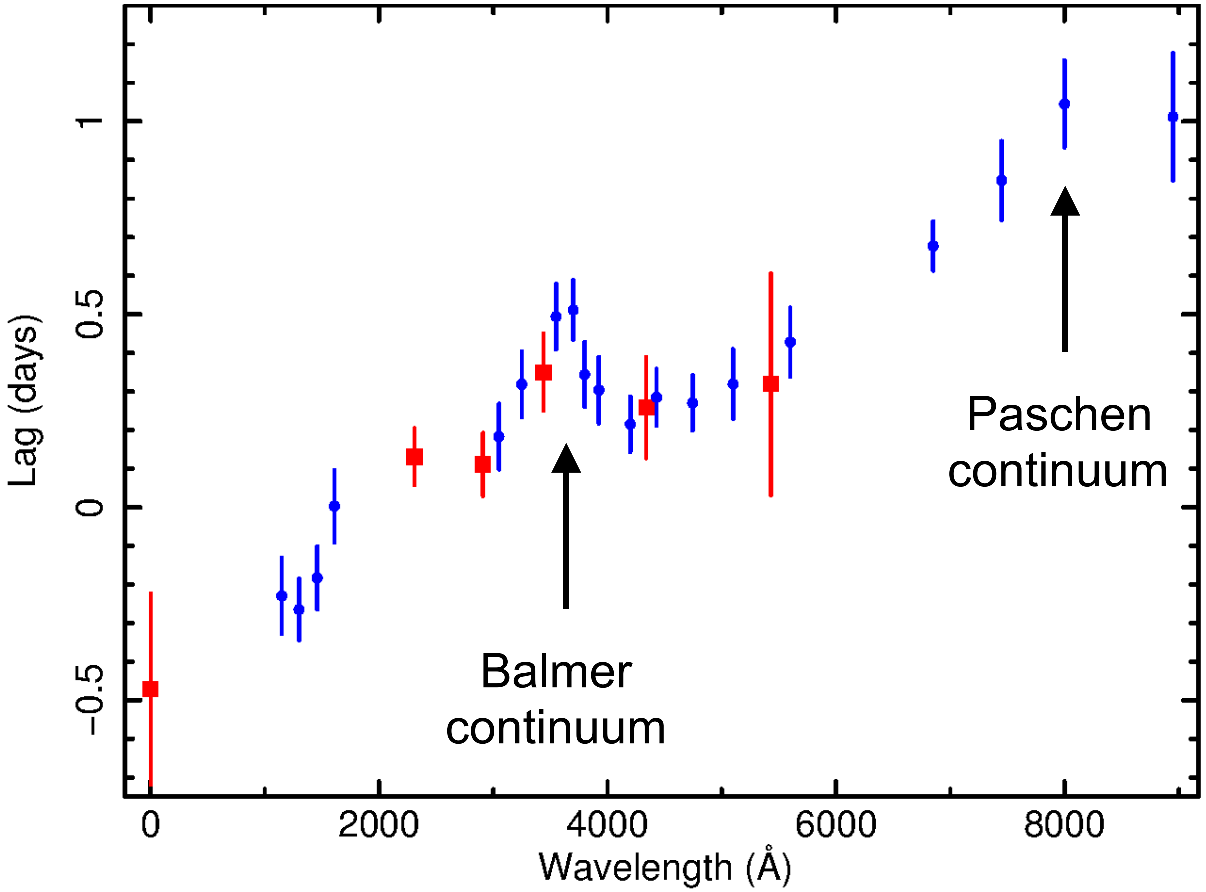
Inhomogeneous disc (Dexter and Agol 2011)?

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

Reprocessing by the broad line region (BLR)


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

NGC4593 Lags



(Lags relative to high quality Swift UVW2)

Swift (McH) and HST (Cackett) combined lags

Balmer emission from BLR very clear (3800A)

(Korista and Goad, 2001)

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

Need X-ray, multiple UV/optical bands, particularly far-UV.
Astrosat can go bluer than Swift. Could be very valuable

NGC4593 XMM PN-OM lag

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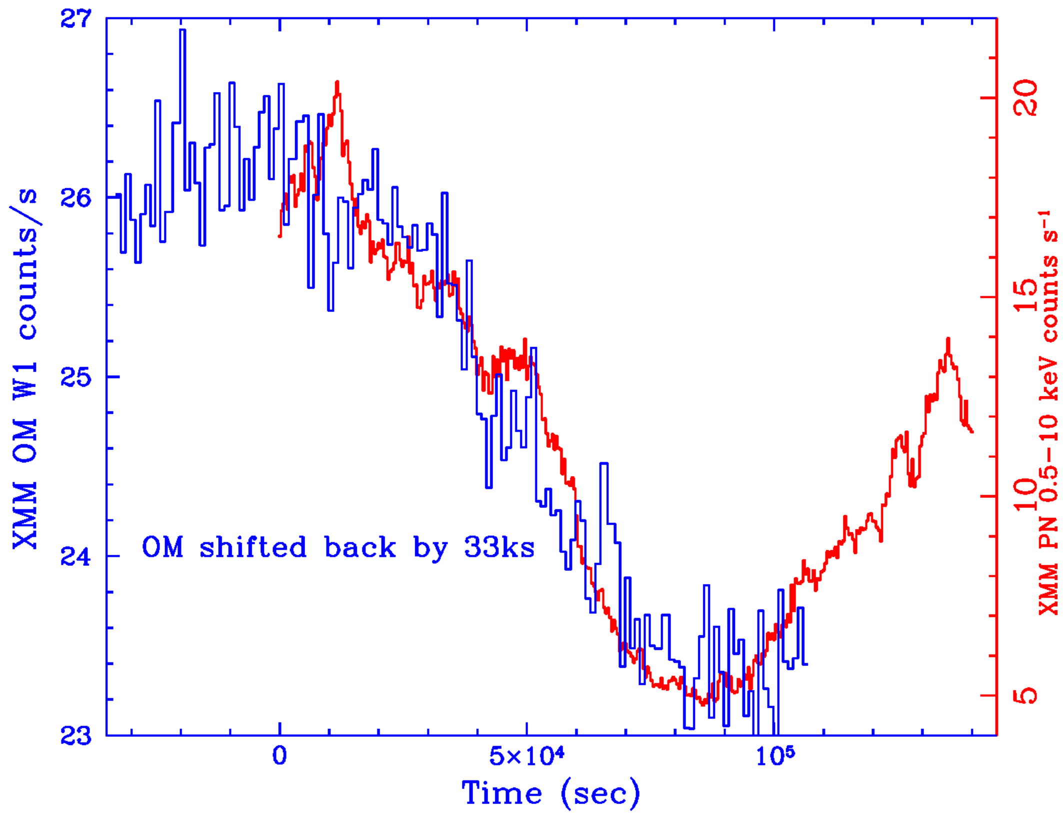

Mass
$6x10^6$

See also XMM PN-OM Lags on NGC4395, McH et al, 2016.

Identical lag measurement to Swift, and easier to make (for 1 UV band). (McH+, in prep).

For masses up to ~few x 10^7, with short lags, quasi-continuous, long, Astrosat observations would be really useful.

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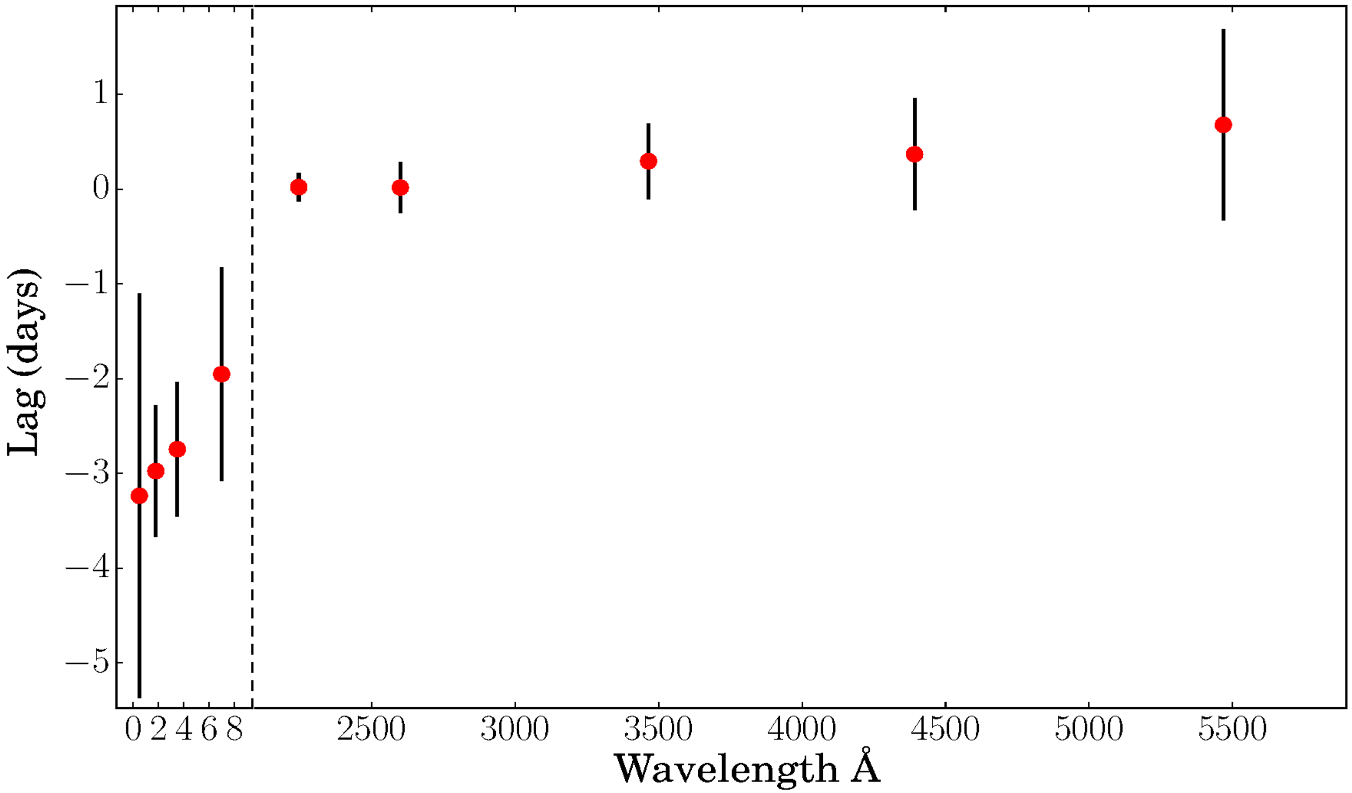
NGC4151 – Offset X-ray Lag



