Multiwaveband Variability of non-Blazar AGN

i.e. Seyferts and LINERS

Any similarities to blazars?

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3708
3708

Outline

X-ray / UV / Optical variability

- Seyferts
- LINERS

X-Ray / mm / Radio variability

- LINERS
- Seyferts

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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

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- **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 above disc also falls off as R^{-3}

In both cases giving

$$T \propto M_{BH}^{-1/4} \dot{m}_E^{1/4} R^{-3/4}$$

i.e.

$$Lag \propto Wavelength^{4/3}$$

(eg Cackett et al 2007)

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

$$Lag \propto Wavelength^{4/2}$$

i.e.

$$Lag \propto Wavelength^{2}$$

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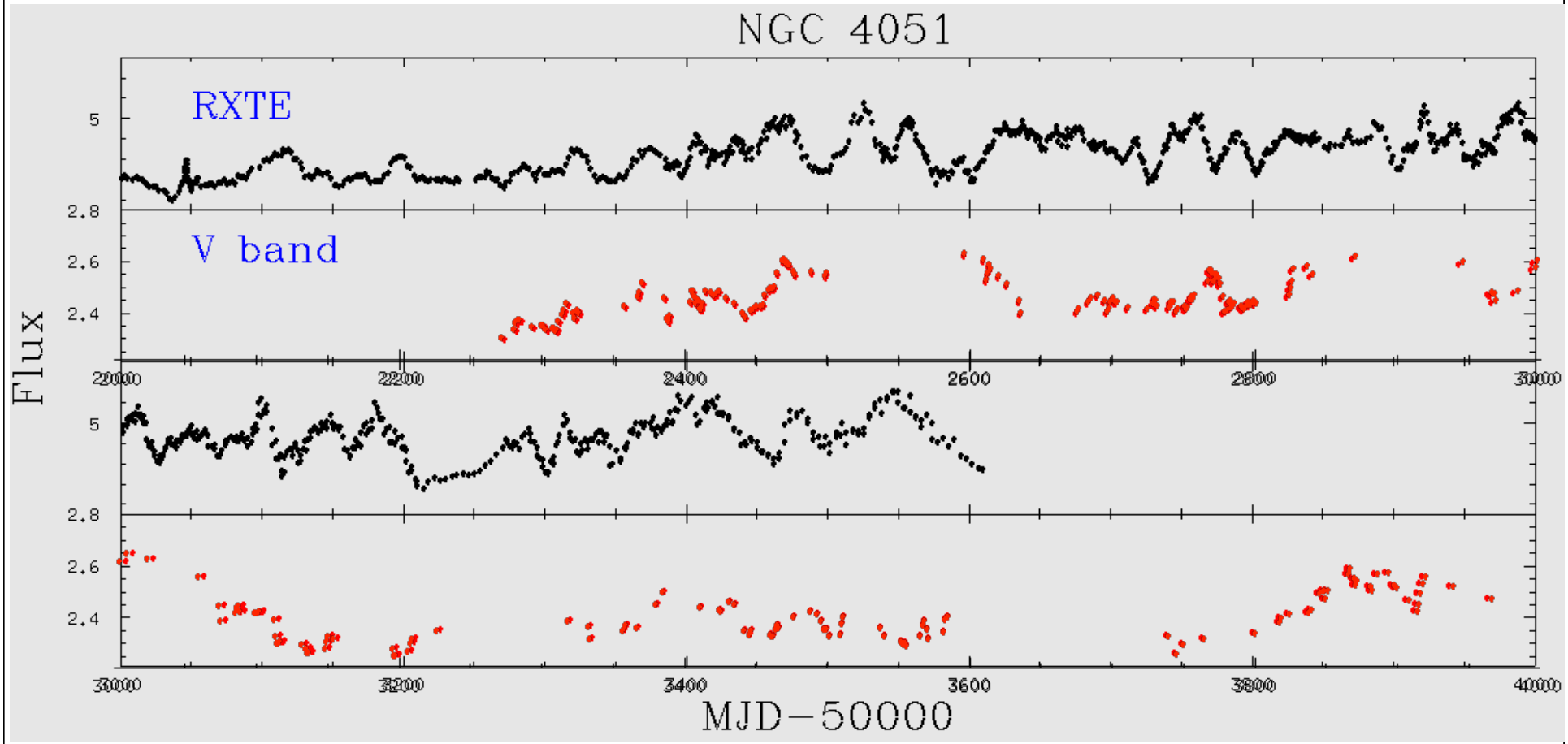
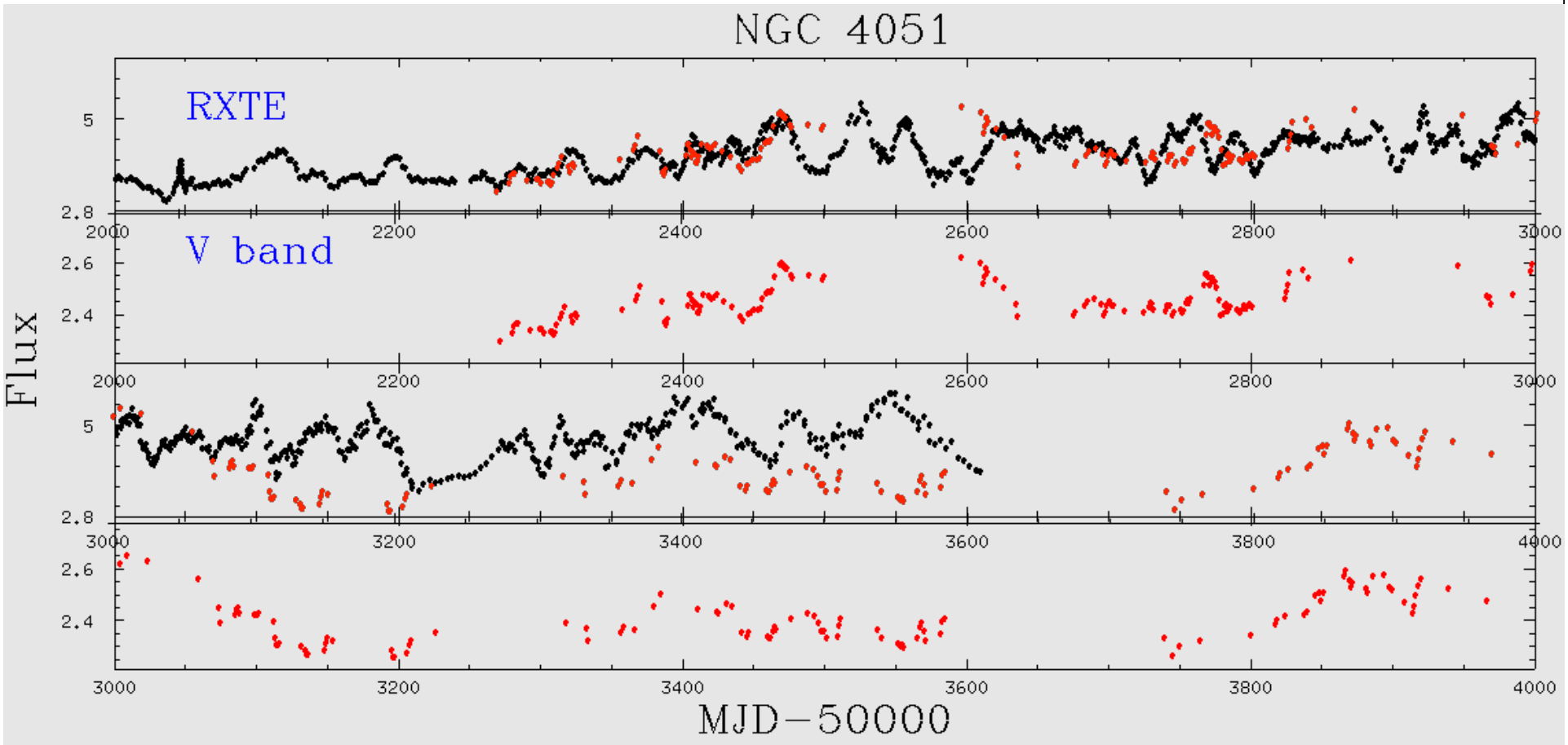
NGC 4051: optical – X-ray

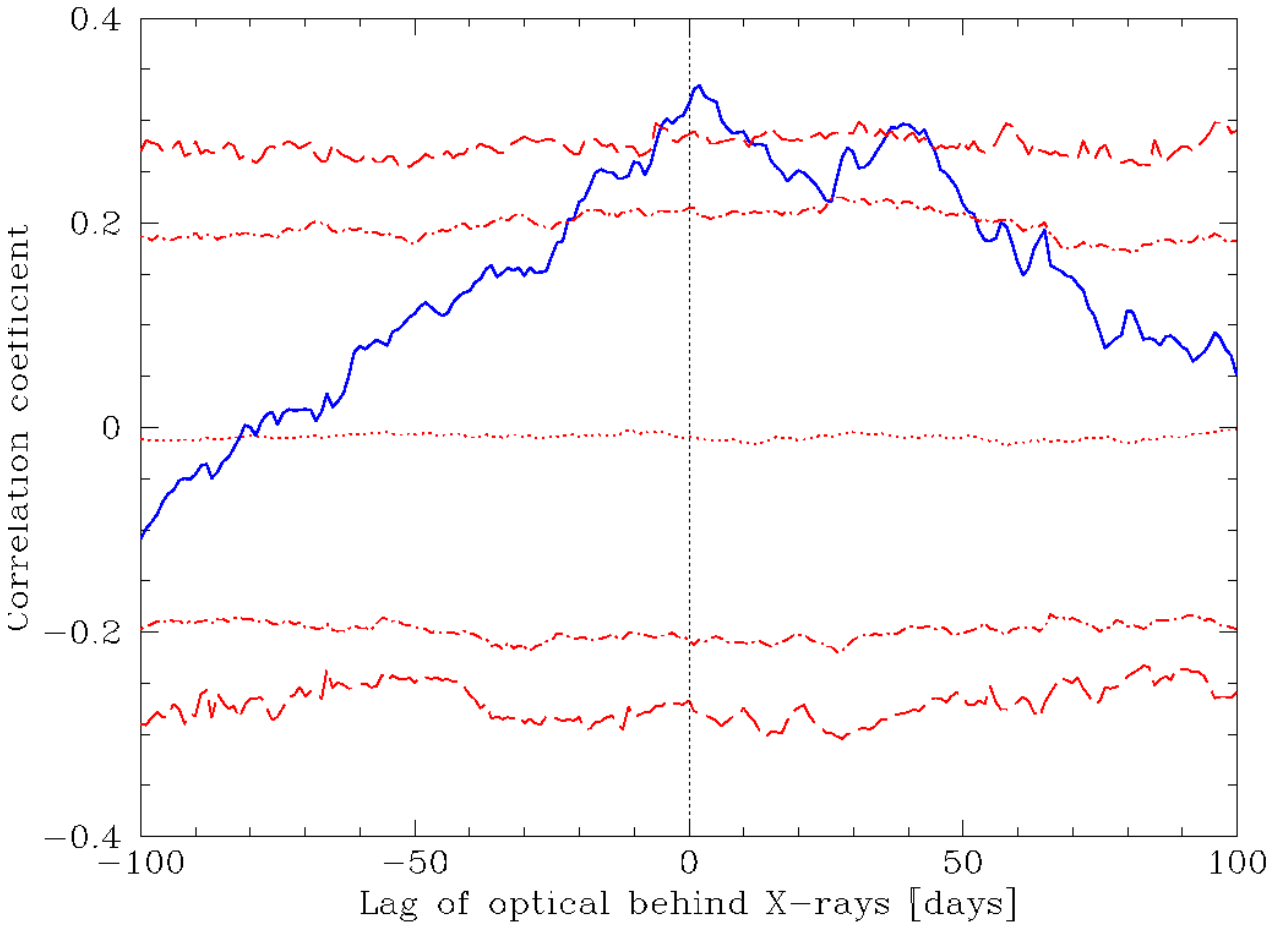


NGC 4051



Short timescale X-ray / optical variations correlate well
But there are long timescales optical trends which you don't see in the X-rays

NGC4051



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

Breedt et al 2010

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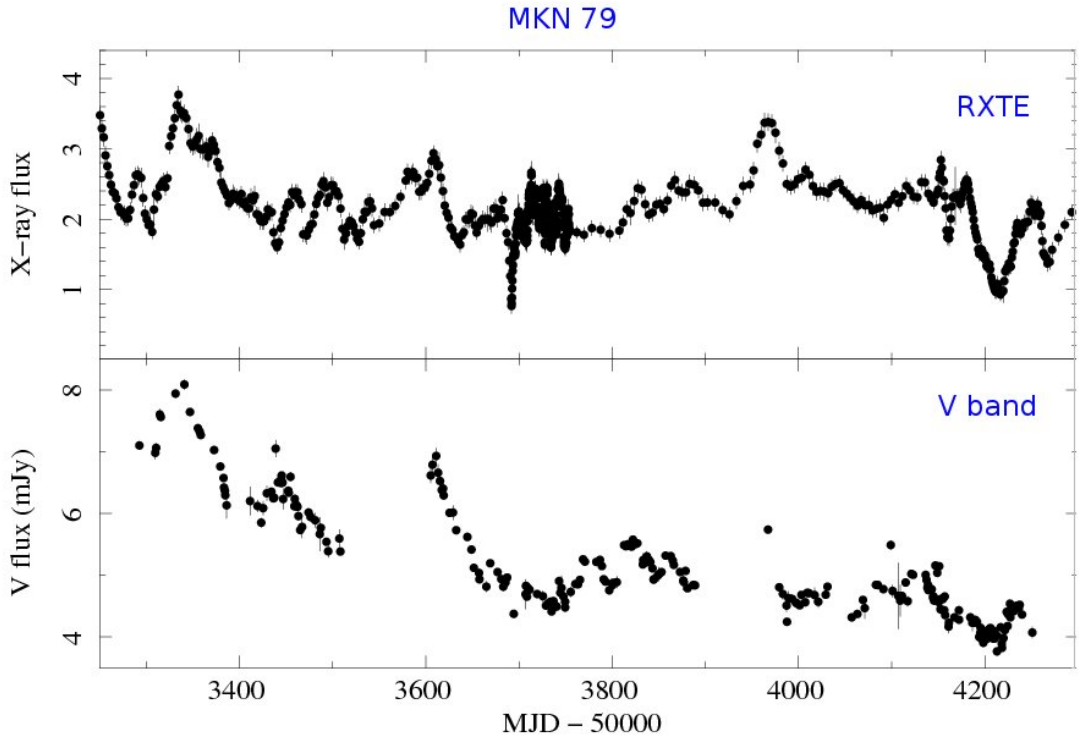
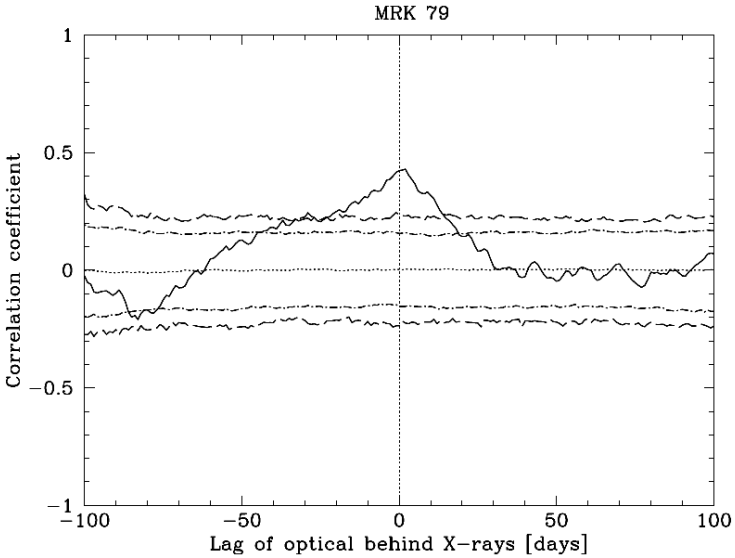
MKN 79



(Breedt et al, 2009, MNRAS)