(Edelson et al, 2016, submitted)

UV-optical lags as in other AGN. But discontinuity to X-rays.

UV / X-ray lag very long and X-ray lags energy dependent.

Absorption and re-emission?

Measured / Expected lags for different AGN

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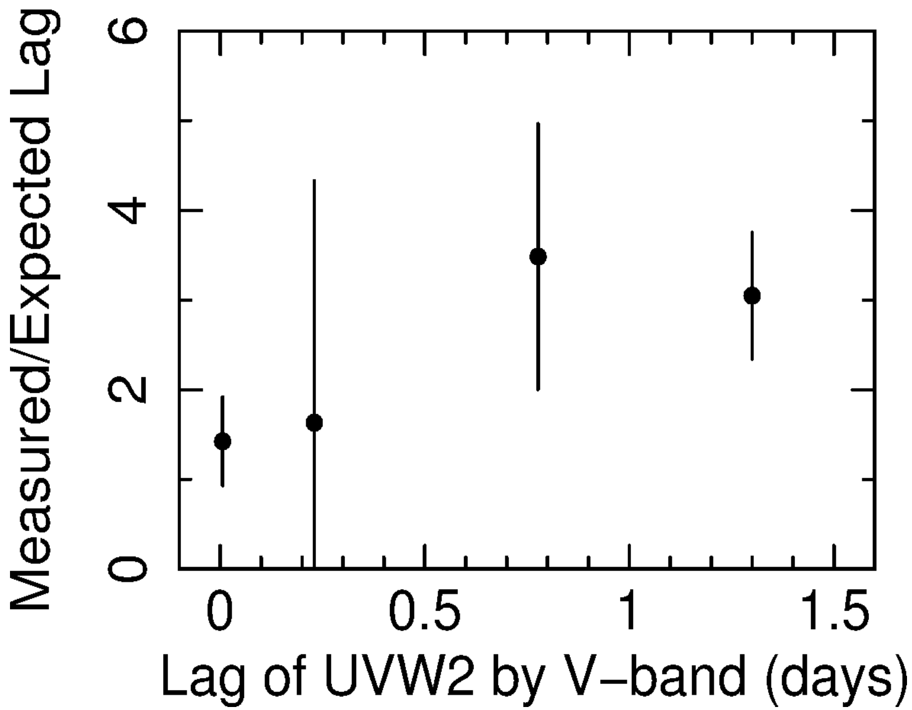

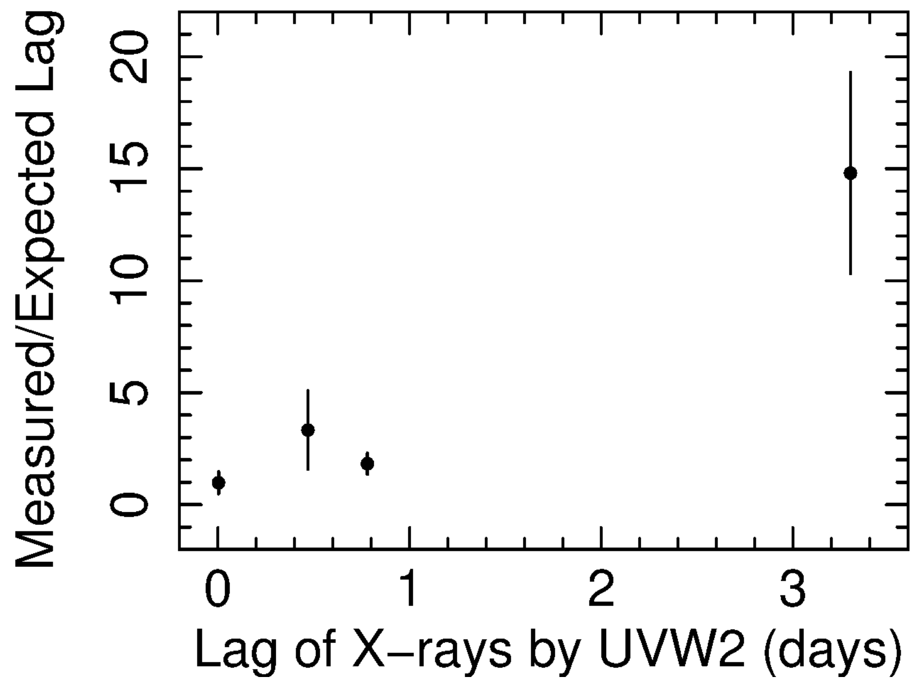

The lags within the UV/optical bands scale broadly similarly in all AGN. So the outer discs are broadly (though not exactly) similar.

The lags between the X-ray and UVW2 are sometimes very different. The X-ray/UV link in some again - NGC4151 particularly - is unclear.

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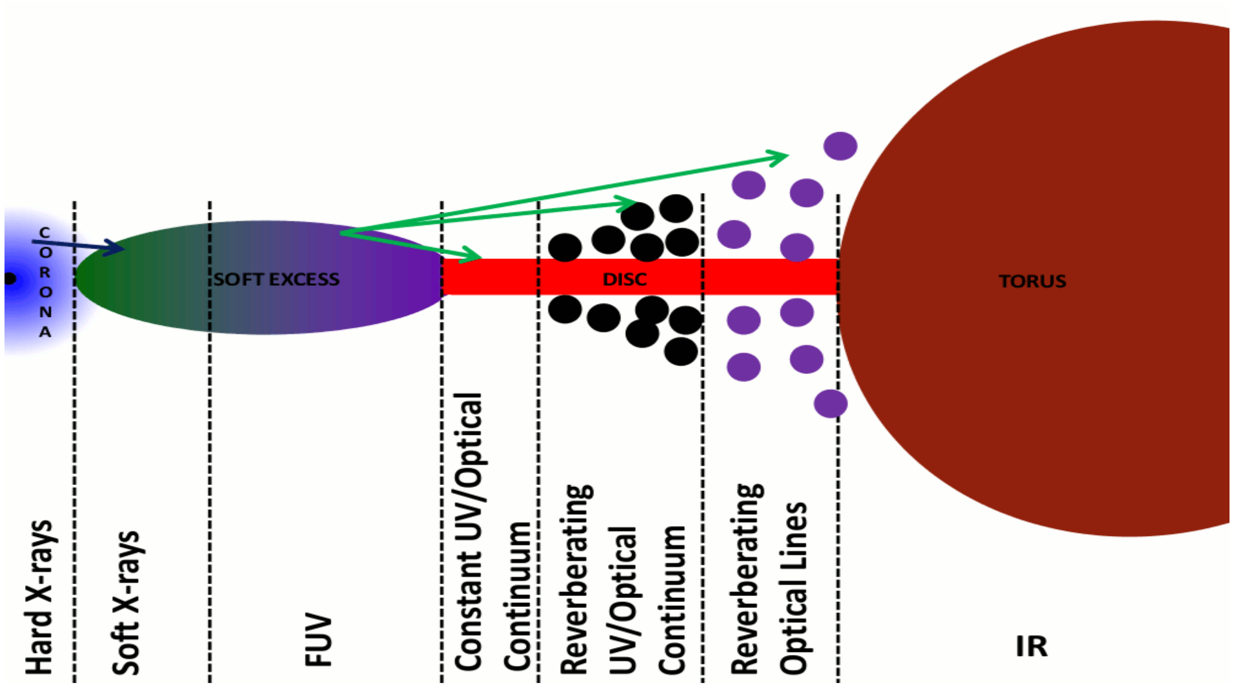
Possible geometry for off-set X-ray lags



Gardner +Done 2016

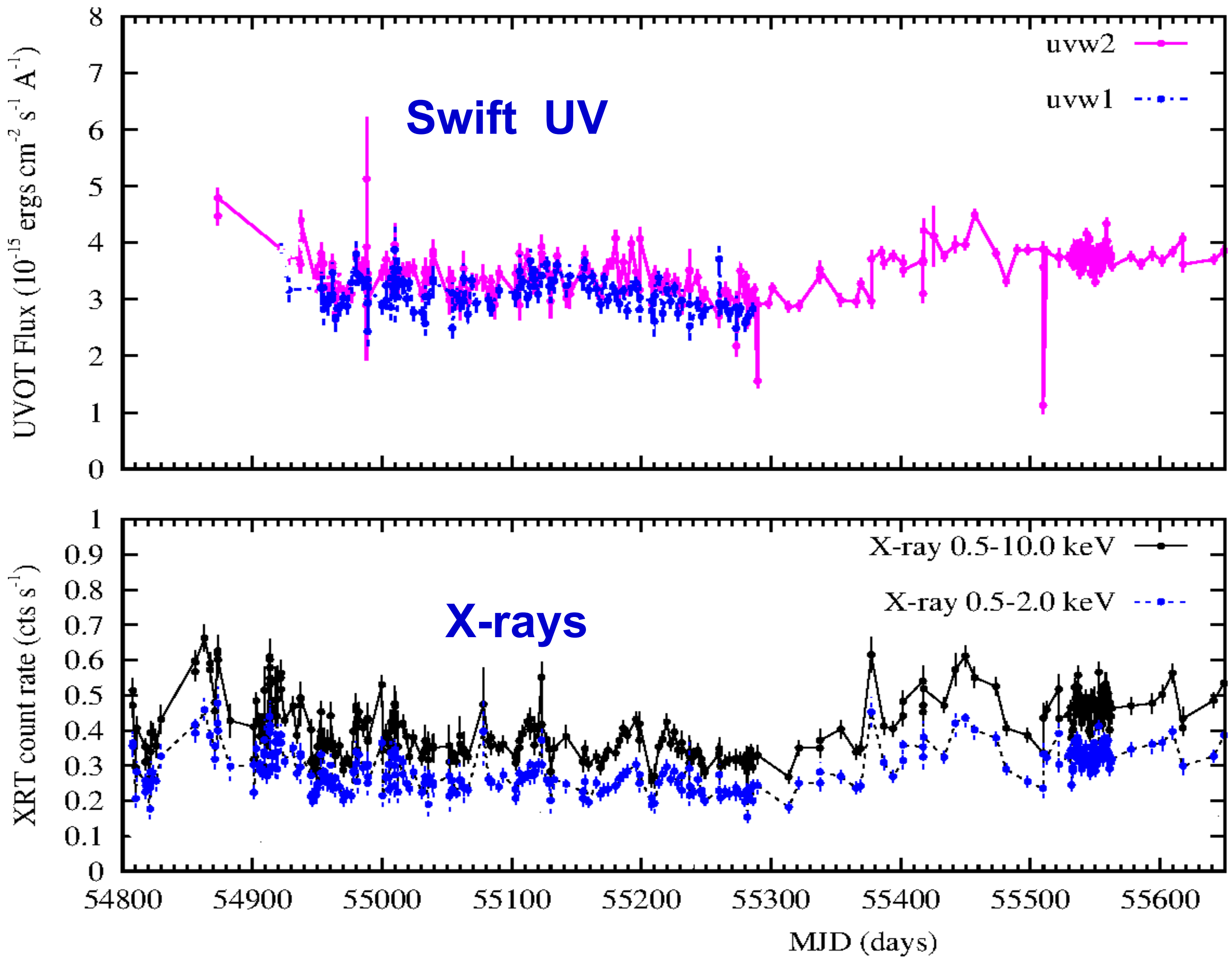
X-rays hit inner part of disc which re-radiates far-UV onto outer part, producing near-UV and optical.

(Inner disc could, of course, also be heated by accretion rate fluctuations. producing UV/optical variations uncorrelated with X-rays on short timescales.)

X-ray / UV Variability of LINER – M81

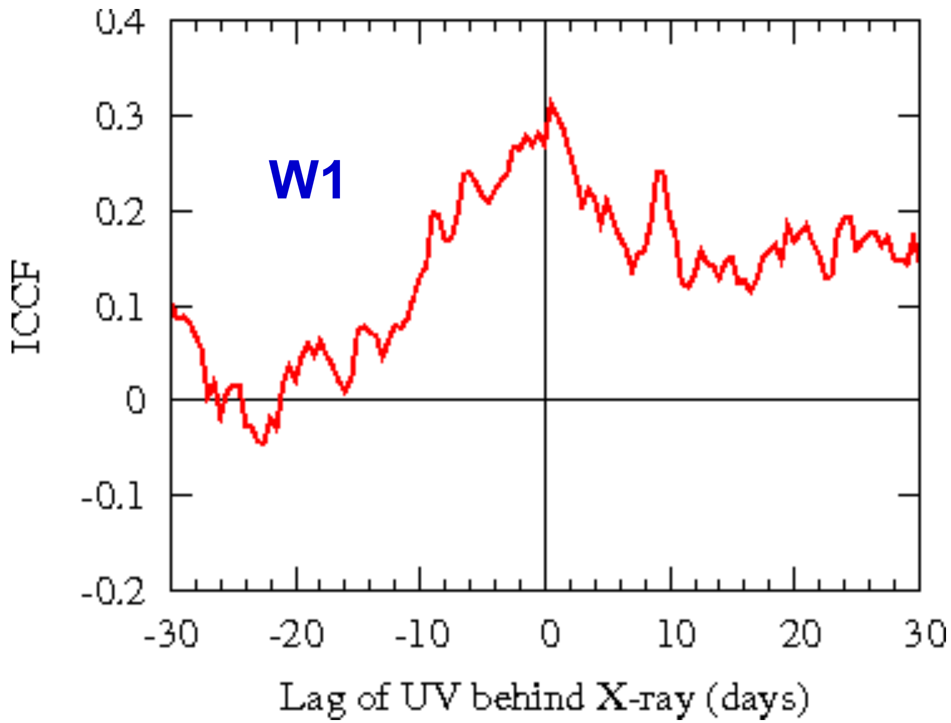
Very low accretion rate - no close-in disc

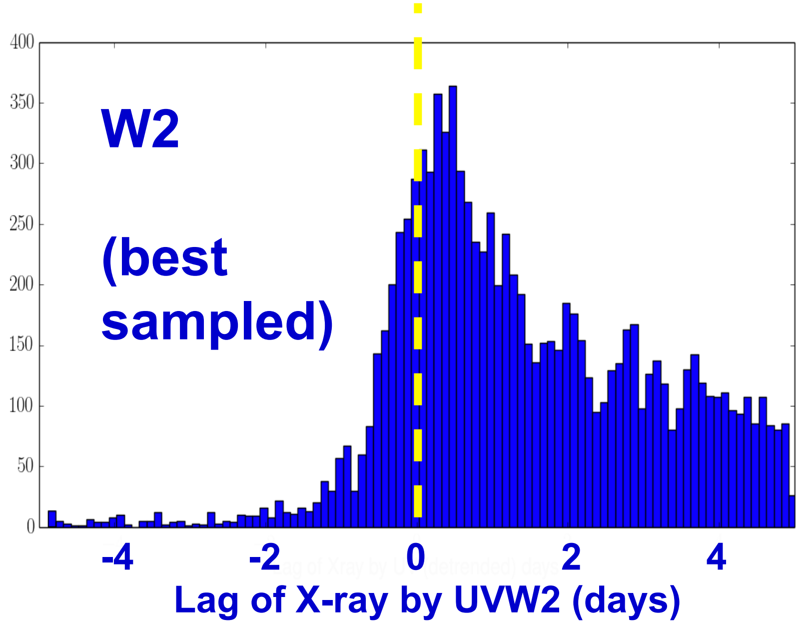
X-ray / UV Variability of M81



Cameron
2014
Phd Thesis
Southampton

X-ray / UV Variability of M81





Javelin result
from Harvey-Taylor
Southampton UG

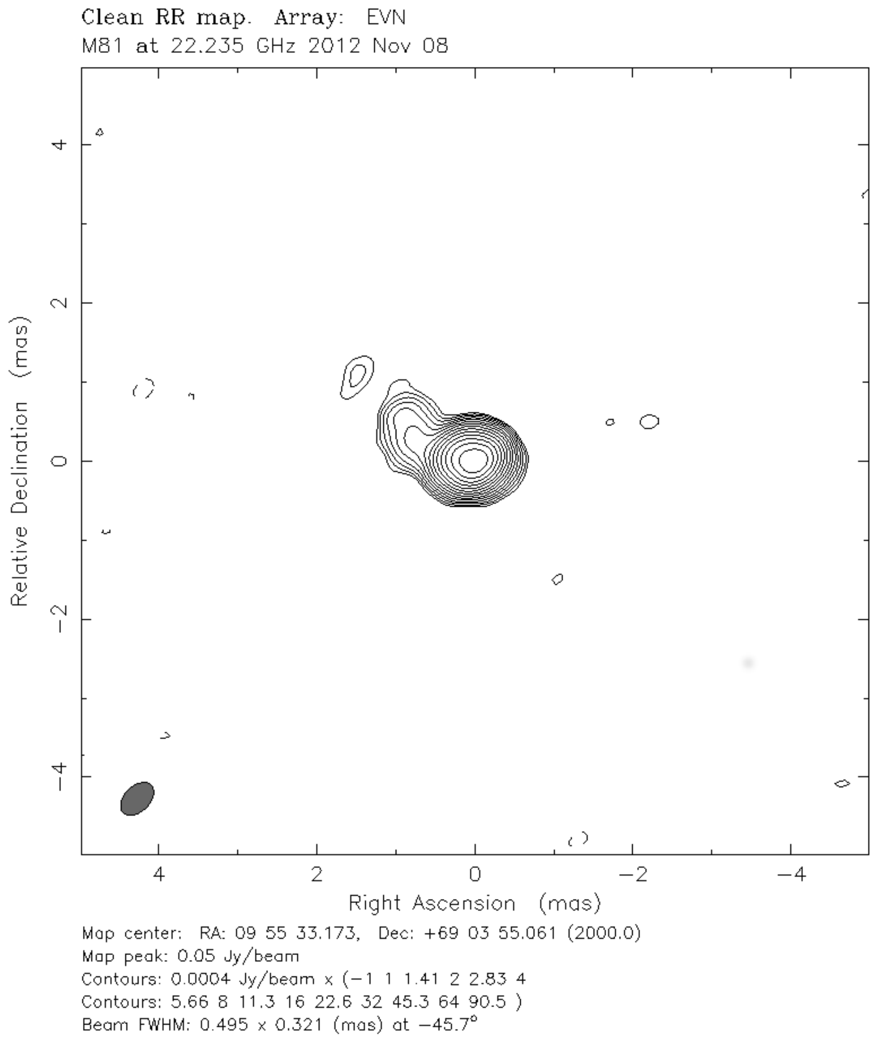
Weak correlations, small UV lag – so UV are not seed for SSC X-rays