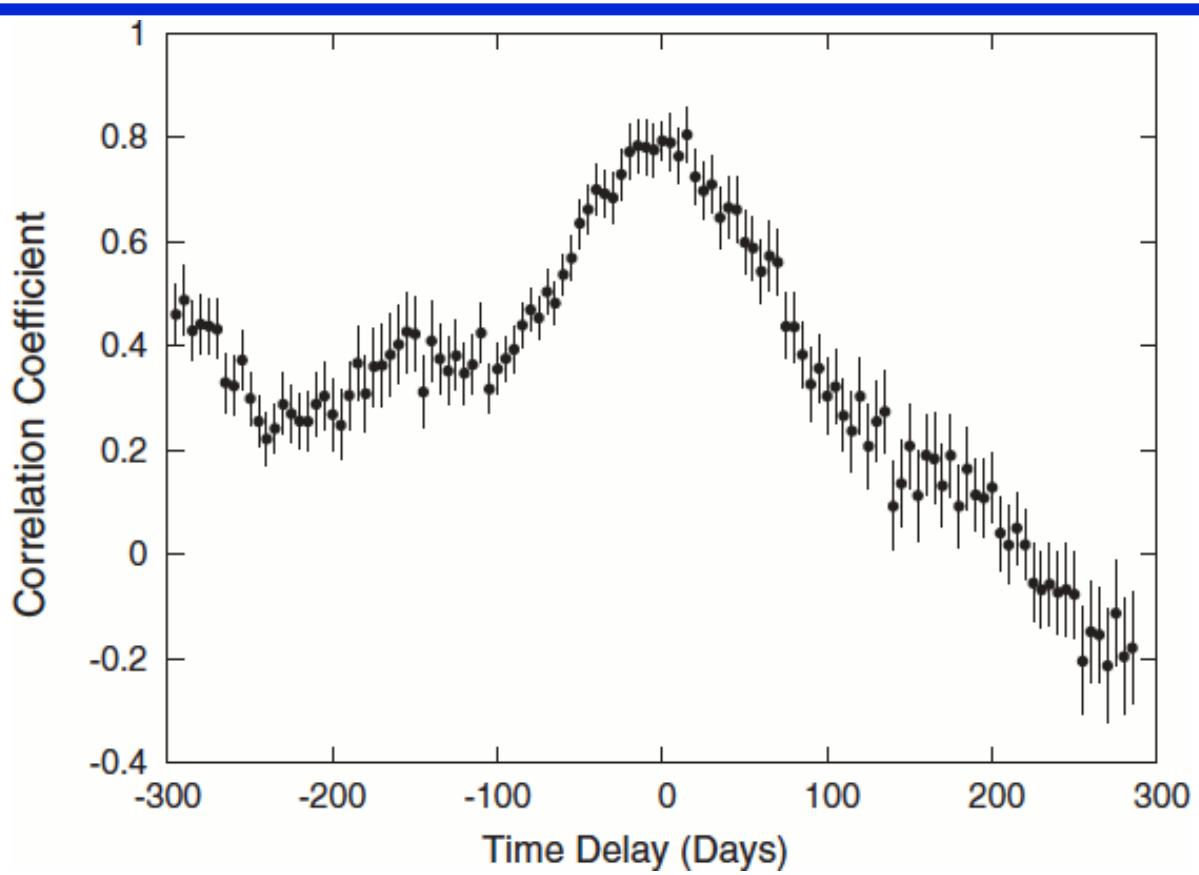
Long timescales (years)

– uncorrelated behaviour. Intrinsic disc variations in optical?

Short timescales (days-weeks)

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

3C120 X-ray / V-band lag



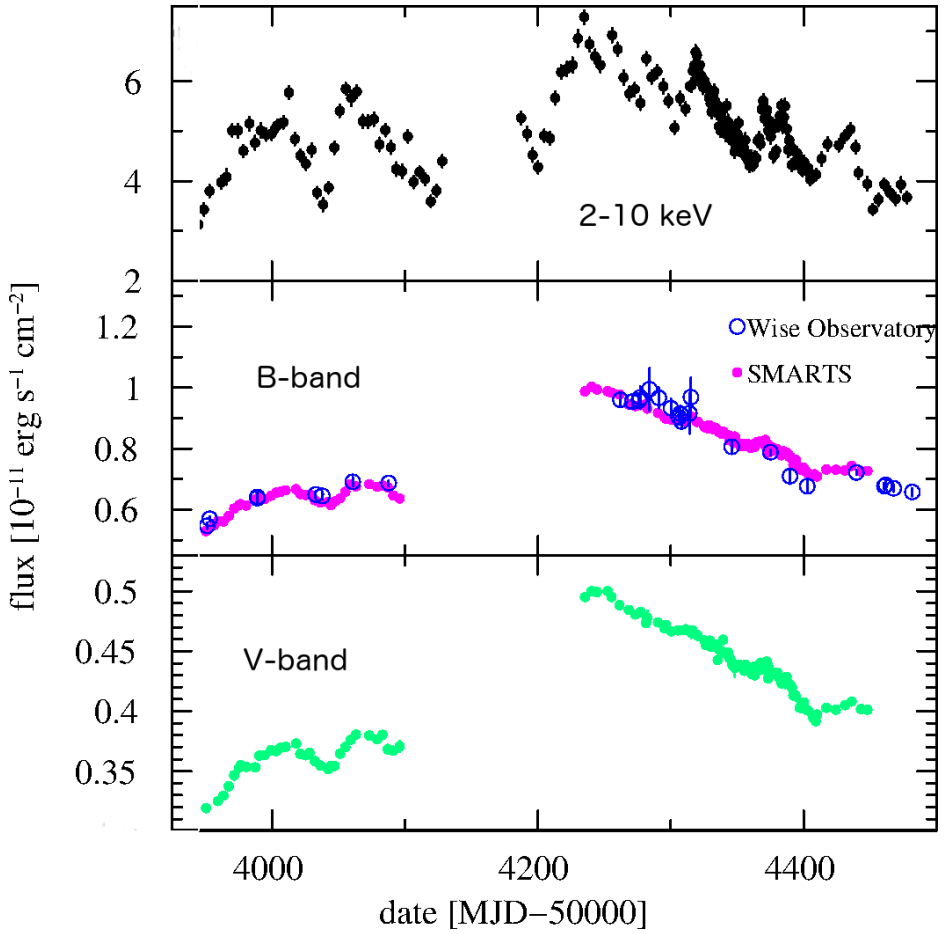
RXTE and ground based; approx 2d sampling

Chatterjee et al (2009); V band lags X-rays by ~0.5d - (mostly)

But Marshall et al (2009) find V band lag of 28d…

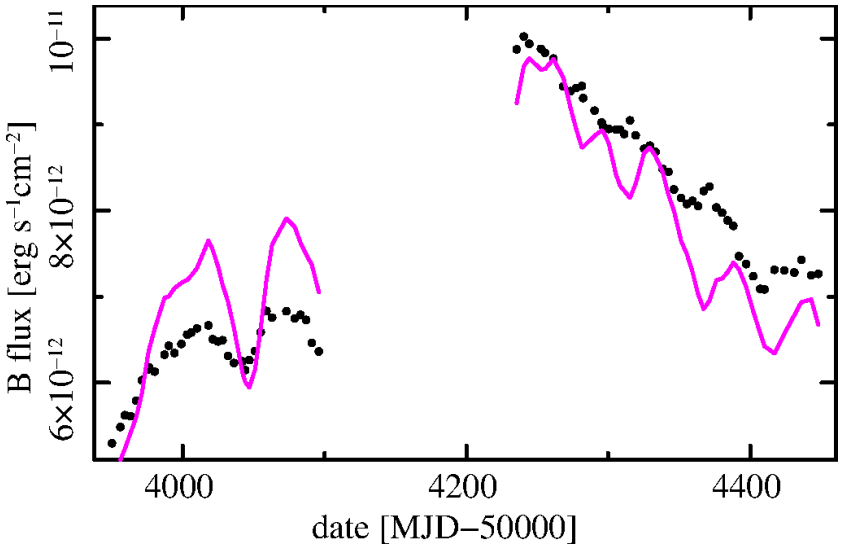
Problems with reprocessing from a disc

MR2251-178
Arevalo et al 2008



Observed B-band lc (black dots) is smoother than model lc (purple)

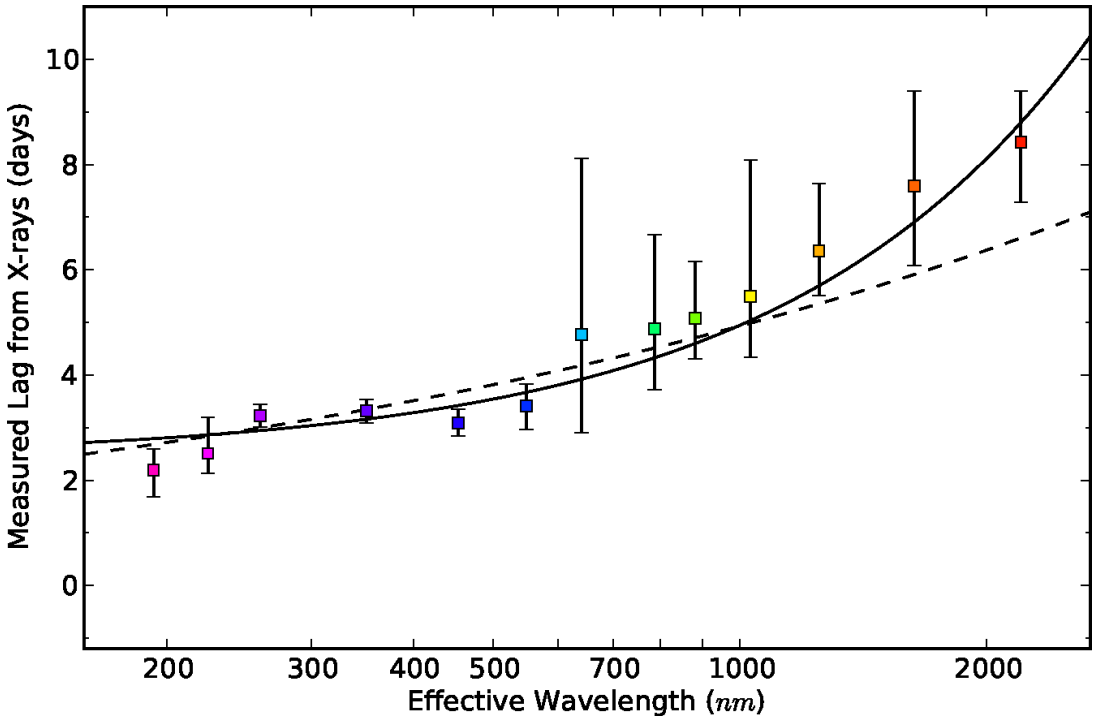
Kasanas+Nayakshin 2001
Arevalo et al 2008, 2009
Gardner+Done 2016



Need illuminating source scale height ~100 Rg for adequate DISC illumination
– much larger than measured for X-ray corona

(eg Emmanoulopoulos et al 2014; Cackett et al 2014)

NGC2617 – Swift + Ground



Shappee et al, 2014

$M \sim 4 \times 10^7$

~60 observations per band

Longer wavelengths smoothed as well as lagged

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

Is this offset real?

Swift Monitoring of NGC5548:

(> 500 observations)

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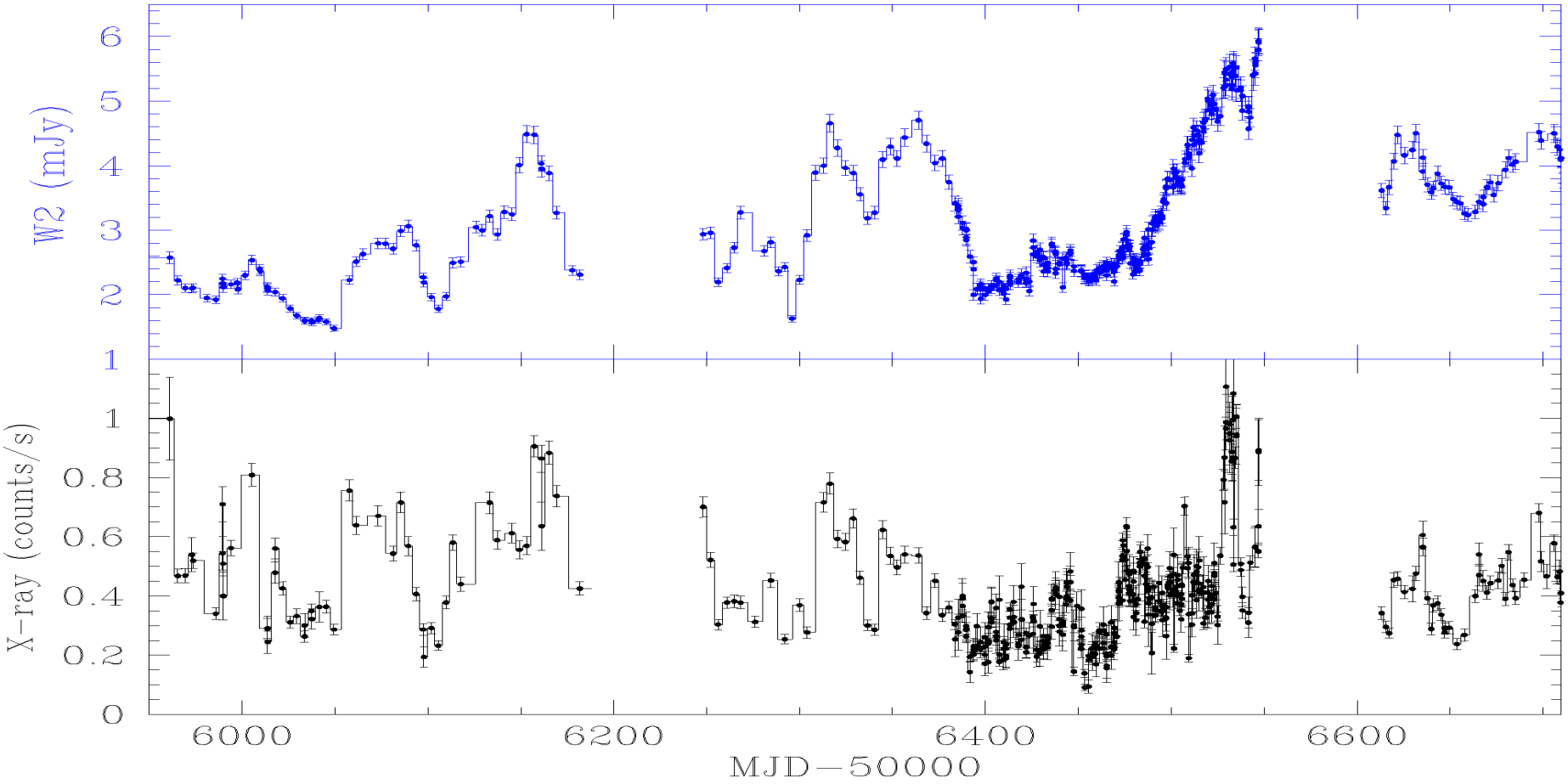
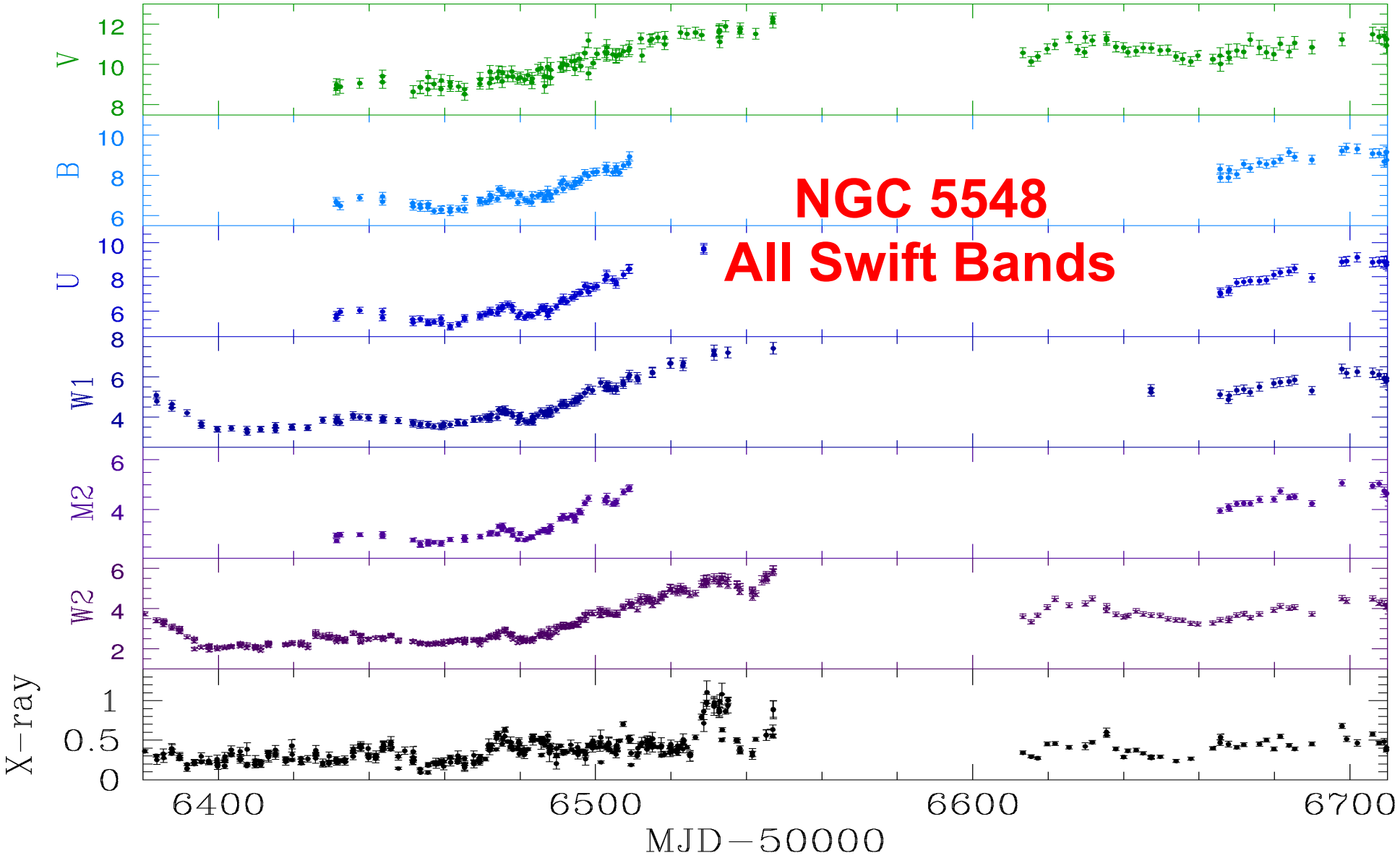