-> UV downstream from X-rays, but close

X-Ray / mm / Radio Relationship in LINERS

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

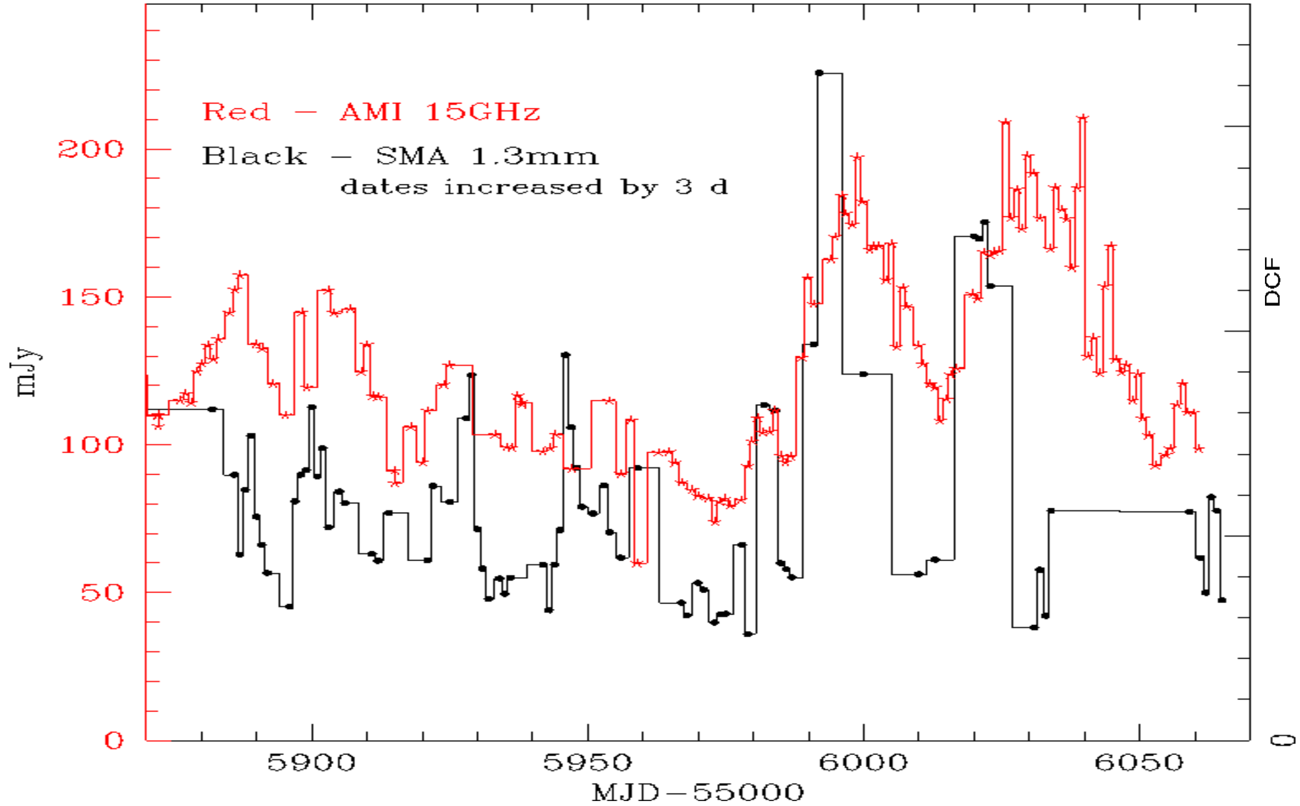
M81 sub-mas structure

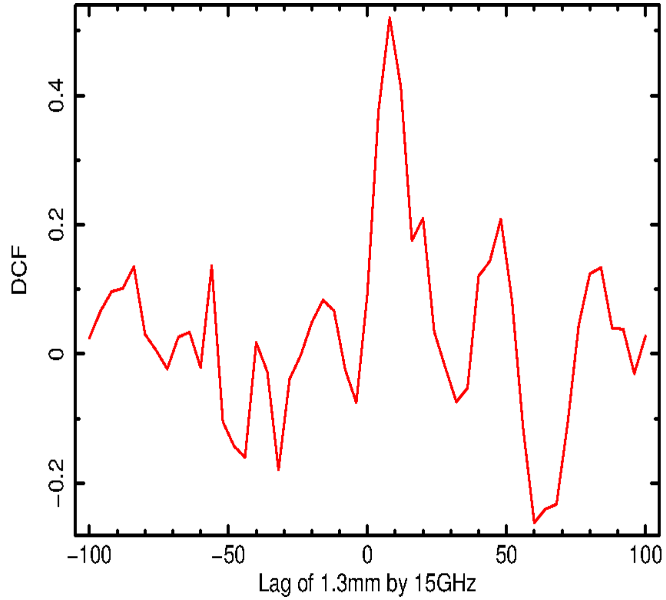


Sub-mas bending jet similar to blazars

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

M81 radio-mm variability: strong correlation



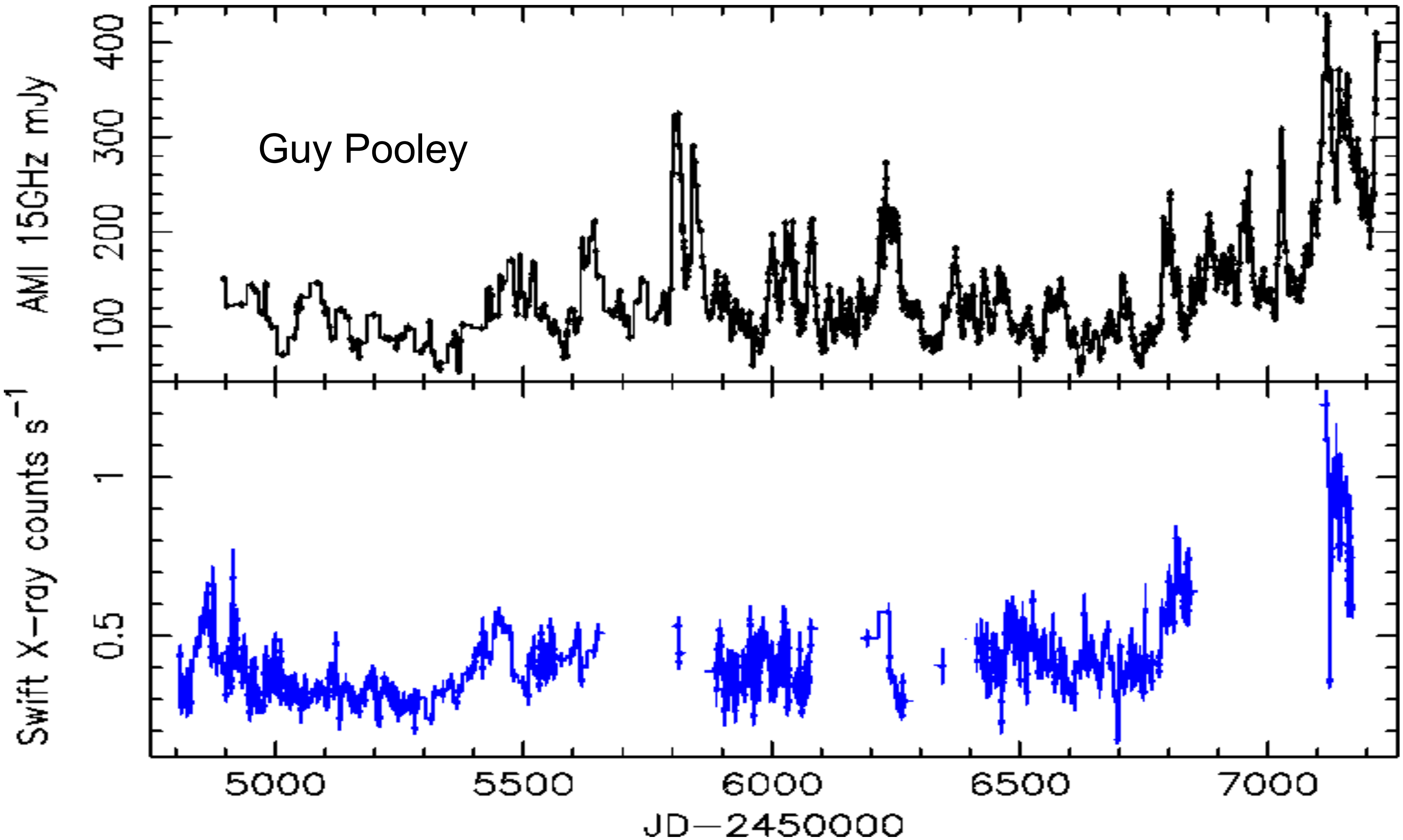


Radio lags mm by ~3 days

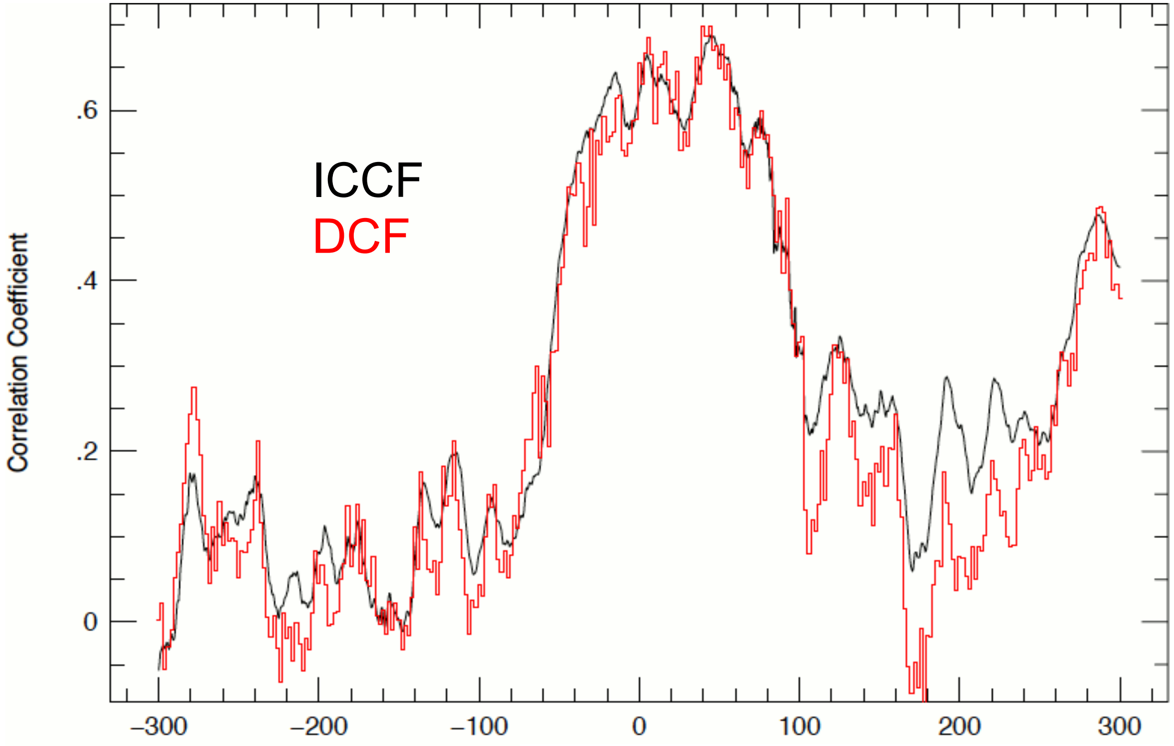
Radio-mm flux densities similar – flat spectrum

Consistent with standard synchrotron jet

M81 Swift X-ray and AMI 15 GHz Radio



M81 X-ray / Radio ICCF / DCF



Lag of X-ray by Radio (days)

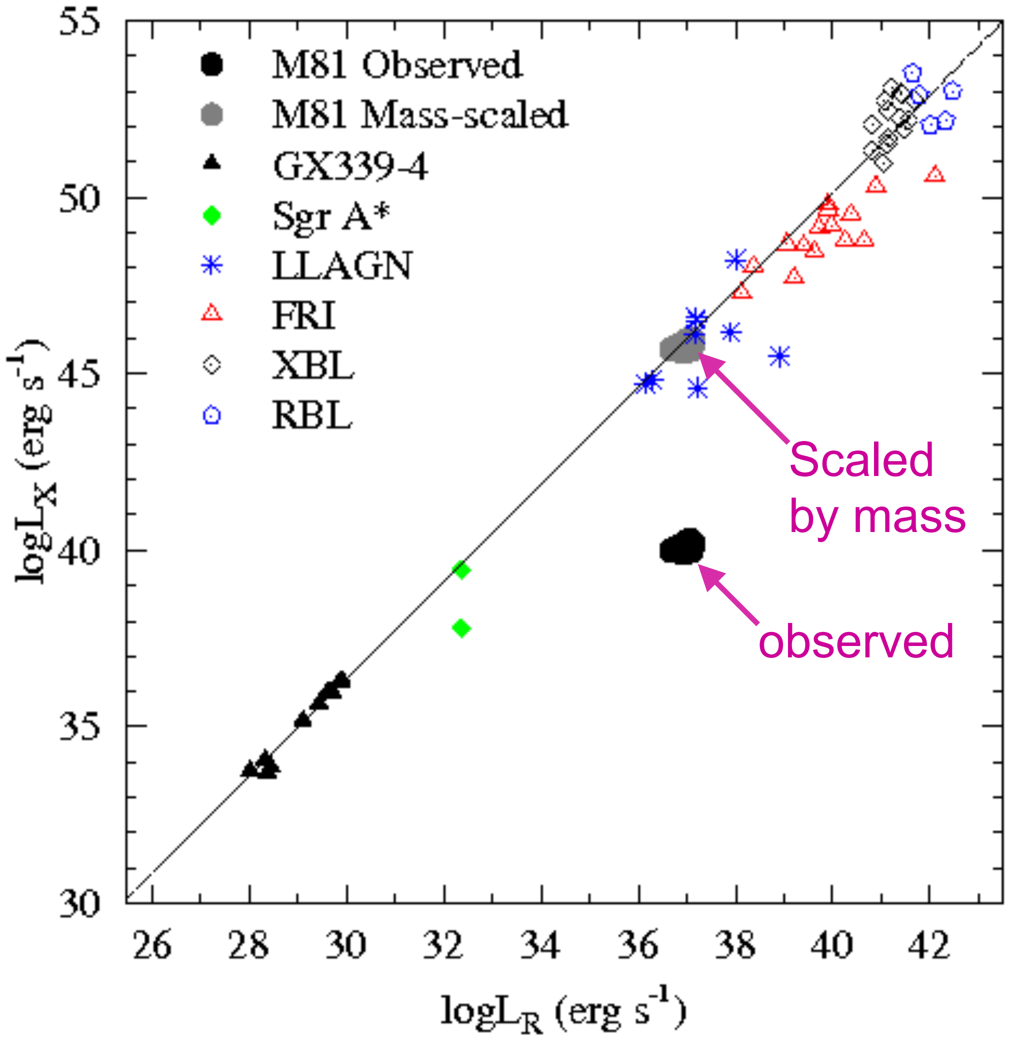
Good overall correlation.

(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 very well,

like a hard state binary

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

M81 – Geometry from lags

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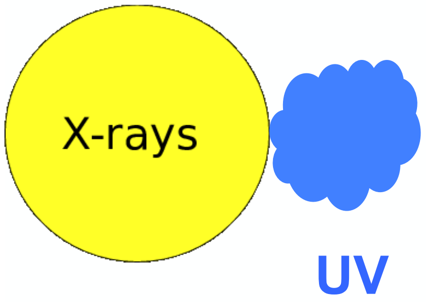
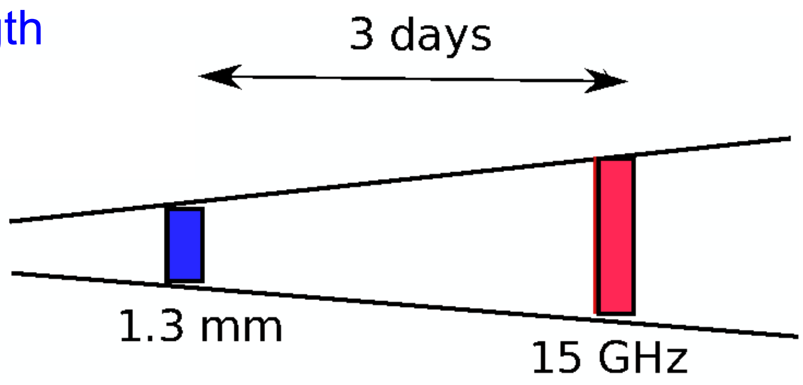
Extrapolate to zero wavelength