Good correlation, but not perfect, eg large W2 rise after day 6480

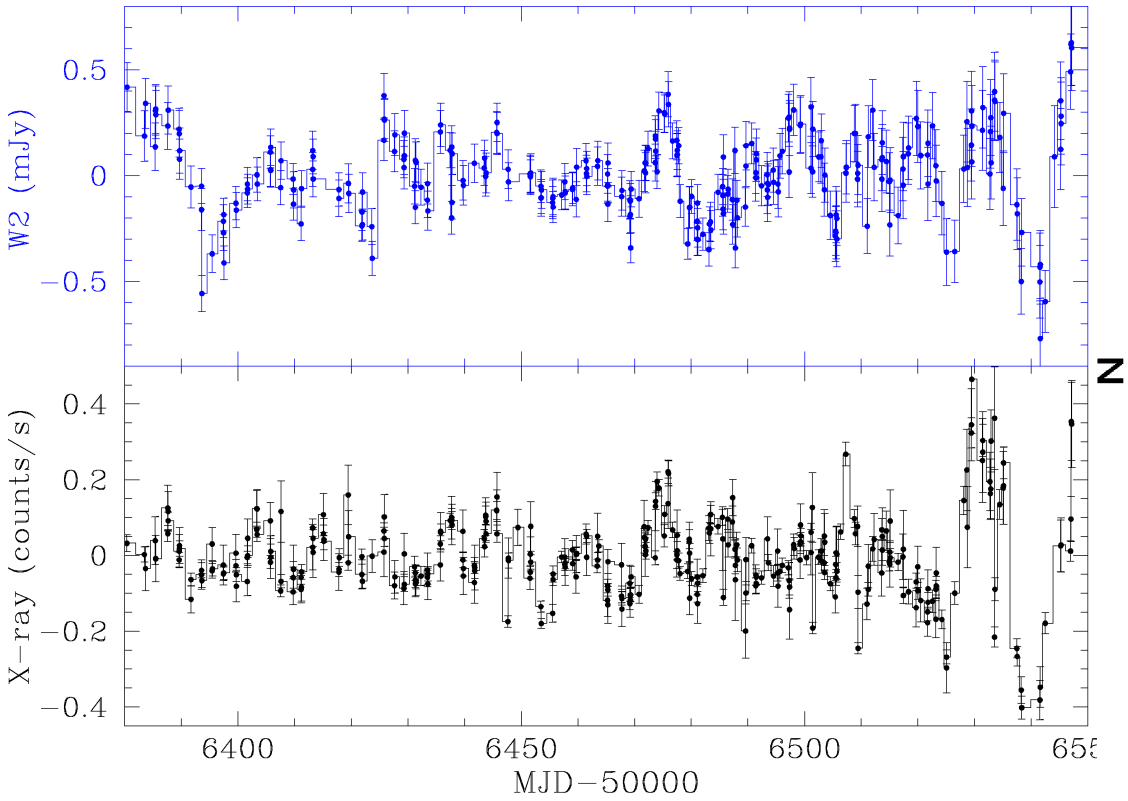
McHardy et al, 2014, MNRAS, 444, 1469



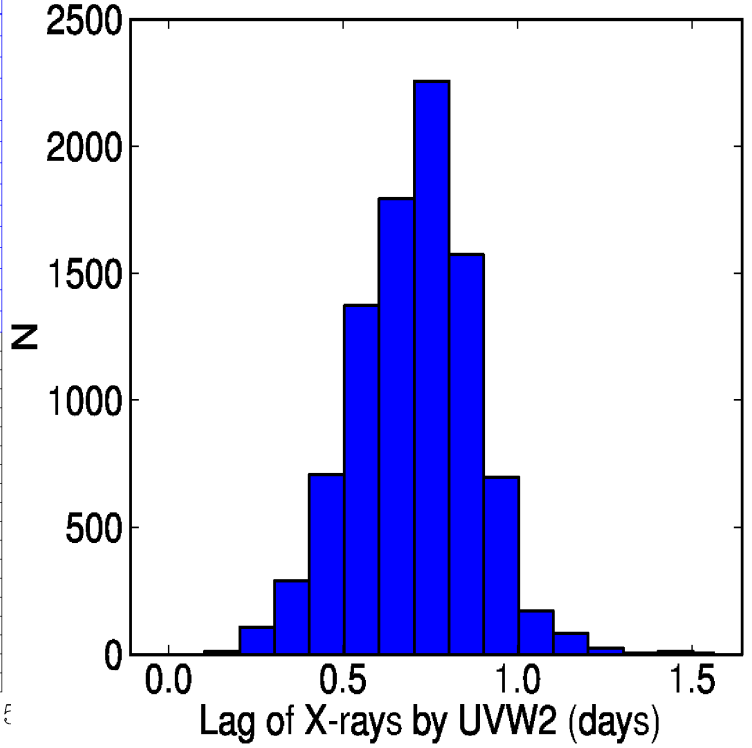
Well correlated long term variability in UV and optical bands, not seen in X-rays

Lag of X-rays by UVW2

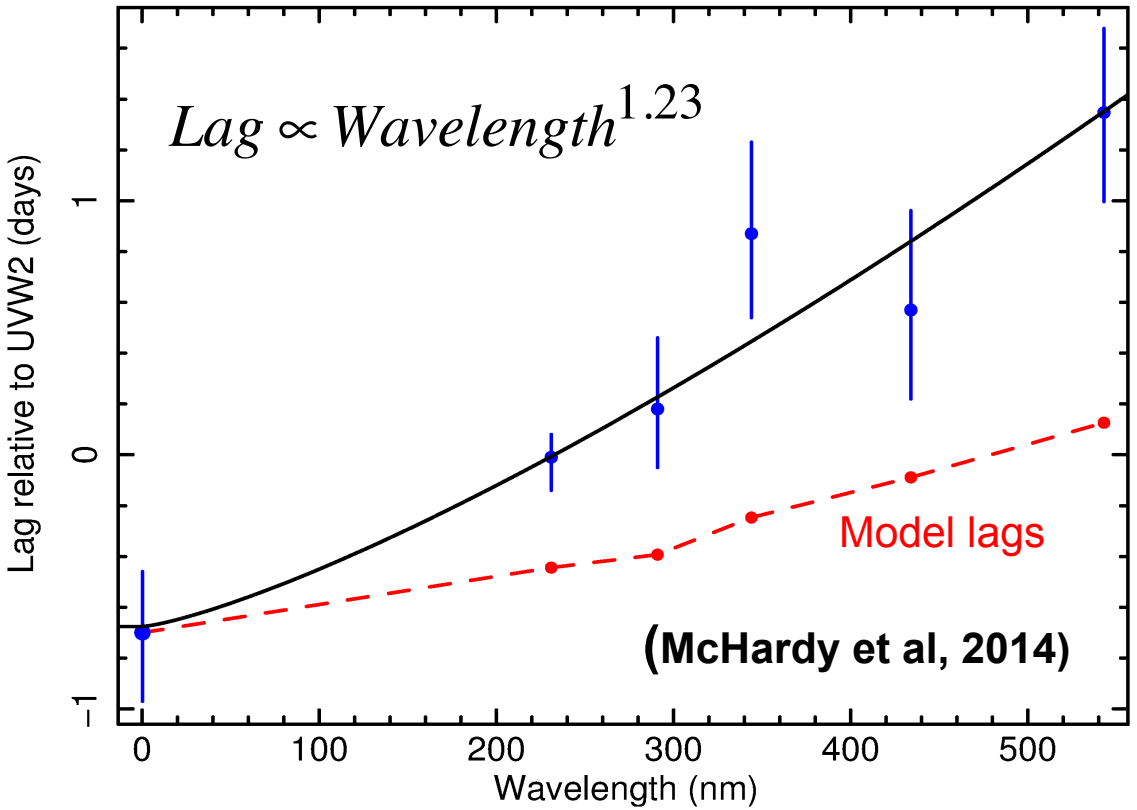
Mean-subtracted lightcurves
Intensively sampled period



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.

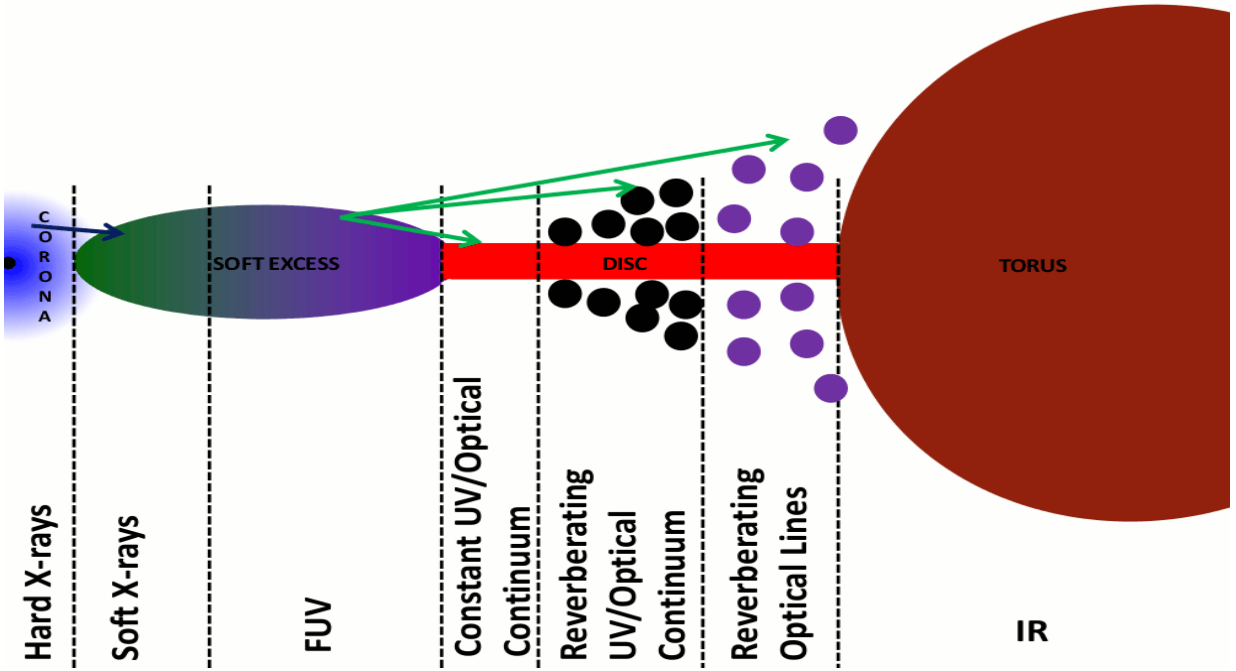
Microlensing obs (eg Morgan et al 2010) also require larger disc than SS model

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)

Possible geometry



Gardner +Done 2016

I would add:

Variable heating of inner edge of disc by accretion rate fluctuations on viscous timescales naturally provides the long timescale UV/optical variations, uncorrelated with X-rays.

Some part of the hard X-rays has to hit the reprocessor to provide short timescale X-ray/UV lag.
- high scale height emission from base of a jet?

Reprocessor has to have flattish geometry to give lag ~ $\lambda^{4/3}$. Hard to do with clouds

X-ray / UV Variability of LINER – M81

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LINERs – very low accretion rate

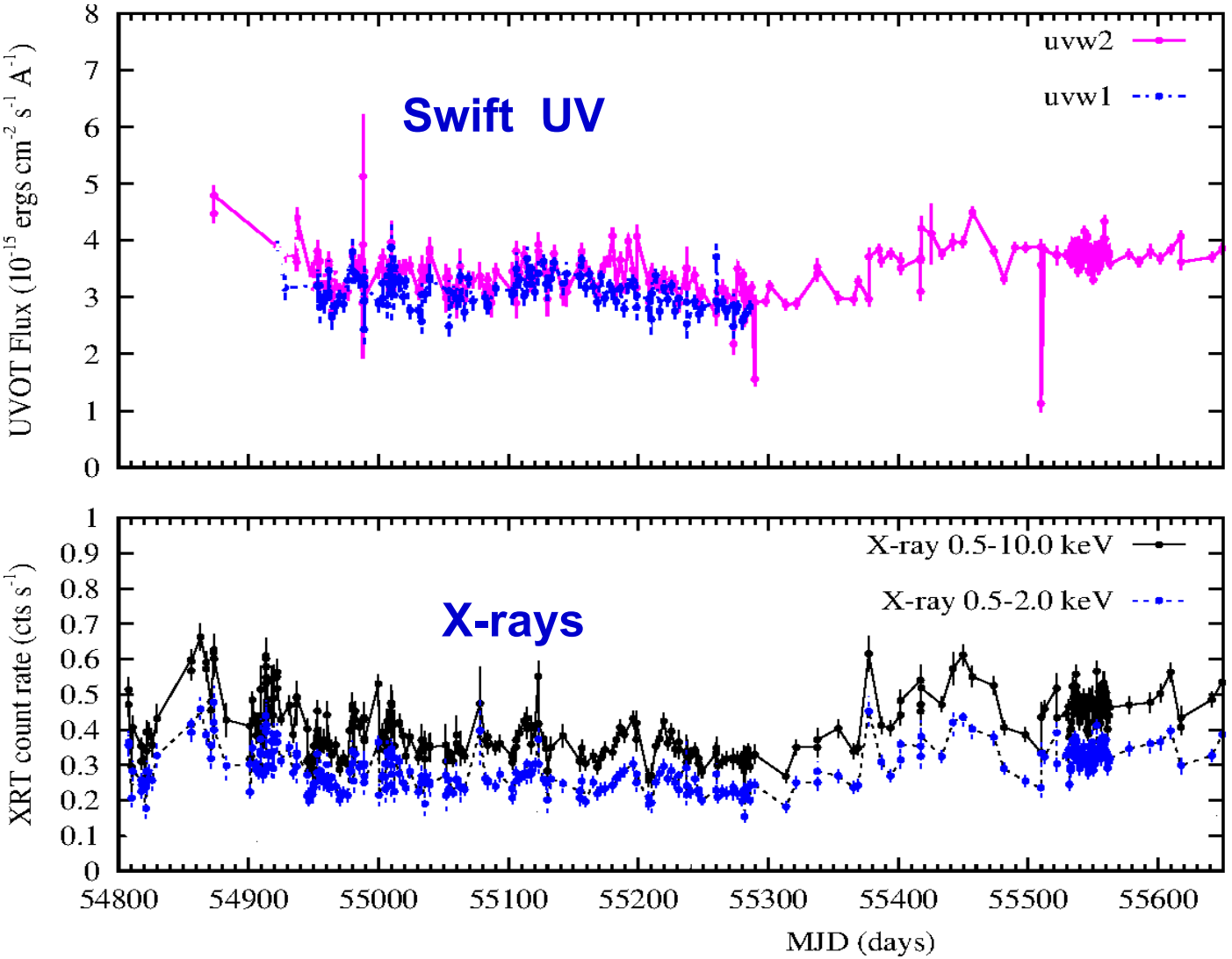
- uv/optical emission will not be from disc