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

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

X-ray / Radio Variability of ‘Radio Quiet’ Seyferts

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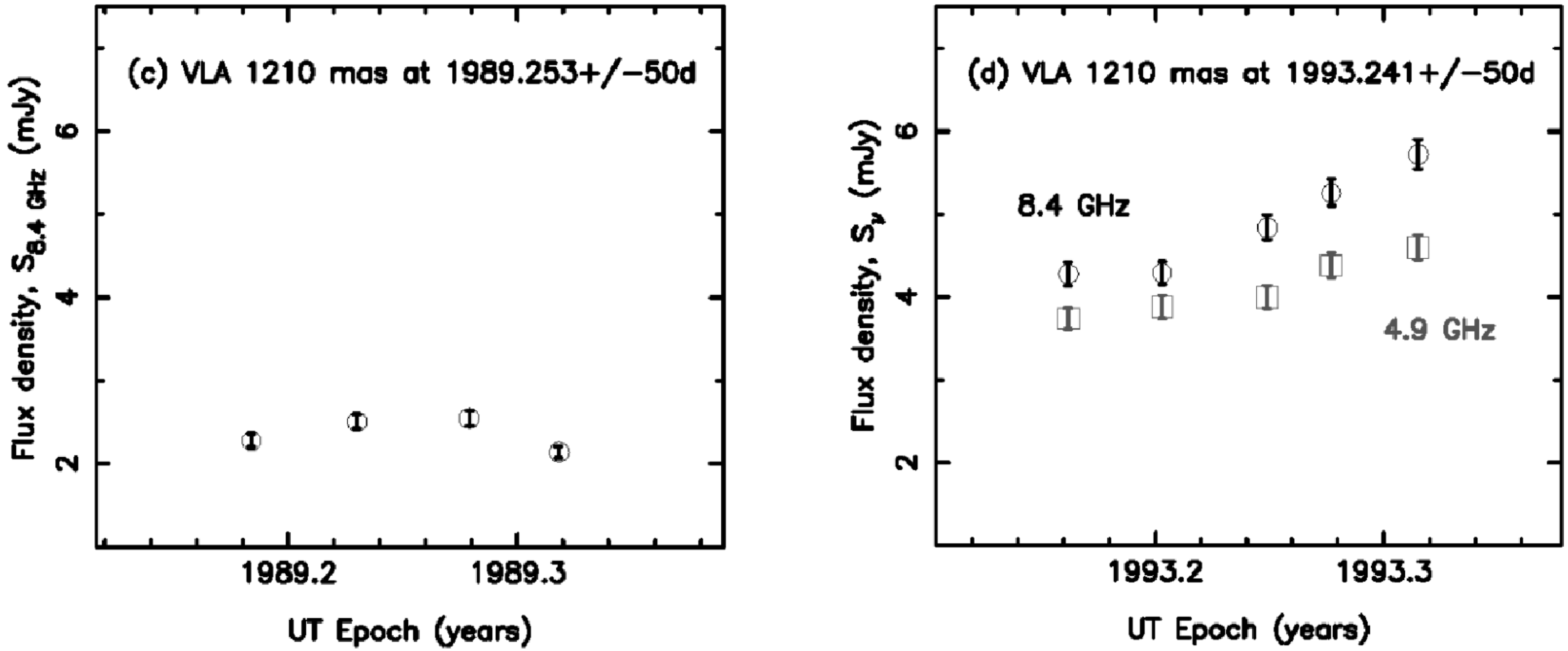
Radio variability from Seyferts, ie high accretion rate AGN

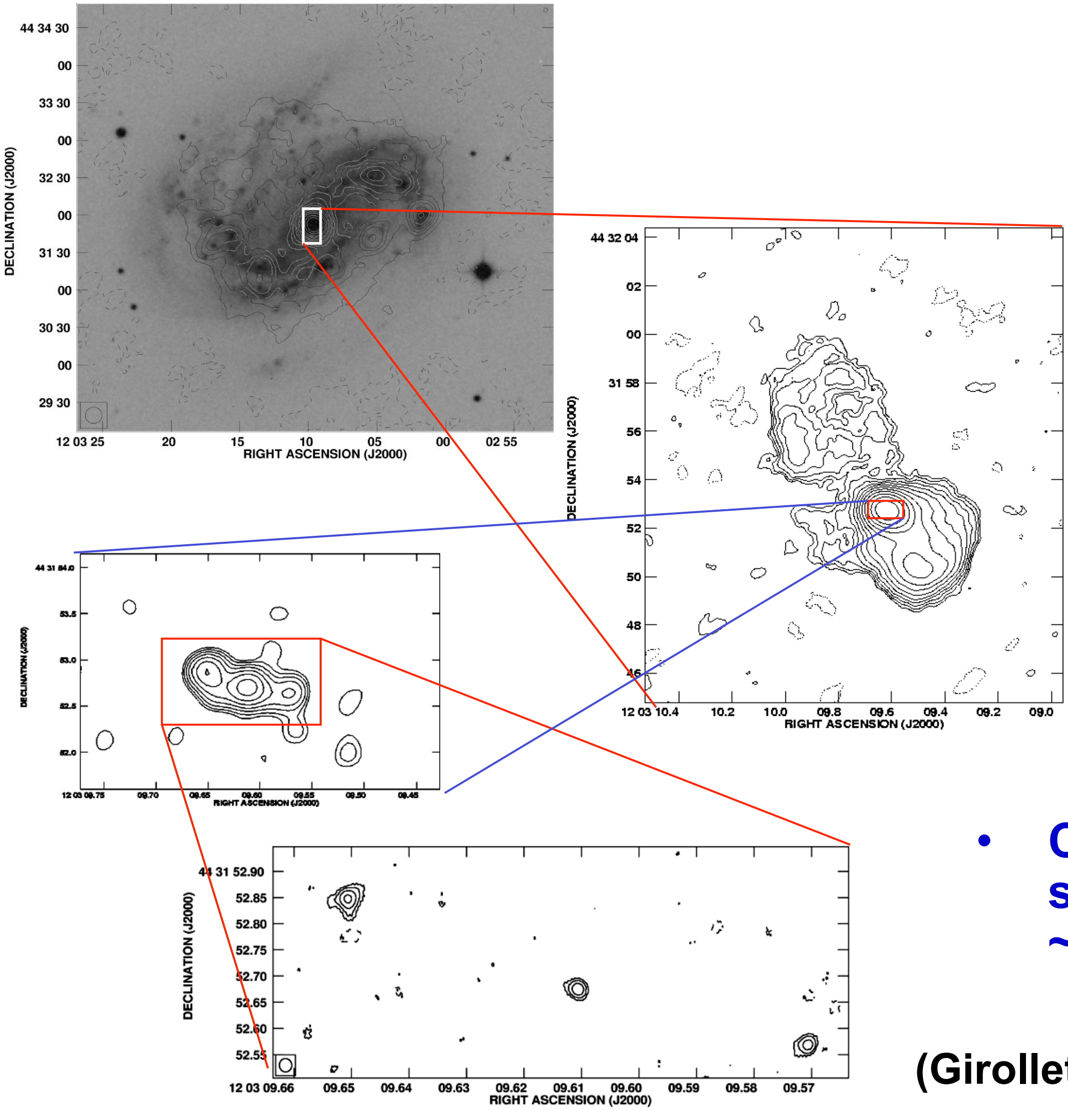


NGC5548 – Wrobel 2000 - radio variability over months but no X-ray observations

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

NGC4051 - Seyfert



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

(Jones et al, 2011, 2017)

- Component separation is ~50 light years

(Girolleti and Panessa 2009)

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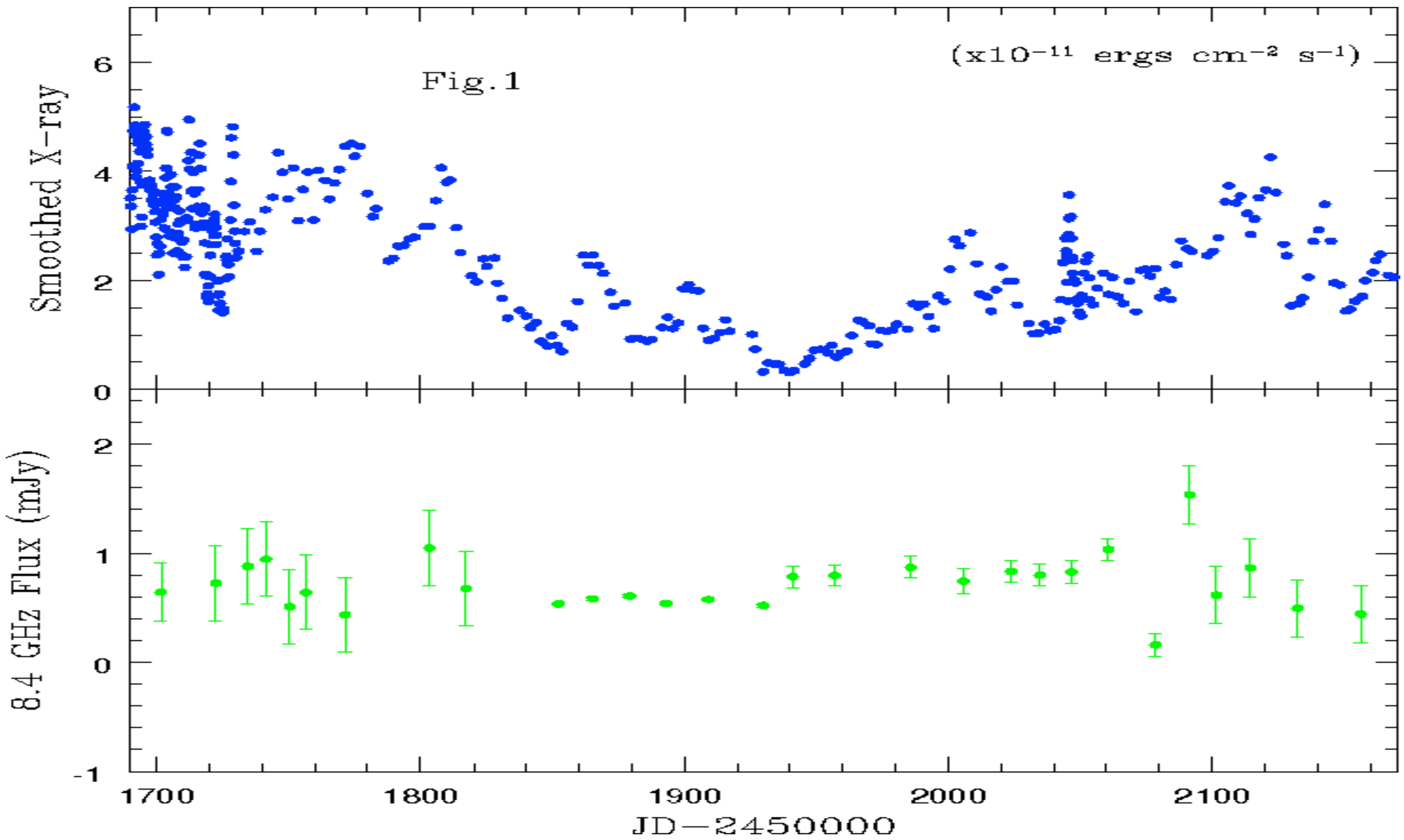
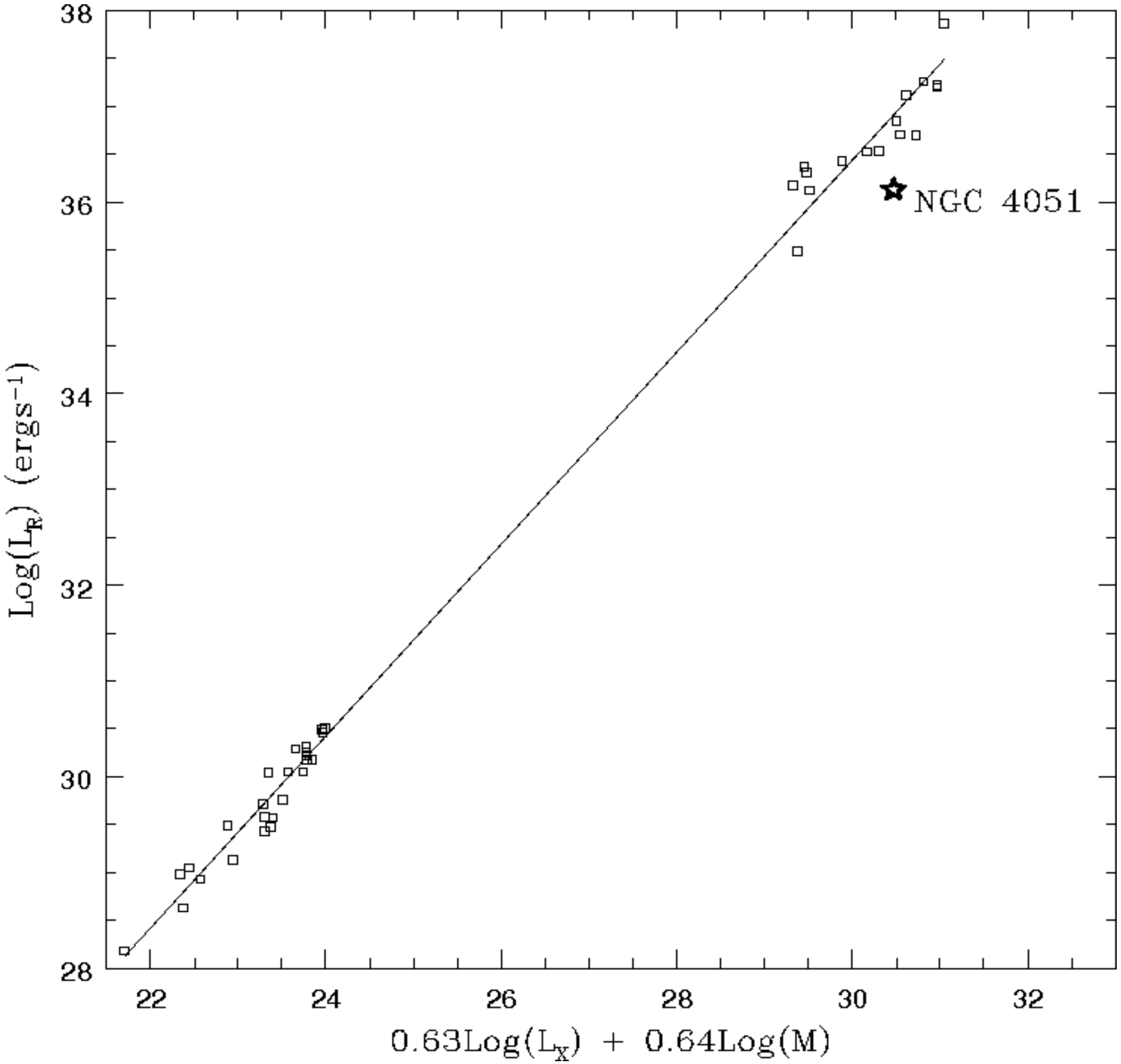
NGC4051 Radio vs. X-ray - VLA all arrays



No strong evidence for large amplitude radio variability **(Jones et al, 2011, 2017)**

- 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

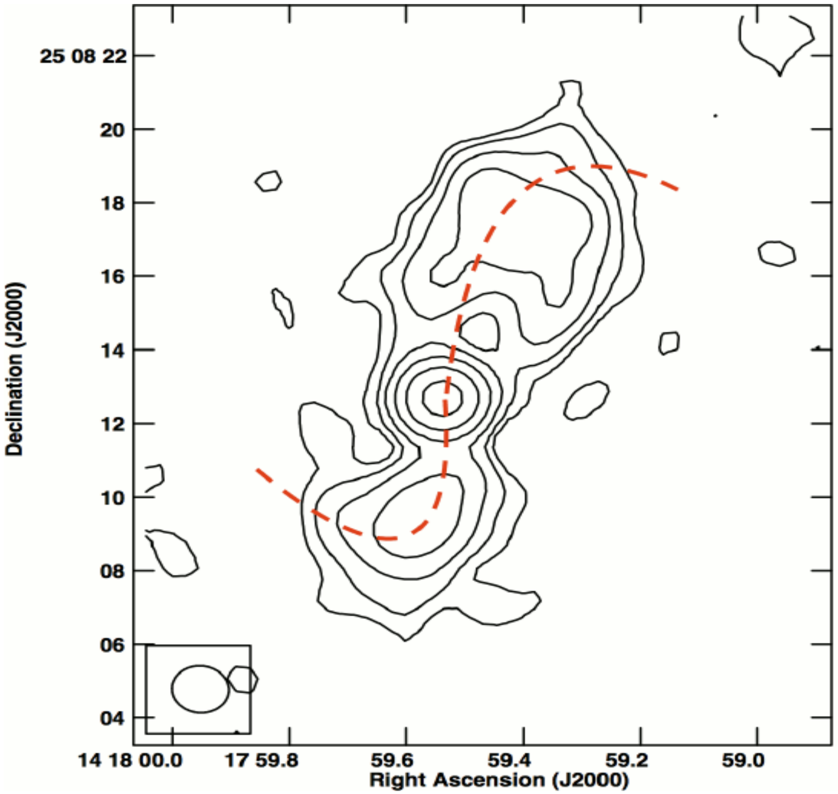
NGC4051 is ~1 decade radio quiet

Jet orientation?

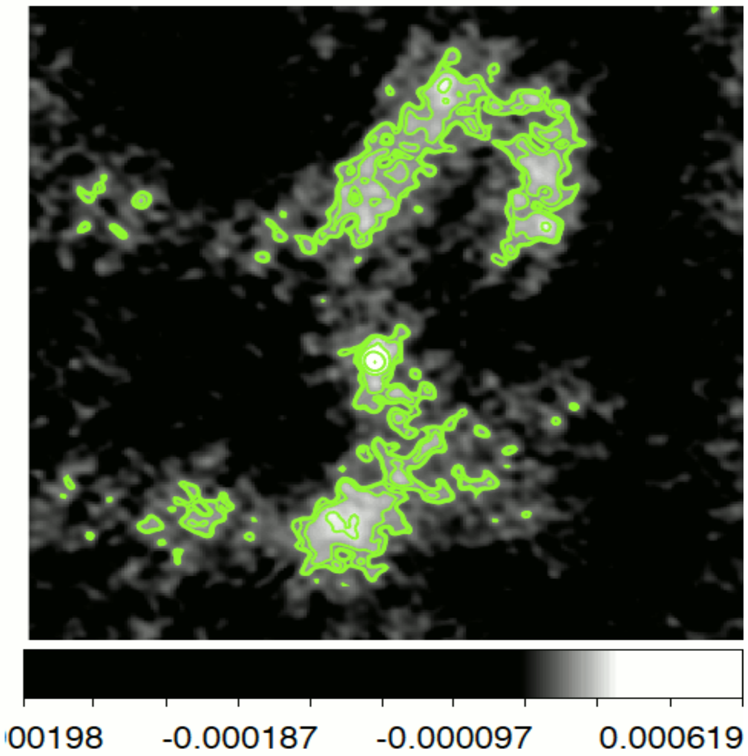
Coronal source?
(Neupert effect, X-ray is integral of radio; too faint to search in 4051)

NGC5548 1.4 GHz

Point source at 15 GHz, but at 1.4GHz..