IF there is a UV/X-ray correlation, then

- X-rays lagging UV: UV could be seed photons for SSC X-rays,

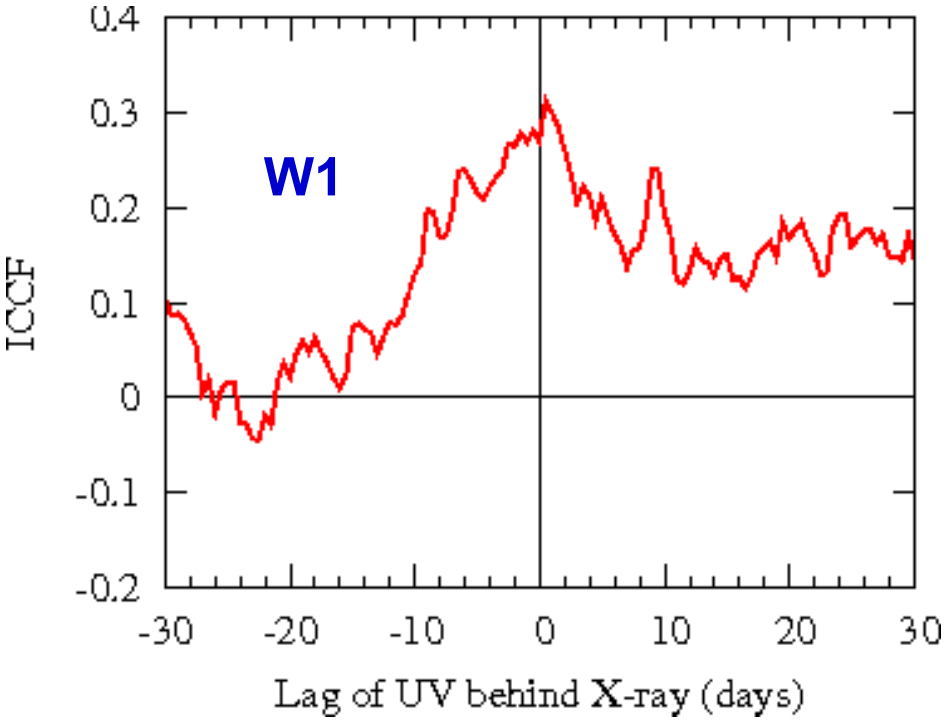
- UV lagging X-rays: UV from synchrotron jet,
downstream from X-ray corona

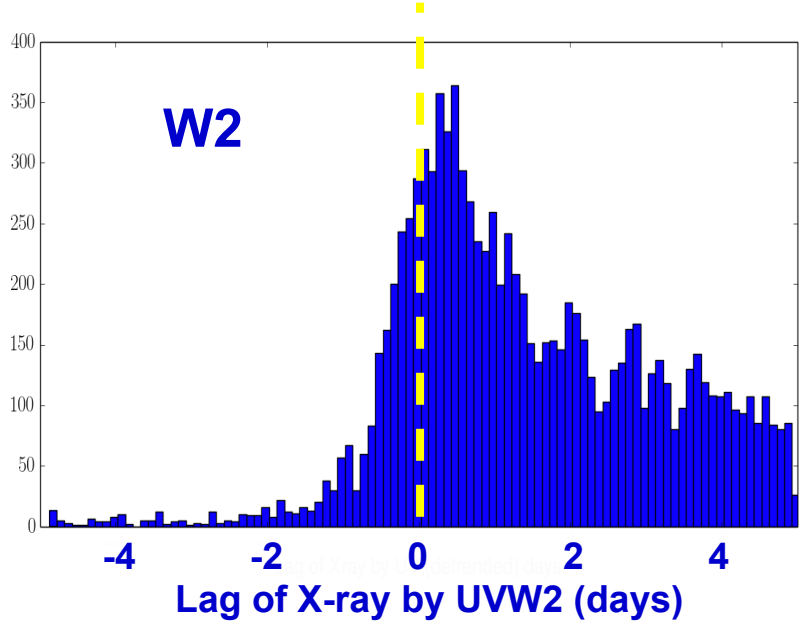
X-ray / UV Variability of M81



Cameron
2014
Phd Thesis
Southampton

X-ray / UV Variability of M81





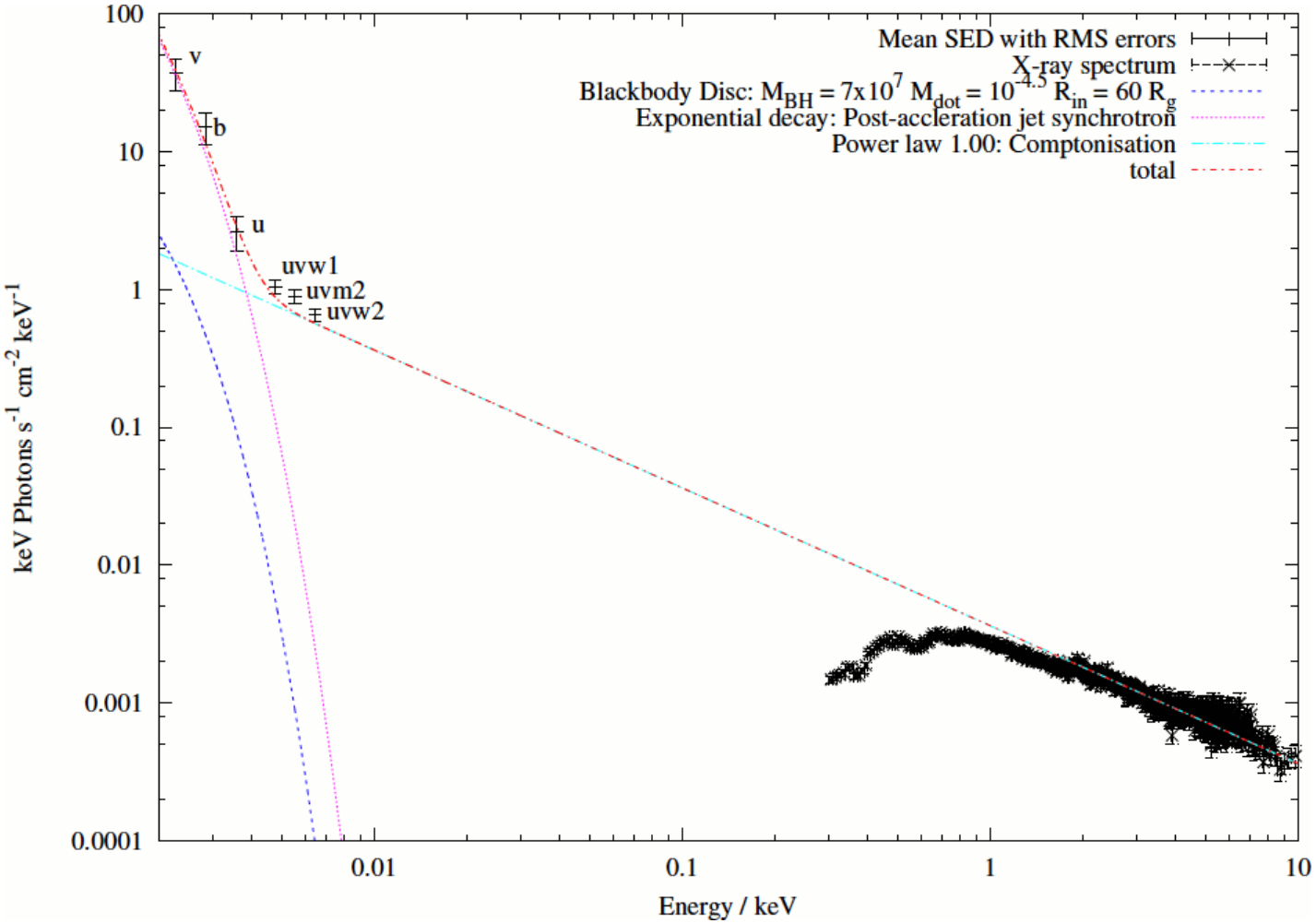
Javelin result
from Harvey-Taylor
Southampton UG

Weak correlations, close to zero lag, possibly small UV lag

Suggests UV are not seed photons for X-rays

Could just be part of same (energy stratified) emission component

X-ray / UV Variability of LINERS



X-Ray / mm / Radio Relationship in LINERS – NGC7213, M81

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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?

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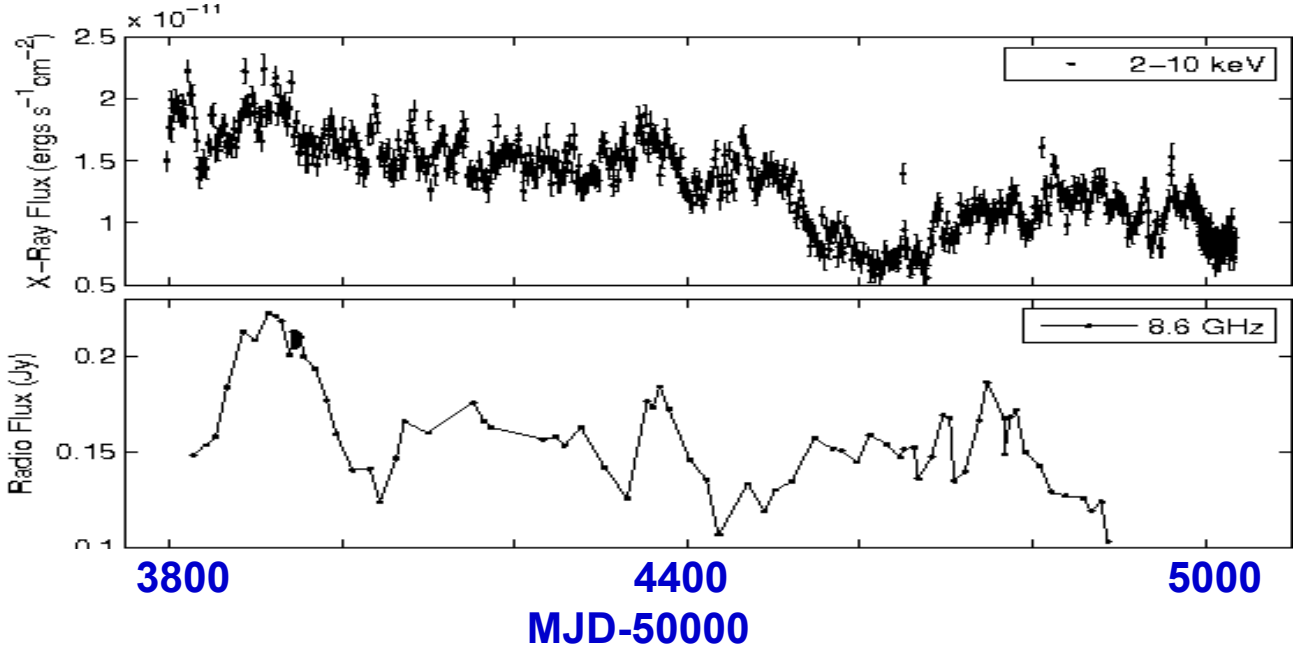
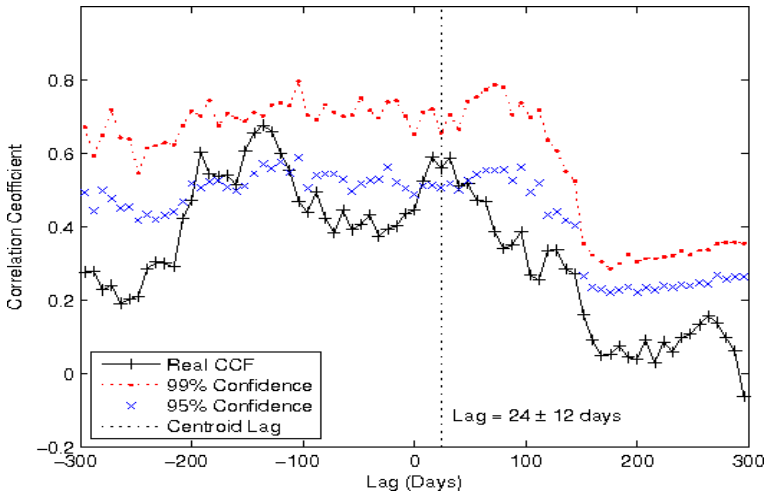
NGC7213 – X-RAY/RADIO

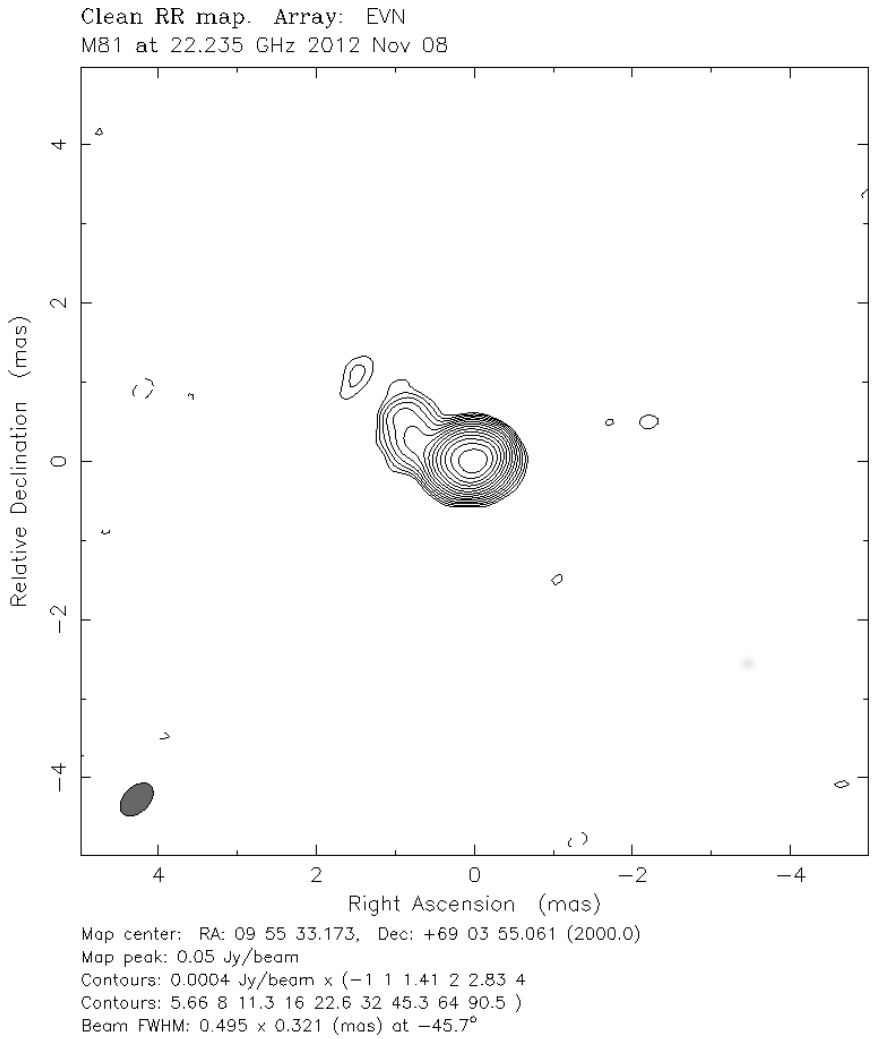


(Bell et al, 2011)



8 GHz may lag X-rays by ~24 days
5 GHz may lag X-rays by ~40 days

M81 sub-mas structure



Sub-mas bending jet similar to blazars

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

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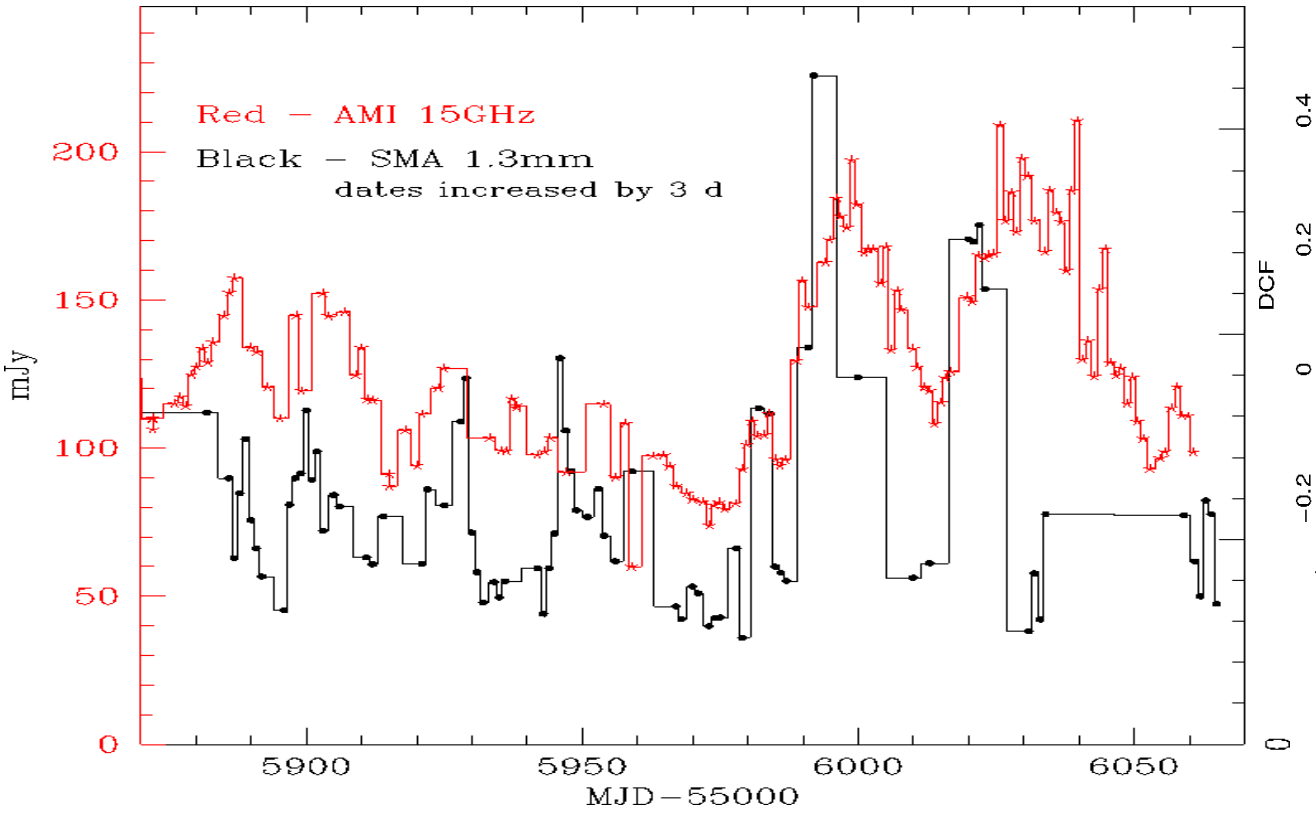
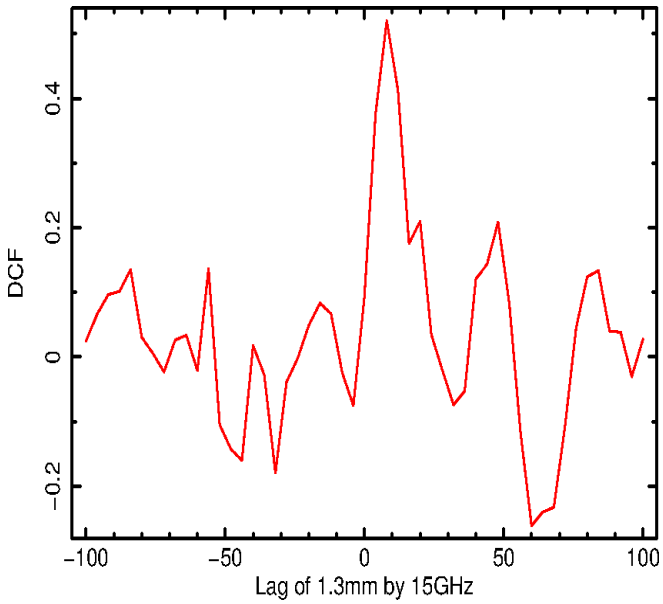
M81 radio-mm variability: strong correlation





Radio lags mm by a few days

Really need to spectrally model the variability to measure lag
Radio-mm flux densities similar – flat spectrum
Consistent with standard synchrotron jet

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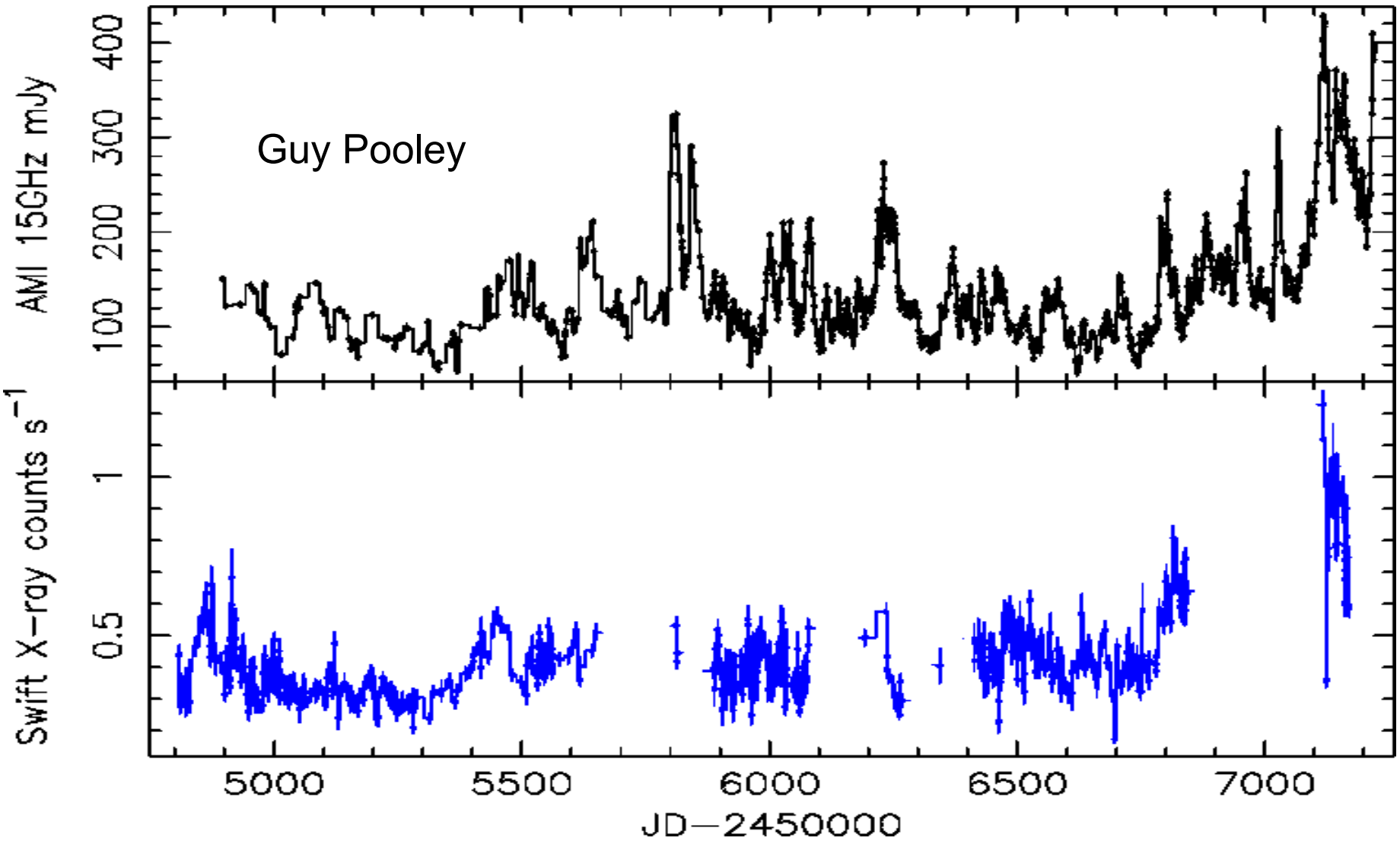
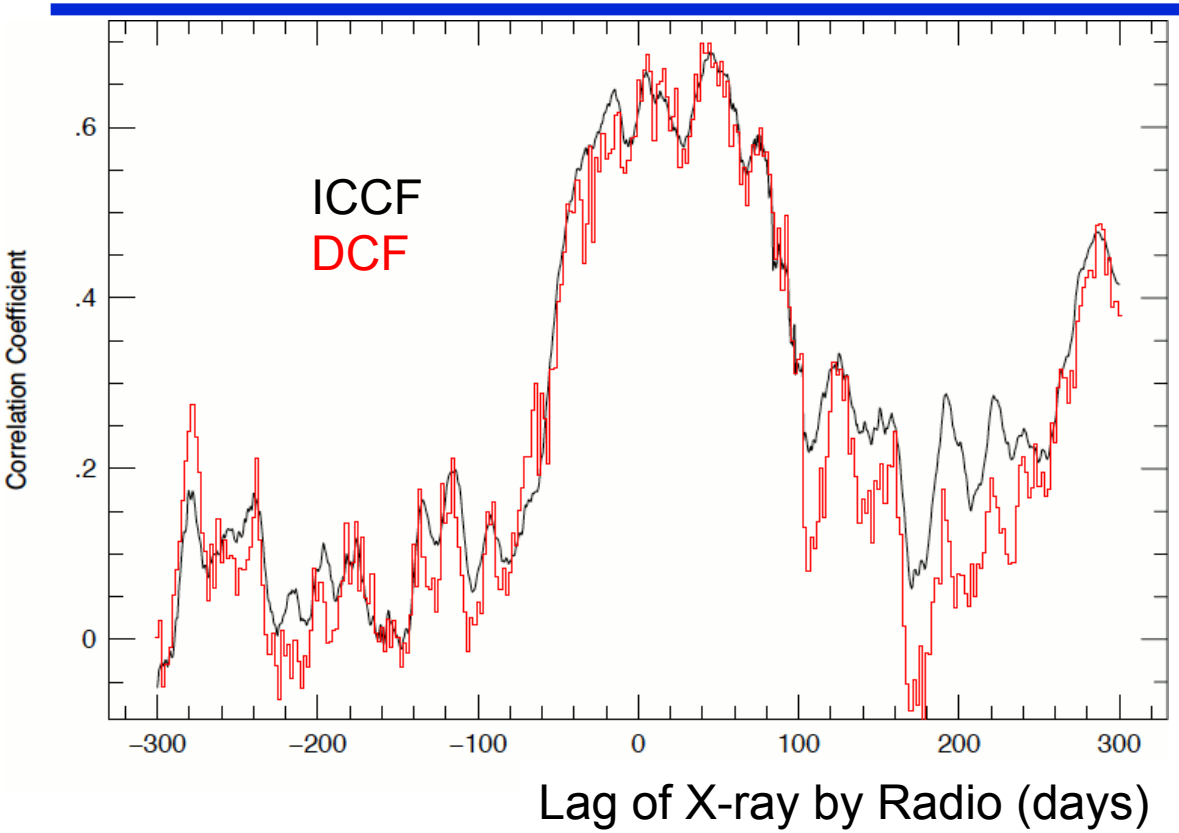
M81 Swift X-ray and AMI 15 GHz Radio



M81 X-ray / Radio ICCF / DCF



Good overall correlation.

.

Centroid of lag, using Peterson FR/RSS simulations 21 +/- 3d

Peak of lag 44 +/- 3d

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

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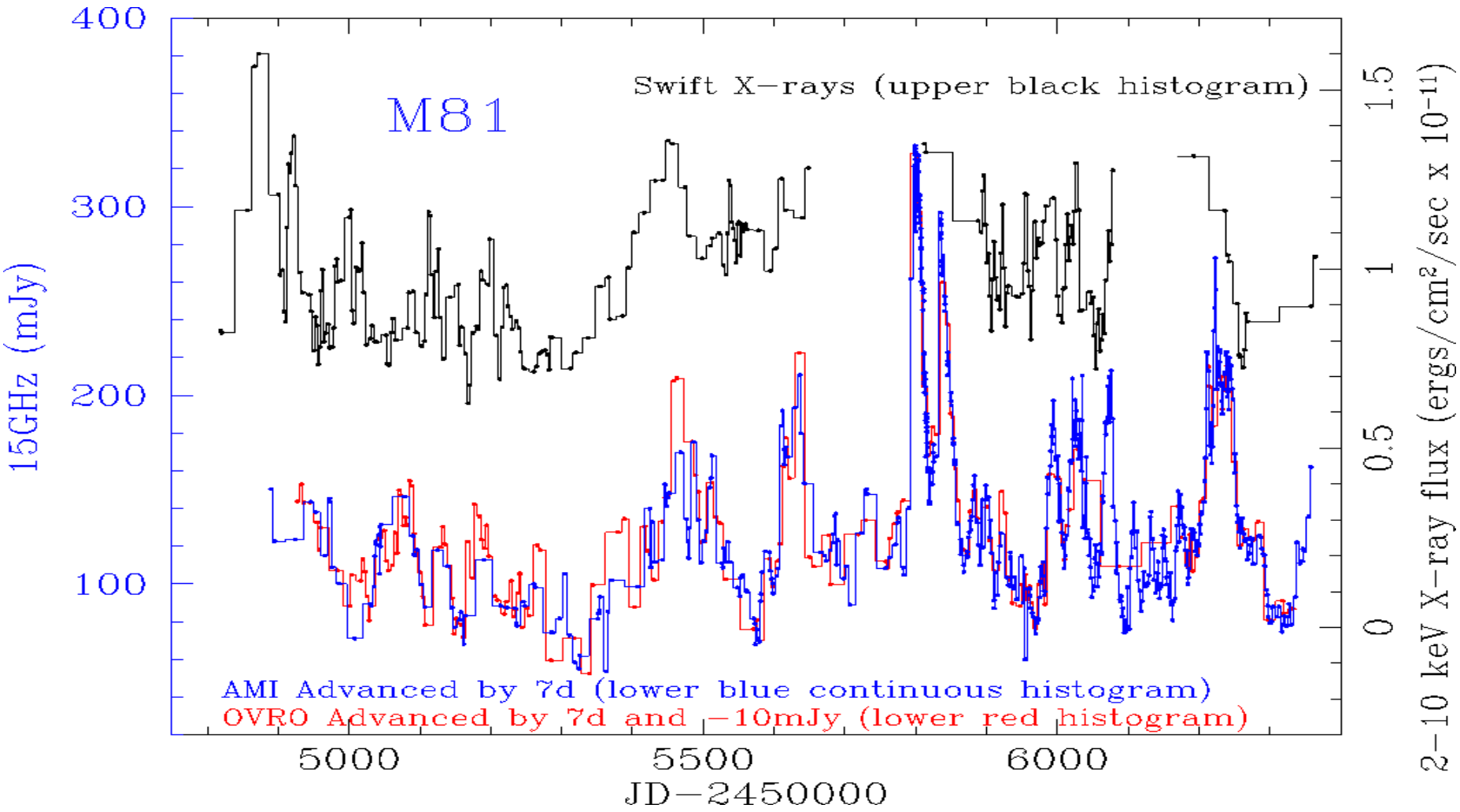
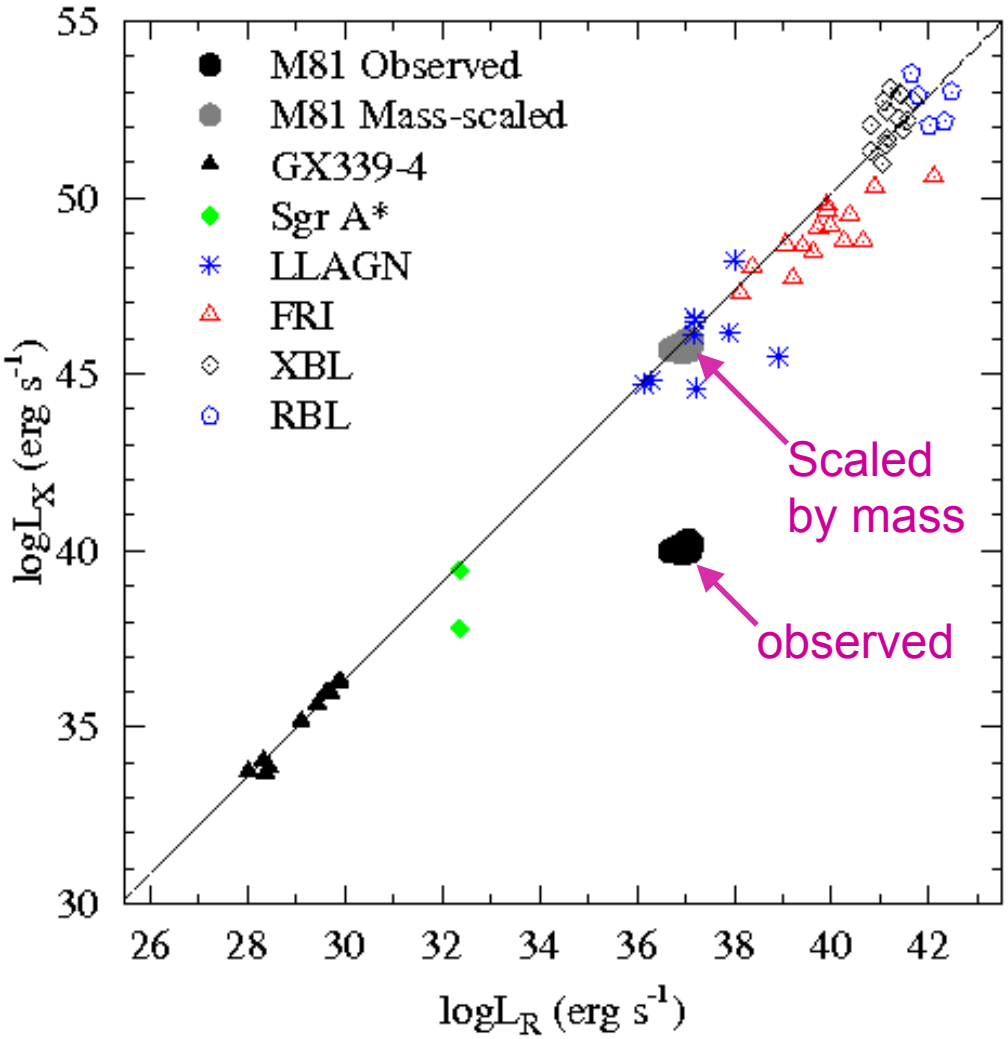
M81 X-ray vs Radio