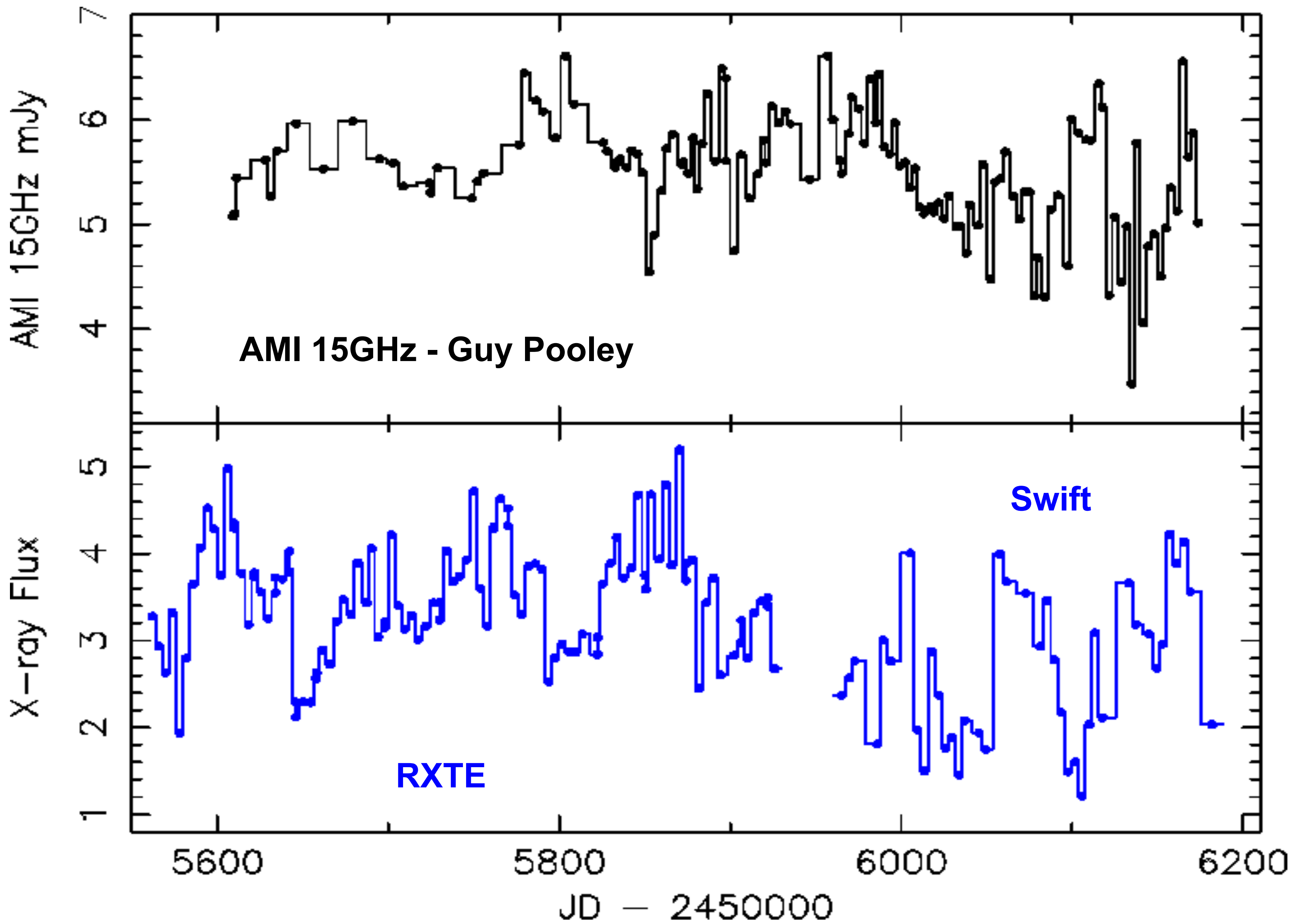
VLA



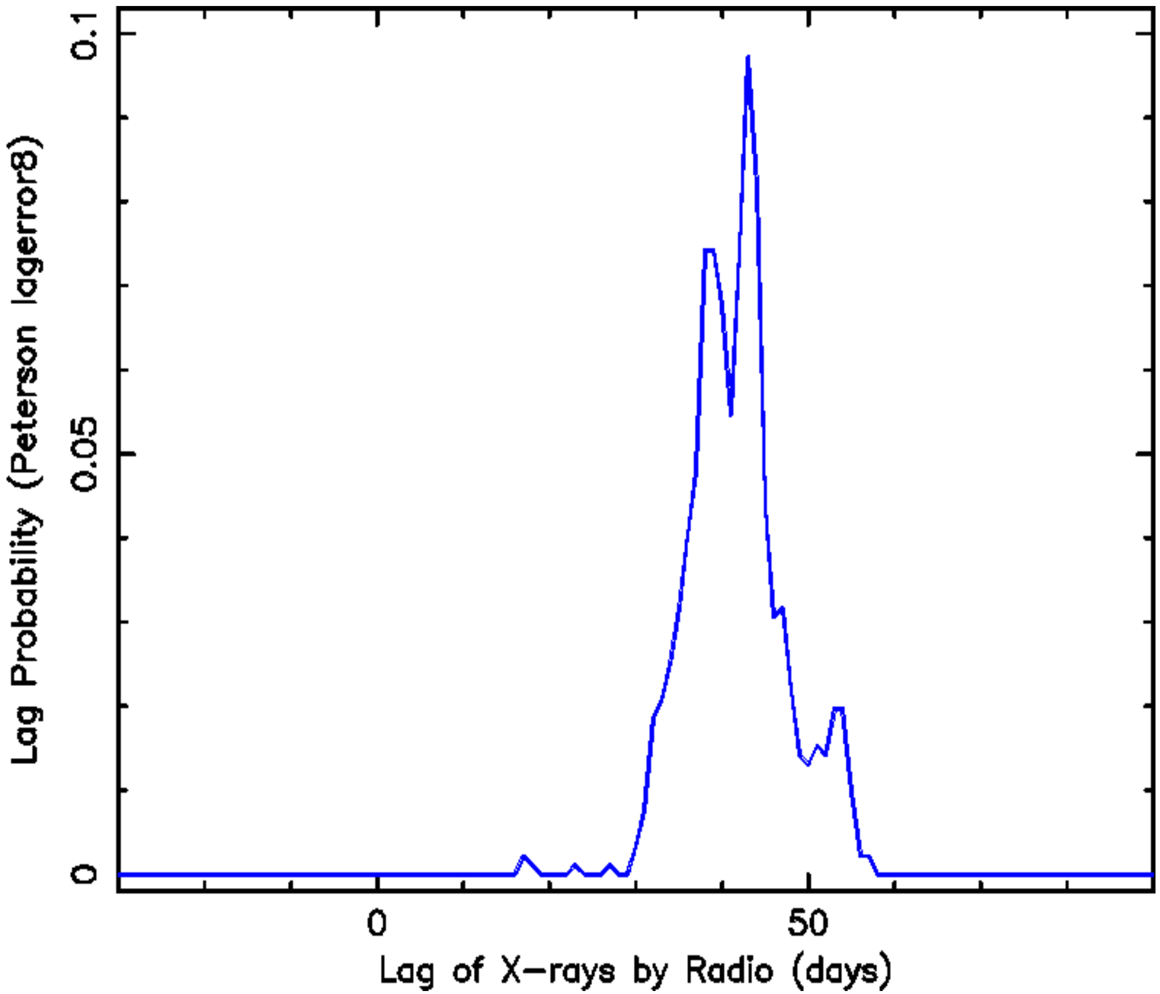
eMERLIN (From LeMMINGS Survey)

(LeMMINGS: McH, Beswick, Williams, Baldi, Kharb, Mathur and others)

NGC5548 X-ray / Radio Variability



NGC5548: X-ray / Radio Lag



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

Similar to M81
(80x more radio luminous)

Normal Seyferts probably the analogues of high accretion rate ‘hard state’ binaries.

(NLS1s are soft-state analogues)

CONCLUSIONS

SEYFERT UV/OPTICAL VARIABILITY

- Short timescale variability is produced by reprocessing from disc and BLR.

- Illumination could be coronal X-rays or far-UV from inner edge of the disc.

- Discs are *probably* bigger than predicted by Shakura-Sunyaev model, but consistent with microlensing observations.
  - Clumpy discs? Or longer lag contribution from BLR

LINER UV VARIABILITY correlates weakly with X-rays with very short lag (<1d).

RADIO/X-RAY VARIABILITY

Correlation in both LINER M81 and Seyfert NGC5584 with radio lagging by 20-40 days. In M81, radio lags mm by ~3d.

X-rays probably from corona around black hole. As in binaries (Malzac), disc perturbations probably carry on through corona down jet.

Base of jet (acceleration region) displaced from BH.
UV emission may be from pre-acceleration region nearer BH.