AMI 15GHz from Pooley; OVRO from Readhead, Pearson and Richards

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

LINER M81 Lags

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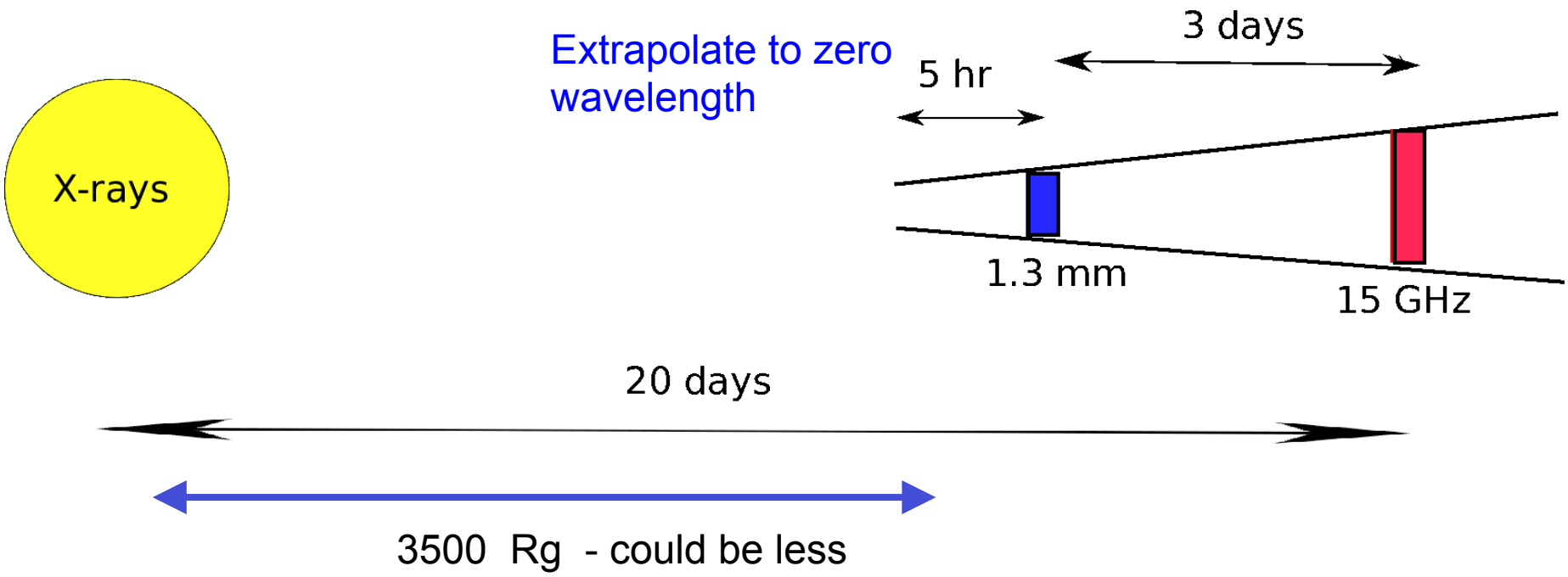
Radio lags X-ray by approx ~ 21d - a messy correlation

Radio lags mm by ~ 3d - good correlation; lag could be longer

UV lags X-rays by ~ 0.5d - weak correlation but lag, well defined.

M81 – Geometry from lags



3500 (ish) Rg is larger than typical 10-100 Rg to the reacceleration zone in the Markoff et al (eg 2005) liner models.

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

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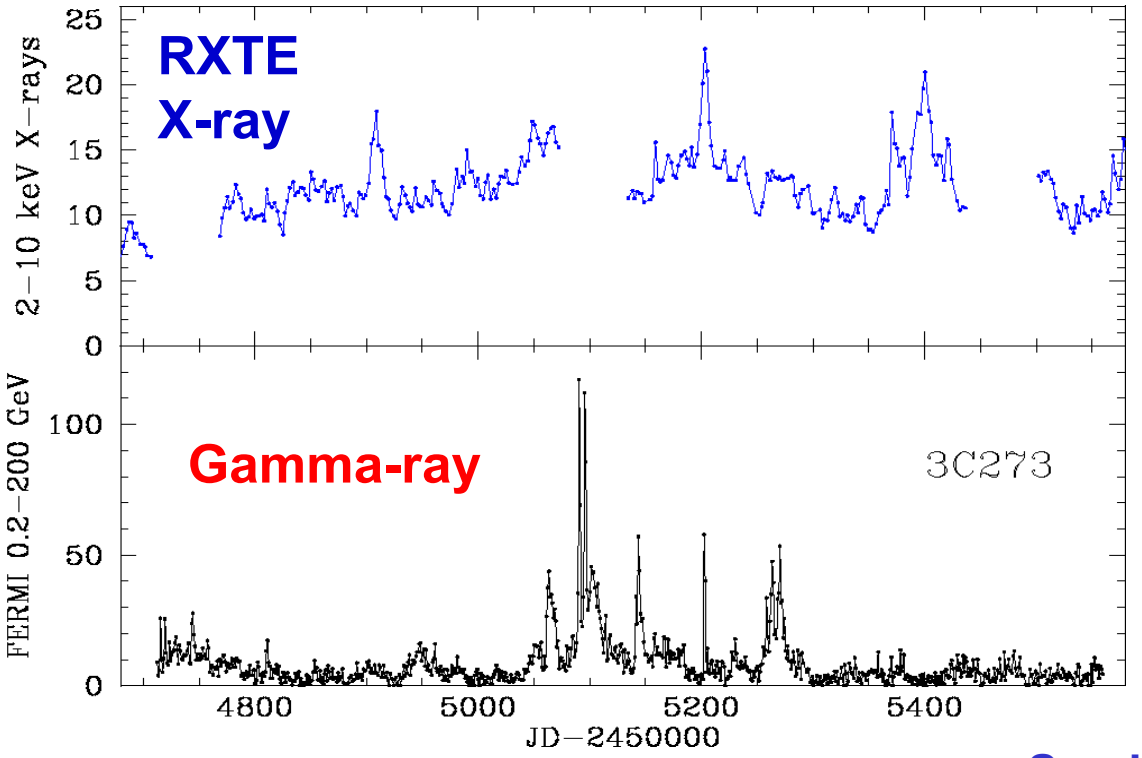
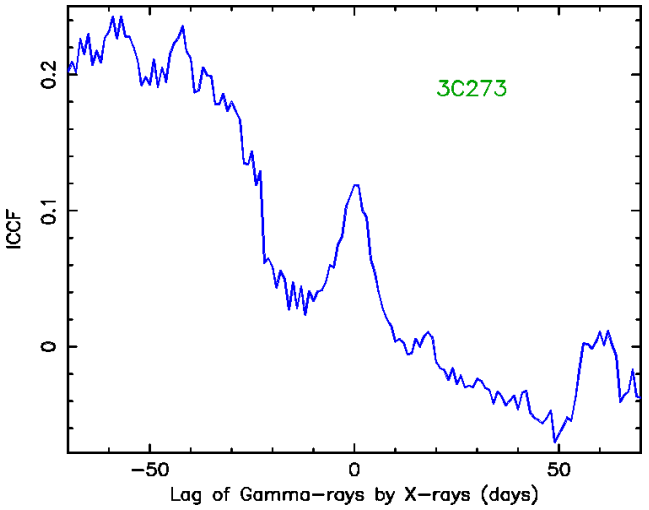
Another Coronal / Jet Connection : QSO 3C273

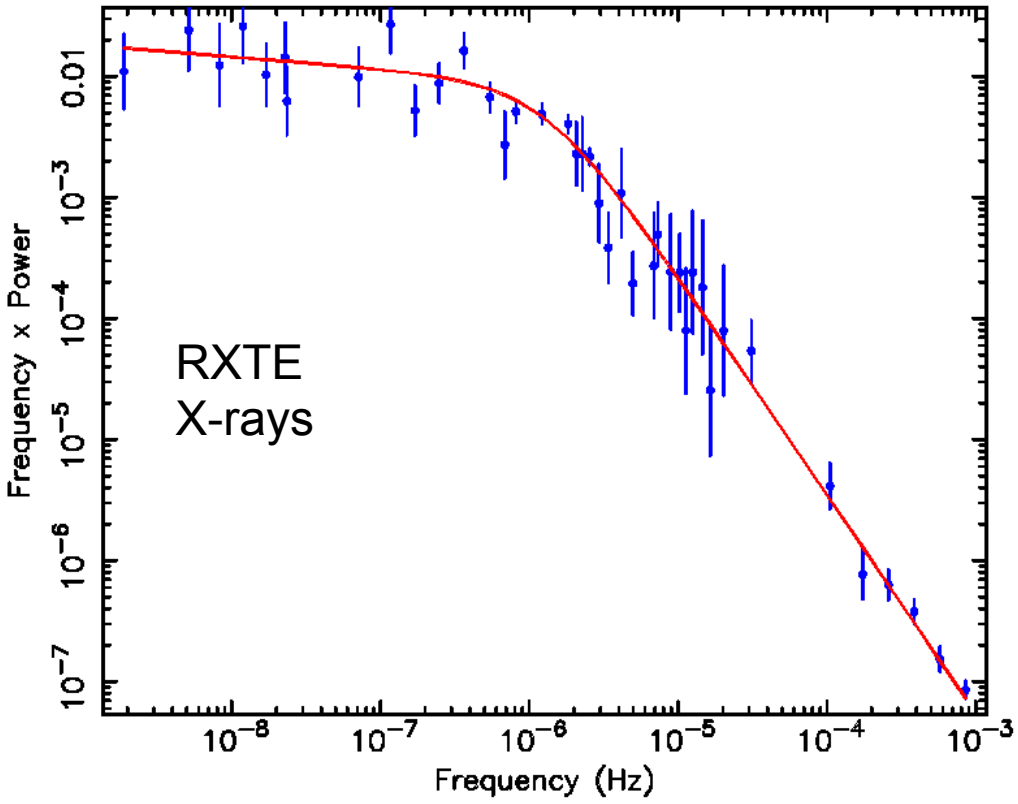


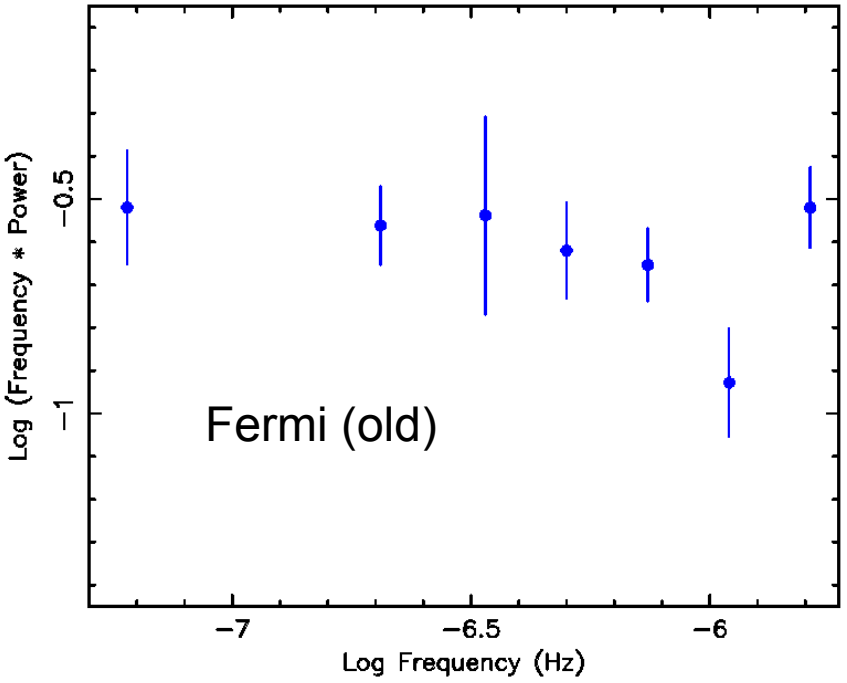


Only occasional simultaneous flares

Small amount of co-spatial X- and Gamma-ray emission (big flares). Most emission from separate regions.

3C273 PSDs





Better available now, Larsson

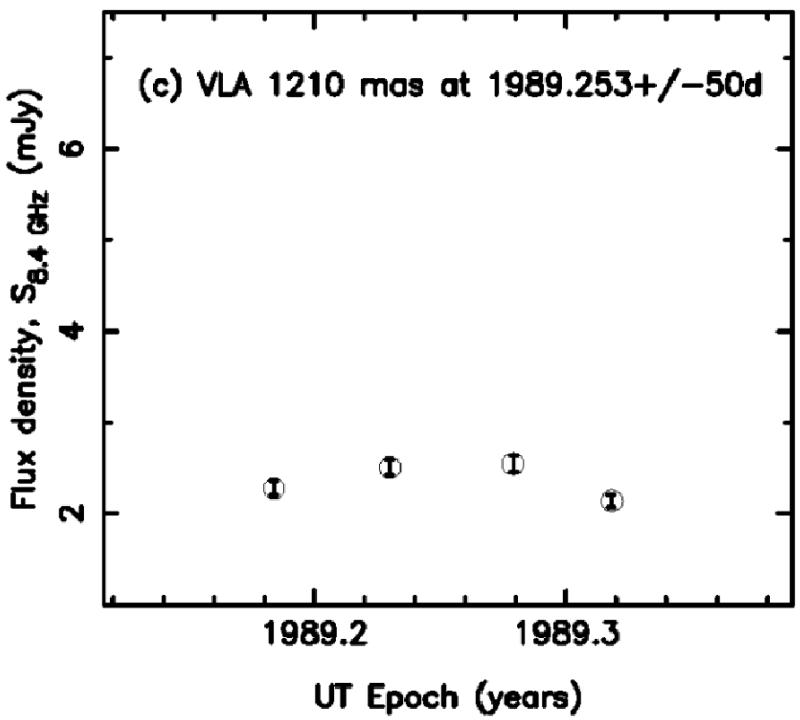
X-ray PSD just like a Seyfert.
X-rays mainly from corona round BH
Some additional X-rays (SSC) from jet flares

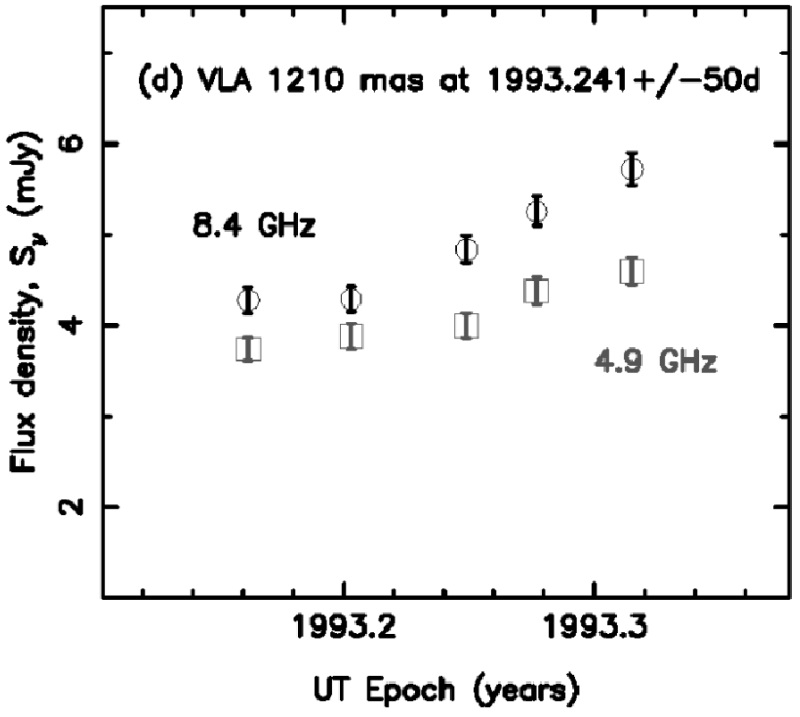
X-ray / Radio Variability of ‘Radio Quiet’ Seyferts

Radio variability from Seyferts, ie high accretion rate, Soft State, AGN

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

See also Mundel et al 2009





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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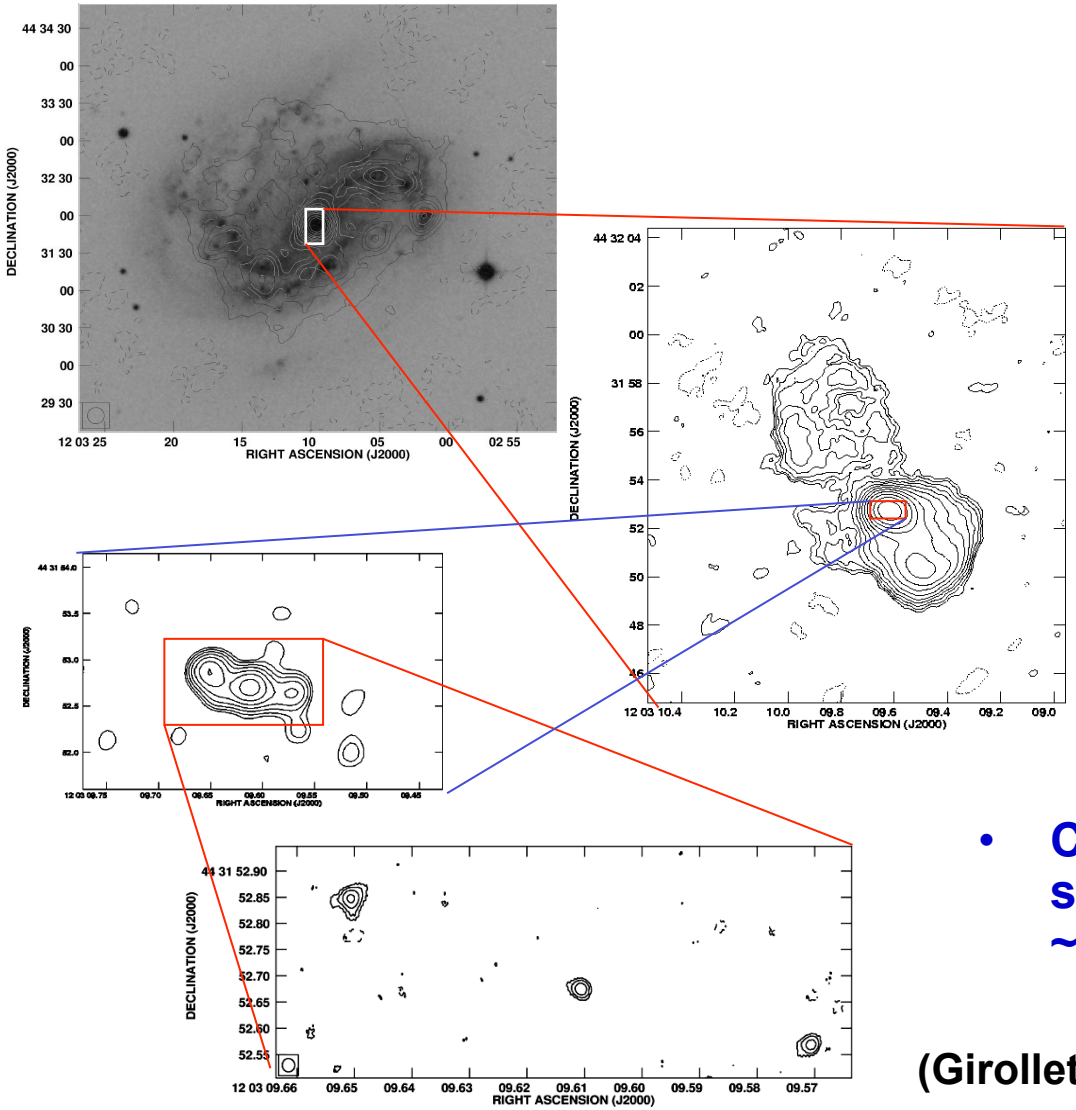
NGC4051 - Seyfert



- **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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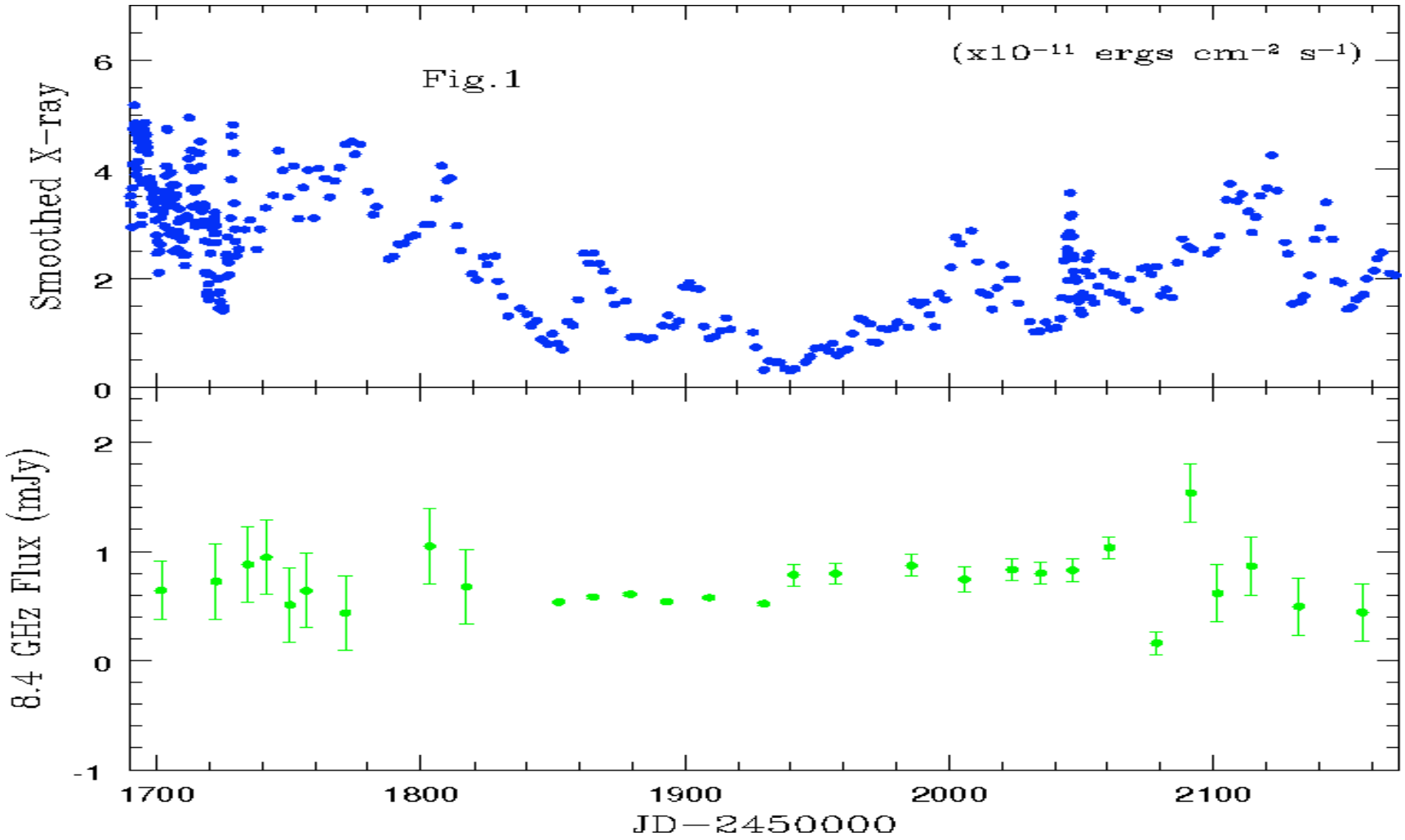
NGC4051 Radio vs. X-ray - VLA all arrays



No strong evidence for large amplitude radio variability

(Jones et al, 2011)

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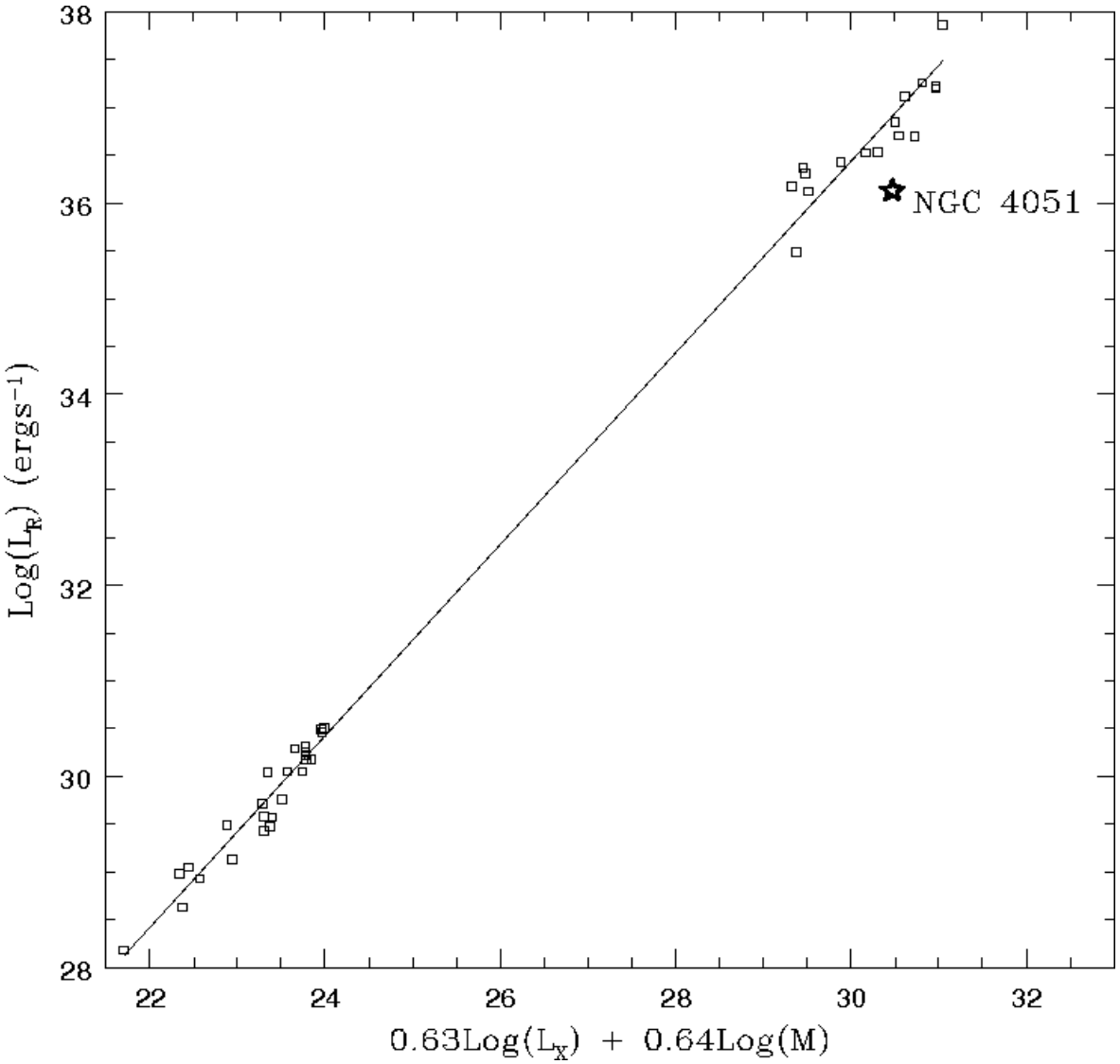
NGC4051 on radio `fundamental plane' for jet-dominated sources

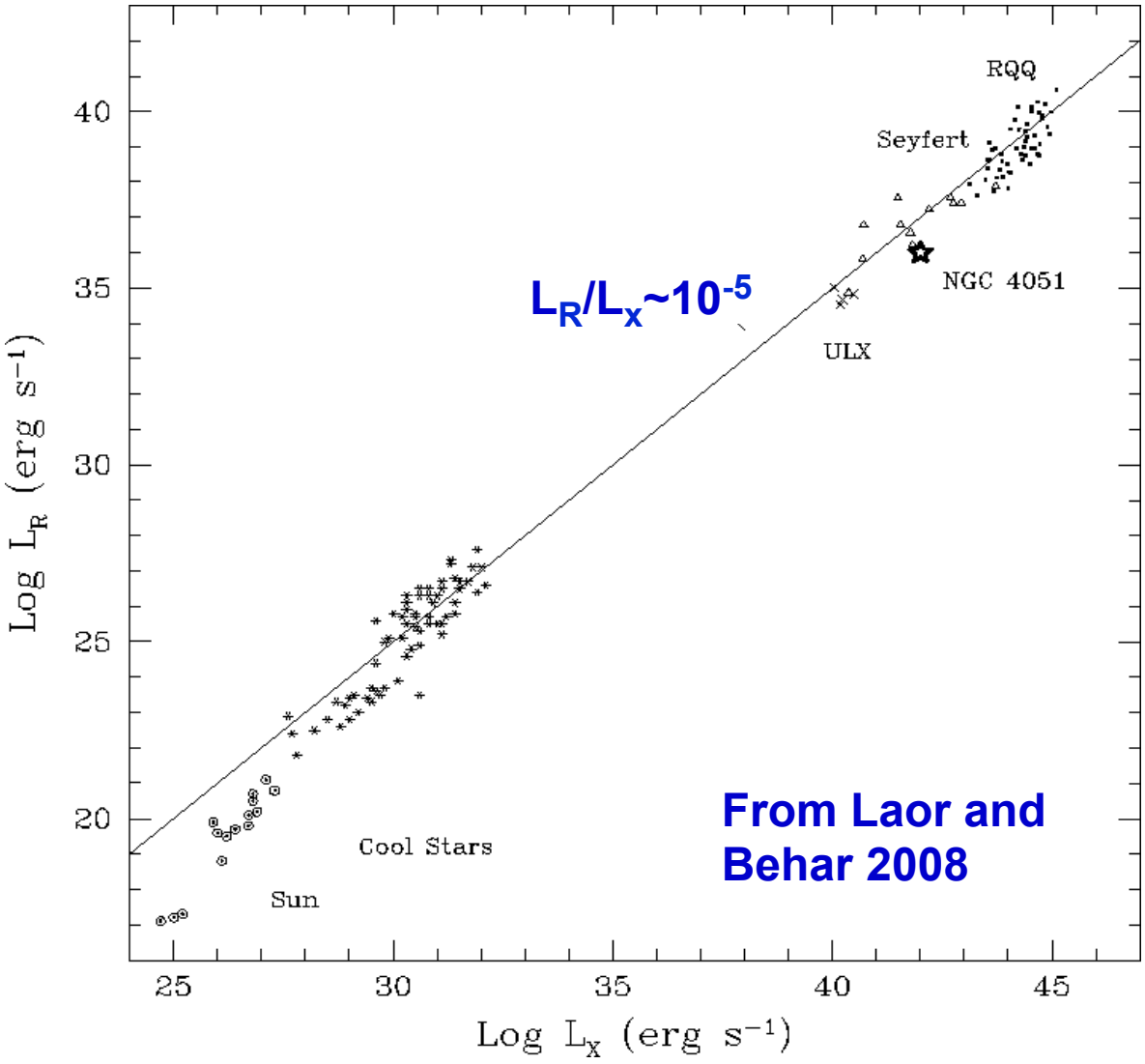


(Merloni et al 2003, Falcke et al 2004, **Koerding et al 2006**

NGC4051 is ~1 decade radio quiet

Jet orientation?

NGC4051 as a coronal radio source?



If so, X-ray is integral of radio emission

(Neupert effect – seen in stellar coronae)

Too faint to search for that effect here.

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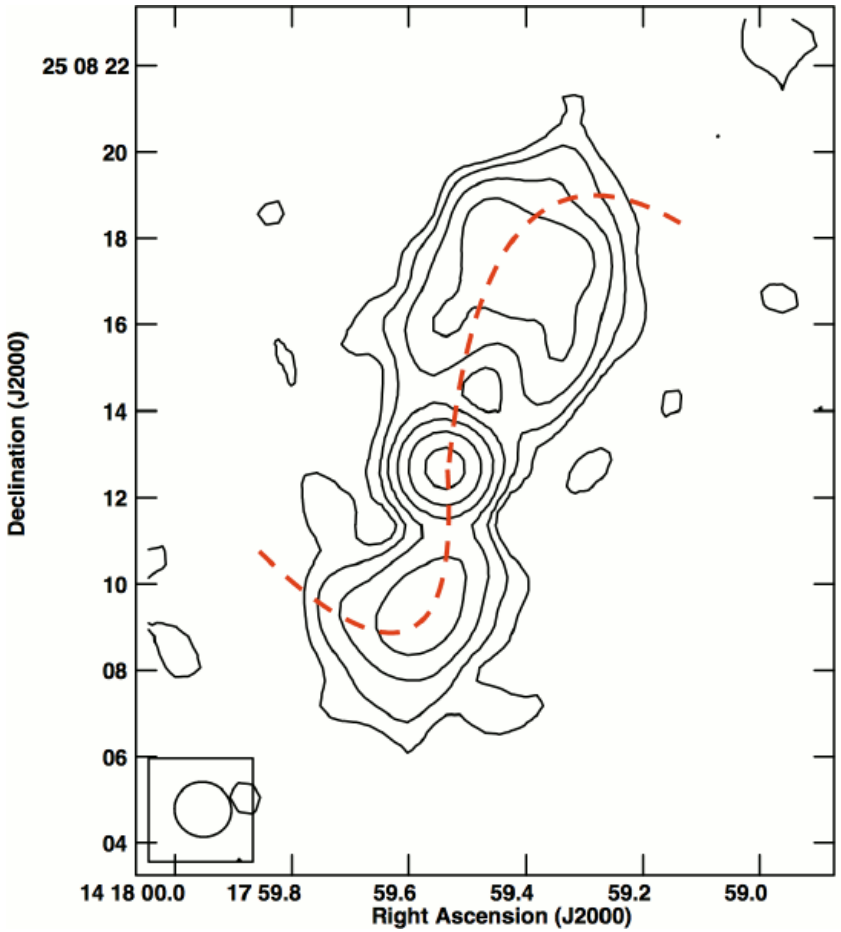
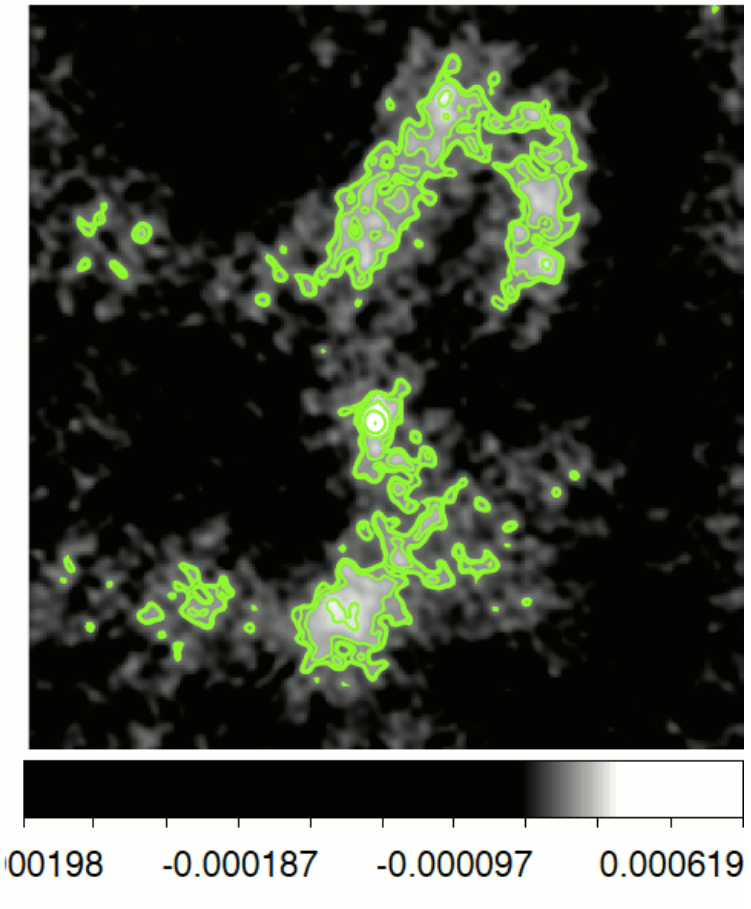
NGC5548 1.4 GHz





VLA **eMERLIN**

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

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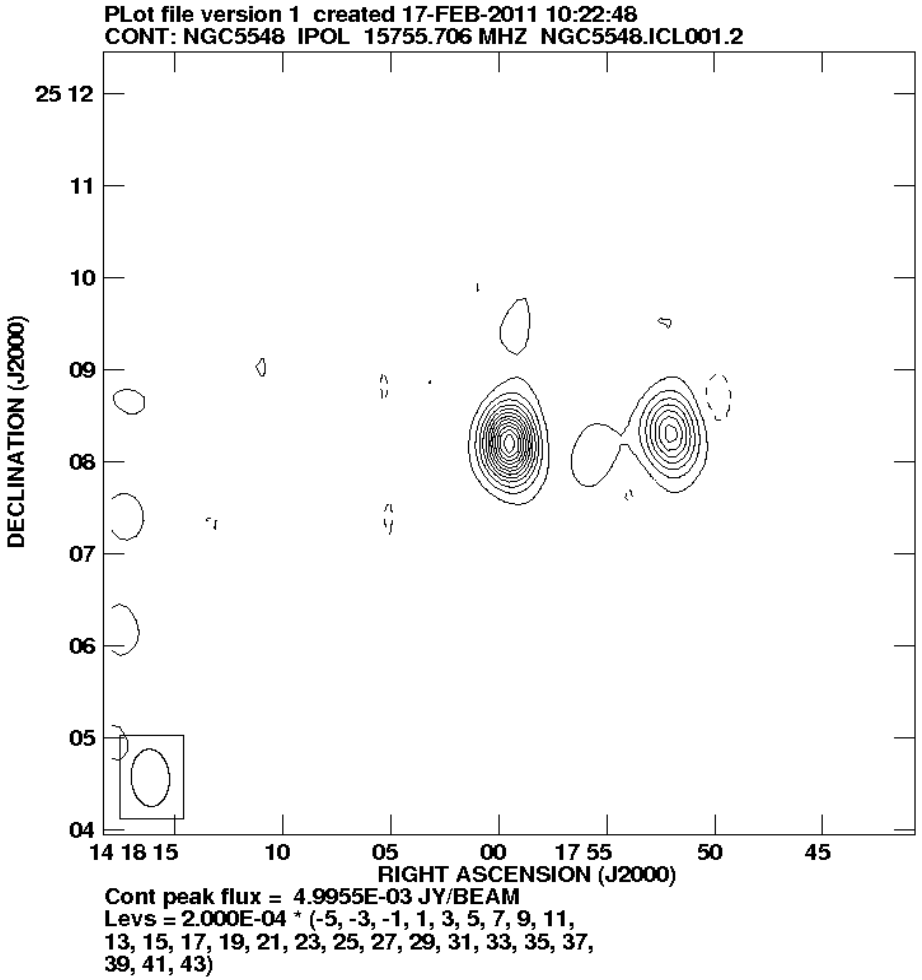
NGC5548 AMI 15GHz



Compact core
(Guy Pooley)

Other source is unrelated

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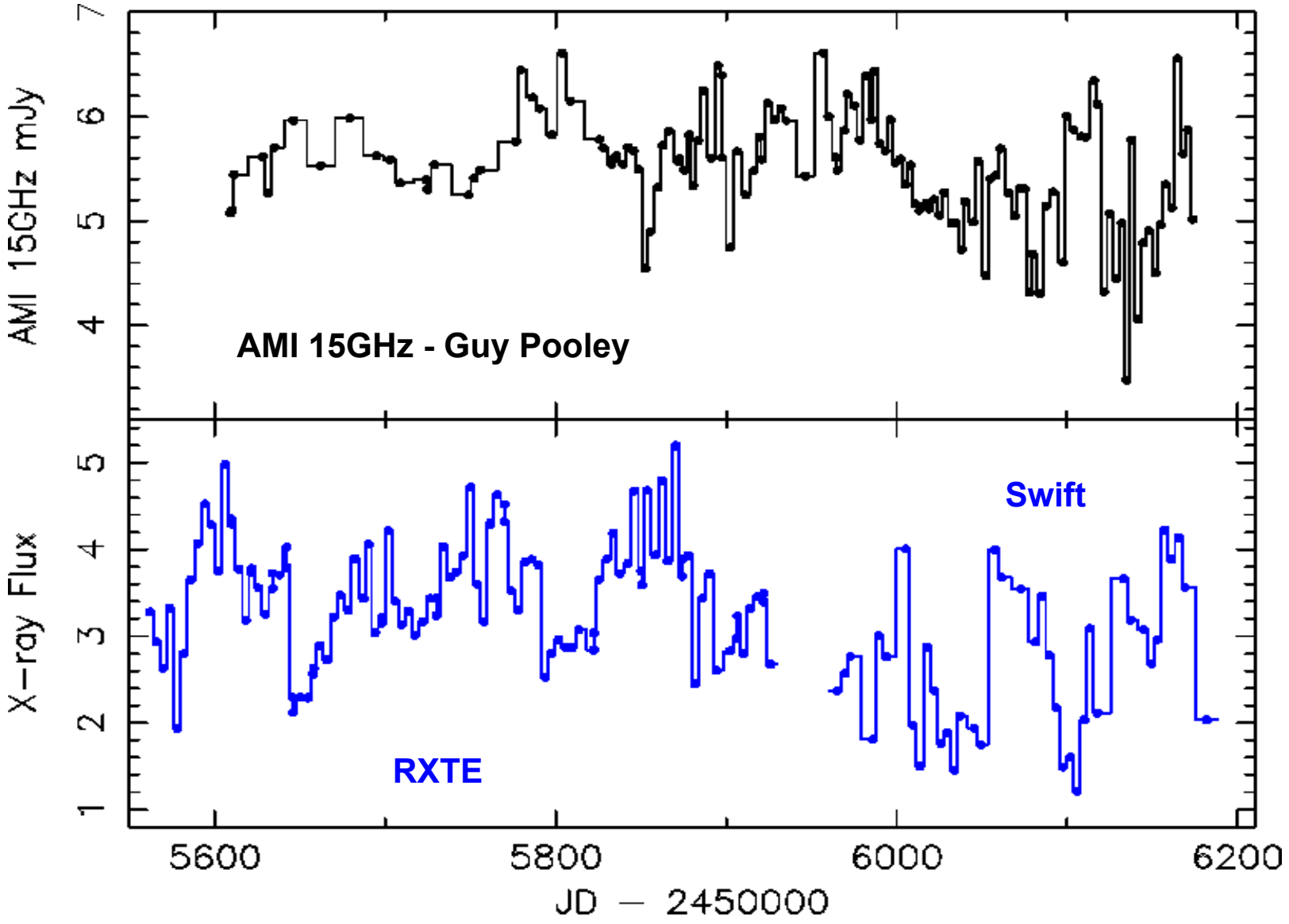
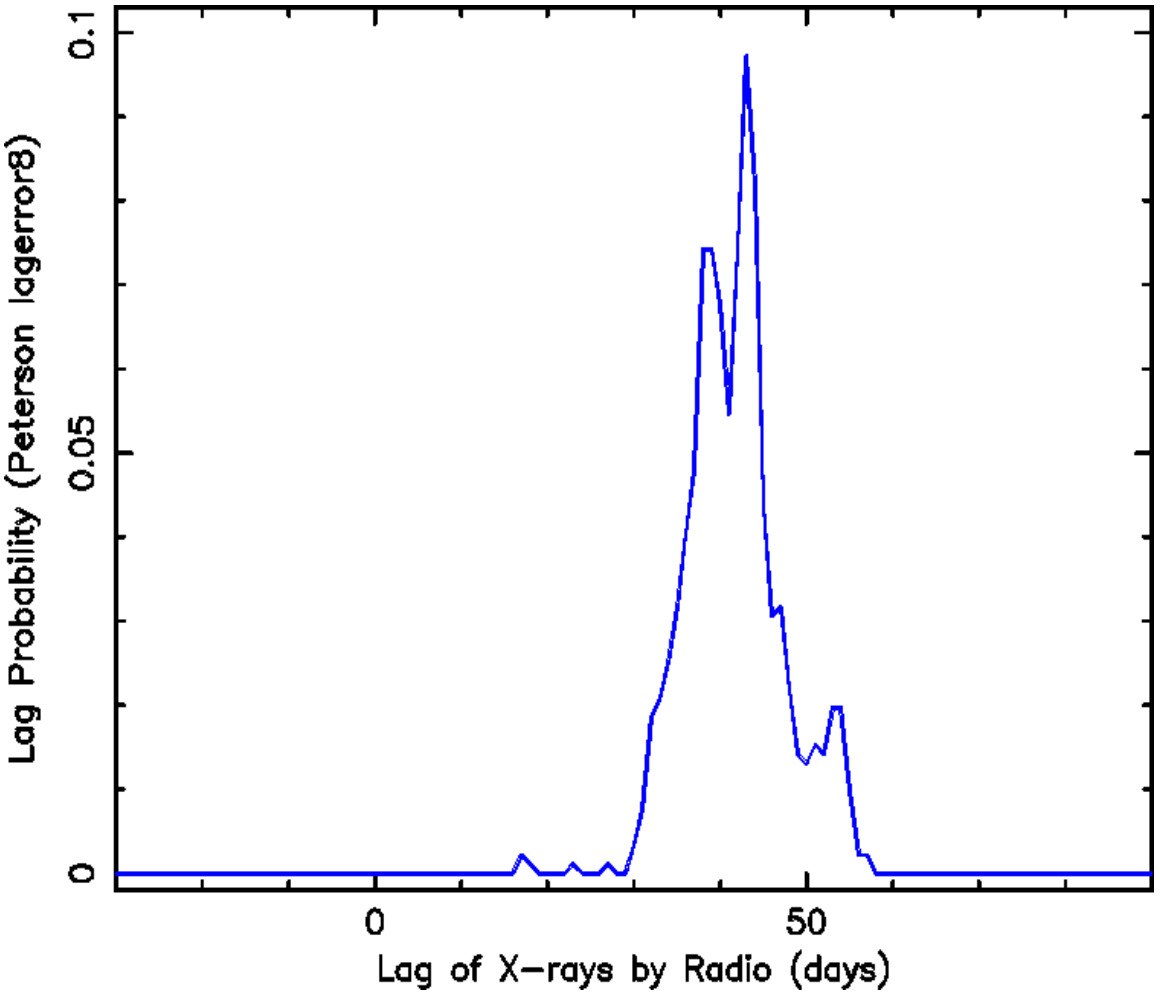
NGC5548 X-ray / Radio Variability



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)

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CONCLUSIONS

Seyfert UV/optical variability
– mainly reprocessing of far-UV from inner edge of disc by outer disc
- inner edge of disc heated by X-rays AND fluctuating accretion rate

In NGC5548, lags are at least x3 longer than predicted by Shakura-Sunyaev disc model, but consistent with microlensing observations. Clumpy disc?

UV in LINER M81 correlates weakly with the X-rays with very short lag. Possibly part of same emission component.

In both LINER M81 and Seyfert NGC5584, radio correlates with X-rays and lags by 20- 40 days.
Probably X-rays from corona around black hole, with perturbations feeding into jet – but jet has a complex response.